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1 **Towards an Ecosystem-Based Marine Spatial Planning in the deep**

2 **Mediterranean Sea**

3

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15

16 **Abstract**

17 The deep sea covers about 79% of the Mediterranean basin, including habitats potentially able to
18 deliver multiple ecosystem services and numerous resources of high economic value. Thus, the deep
19 Mediterranean Sea represents an important frontier for marine resources exploitation, which is
20 embedded within the European Blue Growth Strategy goals and agendas. The deep sea is crucial for
21 the ecological functioning of the entire basin. For this reason, the deep Mediterranean deserves
22 protection from the potential cumulative impacts derived from existent and developing human
23 activities. Marine Spatial Planning (MSP) has been identified as key instrument for spatially
24 allocating maritime uses in the sea space avoiding spatial conflicts between activities, and between
25 activities and the environment. Indeed, MSP incorporates the ecosystem-based approach (EB-MSP)
26 to balance both socio-economic and environmental objectives, in line with the Maritime Spatial
27 Planning Directive and the Marine Strategy Framework Directive. Despite MSP is under
28 implementation in Europe, the Directive is not applied yet for the managing and monitoring of the
29 environmental status of the deep sea. In the Mediterranean, deep areas fall both in internal and
30 territorial waters, and in High Seas, and its management framework turns out to be complicated.
31 Moreover, a certain level of cumulative impacts in the deep Mediterranean has been already identified
32 and likely underestimated because of paucity of knowledge related with deep-sea ecosystems. Thus,
33 the implementation of scientific knowledge and the establishment of a sustainable management

34 regime of deep-sea resources and space is urgent. This study aims at reflecting on the best available
35 ecological knowledge on the deep Mediterranean to incorporate conservation objectives in EB-MSP.
36 We propose a framework to include key ecological principles in the relevant phases of any EB-MSP
37 processes taking in consideration existing socio-economic and conservation scenarios in the region.
38 We add the uncertainty principle to reflect on the still unexplored and missing knowledge related to
39 the deep Mediterranean. Here, we resume some guidelines to overcome limits and bottlenecks while
40 ensuring protection of deep-sea ecosystems and resources in the Mediterranean Sea.

41

42 **Keywords:** deep sea, Mediterranean, EB-MSP, marine conservation, MSFD

43

Acronyms

ABMTs	Area-Based Management Tools	IMO	International Maritime Organization
ABNJ	Area Beyond National Jurisdiction	IUCN	International Union for Conservation of Nature and Natural Resources
CBD	Convention of Biological Diversity	MPAs	Marine Protected Areas
CWCs	Cold Water Corals		
DSWC	Dense Shelf Water Cascading	MSFD	Marine Strategy Framework Directive
GFCM	General Fishery Commission for the Mediterranean	MSP	Marine/ Maritime Spatial Planning
EBA	Ecosystem-Based Approach	PSSA	Particularly Sensitive Sea Area
EBM	Ecosystem-Based Management	RAC/SPA	Regional Activity Center for Specially Protected Areas
EB-MSP	Ecosystem-based Marine Spatial Planning	SPAMI	Special Protection Area of Mediterranean Importance
EBSA	Ecologically and Biologically Significant Marine Area	UNCLOS	United Nations Convention of the Law of the Sea
EEZ	Exclusive Economic Zone	UNEP/MAP	United Nations Environment Programme/Mediterranean Action Plan
EUSAIR	European Strategy for the Adriatic-Ionian Region	VME	Vulnerable Marine Ecosystem
FAO	Food and Agriculture Organisation	WESTMED	Western Mediterranean (blue economy initiative)
FRA	Fishery Restricted Area		

Marine waters jurisdictional framework under UNCLOS

Internal waters: waters on the landward side of the baseline of the territorial sea.

Territorial sea: area delimited by the outer limit of the territorial sea, which is the line every point of which is at a distance from the nearest point of the baseline equal to the breadth of the territorial sea, which corresponds to 12 nautical miles.

Exclusive Economic Zone: area beyond and adjacent to the territorial sea, subject to the specific legal regime established in this Part, under which the rights and jurisdiction of the coastal State and the rights and freedoms of other States are governed by the relevant provisions of UNCLOS. Its outer limit does not exceed 200 nautical miles.

High Seas: all parts of the sea that are not included in the exclusive economic zone, in the territorial sea or in the internal waters of a State, or in the archipelagic waters of an archipelagic State.

47 **1. Introduction**

48 The ecosystem-based (EB) approach is widely recognized as the approach to acquire for the
49 sustainable use of nature space and resources while limiting the environmental impacts of present and
50 future activities (Douvere 2008). Marine Spatial Planning (MSP) is crucially important for the
51 development of the EB approach in the marine environment (Ansong et al. 2017). MSP indeed allows
52 to avoid spatial and management conflicts between maritime uses, and to support the long-lasting
53 preservation and exploitation of marine species and ecosystems (Ehler 2008, Outeiro et al. 2015).
54 MSP is being implemented in the Mediterranean Sea. The Barcelona Convention is supporting all
55 the Mediterranean countries (both Member States and non-EU countries) to implement MSP towards
56 conservation and sustainable development (UNEP(OCA)/MED IG.6/7, 1995). Moreover, Member
57 States are implementing MSP under the Framework Directive on MSP 2014/89/EC (MSPD, EC,
58 2014). The Directive conceives MSP as a comprehensive process that adopt an EB approach,
59 potentially leading the achievement of the goals of both the Blue Growth Strategy (EC, 2012) and the
60 Marine Strategy Framework Directive (MSFD, EC, 2008). MSP can play a fundamental role in
61 supporting environmental conservation (Fraschetti et al. 2018; Shabtay et al. 2019), contributing in
62 decreasing of cumulative impacts to enhance environmental protection and the achievement of
63 Ecosystem-Based Management (EBM) goals (Halpern et al. 2010).

64 In the Mediterranean Sea, about 79% of the basin (ca. 2 million km² with an average depth of 1,500
65 m) includes the sea bottom and the water column below 200 m of depth, thus corresponding to deep-
66 sea habitats potentially able to deliver multiple ecosystem services (ES) and numerous resources of
67 high economic value. Thanks to technological advances, the exploitation of marine resources is
68 moving off-shore and at greater depth, increasing the impacts that deep-sea ecosystems are already
69 facing (Ramirez-Llodra et al. 2011, Fanelli et al. 2016, Grehan et al. 2017). In this context, there is
70 the need of setting up appropriate marine plans for managing and spatially allocating future human
71 uses in the deep sea preserving such environment (Danovaro et al. 2017a). Indeed, the sustainable
72 exploitation and the protection of deep-sea ecosystems is a priority for the sake of preserving the wide

73 and still unexplored biodiversity they host, as well as the outstanding numbers of benefits they
74 provide for humans, as climate mitigation (Thurber et al., 2014; Levin and Le Bris 2015).

75 The MSPD, like the MSFD, has not specifically addressed the deep Mediterranean Sea, despite the
76 growing demand for marine resources exploitation in this environment. Nonetheless, Micheli et al.
77 (2013) found that medium-high cumulative impact levels largely cover the entire Mediterranean
78 basin, reaching pelagic and benthic off-shore ecosystems. The level of impact in deep-sea ecosystems
79 may be even underestimated because of the paucity of knowledge available for assessing their abiotic
80 and biotic features, as well as their biodiversity, functioning and fragility. In fact, data and information
81 are scattered amidst deep-sea environments and marine ecoregions (Ramirez-Llodra et al. 2010, Pape
82 2017, Danovaro et al. 2017b). Despite the raising studies and knowledge on these remote
83 environments (UNEP/MAP-RAC/SPA, 2015), when modelling cumulative effects in the Adriatic and
84 Ionian seas, Gissi et al. (2017) found that deep-sea areas were the least impacted of the entire marine
85 area likely because of the scarcity of knowledge for the deep part of this sub-basin. Nevertheless,
86 decision-makers need to handle this knowledge gap when incorporating deep sea in Ecosystem-Based
87 MSP (EB-MSP). This is especially urgent for the Mediterranean Sea, where the deep sea is part of
88 the territorial waters of several countries.

89 In the present study, starting from the information collected within the framework of three EU-funded
90 projects (IDEM, SUPREME and SIMWESTMED, Friess and Grémaud-Colombier 2019; Danovaro
91 et al., 2020), we revisited the best available knowledge on the deep Mediterranean Sea to incorporate
92 conservation objectives in EB-MSP. Thus, we proposed a framework that includes the ecological
93 principles elaborated by Foley et al. (2010) by distilling and bringing out the necessary and available
94 knowledge more relevant at the basin scale to operationalize conservation in EB-MSP for the deep
95 Mediterranean Sea. Specifically, the four key ecological principles (*EPs*) for EB-MSP
96 implementation focus on maintaining: *EP1) native species diversity*, *EP2) habitat diversity and*
97 *heterogeneity*, *EP3) key species*, and *EP4) connectivity*. Because of the extensive fragmented
98 knowledge regarding the deep sea and its responses to human impacts, especially on a long-term

99 scale, and the willing in considering the precautionary principle (Kriebel et al. 2001), we added the
100 uncertainty principle (*UP*), which is *to consider and incorporate the uncertainty*. In section 2, we
101 presented the characteristics of the deep sea in the Mediterranean, including the future perspective
102 related with its resources' exploitation, and its legal and environmental protection status. The
103 presented information is essential to identify management and conservation priorities in the
104 Mediterranean Sea. Then, in section 3, we described the four *EPs* plus uncertainty (*UP*), based on the
105 environmental characteristics and ecological traits of the deep-sea ecosystems of the Mediterranean.
106 Here, the basic and essential ecological knowledge framework is built to depict deep-sea ecosystems
107 at the basin scale, to inform both deep-sea experts and non-experts (i.e. authorities, decision-makers,
108 planners, NGOs, multi-level stakeholders). In section 4, we incorporated the principles in the relevant
109 phases of any EB-MSP processes (Ehler and Douvère, 2009, Foley et al. 2010), by linking the
110 ecological knowledge to the management and conservation needs. Here, we resumed some guidelines
111 and delivered some suggestions to overcome the bottlenecks and limits while implementing the EB-
112 MSP in the deep Mediterranean Finally, in section 5, on the base of the main results of our study, we
113 identified the most urgent political agenda's priorities to boost EB-MSP in the deep Mediterranean
114 Sea.

115

116 **2. The deep Mediterranean Sea**

117 ***2.1 The new frontier and identified future impacts***

118 Despite the great technological advancements (Aguzzi et al., 2019), the exploration of the deep sea
119 is still one of the main great challenge on Earth (Danovaro et al. 2014, Cunha et al. 2017). The deep
120 Mediterranean Sea represents part of this new frontier providing both biotic (i.e. fishery, genetic
121 resources) and abiotic (minerals and hydrocarbons) resources thanks to its environmental
122 characteristics. Indeed, this basin faced a wide variety of environmental phenomena and changes
123 during its geological history, which make it highly heterogeneous and bio-diversified (Bianchi and
124 Morri 2000, Danovaro et al. 2010). The deep Mediterranean is characterized by different

125 habitats/ecosystems and various geomorphological features supporting high biodiversity and
126 endemism presence, from prokaryotes to vertebrates, as well as high organisms' biomass (Danovaro
127 et al. 2010), also concerning species of high commercial values for fishery, such as red shrimps and
128 European hakes. It also greatly offers non-living resources in the seabed and subsoil, such as oil, gas,
129 and minerals (Piante and Ody 2015).

130 Beyond the overexploitation of fishery resources, which has long affected the basin even in the deep
131 (Tsikliras et al. 2015), many are the growing maritime activities that may potentially affect the deep
132 Mediterranean Sea, such as oil and gas extraction, deep-sea mining, and bioprospecting. For instance,
133 oil and gas research and extraction are growing in the Maltese, Egyptian, Israeli, Syria, Cyprus and
134 Greek agendas (The Petroleum Economist Ltd, 2013). The mining of mineral resources is developing
135 particularly in the Tyrrhenian Sea in the form of sulphide deposits (Safipour et al. 2018). Off-shore
136 sand deposits in the Gulf of Lion will be likely exploited in the near future (Campostrini et al. 2018).

137 On-going plans to increase electricity transmission and communication with new cables and pipelines
138 are present between Italy, Tunisia, and Malta, and among the Greek islands (Campostrini et al. 2018,
139 SUPREME Project, 2017). The outstanding genetic diversity is promising in the bioprospecting
140 scenario (Tortorella et al. 2018). Indeed, the deep Mediterranean hosts a great functional diversity
141 (Mindel et al. 2016), as deep-sea organisms, need to cope with different environmental conditions,
142 showing a wide range of strategic adaptive characteristics. This is particularly true in the deep
143 Mediterranean at all biological levels (Danovaro et al. 2017b).

144 Finally, studies have been carried out to explore the opportunity of inject carbon dioxide under the
145 seafloor, practice that can greatly acidify and sterilize the deep seabed (Carneiro et al. 2015).

146 Other than these natural resources, the deep Mediterranean is able to deliver many other ecosystem
147 services, which are key in making this marine basin a hotspot of biodiversity, favouring
148 biogeochemical processes, and mitigating the effects of climate change and anthropogenic C release
149 (Thurber et al. 2014). In addition, deep-sea fauna and habitats are highly vulnerable (Rigby and
150 Simpfendorfer 2015) to direct and indirect human impacts, such as climate change, especially in the

151 Mediterranean, because of both environmental and topographic characteristics (Lejeusne et al. 2010,
152 Giorgi 2006, Micheli et al. 2013) and historical human activities, such as the deep-sea fishery to red
153 shrimps (Fanelli et al., 2017). Thus, a sustainable management of deep-sea resources is extremely
154 urgent, under a scenario of increasing exploitation.

155

156 ***2.2 Boundaries and jurisdictions***

157 The Mediterranean Sea falls within a complex geopolitical context (Mazor et al. 2013). The countries
158 that surround this basin are both EU and non-EU countries, with different political, legislative, and
159 cultural systems. Furthermore, the partial political instability due to ongoing conflicts in the Middle-
160 East and in some southern countries, such as Libya, prevent from sharing objectives and principles
161 for conservation (Mazor et al. 2013).

162 The deep sea covers more than $\frac{3}{4}$ of the entire Mediterranean Sea, being a predominant part of this
163 marine basin to be planned and managed. It falls both within and beyond countries' jurisdiction. On
164 the base of the spatial measurement calculated starting from the updated national legislative
165 boundaries (DOALOS, Suárez-de Vivero, Juan L. Marineplan, 2019, Figure 1), about 32% of the
166 deep Mediterranean Sea can be defined as 'High Seas' (ca. 646,829.6 km²). It corresponds to the
167 waters on the continental shelf of those states that have not declared the Exclusive Economic Zone
168 (EEZ) yet (Popova et al. 2019). The presence of geopolitical tensions and the lack of agreements
169 relating to the exploitation of natural resources hampers the declaration of the EEZs among the
170 Mediterranean countries (Katsanevakis et al. 2015). At present, only 11 Mediterranean countries have
171 already declared their own EEZ (Table S1A). Considering both EEZ and high seas, several areas of
172 intermediate jurisdiction are present, covering 5.6% of the deep sea. These areas have no official
173 jurisdiction yet defined and agreed between coastal States, so related marine areas remain
174 unmanageable (Suárez de Vivero, pers. Comm.)

175 With the exception of Slovenia, all countries of the Mediterranean basin contain deep-sea waters in
176 their territorial seas. In ten countries, deep-sea areas are present also within inland waters. For

177 instance, Italy and France include 30.8% and 15.7% respectively of deep-sea coverage in their internal
178 waters (Table S1A). Spain is the EU country having declared the EEZ with the highest percentage of
179 deep sea in all its own waters (9.6%), followed by France (3.3%) (Table S2A). If Italy and Greece
180 would declare their EEZ, they would greatly exceed such percentages, reaching ca 21% in both cases,
181 being the Mediterranean countries with the greatest coastline extension (Table S2A). Since MSP is a
182 process carried out at the country level (Article 4, MSP 2014/89/EC), meaning under coastal States'
183 jurisdiction, planning the deep-sea space is and will be part of the MSP processes of the
184 Mediterranean states because of its presence in both internal and territorial waters. Once all EEZs
185 will be defined and declared, no high seas will be present in the Mediterranean Sea, and the deep sea
186 in the EEZs will be part of the national marine plans.

187

188 ***2.3 Area-based management tools (ABMT) for conservation***

189 On the base of the spatial measurement relatively to each ABMT, assessed through the use of data
190 from November 2017 of MAPAMED dataset, about 4.9% of the deep Mediterranean falls within an
191 ABMT for conservation (Table S3A). This percentage poorly represents the whole deep-sea
192 environment (UNEP/MAP-RAC/SPA, 2015; Amengual and Alvarez-Berastegui 2018). More
193 specifically, only the 0.62% of the protected deep sea falls within national MPAs, the only ABMT
194 that manage different human activities entailing multiple conservation objectives (Amengual and
195 Alvarez-Berastegui 2018). The ABMTs for conservation that include high seas in the Mediterranean
196 are mainly designated at international level for specific conservation targets aiming at controlling
197 environmental impacts from individual sectors, or protecting only specific environmental features,
198 not specifically targeting the deep-sea environment. For instance, the Particularly Sensitive Sea Area
199 (PSSA, 0.3% of the deep) was designated by International Maritime Organization (IMO) in the Strait
200 of Bonifacio to control maritime transport impacts. The Pelagos Sanctuary focuses solely on
201 cetaceans' protection and pelagic environment, covering 3.4% of the deep Mediterranean. This is the
202 larger MPA established internationally in the Mediterranean, but its boundaries have been set based

203 on political convenience rather than on ecological priorities, and, nevertheless, it has never been
204 concretely enforced, being defined as a “paper park” (Agardy et al. 2011, Fenberg et al. 2012). The
205 Specially Protected Areas of Mediterranean Importance (SPAMIs), defined under the Barcelona
206 Convention, were indicated as a good example of MPA management (Amengual and Alvarez-
207 Berastegui 2018). Nonetheless, excluding the area corresponding to the Pelagos Sanctuary, also the
208 SPAMIs slightly cover deep-sea areas (0.01%).

209 ABMTs for conservation targeting deep-sea ecosystems have been designated. Seven Fishery
210 Restricted Areas (FRAs) covering 0.9% of the deep were established by the General Fishery
211 Commission of the Mediterranean (GFCM) to control and manage fishery, beyond the already legally
212 binding banning of bottom trawling activity below 1000 m depth. Beyond the MAPAMED dataset,
213 we measured the extent of the ban finding a coverage of ca. 58.4% of the deep Mediterranean. The
214 institution of two new FRAs has been requested to GFCM, because of the occurrence of Essential
215 Fishing Habitats (EFH) and Vulnerable Marine Ecosystems (VME) on one hand, and high human
216 pressure (mostly in terms of trawling activities) on the other. These are the Bari Canyon (recognized
217 as a new coral province, for which the process is running), and the Otranto channel (where both EFH
218 and VME occur), for which the process is just at the beginning. Despite their conservation objective
219 is focused against the fishing impact, the FRAs have been recently proposed to be considered as
220 effective MPAs for their contribution on protecting comprehensively biodiversity and vulnerable
221 deep-sea habitats, actually representing legally-binding multi-objectives conservation tools
222 (Rodríguez-Rodríguez et al. 2016).

223 Finally, the Mediterranean counts for 15 Ecologically or Biologically Significant Areas (EBSAs),
224 defined through scientific criteria and aiming at identifying priority areas for protection for guiding
225 their sustainable use (Johnson et al. 2018). The EBSAs cover ca. 40% of the total deep Mediterranean
226 Sea (Table S3A). Despite they are not an ABMT, because not subjected to proper conservation
227 management regimes, they were been intentionally identified in offshore waters to promote
228 conservation beyond coastal areas (Portman et al. 2013).

229 **3. The five key principles needed to manage the deep Mediterranean Sea**

230 In this section, we fed the four ecological principles developed by Foley et al. (2010) for the deep
231 Mediterranean Sea with the available knowledge to support their operationalization, as well as the
232 fifth principle *UP* related to the uncertainty. We did not pretend to include all of the existing
233 ecological information, but resume some key features more relevant at the scale of the Mediterranean
234 basin to start building the informative framework for an EB-MSP in the deep Mediterranean.

235

236 *3.1 Ecological principle no.1: Maintain native species diversity*

237 Studies on the deep Mediterranean Sea showed that diversity and abundance of the native deep-sea
238 species vary widely, eventually following longitudinal-latitude and depth-range gradients, or even
239 any evident patterns. The geological history of the basin, its complex mosaic of habitats, the
240 variability in trophic resources availability throughout its length, its peculiar biological and ecological
241 characteristics (among which the presence of endemism), drive the biodiversity in the deep
242 Mediterranean (Fanelli et al. 2018). In Table S4A, we resumed the knowledge on the distribution
243 trends of several groups of species that inhabit and spend part of their life in the deep Mediterranean.
244 In general, sharp longitudinal and latitudinal gradients of benthic biodiversity are present in the deep
245 Mediterranean, largely driven by changes in food availability (Danovaro et al. 2008b). Indeed, with
246 increasing water depth, food sources become more limited for deep-sea productivity, which often
247 strongly depends on surface primary production and coastal organic matter inputs (Danovaro et al.
248 2017b). However, the drivers guiding meio- and macrofauna diversity change at different spatial
249 scales, affecting biodiversity pattern estimates (Danovaro et al. 2013).

250 Diversity distribution in deep-sea environments is mostly studied for benthic assemblages because of
251 the difficulties in observing and sampling pelagic organisms. Knowledge on deep pelagic species is
252 scant despite their importance as trophic source for predators, for being predators, and for the many
253 ecological functions they support (Robison 2009), as the case of mesopelagic fishes which act as top-
254 down controllers (Fanelli et al., 2014). However, deep-sea fishes and cephalopods of the

255 Mediterranean were observed facing a community shift at 800 and 200 m depth, respectively (Table
256 S4A). Despite the limited knowledge available, also deep-sea sharks have been observed inhabiting
257 widely the deep Mediterranean Sea, showing different abundance and bathymetric distribution
258 patterns (Carrassón et al. 1992, Sion et al. 2004). Nevertheless, we did not find information on their
259 diversity distribution patterns at the basin scale (Fanelli et al. 2018). Also, some cetacean species
260 have been detected swimming in the deep Mediterranean, some of them showing a predilection for
261 depths even greater than 1200 m, like the sperm whale *Physeter macrocephalus* and the Cuvier's
262 beaked whale *Ziphius cavirostris* (Fiori et al. 2014).

263 Overall, a global study on deep-sea ecosystems, including the Mediterranean, demonstrated a strong
264 relationship between biodiversity and functional diversity, and that ecosystem functioning is
265 positively and exponentially correlated with species number (Danovaro et al. 2008a). Therefore, each
266 single species plays a fundamental role in deep-sea ecosystems to keep them working.

267

268 *3.2 Ecological principle no. 2: Maintain habitat diversity and heterogeneity*

269 The deep Mediterranean Sea is almost homoeothermic in the deep sea beneath 200 m depth, and
270 lowest temperatures never drop below ca 13°C (12.7-13.5 °C in the western basin and between 13.5
271 and 15.5°C in the eastern basin, on average). Deep waters area also characterised by a high salinity
272 levels and oxygen concentrations despite the presence of several deep-water formation sites that make
273 the circulation highly dynamic (Yasuhara and Danovaro, 2016, Skliris et al. 2018, Powley et al. 2016).
274 A strong seasonality and the presence of different topographic contours influence the water
275 circulation in the Mediterranean (Astraldi et al. 1999): Gibraltar Strait, Almeria-Oran Front, Ibiza
276 Channel, Balearic Front, Sicily Channel, Otranto Channel, and the southern margin of the Aegean
277 Sea (Pascual et al. 2017). Generally, regional barriers, as those just mentioned, favour the definition
278 of distinct subregions, and the formation of diverse marine communities (Treml and Halpin 2012,
279 Popova et al. 2019).

280 These peculiarities make the Mediterranean highly heterogeneous hosting diverse valuable habitats.
281 Despite the still limited knowledge on the pelagic domain, Hyrenbach et al. (2000) distinguished the
282 three pelagic hotspots habitats in ephemeral (i.e. up and downwelling systems), persistent (i.e.
283 currents and gyres), and static systems (i.e. the water masses surrounding seamounts). Among these
284 habitats, upwelling and downwelling areas are of paramount importance, and are scattered within the
285 entire Mediterranean basin (Bakun and Agostini 2001). These vary over time being mainly seasonal,
286 but they can also present quasi-permanent or even permanent nature (Sarhan et al. 2000, Di Lorenzo
287 et al. 2017). In both cases, they underpin primary productivity phenomena supporting the whole
288 marine life. For instance, the Pelagos Sanctuary falls within one of these systems becoming a feeding
289 ground for cetaceans (Zeichen et al. 2017). Dense shelf water cascading (DSWC) events are among
290 the main responsible of the transport of organic matter to the deep sea (Canals et al. 2006, Sanchez-
291 Vidal et al. 2008), strongly influencing the functioning of deep-sea benthic communities.
292 As for benthic habitats, a specific zonation for the deep Mediterranean, based on the EUNIS
293 classification (Davies et al. 2004), comes from the experience of the EU Project CoCoNet (towards
294 COast to COast NETworks of marine protected areas, [https://cordis.europa.eu/project/rcn/101654/
295 reporting/en](https://cordis.europa.eu/project/rcn/101654/reporting/en); Fabri et al. 2018). All of the benthic deep-sea habitats that are present in the
296 Mediterranean basin are listed in Table S5A. Their ecological role and spatial distribution are here
297 summarized. Furthermore, the ones mapped until today are represented in Figure 2a.

298

299 3.3 Ecological principle no. 3: Maintain key species

300 In the deep Mediterranean, three main kinds of key species can be identified: 1) ecosystem
301 engineers/habitat forming species; 2) flag species; 3) rare/endemic deep-sea species. For instance,
302 cold-water corals (i.e. *Desmophyllum pertusum* (= *Lophelia pertusa*), *Madrepora oculata*,
303 *Desmophyllum dianthus*) are habitat forming species that support entire ecosystems for their three-
304 dimensionality (Maier et al. 2011). The bamboo coral *Isidella elongata* was recognized as a near-
305 endemic key species of the Mediterranean, creating “beds” which can offer shelter to a large

306 associated fauna, as well as endangered. Although this species has been observed up to 1000 m depth,
307 its main distribution range is 500-700 m (Fabri et al. 2014, Mastrototaro et al. 2017). It is a soft-
308 bottom organism highly threatened by bottom trawling fishery (Cartes et al. 2013), since it is present
309 on muddy soft bottoms and at depth where trawling is permitted (UNEP/MAP-RAC/SPA 2015). The
310 same condition can be described for the colonies of black corals *Anthipatella subpinnata* and
311 *Leiopathes glaberrima*, sharks' nesting sites hosting high biodiversity, which are impacted by by-
312 catch and the disposal of any lost material from the fishing vessels (e.g. long-lines, trammels, ropes;
313 Bo et al. 2014). Demersal sharks, acting as top predators, play a key functional role in deep-sea food
314 web equilibrium highly affecting minor functional groups (Tecchio et al. 2013). These include species
315 of major concern of protection, such as the Bluntnose sixgill shark *Hexanchus griseus*, the dogfish
316 *Squalus acanthias* and *S. blainvillei*, the Kitefin shark *Dalatias licha* and the gulper shark
317 *Centrophorus granulosus* (Cartes et al., 2013; Barría et al. 2015, Navarro et al. 2014). Many endemic
318 species inhabiting the deep Mediterranean have been described up today, belonging to different
319 taxonomic groups (e.g. the ray-finned fish *Paralepis speciosa*, the rays *Raja radula* and *Leucoraja*
320 *melitensis*, and the decapod crustacean *Zariquieyon inflatus*; Tortonese 1985, Bouchet and Taviani
321 1992), and many have yet to be discovered. However, because of the fragmented knowledge
322 concerning deep-sea biodiversity and species ecological roles, the identification of key species in the
323 deep Mediterranean is challenging. Nonetheless, we list and map the proposed species of priority for
324 protection in the deep Mediterranean Sea starting from the common consensus of both scientific and
325 political communities (Oceana 2009, Oceana 2017, Table S1B, Figure 2b), to create awareness on
326 their presence and ecological status. The list does not include only species strictly associated with
327 deep-sea habitats and the Mediterranean, with the intent of including the ecological connectivity that
328 drives species distribution and its variability. Indeed, species that spend part of their life in the deep
329 sea, likely accomplishing specific life stages and satisfying peculiar behaviours, and that have been
330 identified in the Mediterranean, are included. In Figure 2b, the species listed in Table S1B are grouped
331 and represented in Phyla.

332 *3.4 Ecological principle no. 4: Species and habitat connectivity*

333 In the Mediterranean Sea, either longitudinal, latitudinal and vertical (i.e., surface waters and deep-
334 sea environments) connectivity is strong. In fact, the deep Mediterranean is characterised either by
335 upwellings and DSWC events (mainly in the Gulf of Lions, in the northern Adriatic and in the
336 northern Aegean), allowing oxygenated waters to penetrate down to >1500 m depth (Goriup 2017,
337 Canals et al. 2009). Moreover, the water column funnels the organic matter produced at the surface
338 towards the greatest depths, greatly supporting deep-sea food webs (Conese et al., 2019). Both DSWC
339 and organic matter transport to the deep sea are enhanced by the presence of submarine canyons,
340 especially in the western part of the basin. As described in Table S5A, submarine canyons act as
341 corridors for the transport of large amount of organic matter towards the greatest depths, enhancing
342 DSWC and participating to the formation of upwelling systems (Canals et al. 2006).

343 Connectivity allows also populations and species movements and survival strategies through larval
344 recruitment and gene fluxes, both vertically and horizontally, which numerous deep-sea organisms
345 adopt to underpin their reproductive success and resilience to disturbances (Popova et al. 2019).
346 Dubois et al. (2016) argued the influence of convergence and divergence currents (down and
347 upwelling, respectively) on the retention or supply of larval stages in the entire Mediterranean Sea.
348 Deep-sea habitats can, in fact, represent sinks of resting stages, contributing to the supply of new
349 recruits to shallower populations (Della Tommasa et al. 2000, Canepa et al. 2014). Vice versa, some
350 deep-sea populations can depend by external larval supply. As an example of connectivity, the
351 economically valuable shrimp *Aristeus antennatus* migrates towards shallower depths promoting a
352 significant larval dispersal and vertical adults' recruitment, supporting, through gene flow, the
353 homogeneous structuring of meta-populations along the entire Mediterranean basin (Company et al.
354 2008, Maggio et al. 2009). This biological behaviour prevents the collapse of this species, despite the
355 great fishery pressure acting on it.

356 However, different oceanographic processes lead to the formation of frontal systems, as described in
357 *section 3.2*, which create real pelagic ecotones, concrete boundaries able to influence marine

358 communities' structure and distribution (Louzao et al. 2017). Both environmental (current systems
359 and geomorphologic features) and biological processes in the Mediterranean can limit the
360 connectivity between deep-sea populations, thus affecting their dispersal potential. Then, also species
361 with long dispersal capability can be separated through speciation processes, specifically when their
362 reproductive period temporally overlaps with these fronts' formation (Pascual et al. 2017).
363 The strong connectivity across habitats is able to supply larvae and propagules from source areas to
364 degraded deep-sea systems, thus offering opportunities for resilience.
365 Connectivity can also lead to negative implications. Contaminants can reach and accumulate within
366 the organisms even at the greatest depths (Ramirez-Llodra et al. 2011), for example through
367 submarine canyons, which play a role in deep-sea contamination processes (Fernandez-Arcaya et al.
368 2017). In addition, deep-sea environments are not isolated and protected from the effects of climate
369 changes, which are also foreseen as drivers influencing important episodic events, as DSWC (Canals
370 et al. 2006, Pusceddu et al. 2013). Danovaro et al. (2004) also observed strong effects even at slight
371 temperature variations on deep-sea biodiversity in the Mediterranean.

372

373 *3.5 Uncertainty principle (UP): Uncertainties (what we know not to know)*

374 It has been estimated that about 75% of the diversity inhabiting the deep Mediterranean is still
375 unknown (Costello et al., 2010). If deep-sea biodiversity is so far from being extensively assessed,
376 even less the functioning of deep-sea ecosystems and their status are. For instance, most of the deep
377 seabed corresponds to soft bottoms, whose ecological role is not fully understood, and therefore easily
378 underestimated as priority conservation habitats. As an example, the bamboo coral *I. elongata*, an
379 endangered key species mentioned in *section 3.3*, is mainly distributed on muddy bottoms of the open
380 slope.

381 From one side, novel habitats and biotopes are continuously discovered in the deep Mediterranean.
382 This is the case of the hydrothermal vents (Esposito et al. 2018), and of the novel deep-water corals-
383 bivalve biotope (Taviani 2014, Taviani et al. 2019), both found in the Tyrrhenian Sea (Western

384 Mediterranean). From the other side, the distribution and extension of these and of other known
385 habitats is almost completely unknown. The risk, related also to authorizations for industrial
386 activities, is assuming that nothing is in the deep because information is not available, whereas
387 priority habitats and species for conservation do exist, and are widely spread.

388 Because of the paucity of knowledge on deep-sea species composition, behaviour, and functions,
389 Ramirez-Llodra et al. (2011) tried to score human impacts on deep-sea habitats at global scale, facing
390 concrete difficulties. So far, the uncertainty related to the effect of anthropogenic and climate impacts
391 impinging on deep-sea ecosystems is real, especially in the deep Mediterranean (Lejeusne et al. 2010,
392 Giorgi 2006). The vulnerability and potential recovery estimates for the species and habitats that
393 populate this environment are scarce. In addition, the unbalance of data availability among the
394 Mediterranean sub-regions leads to the presence of important biases in the knowledge framework at
395 the basin level (Fraschetti et al. 2011). Thus, the uncertainty principle explains the need of embedding
396 the precautionary principle in the ecosystem-based management of deep-sea ecosystems (Danovaro
397 et al. 2017a).

398

399 **4. Setting EB-MSP in the deep Mediterranean Sea**

400 In this section, we incorporated the knowledge about the four ecological principles and the uncertainty
401 principle in the relevant phases of any EB-MSP processes (Ehler and Douvère, 2009, Foley et al.
402 2010). We reported some considerations based on the evidences emerged from the description of the
403 above cited principles for the deep Mediterranean Sea and resumed in Figure 3. The incorporation of
404 the ecological principles and uncertainty within the EB-MSP process for the deep Mediterranean Sea
405 is also schematically summarized in Figure 4. These are initial considerations based on described
406 ecological knowledge presented in section 3 with the intention of paving the way toward an EB-MSP
407 of the deep Mediterranean.

408

409 *Step 1. Planning goals and objectives*

410 The main goal of EB-MSP is of balancing socio-economic development and environmental
411 conservation, anticipating conflicts between uses, and between uses and the environment, and
412 contrasting single sectorial policies (Douvere 2008, Day 2008). In the perspective of the claimed
413 CBD target of protection by 2020, conservation objectives should be of priority in the deep
414 Mediterranean. On one hand, the deep Mediterranean Sea is witnessing an intensification of demand
415 for space and natural resources (see *section 2.1*). On the other hand, we found that only the 0.62% of
416 the deep Mediterranean Sea falls within a National MPA, and also considering the existing FRAs, as
417 recently suggested in the count of the enforced and legally binding MPAs (Rodríguez-Rodríguez et
418 al. 2016, Fanelli et al. submitted), the percentage of protected deep sea rises to 1.52%. Including the
419 extension of the trawling ban within the count would greatly increase the deep-sea area under
420 protection in the Mediterranean; but this ABMT, as well as the FRAs, are actually enforced only
421 toward fishery limitation, not fitting the existing ecosystem-based approach context, *sensu* MSFD.
422 To overcome these limitations, the achievement of the 10% conservation target should pass through
423 the designation and enforcement of new and existing ABMTs for conservation in the Mediterranean.
424 This should be done on the base of the available ecological knowledge related to habitats and species
425 of priority for protection, and by balancing the costs and benefits of conservation (Gissi et al. 2018).
426 Indeed, beyond MPAs declaration and enforcement, considerations related to trade-offs and synergies
427 between protection and use of the natural resources of the deep Mediterranean should guide the
428 sustainable and long-lasting use of the deep marine space and services as a priority objective to be
429 set. Such approach would favour the achievement of the range of goals to which the EB-MSP aims:
430 controlling, monitoring, and limiting human impacts, which are essential actions for supporting the
431 protection of the deep Mediterranean ecosystems. The planning objectives should be articulated in
432 sub-levels of measurable objectives based on the existing knowledge (described in section 3).
433 Moreover, objectives should incorporate already the uncertainty and its sources, and set as priority
434 goal the improvement of the ecological knowledge necessary to inform MSP in the deep
435 Mediterranean.

436 Overall, the planning objectives should be clear and transparent to enable a proper gathering of
437 knowledge that needs to be scientifically-based. Clear planning and conservation goals, in fact, enable
438 the science-based collection and production of data and information that should drive their
439 achievement (Galland et al. 2018).

440

441 *Step 2. Defining the existing and future conditions*

442 Though knowledge is scarce and scattered, we can draw some initial considerations that can guide
443 planners and decision-makers in approaching the analysis of existing and future conditions in the
444 deep Mediterranean Sea. In *section 3.1* related to the ecological principle 1 (maintain native species
445 diversity), we have identified some critical depths for pelagic populations of the deep Mediterranean
446 (Table S4A). In particular, fish and cephalopods have been found shifting in community structure
447 and increasing in abundance after a previous decreasing with water depth (800 and 200 m depth,
448 respectively). Thus, effective management measures for these two components, as well as their
449 response to any types of pressures, could change at those depths depending on the different species
450 present and their biological characteristics. This type of considerations may orient vertical zoning,
451 hypothesis that can be further analysed and tested, for example, with modelling strategies (e.g., Levin
452 et al. 2018). Furthermore, the dependency of fish species on trophic source availability means that
453 any impact affecting their preys can indirectly have great effects on their status. Thus, human impacts
454 affecting different levels along the pelagic food web should be identified and managed properly.
455 Moreover, we found the occurrence of certain cetaceans at greater depths, which indicates their
456 preferences in swimming and feeding in deep environments, despite they are not exclusively deep-
457 sea species. This information has great implication for controlling potential drivers of stressors from
458 human uses (e.g., oil and gas exploration, mining).

459 Moreover, the analysis of current and future conditions can focus on the habitats described in *section*
460 *3.2* as biodiversity hotspots, needful for the Mediterranean Sea productivity, and for the existence of
461 both shallow and deep-sea organisms. For instance, the particular influence of upwelling currents is

462 an evidence for pelagic-benthic coupling. Canyons and seamounts are defined as biodiversity hotspot
463 supporting both benthic and pelagic organisms and complex food webs (i.e. cetaceans, see *section*
464 *3.1*), and their presence within the MSP planning area should be carefully acknowledged.

465 Information on the reported benthic communities (meio- and macrofauna, Table S4A) highlighted the
466 importance of the spatial scale of the analysis for their biodiversity estimates. This evidence suggests
467 the need to define the geographical scope of the plan, the spatial extension of the area to be planned
468 and managed, before the gathering and interpreting of the ecological data related to marine
469 communities. Eventually, the application of a nested approach can be a suitable strategy in order to
470 consider in parallel different spatial scales. However, the species composition of the deep
471 Mediterranean communities is far from having been thoroughly assessed and even observed, poorly
472 orienting biodiversity conservation priorities at this large scale. Nonetheless, the benthic habitats
473 recognized as hotspots of biodiversity (Table S5A, Figure 2a), and the listed species in Table S1B
474 and mapped in Figure 2b, can help in identifying priority areas for conservation within EB-MSP. In
475 fact, information on biogenic reefs, submarine canyons, and seamounts of the deep Mediterranean
476 are many. These habitats are widespread and partially localized along the entire basin. These key
477 habitats and features need protection from all the activities that can directly impact their status.
478 Indeed, albeit their key role, submarine canyons are highly threatened by fishery and marine and land-
479 based pollution, and potentially by many of the human activities that are growing in the deep
480 Mediterranean, as oil and gas exploration and extraction (see section 2, Fernandez-Arcaya et al.
481 2017).

482 Limiting the allocation of activities that directly impact priority habitats for conservation may not be
483 enough to preserve them. We highlighted the role that bioregions can play in determining and
484 isolating distinct marine communities thus affecting their resilience to human impacts (*section 3.2*).
485 In *section 3.4* we also depicted many connectivity mechanisms, both vertical and horizontal between
486 deep-sea species and habitats. When analysing and assessing potential drivers of threats for the deep,
487 it is necessary to consider all these mechanisms influencing connectivity. For instance, deep-sea

488 biogenic reefs exist thanks to key benthic megafaunal organisms, namely cold-water corals (CWC).
489 These organisms live mostly within canyons and seamounts, where they find the appropriate substrate
490 and the suitable trophic and oceanographic conditions to settle and thrive (Table S5A). Thus, marine
491 currents are critical since filter feeders, as CWCs, prefer areas characterised by steep slopes and
492 elevated topography, where moderate currents occur (Davies and Guinotte, 2011). As described in
493 *section 3.4*, currents not only bring nutrients, oxygen, and larvae, but also contaminants and
494 pollutants, even of land origin, which cross long distances reaching the greatest depths and affecting
495 CWCs and other deep-sea communities.

496 Three main sites of origin of DSWC, which are important engines of deep-sea currents and underpin
497 upwelling systems, have been identified so far (*section 3.4*). Furthermore, submarine canyons, besides
498 being biodiversity hotspots, have been identified as structures that favour downwelling currents as
499 well as litter and pollutants transport. These sites and submarine structures, and everything that
500 happens close to them, should be considered critical to manage in order to protect deep-sea habitats.

501 The definition of the future trends of deep Mediterranean ecological status seems a challenge, when
502 the assessment of the present one is still based on scarce and fragmented knowledge. Habitat
503 connectivity, the trophic links amidst species, and the seasonal variability of dynamic processes are
504 part of the missing knowledge. To overcome the limits due to this lack of empirical knowledge,
505 several strategies can be put in place. Firstly, habitat mapping techniques (Fraschetti et al. 2011) and
506 predictive suitability models are highly informative because fundamental to assess both habitats and
507 species distribution, when supported by reliable data. Supporting scientific research in the deep is
508 essential, as well as incorporating timely new knowledge in the plans. Secondly, climate and
509 cumulative impacts models, aiming at assessing present and future environmental conditions through
510 scenario analysis can be suitable tools, since they often incorporate multiple sources of information
511 through expert judgement, which is necessary to overcome the lack of knowledge when decisions are
512 needed (Martin et al. 2012). However, cumulative models have never been applied specifically to the
513 deep Mediterranean, and, still, uncertainty hampers the robustness of tools' results (Gissi et al. 2017).

514 Nonetheless, predictive models can be of great support especially when coupled with real data, and
515 the gathering of new knowledge in real-time can make them more reliable. Finally, the continuous
516 up-take of new knowledge and strict relationship between science, policy, and managers will be
517 essential to predict future conditions.

518

519 *Step 3. Spatially-explicit measures*

520 Here, we reported some considerations for incorporating the four ecological principles and the
521 uncertainty principle that may be inspirational for the future purposes of EB-MSP.

522 Since conservation is considered as priority objective of EB-MSP in the deep Mediterranean, the
523 spatial allocation of human uses should be set once priority conservation areas are defined and their
524 ecological status assessed. Biodiversity hotspot and vulnerable habitats represents the most effective
525 conservation targets, at the current level of knowledge (O’Leary et al. 2012). Anyway, protection
526 goals should go beyond the protection of single species.

527 So far, the spatial identification of deep-sea priority areas of conservation has followed two main
528 approaches. One is the definition of Vulnerable Marine Ecosystems (VMEs), identified on the base
529 of predefined scientific criteria (FAO, 2009), which are set up against significant adverse impacts
530 from fishing activities with bottom-contact gears. According to FAO (2009) VMEs are defined on
531 the base of their i) uniqueness or rarity, ii) functional significance, iii) fragility, iv) recovery difficulty
532 and v) structural complexity. Another approach is the identification of Ecologically or Biologically
533 Significant Marine Areas (EBSAs), which apply similar criteria, but taking into account all human
534 activities, beyond fishery, although never enforced. However, the identification process of both
535 VMEs and EBSAs poorly embedded functional connectivity (Kenchington et al. 2019, Johnson et al.
536 2018). In the deep Mediterranean, the approach of the critical habitats seems more promising, because
537 it incorporates connectivity. Critical habitats, in addition of being essential for the existence of a vast
538 and precious biodiversity, are intended as nodes of connectivity suitable for hosting the recovery of
539 endangered species in the future, thus ensuring their persistence in time (Camaclang et al. 2015). The

540 identification of connectivity nodes amidst deep-sea habitats are of priority concern for protection
541 from both present and future threats. Moreover, the identification and conservation of nursery and
542 spawning grounds of mobile species are essential prerequisites to guarantee pelagic and nekto-benthic
543 species survival (Colloca et al. 2015).

544 Spatial decision should be addressed towards the multiple dimensions of the marine environment and
545 its dynamism (Manea et al. 2019), as emerged in the previous step (*Step 2*). Despite IUCN's
546 guidelines (Day et al. 2012) discourage the application of vertical zoning when dealing with MPAs
547 for the limited knowledge related with benthic-pelagic connectivity, such approach may be beneficial
548 when dealing with multiple planning objectives. Furthermore, beyond static spatial zoning, the
549 dynamic management would be highly beneficial to protect diverse and highly mobile pelagic species
550 (Maxwell et al. 2015). Finally, to ensure a continuous improvement of knowledge, and the long-term
551 monitoring and research activities, the allocation of areas for scientific research and for observing
552 and monitoring systems is suggested, giving priority to historically-studied sites.

553

554 *Step 4. Marine Spatial Plan implementation*

555 The stewardship of the different maritime activities as well as of deep-sea conservation should be
556 coordinated, shared, and act in synergy at both country and regional levels.

557 We found the 32% of the deep Mediterranean corresponds to high seas, whose water column is
558 outside the jurisdiction of any countries until they will declare their EEZ. Moreover, 5.6% of deep-
559 sea waters falling within undefined jurisdictional areas, witnessing a series of geopolitical concerns
560 which are out of the scope of this paper. All these un-managed areas are likely understudied, and no
561 competent authority exists yet to designate and implement them for conservation purposes. However,
562 EB-MSP has to consider conservation priorities towards significant and sensitive deep-sea areas,
563 regardless they fall or not within national jurisdiction.

564 The jurisdictional coverage of deep-sea space between countries is differently distributed. Indeed, we
565 found Spain and France embracing a wider portion of deep sea within their EEZs, and Italy and

566 Greece potentially overtaking with their future EEZs (ca. 21% both). Despite this may raise the idea
567 that the responsibility of the parties involved could be proportional to the potential area managed by
568 each, this may not be the right conclusion. Despite EEZs will be the planning units of MSP in the
569 Mediterranean, the intrinsic ecological connectivity of marine systems contrasts the existing
570 geopolitical boundaries and suggests that, despite the existing difficulty in its implementation, cross-
571 country collaboration makes sense (Mackelworth 2012) to both sustainably exploit and protect deep-
572 sea ecosystems, as already demonstrated for the Adriatic and Ionian Region (Gissi et al. 2018).
573 Nonetheless, the value of declaring the EEZ is on manage and control the sustainable and coordinated
574 exploitation of natural resources, and for this reason, there is the need of multilateral agreements
575 (Chevalier, 2005). Indeed, Mazor et al. (2013) found that conservation efficiency in the
576 Mediterranean would be higher with coordinated plans among multiple countries, highly decreasing
577 its costs.

578 While waiting for EEZs declaration, areas under intermediate jurisdictions should be given priority
579 to apply the precautionary principle, because understudied and unmanaged. These areas can be of
580 priority for international scientific efforts. Moreover, the convergence and collaboration of multiple
581 initiatives towards conservation can be an effective strategy for the deep Mediterranean. The UN
582 Mediterranean Action Plan (UNEP/MAP) and the Barcelona Convention, which are regional
583 initiatives for protecting the Mediterranean Sea, brings good expectations in the view of future
584 international conservation agreements (Rochette et al. 2014). Moreover, the European Union may
585 represent the starting platform for establishing transboundary collaboration (Kark et al., 2009). The
586 two regional strategies for the East (EUSAIR, EC, 2014) and the West Mediterranean (WestMED,
587 EC, 2017) are envisaged as the platforms to collaborate and coordinate the efforts of EU Member
588 States for sustainable blue growth in the Mediterranean. Conservation and sustainable development
589 programmes embracing also the North African countries exist and identify MSP as empowering tool
590 (IUCN, North Africa Programme 2017-2020). MSP is indeed advocated to be one of the most

591 promising tools able to operationalize international agreements under a common regional umbrella,
592 as well as to support conservation (Fraschetti et al. 2018).

593

594 *Step 5. Plan monitoring*

595 The monitoring and evaluation of the plan are the basis to implement EB-MSP as an adaptive process
596 (Ehler 2014). Indeed, monitoring is essential to test past and new plans, feed predictive models, learn
597 from the experience, and reflect habitats and species peculiarities, thus following the mutable nature
598 of both marine environment and human needs (Gissi et al. 2019). The continuous up-take of new
599 knowledge and strict relationship between science and policy will be essential to test on-going plans
600 and predict future conditions, especially in the deep Mediterranean, where knowledge is being
601 produced with multiple efforts from public funds (e.g. HERMES, HERMIONE, MIDAS projects
602 financed by the European Commission).

603 Thus, the planning process of the deep Mediterranean Sea, especially the first planning cycle, should
604 be envisaged as a co-learning process with all the actors that operates in the deep, to gather both
605 existing and missing knowledge. To overcome barriers and bottlenecks, the strict collaboration with
606 multidisciplinary expert groups turns out to be relevant, as past experience demonstrated (Ramirez-
607 Llodra et al. 2011). The identification of knowledge needs for the decisions is confirmed as a priority.

608

609 **5. Conclusions**

610 On the light of the results of the present study the following:

611 **1. Capitalize on the available knowledge while acquiring data.** Most of the scientific knowledge
612 available today needs to be elaborated and harmonized to be functional for a scientifically informed
613 plan. Data-poor marine areas exist, but this does not mean that where data are present, they are
614 actually used to develop effective management plans. The absence of data cannot be an excuse for
615 inaction and all the available data should be actually used to act effectively and oriented. Moreover,

616 climate change impacts on deep-sea ecosystems need to be explored, and related knowledge must be
617 used to orient possible mitigation measures.

618 **2. Incorporate connectivity and multidisciplinary approach.** EB-MSP, by anticipating all the
619 potential impacts affecting the marine components of priority for conservation, whether pelagic or
620 benthic and even beyond the establishment of MPAs, does incorporate the connectivity principle on
621 a large scale. The spatial distribution of species and habitats coupled with a molecular analysis of the
622 relatedness of populations across deep-sea areas is crucial to take into consideration the interactions
623 between Mediterranean areas, source and sink areas, and to identify the priority areas to be protected.

624 **3. Natural capital and ecosystem services of the deep sea.** At present we have no clear idea of the
625 quantitative relevance of the natural capital of deep-sea Mediterranean ecosystems and we have to
626 adopt a conservative approach or use proxies. At present, the best proxy of ecosystem services is
627 represented by biodiversity, and EB-MSP and the identification of biodiversity hot spots is a priority.

628 **4. Move forward for deep-sea protection.** There is no way to achieve the Aichi targets without
629 including the deep sea within the target areas for protection. However, the identification of the best
630 areas to be protected requires as a pre-requisite an informed EB-MSP. We support the reinforcement
631 of the already existing conservation tools, as the FRAs, through their implementation as an
632 ecosystem-based conservation measure and not only fishery-oriented. However, this model of marine
633 protection does need clear enforcement and must be fed by the connectivity principle to guarantee
634 that deep-sea species and habitats are actually protected.

635 **5. Calling for multi-lateral agreements.** Managing deep-sea habitats means, especially in the
636 Mediterranean Sea, the definition of bi- or multilateral agreements, as all of the deep-sea
637 biogeographic areas are shared between at least 2 countries.

638 We proposed that marine spatial plans coordinate with each other respecting the sub-regional strategy
639 set up and adopted by the ongoing conservation initiatives.

640

641

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651

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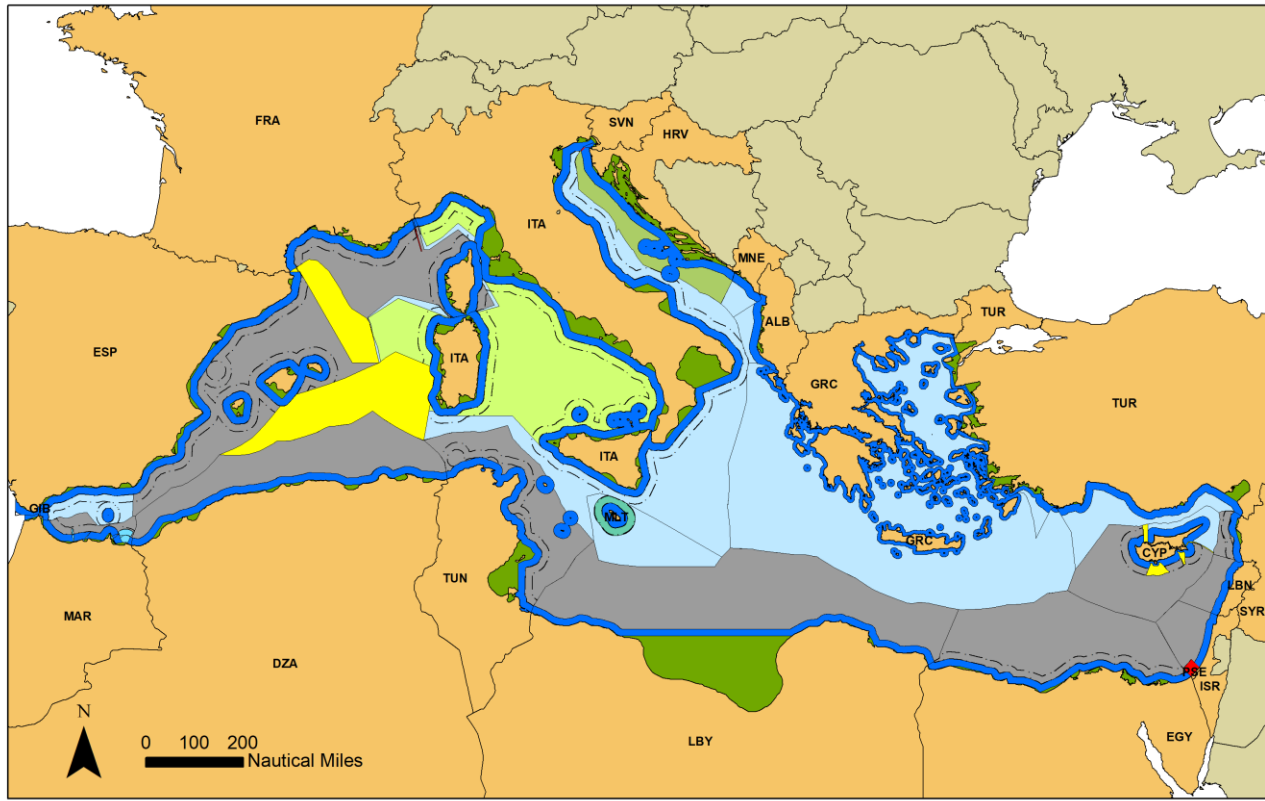
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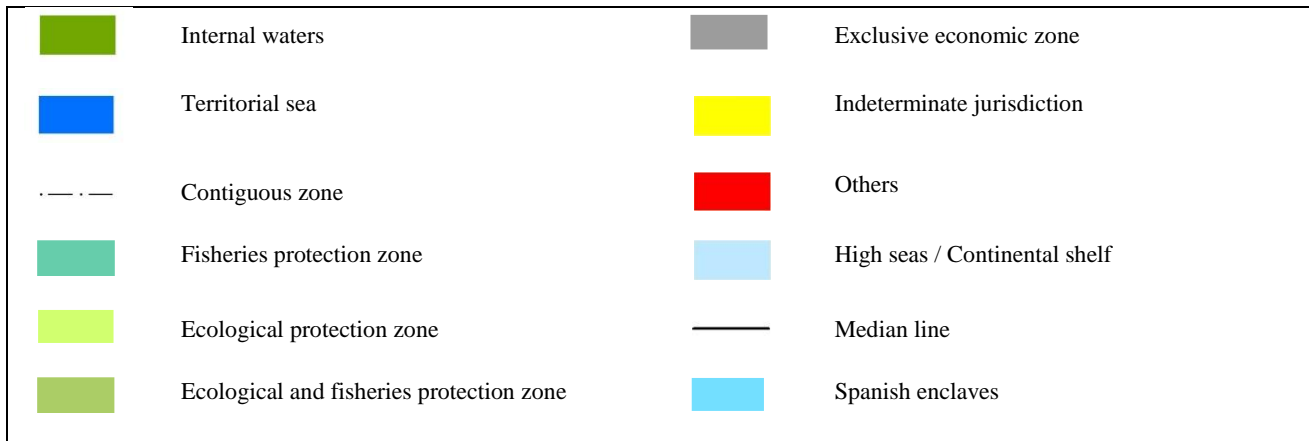
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1075 **Figures**



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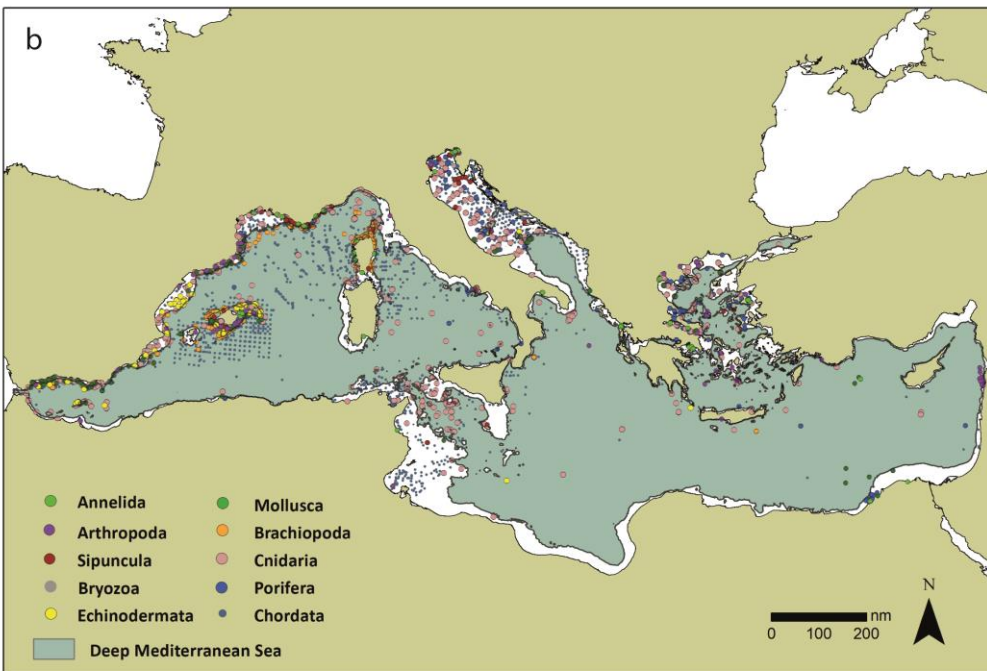
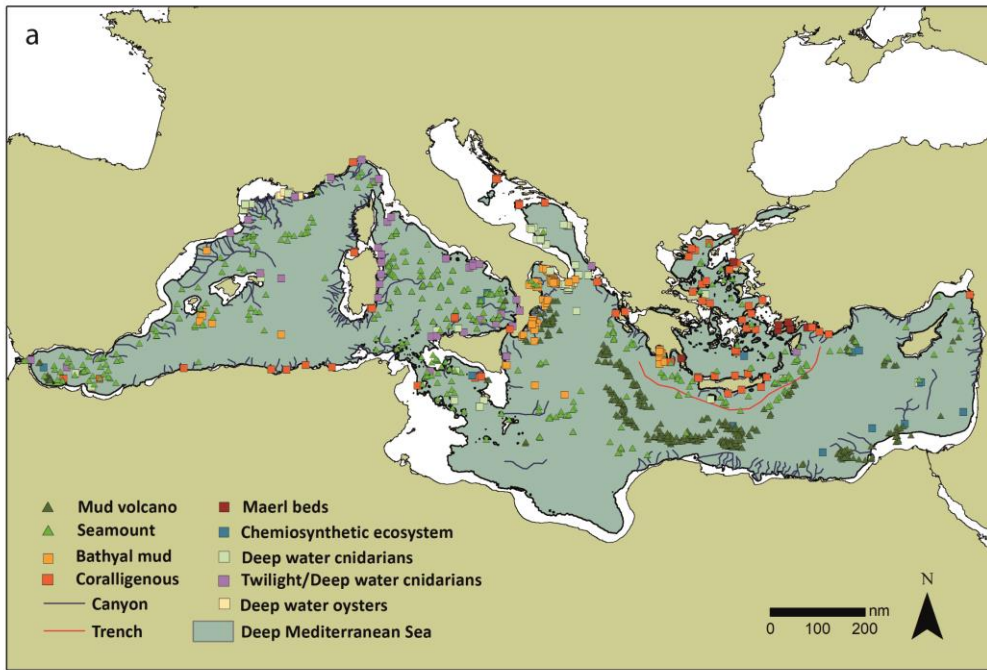
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1078 **Figure 1.** Existing national legislation on the United Nations website: DOALOS. Source: Suárez-
 1079 de Vivero, Juan L. Marineplan, 2019 (www.marineplan.es).

1080 *Disclaimer: The mapped jurisdictions are those that each state has declared and do not imply their
 1081 recognition by third states.

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 1085 **Figure 2. (a)** Map of the benthic deep-sea habitats of the Mediterranean Sea mapped until today.
 1086 Source: Chemosynthetic ecosystems come partly from the literature review made in the framework
 1087 of the IDEM Project (Fabri et al. 2018), and are partly adapted from the CoCoNet database. Mud
 1088 volcanos and seamounts come partly from UNEP database (<http://data.unep-wcmc.org/>), and partly
 1089 from Mascle et al. 2014 and Würtz and Rovere 2015 (<https://portals.iucn.org/library/node/45816>),
 1090 respectively. Submarine canyons were adapted from Migeon et al. (2012) by Fabri et al. (2018),
 1091 which also mapped the Hellenic trench. **(b)** Map of the sightings of the species proposed as of
 1092 priority for protection in the deep Mediterranean Sea (Oceana 2009, Oceana 2017) grouped and
 1093 represented in Phyla. The species are not only the ones strictly associated with deep-sea habitats and
 1094 the Mediterranean, but also species that spend part of their life in the deep Mediterranean Sea,
 1095 during specific life stages and following peculiar behaviours. Source: OBIS database (Ocean
 1096 Biogeographic Information System, <https://mapper.obis.org/>)

Steps of the EB-MSP process* based on Ecological Principles **	Application of the Ecological Principles in the EB-MSP of the deep Mediterranean Sea	Incorporation of the Uncertainty Principle in the EB-MSP of the deep Mediterranean Sea
1. Objectives of MSP in the deep Mediterranean Sea		
<ul style="list-style-type: none"> -> Delimiting targets of environmental conservation and maritime uses based on natural resources. 	<ul style="list-style-type: none"> -> Establish new and enforced ASMTs, based on the knowledge related to habitats and species of priority for protection. -> Balance the costs and benefits of conservation across shallow and deep-sea areas. -> Control, monitor, and limit existing and growing human impacts (e.g. renewable energy, marine bioprospecting, mining). -> Establish priorities for conservation at deep-sea biogeographical regions. 	<ul style="list-style-type: none"> -> Include the objective of increasing the knowledge and support scientific research in the objectives of the plan. -> Support the process of knowledge building by ensuring that scientific research can last long in time.
2. Defining the existing and future conditions		
<ul style="list-style-type: none"> -> Building of a planning-oriented data and knowledge collection for an informed marine spatial plan. 	<ul style="list-style-type: none"> -> Map priority species and habitats for conservation (e.g. submarine canyons, seamounts, coral gardens). -> Consider dynamism and mobility of organisms, both horizontally and vertically, at the scale of deep-sea biogeographical regions (e.g. cetaceans, fish communities, migrant species). -> Consider oceanographic features (e.g. upwelling and dense shelf water cascading events - DSWC). -> Consider both connectivity and the isolated nature of deep-sea ecosystems. 	<ul style="list-style-type: none"> -> Map knowledge availability on habitat connectivity, species, trophic links and functions, seasonal variability of dynamic processes. -> Adopt modelling techniques (e.g. habitat mapping, predictive suitability models, climate and cumulative impacts models) as decision support tools for EB-MSP. -> Increase the knowledge and support scientific research in the deep by mapping research institutes that work on producing deep-sea knowledge, and research sites and activities (e.g. research cruises, sampling sites).
3. Spatially explicit measures		
<ul style="list-style-type: none"> -> Identify priority areas for conservation. -> Allocate human uses. 	<ul style="list-style-type: none"> -> Protect critical habitats (CH) as nodes of connectivity (e.g. Cold-Water Corals, CWC). -> Consider vertical zoning according to the marine multi-dimensionality and the mobility of key species over space and time, to control and reduce potential impacts from maritime uses. -> Consider seasonality and temporal variations of migratory species (e.g. cetaceans) to adopt a dynamic ocean management approach. 	<ul style="list-style-type: none"> -> Put in place sustainable management measures for the sustainable use of the deep to control potential impacts out of the priority areas of conservation (Precautionary principle). -> Allocate areas for scientific research (to support the increasing of knowledge and scientific research), giving priority to historically-studied sites, to support long-term monitoring and research. -> Establish a monitoring plan of the deep Mediterranean in time and space.
4. Marine Spatial Plan implementation		
<ul style="list-style-type: none"> -> Establish multi-lateral and international agreements. -> Support transboundary and coordinated MSP. 	<ul style="list-style-type: none"> -> For priority deep-sea areas of conservation in territorial waters, adopt planning instruments under the premises of coastal States (UNCLOS). -> For priority areas of conservation in the high seas, build the implementation of the measures on the instruments from existing legal sources (e.g. Barcelona Convention, EU Directives, regional strategies), and engage with existing platforms for collaboration (e.g. EUSAIR, WestMED). -> Explore areas on which to coordinate with non-EU countries based on shared priorities and agendas. 	<ul style="list-style-type: none"> -> In international fora, areas under intermediate jurisdictions should be given priority to apply the Precautionary principle, because undisturbed and unmanaged. These can be the priority focus for international scientific efforts. -> Secure and control that monitoring and scientific research is carried on according to the plans. Secure funds for plan implementation and scientific research as international priority.
5. Plan monitoring and evaluation		
<ul style="list-style-type: none"> -> Apply adaptive management. -> Carry on an enforced monitoring. 	<ul style="list-style-type: none"> -> Collect data, information, and knowledge acquired from the implementation of the plan in the deep Mediterranean Sea (learn from the experience) from multiple sources (e.g. scientists, economic actors, decision makers, stakeholders). -> Set-up an evaluation mechanism that include deep-sea experts, policy makers, and stakeholders, to assess the efficiency and effectiveness of the plan in the deep sea (relationship between science and policy), adopting a multidisciplinary approach. 	<ul style="list-style-type: none"> -> Assess the knowledge acquired and the new sources of uncertainty (including new areas of priority) to readdress the research questions in light of the learning co-production conducted through the planning process.

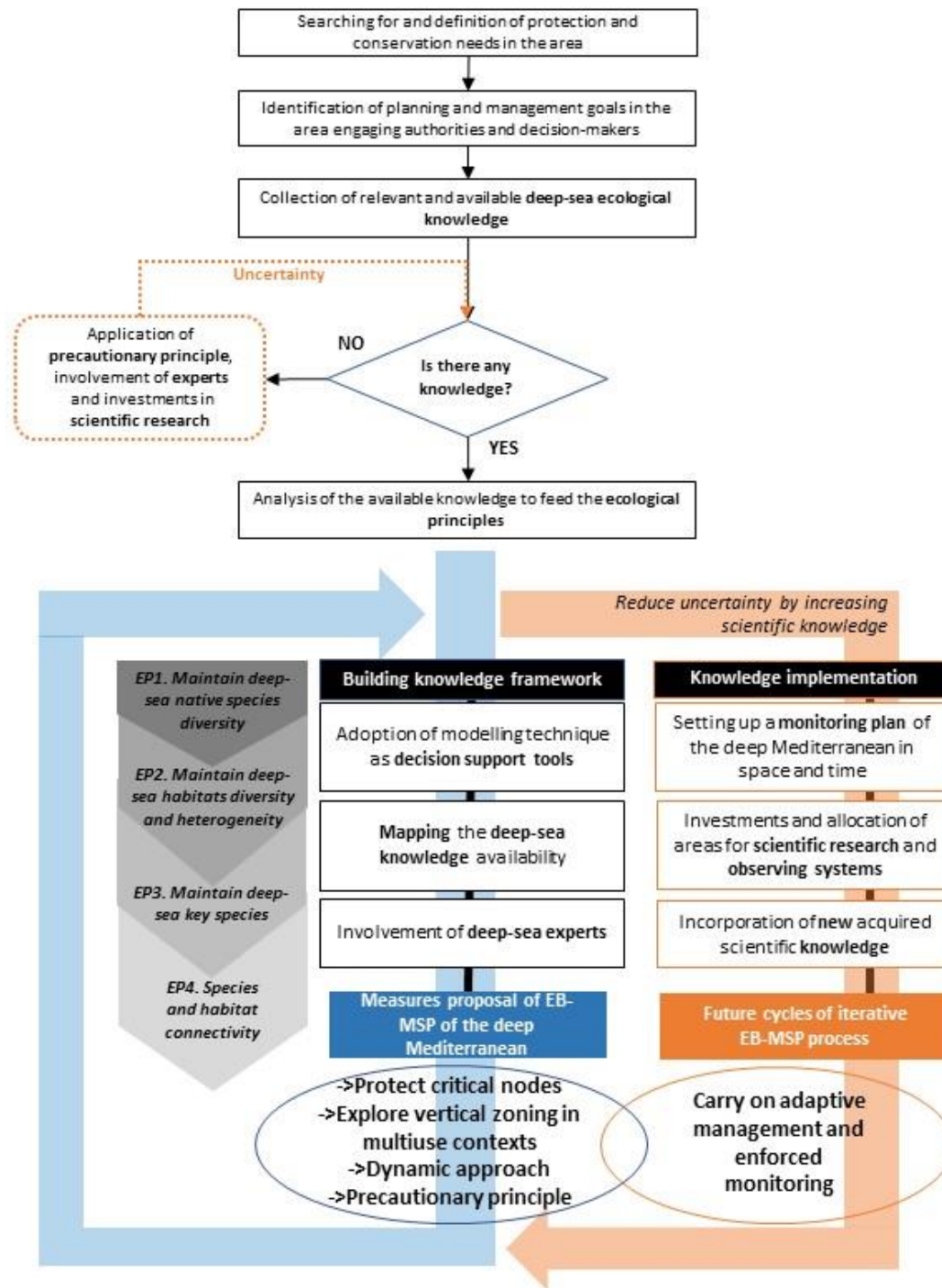
*from Ehler and Douvrou 2009

**from Foley et al. 2010

* according to the existing knowledge available from literature and ongoing studies

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Figure 3. Guidelines to implement an EB-MSP of the deep Mediterranean Sea built on the existing and available knowledge. The recommendations are developed on the basis of the four ecological principles (according to Foley et al. 2010), and the uncertainty principle, and are reported per each key step of the EB-MSP process (Ehler and Douvrou 2009).



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1105 **Figure 4.** Incorporation and application of the ecological principles (*EPs*) and uncertainty principle
 1106 (*UP*) in the EB-MSP of the deep Mediterranean Sea. The use of the **light-blue color** is related to
 1107 the incorporation of the *EPs* within the EB-MSP process to build the necessary knowledge
 1108 framework on which to base the measures proposal. The use of the **orange color** is related to the
 1109 *UP*, which is incorporated in the EB-MSP process through the adoption of the Precautionary
 1110 principle and which is reduced by implementing the available ecological knowledge. The actions
 1111 related to the integration of all principles are synergistic and are embraced in an adaptive and
 1112 iterative process that foresees future cycles of the EB-MSP. More details are present in Figure 3.