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1 **A fast-moving target: achieving marine conservation goals under shifting**
2 **climate and policies**

3

4 Running head: conservation & climate and policy shifts

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33

34 **Abstract**

35 In the Anthropocene, marine ecosystems are rapidly shifting to new ecological states.
36 Achieving effective conservation of marine biodiversity has become a fast-moving target
37 because of both global climate change and continuous shifts in marine policies. How prepared
38 are we to deal with this crisis? We examined EU Member States Programs of Measures
39 designed for the implementation of EU marine policies, as well as recent European Marine
40 Spatial Plans, and discovered that climate change is rarely considered operationally. Further,
41 our analysis revealed that monitoring programs in marine protected areas are often insufficient
42 to clearly distinguish between impacts of local and global stressors. Finally, we suggest that
43 while the novel global Blue Growth approach may jeopardize previous marine conservation
44 efforts, it can also provide conservation opportunities. Adaptive management is the way
45 forward (e.g. preserving ecosystem functions in climate change hotspots, and identifying and
46 targeting climate refugia areas for protection) using Marine Spatial Planning as a framework
47 for action, especially given the push for Blue Growth.

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52 **Introduction**

53 Current local and global stressors continue to alter marine ecosystems at alarming rates
54 (Halpern et al. 2008, Hoegh-Guldberg and Bruno 2010, Poloczanska et al. 2013, Halpern et al.
55 2015), despite considerable intentions in the past few decades to turn the tide. Marine
56 protected areas (MPAs), and especially no-take marine reserves, are considered one of the
57 main instruments for achieving the objectives of marine conservation (Halpern et al. 2010).
58 Several decades of studies have indeed shown that, when well managed and enforced, MPAs
59 can maintain and restore biodiversity and ecosystem functions (Edgar et al. 2014, Sala and
60 Giakoumi 2017). A decade ago, Parties of the Convention on Biological Diversity agreed to
61 protect 10% of their marine waters by 2020 (Aichi Target 11). Nonetheless, recent
62 assessments showed that, so far, only about 2% of the global ocean is included in fully or
63 highly protected areas (Lubchenco and Grorud-Colvert 2015, Claudet and Pendleton 2018),
64 the two classes of MPAs unambiguously providing high ecological benefits (Zupan et al.
65 2018b). The rest of the designated MPAs either allow significant extractive activities that
66 undermine biodiversity conservation objectives (Giakoumi et al. 2017) or are “paper parks”
67 with little positive impact on marine ecosystems (Lubchenco and Grorud-Colvert 2015, Sala et
68 al. 2018). During the 2014 World Parks Congress it was stressed that the current 10% target,
69 recently reached in European waters ([https://www.eea.europa.eu/highlights/eu-reaches-the-](https://www.eea.europa.eu/highlights/eu-reaches-the-aichi-target)
70 [aichi-target](https://www.eea.europa.eu/highlights/eu-reaches-the-aichi-target)), will not be sufficient to achieve conservation goals, and that 30% protection or
71 more for each marine habitat could be required (O’Leary et al. 2016). In this already
72 problematic arena, two looming challenges could further jeopardize the contribution of MPAs
73 to achieving conservation goals.

74 The first fast-unfolding challenge is global climate change, which modifies the marine
75 environment at alarming rates, with severe impacts on marine ecosystems (Hoegh-Guldberg
76 and Bruno 2010, Poloczanska et al. 2013, IPCC 2014, Gattuso et al. 2015, IPCC 2018).
77 Recently, it was shown that the ocean is warming even faster than previously thought (Cheng
78 et al. 2019). In areas where climate change is rapidly altering the ocean physico-chemical
79 conditions, local populations of species are collapsing or expanding with changes in
80 assemblage configurations inevitably leading to changes in community interactions and
81 possibly also in ecosystem functioning. Under the threat of climate change, preserving marine
82 ecosystems and local biodiversity is an increasingly difficult challenge and potentially
83 unachievable target, even within effectively managed MPAs.

84 The second challenge is the ratchet-like adoption of new marine policies. Their
85 implementation, while promoting jobs and innovation in the short-term, could have
86 antagonistic objectives difficult to reconcile and potentially conducive to new sources of
87 disturbance, undermining the essential functions of MPAs that are intended to be very long-
88 term. Most notable is the recent push towards policies supporting Blue Growth that was
89 initiated in 2012 by the 4th United Nations Conference on Sustainable Development Rio+20,
90 and was strongly supported by the Food and Agriculture Organization (FAO). Blue Growth is
91 clearly reflected in the United Nations Sustainable Development Goal no. 14 for 2030 that
92 aims to “conserve and sustainably use the oceans, seas and marine resources” (Nations 2015).
93 The concept of Blue Growth is young and it has no generally agreed definition (Eikeset et al.
94 2018). This leads to many problems in its interpretation (Voyer et al. 2018), and shifts back
95 from a pure conservation perspective to a utilitarian sustainable use perspective. Still,
96 sustainability in a Blue Growth context has been only vaguely defined and, if misused, can be

97 a slippery slope of compromises to permanent harm. The global shift from sectorial
98 management to Marine Spatial Planning (MSP) (Ehler and Douvère 2009) has the potential to
99 further restrict the space for biodiversity conservation in the ocean if conservation targets are
100 not explicitly included in plans. These situations may increase the risk that the main
101 motivation of stakeholders and managers of marine resources will be monetary and not based
102 on conservation goals. Under the imperative of exploiting marine resources to support Blue
103 Growth, also included in the goal no. 14 of the United Nations Sustainable Development goals
104 (UN, 2015), countries can be driven to plan new uses at sea primarily by economic
105 motivations, overlooking environmental conservation goals, as well as social equity, the other
106 two pillars of sustainable development (Gee 2019). This increases the risk that stakeholders
107 and managers of marine resources overlook hidden ecosystem benefits and costs if only
108 commercial revenues and costs are considered (Börger et al. 2014), at the expenses of multiple
109 environmental, social, and economic benefits and ecosystem services arising from healthy,
110 productive, and resilient ecosystems (Cavanagh et al. 2016).

111 Faced with these two unfolding challenges, effective marine conservation becomes a
112 fast-moving target such that policymakers, managers and scientists have to adjust their
113 expectations and strategies constantly for conservation planning. Here, we aim to address the
114 challenge of achieving conservation targets under shifting conditions, specifically: (1) global
115 environmental change; and (2) policy shift from pure focus on biodiversity conservation to
116 sustainable use of the oceans, and within it the specific change in management strategies, from
117 designating single MPAs to networks of MPAs within an overarching marine spatial plan
118 framework. The European Union (EU) is used here as a case study to examine how these
119 challenges are tackled by a large coordinated group of developed countries with well-

120 developed environmental policies. In particular, we reviewed European programs of measures
121 for achieving good environmental status in European Seas, existing marine spatial plans, and
122 monitoring schemes in MPAs to investigate whether climate change is sufficiently accounted
123 for and whether conservation objectives are embedded into the revised policy toolbox which
124 largely mirror the need for Blue Growth initiatives. We also propose strategies and possible
125 solutions to address the impacts of global change and improve the effectiveness of
126 conservation efforts.

127 **Global change can strongly disrupt current conservation efforts**

128 Current and expected climate change impacts, even under the most optimistic
129 Intergovernmental Panel on Climate Change scenarios (IPCC 2018) pose a tremendous
130 challenge to marine conservation (Pressey et al. 2007). The geographic distribution of species
131 pools is altering rapidly in many regions in part reflecting shifts in ocean isotherms (Pinsky et
132 al. 2013, Burrows et al. 2014, Molinos et al. 2015), and because native species are often
133 replaced by thermophilic invaders (Rilov 2016, Rilov et al. 2018). Heat waves cause mass
134 mortalities (Garrabou et al. 2009) while “dead zones” are expanding along with episodic
135 phenomena that cause large-scale hypoxia events (Bakun 2017). As a consequence of such
136 complex processes major ecological shifts, including local or even regional collapse of entire
137 ecosystems such as coral reefs (Hughes et al. 2017) or macroalgal forests (Vergés et al. 2016,
138 Wernberg et al. 2016), are increasingly observed. Deep-sea biodiversity can also be vulnerable
139 to global climate change (Danovaro et al. 2017b). Synergistic effects among stressors are
140 increasingly documented and predicted as well (Mora et al. 2013, Boero et al. 2018). In such
141 dynamic conditions, even the largest and best managed MPAs cannot be expected to achieve

142 their conservation goals, especially in global change hotspots where both environmental
143 conditions and ecological communities are shifting rapidly.

144 Recently, Roberts et al. (2017) listed some ecological pathways in which well-
145 managed MPAs can actually aid in mitigation and adaptation to many aspects of climate
146 change. However, empirical evidence for mitigation or adaptation is still rare, and some
147 climate effects are surely unavoidable inside MPAs. Bruno et al. (2018) have recently
148 observed that the thermal ranges of marine communities will be crossed in the tropics by 2050,
149 and further stated that climate change severely threatens many of the world's MPAs,
150 especially at low latitudes. Undoubtedly, local population collapses of native species that are
151 sensitive to ocean warming cannot be realistically mitigated even by the most effectively
152 protected MPAs. For example, in the southeastern Mediterranean Sea, where coastal waters
153 have warmed by 2-3°C in the past few decades, sea urchin populations totally collapsed along
154 the entire coastline (Yeruham et al. 2015, Rilov 2016), including within the only well-enforced
155 marine reserve that has been protected for over two decades (Rilov 2016, Rilov et al. 2018).
156 At the same time, MPAs cannot prevent the establishment of spreading thermophilic (often
157 alien) species, unless they specifically facilitate native populations of strong competitors or
158 predators (Giakoumi et al. 2018). In this situation, the chances of maintaining existing species
159 communities are most probably very low even under the most stringent management regimes.
160 Should we then keep targeting the protection of the established native biodiversity only, or
161 perhaps accept the new situation and set fresh criteria for a healthy ecosystem state under a
162 shifting ocean climate? In other words, in climate change hotspots, should managers give up
163 their attempts to preserve native communities (a main statutory conservation goal) and shift
164 their attention to other areas, or should they rather shift their expectations and adjust their

165 conservation targets to better suit the new situation imposed by global stressors? We address
166 some of these questions below.

167 **The policy shift from pure conservation targets to sustainable ocean use**

168 The global consensus to protect marine ecosystems dates back to the 1950's when the
169 Geneva Convention on the Law of the Sea was adopted. After that period, in the 1970's
170 several other conventions (e.g., Ramsar, World Heritage) and the United Nations Environment
171 Program (UNEP) were launched. More recently, the United Nations Convention on the Law of
172 the Sea (UNCLOS) and the Convention on Biological Diversity (CBD) came into force (in
173 1982 and 1993 respectively), highlighting and strengthening the role of MPAs. Global efforts
174 to implement the CBD led to a substantial increase of MPAs worldwide and to the
175 establishment of important networks of protected areas, such as the Natura 2000 network in
176 Europe, which includes 3957 marine sites, covering 11.7% of EU Member States' territorial
177 waters (Mazaris et al. 2018).

178 In the last decade, meanwhile, the oceans have been conceptualized as spaces that offer
179 development opportunities for a so-called blue economy (Voyer et al. 2018), (U.N. 2012).
180 Some consider oceans to be a modern economic frontier (OECD 2016), to respond to global
181 challenges such as food security, medical care, and renewable energy. Emerging ocean-based
182 industries for the support of Blue Growth often include, coastal tourism, aquaculture, offshore
183 wind farms, marine biotechnology, and seabed mining (e.g. EC, 2012).

184 In principle, "blue economy" aims to support and improve human welfare and social
185 stability, while at the same time intends to reduce environmental risks and ecological losses
186 (UNEP et al. 2012), which is essentially in line with the aim of MPAs as tools for achieving

187 conservation objectives. Even heavily impacting activities like seabed mining may offer a
188 strong leverage for marine conservation through the expansion of networks of offshore MPAs
189 to protect the deep sea (Mazaris et al. 2018). For example, because of the evidence that deep-
190 sea areas that host high biodiversity coincide with ferro-manganese crusts, and thus are rich in
191 nodules and seamounts, the EU is supporting the creation of networks of offshore MPAs to
192 protect unique deep ecosystems and pose restrictions to mining activities based on strategic
193 environmental assessments (EU 2017). The momentum created by several G7 and G20 States
194 for the exploration and possible exploitation of mineral resources in the deep Atlantic and
195 Pacific Oceans and in the Mediterranean Sea is pushing the international scientific community
196 to investigate the potential consequences and, eventually, to propose the establishment of
197 different forms of marine protection in the deep sea (Danovaro et al. 2017a).

198 Coastal tourism can also offer opportunities for marine conservation. Worldwide,
199 MPAs often failed to achieve their conservation objectives due to lack of funding, while with
200 the right policies and governance, the development of coastal tourism can offer economic
201 support to the viability of MPAs (Depondt and Green 2006). Bioeconomic models have shown
202 that marine reserves can represent a tool for Blue Growth, as in the medium term they increase
203 the benefits for the local economy offsetting management and opportunity costs (Roncin et al.
204 2008, Sala et al. 2013). Protected areas associated with socioeconomic benefits for local
205 people are more likely to produce positive conservation outcomes (Oldekop et al. 2016,
206 Pascual et al. 2016), and can have higher acceptance and support by stakeholders, which is a
207 prerequisite for their effectiveness (Gleason et al. 2010, Di Franco et al. 2016, Christie et al.
208 2017). Overall, then, MPAs are not *per se* in conflict with Blue Growth.

209 However, in practice there is always the risk that a policy with negative implications
210 for conservation will be greenwashed with the application of a ‘Blue Growth’ label (Howard
211 2018). A tendency of designating remote and isolated areas for conservation, residual to
212 commercial use and therefore not yet heavily exploited is acknowledged in the literature
213 (Devillers et al. 2015), with the result of aiding a country's progress towards the Aichi target,
214 while missing the representativeness and effectiveness of conservation (Jones and De Santo
215 2016). For example, the continental shelf of Australia – where most activities potentially
216 harmful to marine biodiversity are concentrated – is scarcely covered by MPAs (Barr and
217 Possingham 2013), and in some cases, this was due to “a deliberate avoidance of areas with
218 high fishing value and mineral resources” (Edgar et al. 2008) (e.g., Spalding et al. 2013,
219 Devillers et al. 2015, Bax et al. 2016). Such “tactics” should certainly be avoided.

220 **The policy shift from single MPAs to MPA networks, and finally to conservation through**
221 **marine spatial plans**

222 Initially, MPAs were designated on a case-by-case basis but soon the vision of moving
223 from single MPAs to MPA networks gained momentum (Sala et al. 2002, Boero et al. 2016)
224 (Grorud-Colvert et al. 2014). Conservation and ecological networks of MPAs are not ad hoc
225 aggregations of independently-designed MPAs but a system of MPAs in a given area aimed at
226 protecting conservation priority sites and/or connected by the movement and dispersal of
227 larvae, juveniles, or adults (Grorud-Colvert et al. 2014). Networks of MPAs have important
228 ecological benefits, such as adequate representation of marine biodiversity, protection of all
229 stages of life cycles, provision of stepping stones of genetic, demographic and ecological
230 connectivity, and better overall resilience to climate change impacts (Olsen et al. 2013). Over
231 time, MPA networks have been incorporated within the wider concept of ecosystem-based

232 marine spatial management, which recognizes the full array of interactions within an
233 ecosystem, including human uses (Katsanevakis et al. 2011).

234 In parallel with the growth of the idea of MPA networks, the recognition of the need
235 for a more holistic marine spatial planning process has developed by different nations. Marine
236 spatial plans are considered as a tool to support ecosystem-based management of the oceans
237 (Ansong et al. 2017, UNEP 2017). Marine spatial planning is a “public process of analyzing
238 and allocating the spatial and temporal distribution of human activities in marine areas to
239 achieve ecological, economic, and social objectives that are usually specified through a
240 political process” (Ehler and Douvère 2009). Marine spatial planning has its roots in marine
241 conservation, and the original zoning plan of the Great Barrier Reef Marine Park in Australia
242 is considered to be the initiator of marine spatial planning globally (Jay et al. 2013). Today,
243 nearly 27% of the world’s exclusive economic zones (EEZs) are managed by enforcing marine
244 spatial plans in 22 countries, and about 26% more will be managed in the near future due to
245 the ongoing marine spatial planning processes in 44 additional countries (Frazao Santos et al.
246 2019). However, since its inception the conservation focus of marine spatial plans seems to
247 have weakened with an increasing focus on managing disputes for marine space among
248 different users of the sea (Merrie and Olsson 2014).

249 If marine spatial planning is applied – as it should be – through an ecosystem-based
250 approach, it has the potential to substantially benefit marine conservation (Fraschetti et al.
251 2018). Nevertheless, there are several concerns regarding the different interpretations of the
252 sustainability concept between marine spatial plans and marine environmental policies (Qiu
253 and Jones 2013). Under the Integrated Maritime Policy (EC 2007), the European Union
254 conceived environmental protection and sustainable development as two pillars of the same

255 strategy, by issuing two distinct Directives, the Marine Strategy Framework Directive
256 2008/56/EC (EC, 2008), and the Maritime Spatial Planning Framework Directive 2014/89/EC
257 (EC, 2014). However, they addressed contradictory policy goals (Gee 2019), compounded by
258 the linguistic choice of “maritime” instead of “marine” spatial planning. Very recently, the
259 new “MSP Global” initiative, a joint roadmap to accelerate “Maritime/Marine Spatial
260 Planning” processes worldwide launched by UNESCO-IOC and the European Commission,
261 specifically focuses on priority actions related, among others, to implementing Ecosystem-
262 based marine spatial planning in practice (source: <http://www.MSPglobal2030.org/>). Indeed,
263 the way countries will operationalize sustainable development between the power-play of
264 maritime activities and uses in their national marine spatial planning initiatives will potentially
265 bring both threats and opportunities for conservation and human wellbeing.

266

267 **Is climate change sufficiently addressed in marine conservation planning and policy**
268 **implementation? The European case**

269 We utilized the European seas as a case study to test how climate change
270 considerations are integrated into policies and legislation related to marine conservation and
271 planning. The EU has issued a number of legislative acts that directly address marine
272 conservation (Fraschetti et al. 2018). The most recent (but already in place for a decade) is the
273 Marine Strategy Framework Directive (MSFD, Council Directive 2008/56/EC; amended by
274 the Commission Directive 2017/845). The MSFD is of direct relevance to the Birds (Council
275 Directive 79/409/EEC) and Habitats (Council Directive 92/43/EEC) Directives, which are the
276 EU legislative instruments that set out the rules for the establishment of the Natura 2000
277 network of marine and terrestrial protected areas. The basic goal of the network is to ensure

278 the long-term maintenance of Europe’s endangered species and habitats at a “favourable
279 conservation status” (Fraschetti et al. 2018). The MSFD aims at achieving good environmental
280 status (GES) of the EU’s marine waters and fosters the use of MPAs (inclusive of the Natura
281 2000 network) as an important tool to fulfill this objective. The MSFD requires EU Member
282 States to develop strategies to achieve GES. In this regard, EU Member States have published
283 their Programmes of Measures (PoM) that identify those actions needed to be taken in order to
284 achieve or maintain GES. However, GES can be put at significant risk by climate change,
285 which exerts its influence on a broader scale and with less predictable trends and patterns than
286 any local human activity. This is acknowledged in the preamble of the MSFD which states
287 that “in view of the dynamic nature of marine ecosystems and their natural variability, [...]”
288 and the impact of climate change, it is essential to recognise that the determination of good
289 environmental status may have to be adapted over time.”

290 To examine how the issue of climate change is being treated in practice, we scanned
291 the recently published PoMs by the twenty-three coastal EU Member States to assess if and
292 how climate change is being addressed in their current implementation of MSFD. The results
293 showed that climate change was not mentioned at all in four PoMs (Denmark, Greece, Ireland
294 and Latvia). In eight countries (Spain, France, United Kingdom, Germany, Croatia, Estonia,
295 Romania and Finland) specific measures and objectives address climate change (See Table S1
296 in Supporting Information for further details). In the PoMs of the remaining eleven countries,
297 climate change was only mentioned in general statements but no specific measures were
298 foreseen (Figure 1). Climate change is considered in these PoMs as an interaction influencing
299 other environmental and human components, such as biodiversity, fisheries and sea-level rise.
300 Nevertheless, some of the countries have published national strategies specifically to address

301 adaptation to climate change, for example Portugal, Italy and Croatia (UNEP 2015; Resolution
302 of the Council of Ministers no. 56/2015, Galluccio et al. 2017)).

303 The Natura 2000 network potentially offers a solid basis for EU Member States to
304 satisfy many of the criteria required for determining GES, including the establishment of
305 systematic monitoring schemes and thus the production of comparable outcomes across
306 countries. However, what is missing is a clear direction towards integrating and utilizing the
307 collected information on species, habitats and threats with comprehensive, flexible and
308 consistent site-based assessments (including long-term monitoring) that also address possible
309 impacts of climate change (Rilov et al. 2019). The lack of criteria and practical rules for
310 translating the knowledge collected in the Natura 2000 sites into GES assessments and thus to
311 conservation recommendations and priorities is problematic.

312 We also scanned the marine spatial plans published by different European countries
313 (some are not published yet) to assess how they address climate change. We found that climate
314 change is considered mainly as a challenge in the general planning framework of marine
315 spatial plans (Figure 2, 3, Table S2). Only in three countries (UK, Netherlands and Sweden)
316 considered adaptation and mitigation to climate change in the marine environment as an
317 objective of their plan, for which specific actions are put in place. All other countries ignore
318 this threat entirely in their plans. Interestingly, the British and Dutch plans also include climate
319 change as a management concern in the plan's monitoring phase, in order to get new
320 knowledge about the effects and the response of the marine environment and of human uses to
321 climate change along with the implementation of the plan. The fact that climate change as a
322 threat and challenge is basically absent in the PoMs and marine spatial planning documents of

323 most EU Member States clearly indicates that in practice present and future climate change
324 impacts are largely ignored by marine and maritime managers.

325 **Can existing MPA monitoring schemes help to detect climate change impacts?**

326 In order to distinguish between the effects of local stressors (e.g., some fishing or
327 recreational activities) that occur with varying intensity inside or outside MPAs (Zupan et al.
328 2018a), and global stressors occurring both inside and outside (e.g., warming), the best
329 monitoring design would include time series from both inside and outside MPAs, before and
330 after the establishment of the MPA (Benedetti-Cecchi 2001, Thiault et al. 2017). To test if the
331 information gathered from ecological studies carried out in MPAs would allow for the
332 detection of climate change impacts through long-term monitoring, we carried out a
333 systematic scientific literature review (that is, not including reports and grey literature) (details
334 in Table S3) to evaluate the existence of time series longer than two years across
335 Mediterranean nationally-designated MPAs and EU Natura 2000 sites (treated jointly as
336 MPAs hereafter). For this analysis, we focused on the Mediterranean Sea as it represents a
337 major hotspot of climate change with strong impacts already acting on its ecological
338 communities (Lejeusne et al. 2010, Marbà et al. 2015) and where marine ecological research
339 has a long tradition. Overall, we examined 89 scientific publications covering 35 different
340 protected areas including 24 nationally designated MPAs, 10 EU Natura 2000 sites and one
341 international sanctuary (Figure 4, Table S3). Our analysis shows that most research efforts
342 were concentrated in the western Mediterranean (Spain, Italy and France), with only a few
343 studies showing coordinated activities in more than one of these countries (e.g., study ID 22,
344 43-46, 85, 86 in Table S3). The majority of the studies were largely fragmented, covered a
345 time span shorter than 10 years and very few exceeded 10 successive sampling dates (e.g.,

346 study ID 19, 30, 46, 61, 87). The most recent literature reporting time series does not provide
347 data beyond 2014 (with the exception of (Mazaris et al. 2017) on sea turtles), and 75 out of the
348 89 published time series were completed before 2010. Interestingly, most long-term series
349 were carried out with the support of regional, national or European research projects, and were
350 only occasionally totally or partially financed by the MPA's management body as part of a
351 continuous monitoring plan (16 studies; e.g. study ID 5, 12, 33, 51, 65). Few studies benefited
352 from private or university funding (e.g. study ID 30, 34, 46, 87).

353 The focus of the monitoring programmes was either on a single species (37 studies, for
354 a total of 14 different species; e.g. study ID 39, 60, 89) or, more generally, on a guild of
355 species or the entire assemblage (52 studies; e.g. study ID 21, 41, 80). The most explored
356 habitats were subtidal rocky reefs and seagrass (*Posidonia oceanica*) meadows, followed by
357 coralligenous formations. Different response variables were investigated, including density or
358 cover (e.g. study ID 35), abundance (e.g. study ID 12), biomass (e.g. study ID 34), diversity
359 (e.g. study ID 29), age and sex of the organisms (e.g. study ID 4, 19), life-history traits (e.g.
360 study ID 39), behavior (e.g. study ID 60), biochemistry (e.g. study ID 74), variables utilized as
361 proxies of the effect of natural or anthropogenic stressors (e.g. study ID 19), and catch data for
362 fish assemblages (e.g. study ID 4) (Fig. 5). Overall, only 32.6% of studies adopted a sampling
363 design allowing a comparison between areas with different protection regimes (fully protected
364 vs. partially protected or unprotected zones) or estimated the effect of protection in MPAs by
365 comparing data acquired before and after the protection started (e.g. study ID 4, 27, 54). Few
366 studies (ca. 20%) considered the effects of global climate change, either correlating one or
367 more environmental variables to the biotic response variable as a proxy of change (8 studies
368 out of 18) or suggesting the potential influence of climate change in the discussion of the

369 article. The most cited process influencing natural assemblages was global warming (e.g.
370 study ID 43, 68), followed by extreme events (e.g. study ID 61, 80), variation in the rainfall
371 regime, variations in the North Atlantic Ocean Index (representing different phases of the jet-
372 stream that affect weather patterns) (e.g. study ID 32), and introduction of invasive species
373 (e.g. study ID 35, 62). However, no study citing climate change adopted a sampling design
374 comparing protected and non-protected areas in an attempt to disentangle the potential effects
375 of protection from the effects of climate change, thus lacking the means to separate the effects
376 of local and global stressors. Practical constraints often limit the potential to adopt rigorous
377 experimental designs in contexts like this one; nonetheless, so far, in most of the cases, heat
378 stress events reported within MPAs *have been* linked to climate change. We stress that
379 applying rigorous experimental designs using MPAs to assess one of the most important
380 processes occurring at basin scale should be a priority.

381 In summary, the lack of long-term monitoring data poses serious limits to our potential
382 to assess the role of MPAs in reaching GES, including their ability to help in assessing or
383 mitigating the effects of climate change impacts (as suggested by (Roberts et al. 2017)). This
384 result is of particular concern considering the tremendous impacts described in the previous
385 sections, and shows that we are substantially ill-equipped to handle the consequences of
386 climate change, even in those areas that can be considered sentinel observatories of the
387 impacts of ocean warming and more broadly to the state of the marine environment as a
388 whole.

389 **Adaptive conservation strategies to address the impacts of global change**

390 Although dealing with global climate change is a huge challenge, changes in perception, and
391 adaptive and creative thinking may offer some plausible courses of action. Here we list some
392 ideas on how to deal with this problem.

393 *Shifting the focus from species to functions in climate change hotspots.* It is quite
394 certain that in the long run we will not be able to protect species sensitive to warming in
395 climate change hotspots, namely areas where climate is changing the most, e.g., where
396 heatwaves are most frequent or intense (Holbrook et al. 2019, Smale et al. 2019). Therefore, a
397 possible solution might be to adapt to the new situation by focusing on maintaining ecosystem
398 functions (support of processes) and services that might otherwise be impacted by changes in
399 species occurrences (Worm et al. 2006). A possible criterion could be that as long as the main
400 ecosystem functions are maintained in a region, regardless of the origin of the species
401 involved, the system is in a good status and protection goals are met. That is, if a native
402 species sensitive to warming has been functionally replaced by an alien or range-expanding
403 species, a good status has been maintained. As a consequence, monitoring should also focus
404 on assessing critical ecosystem functions in the evaluation of conservation targets, using
405 indirect methods such as biological traits analysis (Bremner et al. 2006) and, where possible,
406 direct measurements of ecosystem functions and processes (such as habitat provisioning,
407 community productivity, food web structure, nutrient cycling, metabolic functions). The use of
408 global standardized measures for monitoring, such as Essential Biodiversity Variables (EBVs)
409 (Pereira et al. 2013) and the more recent, marine focused Essential Ocean Variables (EOVs)
410 (Miloslavich et al. 2018), might provide common standards for some of these components.
411 SMART conservation objectives (and adequate indicators) are needed for effective evaluation
412 of management performance (ICES 2005), i.e. (i) Specific: clearly identifying the state to be

413 achieved; (ii) Measurable: referring to measurable properties of ecosystem functioning, so that
414 the development of indicators and reference points is feasible; (iii) Achievable: being possible
415 to achieve (e.g. not including conflicting objectives, properly accounting for global change);
416 (iv) Realistic: being feasible to achieve with the available resources for monitoring and
417 management; and (v) Time bound: having a clear time scale for their achievement.

418 *Adaptive conservation planning in marine spatial planning.*

419 The implementation of marine spatial planning provides not only challenges but also a
420 series of opportunities for conservation globally. For example, if systematic conservation
421 planning is applied and implemented in the framework of marine spatial planning, advances
422 can be made in marine conservation by extending MPAs, in particular fully protected areas or
423 zones, and by creating MPA networks that are coherent, representative, and more robust at
424 multiple spatial scales. Effective design of networks will rely on advances made in mapping
425 population connectivity, by combining genetic and oceanographic data and models (Hodgson
426 et al. 2009, Andrello et al. 2013, Coleman et al. 2017, Padrón et al. 2018). Systematic
427 conservation planning puts operational targets for all ecological components but also accounts
428 for the distribution of human activities and thus can settle disputes among sectors and balance
429 conservation and economic activities (Gissi et al. 2018). A basic requirement of marine spatial
430 planning (but not commonly applied in practice) is adaptive management, in which decisions
431 can be modified based on new knowledge acquired on the system, environmental change, and
432 assessment of the effectiveness of previous decisions and management actions (Parma 1998,
433 Katsanevakis et al. 2011). It is in the light of such knowledge that new policies should be
434 formulated rather than the ad hoc short-term and static manner that happens today.

435 Ideally, marine spatial plans will be revised taking account of monitoring results and
436 evaluation of their effectiveness to achieve the established planning objectives (Ehler 2014,
437 Gissi et al. 2019). The assessment of the coherence with (potentially adaptive) conservation
438 targets and sustainability of the actions and measures proposed through the marine spatial
439 plans can be performed in relation to conservation policies and targets. It is the sustainability
440 achieved through implementing the marine spatial plans that must be assessed over time, such
441 plans (ideally) being instruments to achieve both Blue Growth and conservation targets in the
442 changing ocean. However, the temporal framework of the planning revisions might not be able
443 to detect shifts that take place at different temporal scales (Kidd and Ellis 2012), as dramatic
444 changes over months or days can also occur (Hein et al. 2016). The implementation of
445 dynamic ocean management (Maxwell et al. 2015) within marine spatial plans can constitute
446 an opportunity to adapt to ecological shifts, by acting in real-time. In this context, working to
447 incorporate change in marine spatial plans is crucial, since currently only a few studies on
448 marine spatial plans incorporate climate change in marine spatial planning processes (Gissi et
449 al. 2019). Finally, long-term monitoring will be of paramount importance to assess the effects
450 of climate change and to disentangle global and human-induced changes in marine ecosystems
451 contrasting time series of data collected inside and outside MPAs (McQuatters-Gollop 2012)

452 ***Targeting refugia from global climate change.*** Where relevant, marine spatial plans
453 should include a climate-ready response strategy that contains areas that can serve as potential
454 climate refugia. Climate refugia are areas where climate-induced physical and biological
455 changes are slower or those that are significantly colder (e.g., upwelling areas or deeper
456 waters) than surrounding areas, especially in fast-warming regions (Keppel et al. 2012, Keppel
457 and Wardell-Johnson 2012). Including refugia habitats in conservation plans (e.g., Smythe and

458 McCann 2018) is a promising approach to help mitigate for climate change implications
459 (Keppel et al. 2015, Jones et al. 2016), especially when these refugia are assembled as a well-
460 connected network or a series of “stepping stones” (Hannah et al. 2014). Strategies for the
461 detection and operationalization of refugia include the use of climate forecasts (in both mean
462 and extreme conditions) to prioritize areas where climate change will not have a considerable
463 effect (Levy and Ban 2013), identifying where current and future species distributions overlap
464 (Terribile et al. 2012), and using historical or current climatic factors (Hermoso et al. 2013).
465 Some countries are already thinking along these lines; for example, Sweden is considering the
466 incorporation of climate refugia in its marine spatial plan in order to identify new MPAs
467 within the planning framework.

468 *Assisted (evolution) adaptation.* Another increasingly-discussed approach of dealing
469 with the climate change challenge is harnessing nature’s innate ability for rapid adaptation
470 through transgenerational plasticity, epigenetics and natural selection (Calosi et al. 2016). For
471 some sensitive native species that are critical for local ecosystem functions, or those that have
472 great economic value, “assisted evolution” has been suggested as at least a partial solution.
473 Webster et al. (2017) recently argued that instead of trying to predict which species will be
474 winners under climate change or create potential winners through assisted evolution, we
475 should adopt a “diverse portfolio” strategy to promote climate adaptation. It should be driven
476 by designing actions to facilitate different opportunities for selection across environmental
477 conditions through diverse networks of protected areas, which goes back to developing proper
478 marine spatial plan initiatives while taking these aspects into consideration. Since there is no
479 single solution, the adoption of different tools to enhance the resilience of marine habitats
480 should be the way to go, and MPAs might also benefit from local restoration actions using

481 heat resistant lineages. In this framework, large scale interventions still seem to be challenging
482 but a solid in-depth knowledge of both the selected species and the system to be restored,
483 together with the development of appropriate techniques might become another possibility to
484 address the effects of climate change in the coming decades.

485

486 **Conclusions**

487 Despite the increasing impact of global climate change on marine biodiversity, and some
488 rudimentary efforts to deal with it in nature conservation, it seems that we still mostly plan for
489 the present, i.e. in a business-as-usual scenario, and not for the future, as there is an evident
490 lack of consideration of climate change issues in actual marine management practice. Part of
491 the problem is that the strongest tool that should allow us to distinguish between local and
492 global stressors (mainly climate change) — long-term ecological monitoring inside and
493 outside properly managed MPAs — is still rarely conducted. These problems translate into the
494 difficulty in setting conservation priorities through an marine spatial planning process,
495 although MPAs are considered among the strongest tools for ecosystem-based management in
496 a marine spatial plan context (Katsanevakis et al. 2011). We suggest that stakeholders need to
497 more fully acknowledge the fact that marine conservation is becoming a fast-moving target
498 because of climate change and ongoing unrelated shifts in policies; and we need to address
499 them accordingly. Then, in our efforts to establish networks of effective MPAs we should
500 focus on: (1) making sure we do the science right by continuing (where present) or starting
501 and then maintaining well designed physical and ecological monitoring programs in MPAs;
502 (2) finding the way to deal with climate change hotspots where change is fast and inevitable
503 (i.e., frequency of marine heat waves is increasing and mass mortalities occur or are

504 approaching), and identifying and considering potential refugia areas (where safety margins
505 are large) in conservation plans; (3) thinking about how to set different targets or criteria for
506 the health of the system in climate hotspots (for example, focus on maintaining functions); (4)
507 counting on safety in numbers and habitat diversity by ensuring that protection networks
508 reflect different environmental conditions to allow for climate adaptation; and (5) taking
509 account of these issues when formulating new policies. With eyes wide open, in the
510 framework of both marine spatial plans and Blue Growth, we still have to solve the potentially
511 growing conflicts between protection and increasing human uses, first of all by facing the
512 challenge to define precisely what is ecologically sustainable in the fast-changing ocean we
513 see today.

514

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883

884 **Figures**

885

886 **Figure 1.** How Climate Change (CC) is addressed in the Programmes of Measures (PoMs) for
887 the Marine Strategy Framework Directive (MSFD) by the Coastal EU Member States.

888 Information was taken and categorized from the text and summarized in table S1, where it was

889 possible to review the details of the sections dedicated to CC of each PoM. The figure shows,

890 as follows: PoM not published (Red), CC not mentioned (Orange), CC simply mentioned

891 (Yellow), and CC addressed within Objectives and Measures (Green). Since the MSFD is

892 focused on the marine environment, the colored areas represent the national jurisdiction

893 defined under the United Nation Convention of the Law of the Sea (1982), including also the

894 Ecological Protection Zone (EPZ) of Italy (Decree of the President of the Republic 209/2011)

895 and the Ecological and Fishery Protection Zone of Croatia (ZERP) (Law 331/2003) where

896 coastal states have the right to enforce their jurisdiction for the preservation of the marine

897 environment.

898 **Figure 2.** How Climate Change (CC) is addressed in marine spatial plans in EU marine

899 waters. Colours in the map represent the phase/s in the planning where climate change is

900 considered/mentioned in marine spatial plans. Phases of the plans are a synthesis from Ehler &

901 Douvere (2009). In grey the countries that are in the process of preparing their marine plans

902 according to the EU Directive 2014/89/EU and do not have an approved plan yet. In dark grey

903 the marine waters of Lithuania, where the existing marine spatial plan does not mention CC.

904

905 **Figure 3.** Marine spatial plans in the EU, and the phase/s in the planning where climate
906 change is considered/mentioned. Phases of the plans are a synthesis from Ehler & Douvere
907 (2009). In grey the countries that are in the process of preparing their marine spatial plans
908 according to EU Directive 2014/89/EU and do not have an approved plan yet. The marine
909 spatial planning initiatives are the following (where no marine spatial plan is available, we
910 mention “no plan” and the state of the marine spatial plan initiative, if any): 1. Marine Spatial
911 Plan for the Belgian part of the North Sea, 2014, 2. Belgian Vision for the North Sea 2050,
912 Think Tank North Sea, 2017, 3. No Plan, Analysis for planning, 4. Coastal Plan for the
913 Šibenik-Knin County, 2016, 5. Zadar County Integrated Sea Use and Management Plan, 2001,
914 2015, 6. No plan, preplanning, 7. No plan, preplanning, 8. Pärnu Bay area pilot, 2017, 9. Hiiu
915 Island MSP# Pilot Plan, 2016, 10. Regional Land Use Plan for the Sea, Kymenlaakso Region,
916 2013, 11. No plan, National Strategy for the Sea and Coastlines, 2014, Preplanning, 12.
917 Maritime Spatial Plan for the German EEZ in the Baltic Sea, 2009, 13. Maritime Spatial Plan
918 for the German EEZ in the North Sea, 2009, 14. State Development Plan for Schleswig-
919 Holstein, 2010, 2015, 15. Spatial Development Programme of Mecklenburg-Vorpommer,
920 2005, 2016, 16. Spatial Planning Programme of Lower Saxony, 1994, 2008, 2017, 17. No
921 plan, preplanning, 18. No plan, analysis for planning, 19. No plan, preplanning, 20. Maritime
922 spatial plan for the internal marine waters, territorial waters and exclusive economic zone of
923 the Republic of Latvia, 2016, 21. Comprehensive Plan of the Republic of Lithuania (and its
924 part “Maritime territories “), 2015, 22. Strategic Plan for the Environment and Development ,
925 2017, 23. Policy Document on the North Sea 2016-2021, 24. Pilot Maritime Spatial Plan for
926 the Western part of the Gulf of Gdańsk, 2003, 2008, 25. Pilot Maritime Spatial Plan for

927 Pomeranian Bight/Arkona Basin, 2012, 26. Pilot Maritime Spatial Plan plan for Southern
928 Middle Bank, 2012, 27. Situation Plan of Maritime Spatial Planning (PSOEM) in preparation,
929 28. No plan, National plan in preparation, 29. No plan, National plan in preparation, 30. No
930 plan, preplanning, 31. Swedish marine spatial plans for three planning areas, published for
931 consultation, 32. South Inshore & Offshore Plan, 2018, 33. East Inshore and Offshore Marine
932 plan, 2014, 34. Scotland's National Marine Plan, 2015. UK stays for United Kingdom.

933

934 **Figure 4.** Duration of long-term monitoring or repeated samplings in marine protected areas.
935 Each horizontal bar shows the years of sampling for the corresponding article. The geographic
936 area of the study is also indicated (C = Croatia, F = France, I = Italy, S = Spain). Different
937 colors specify the habitat sampled; white stripes in the bars indicate years of sampling before
938 the institution of the protection regime, intermittent white stripes represent studies
939 investigating several MPAs, some before and some after the institution of protection regime.

940

941 **Figure 5.** Number of monitoring studies reporting different types of response variables.

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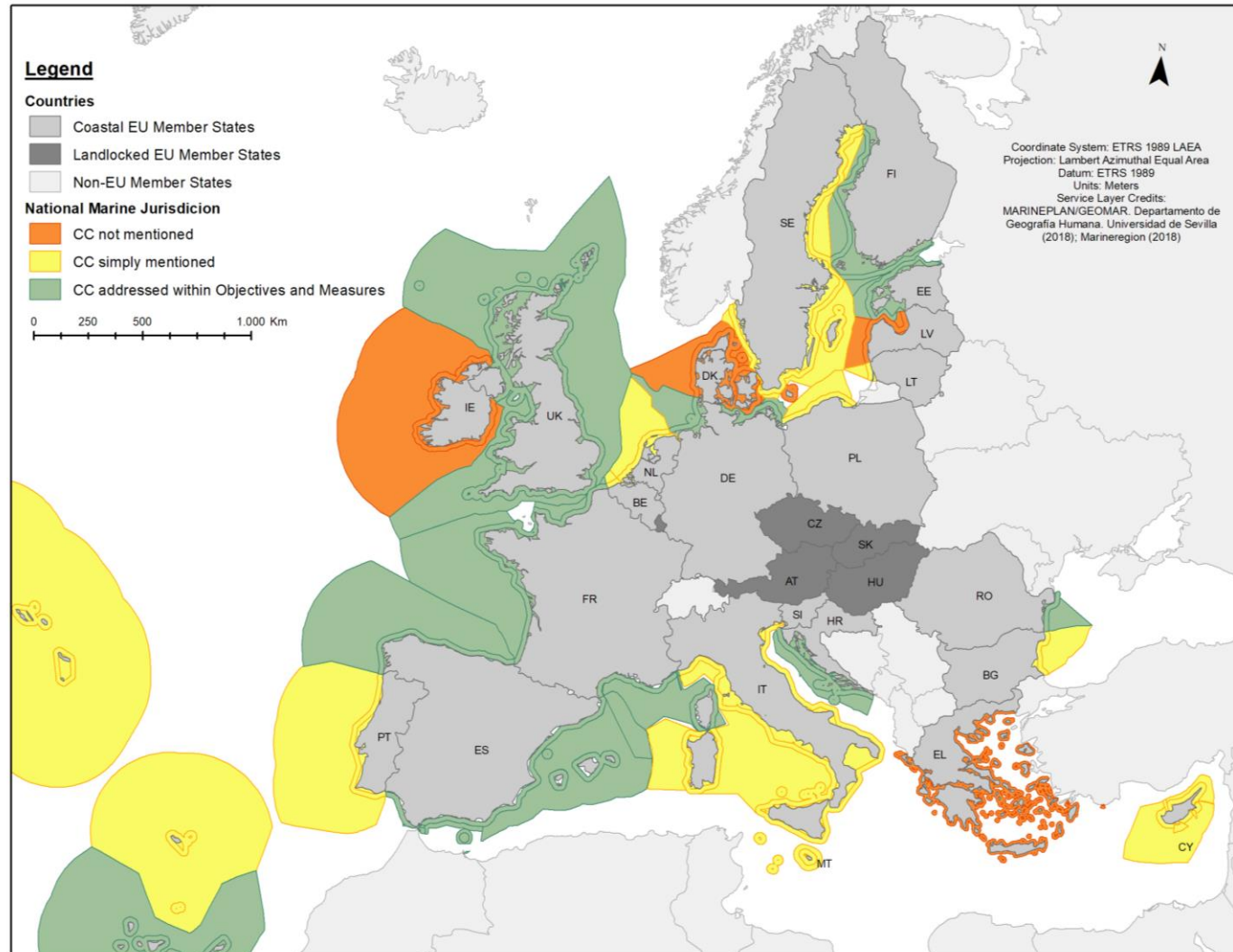
943

944 Figure 1.

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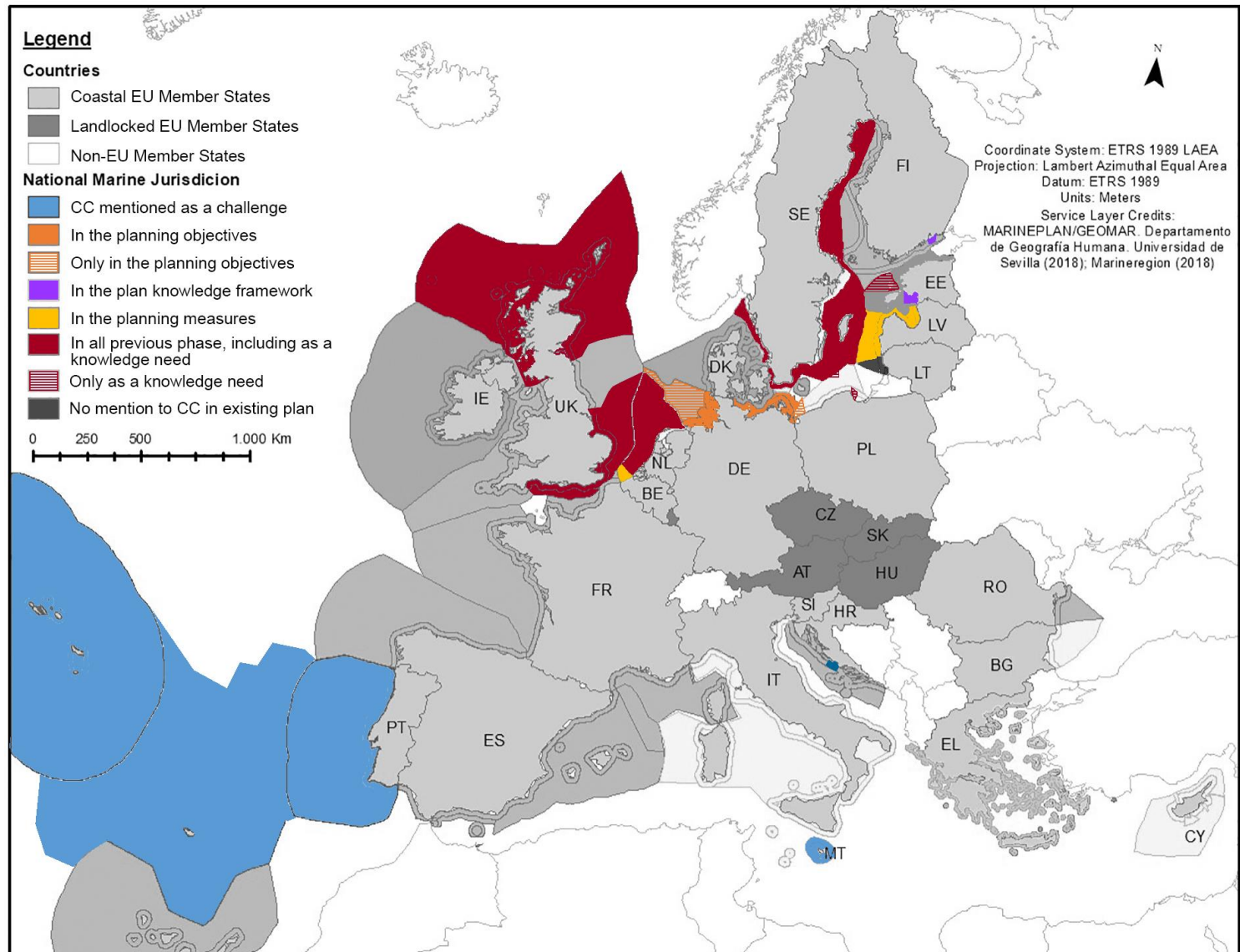
947



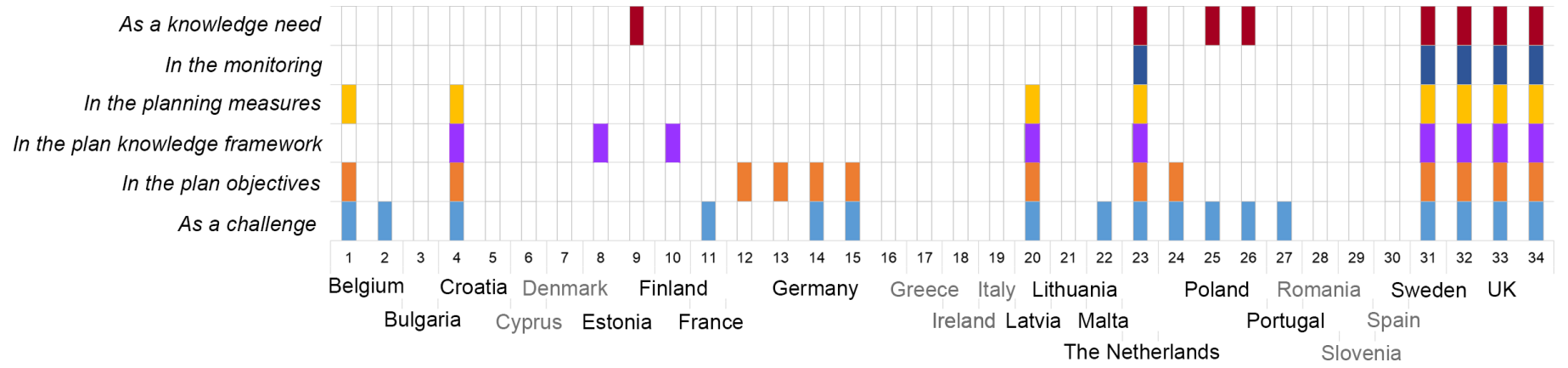
948 Figure 2.

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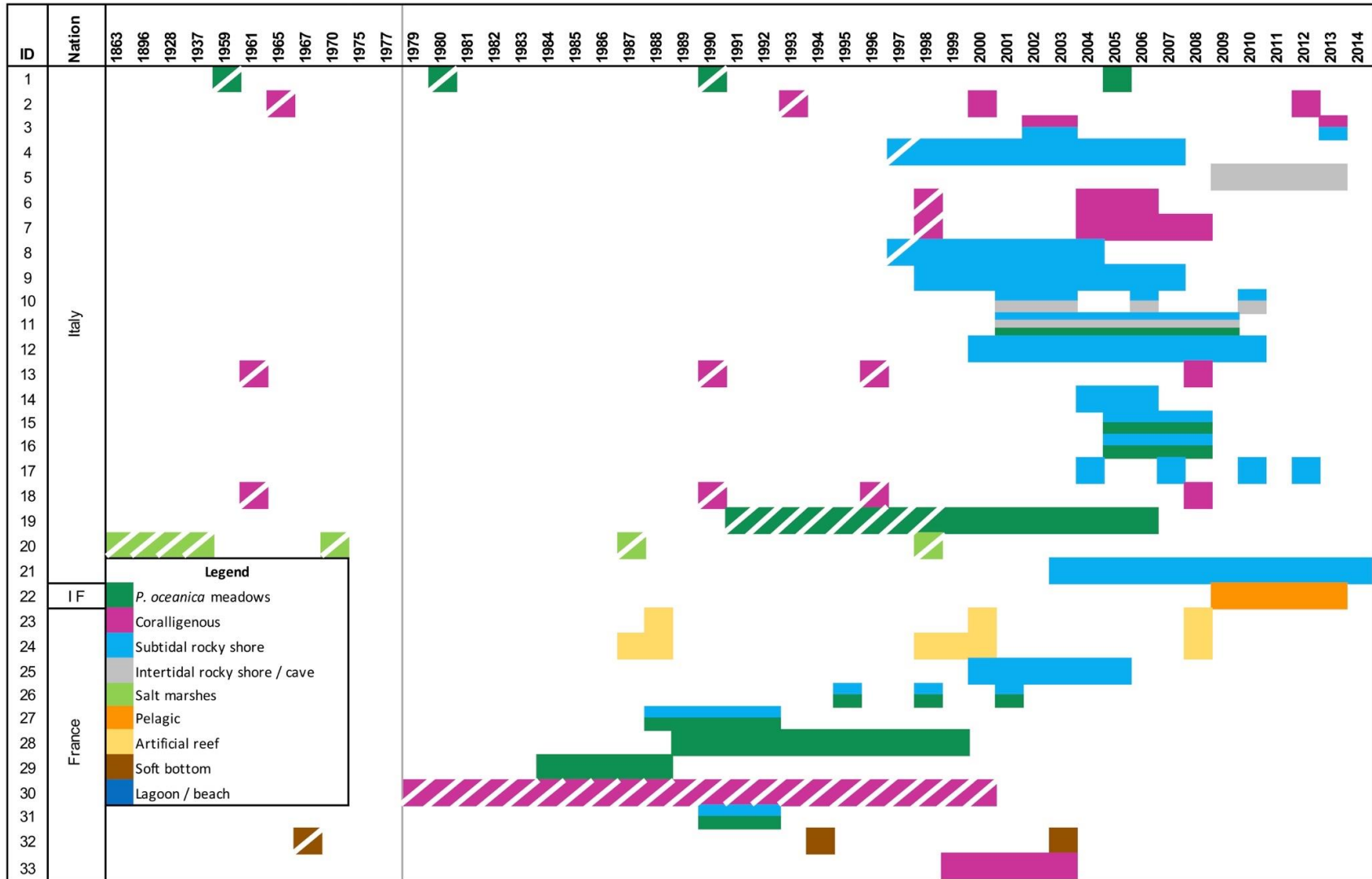
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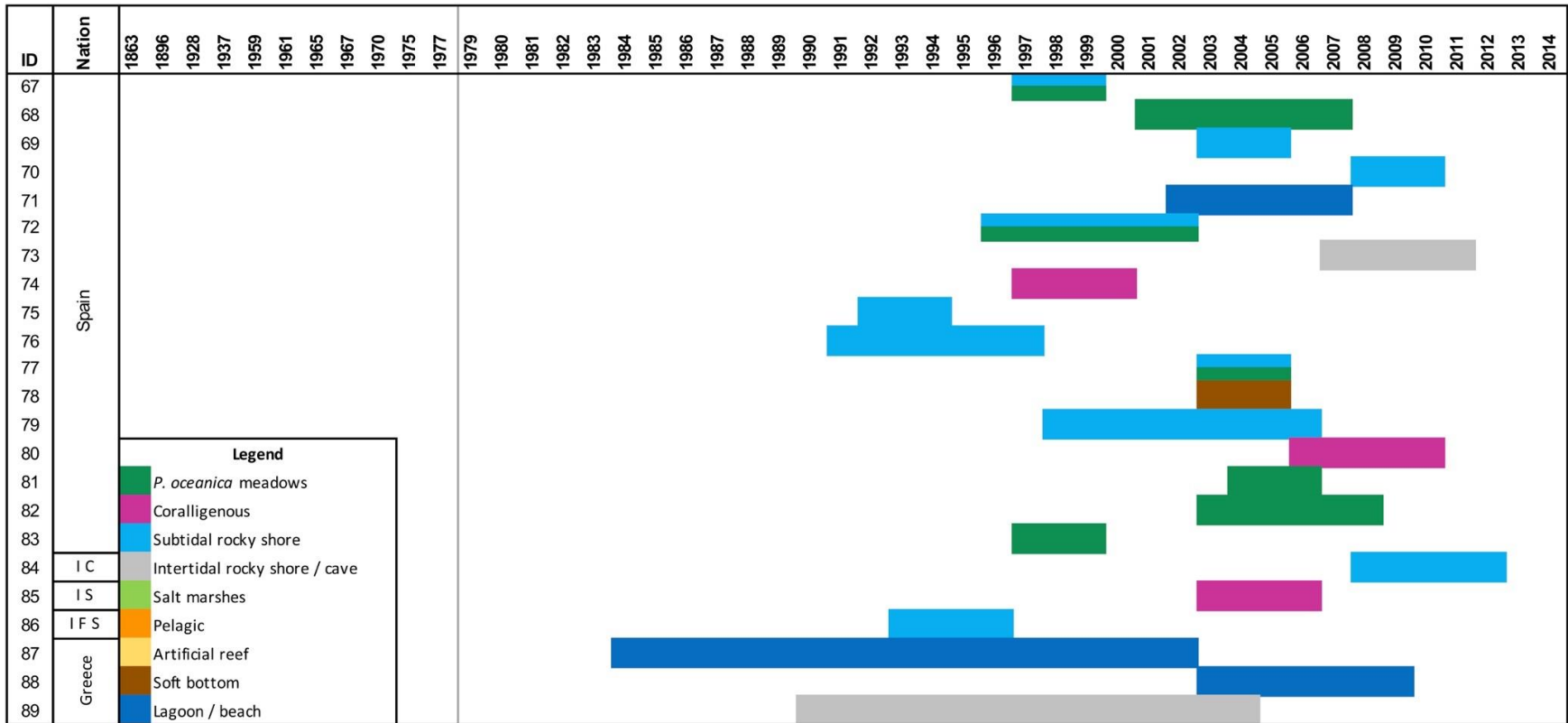
951 **Figure 3.**



952 Figure 4



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958 Figure 5

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