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Existing evidence on the impact of changes in marine ecosystem structure and functioning on ecosystem service delivery: A systematic map

Authors' contacts

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Abstract

Background The current biodiversity crisis underscores the urgent need for sustainable management of the human uses of nature. In the context of sustainability management, adopting the ecosystem service (ES) concept, i.e., the benefits humans obtain from nature, can support decisions aimed at benefiting both nature and people. However, marine ecosystems in particular endure numerous direct drivers of change (i.e., habitat loss and degradation, overexploitation, pollution, climate change, and introduction of non-indigenous species) all of which threaten ecosystem structure, functioning, and the provision of ES. Marine ecosystems have received less attention than terrestrial ecosystems in ES literature, and knowledge on marine ES is hindered by the highly heterogeneous scientific literature with regard to the different types of marine ecosystem, ES, and their correlates. Here, we constructed a systematic map of the existing literature to highlight knowledge clusters and knowledge gaps on how changes in marine ecosystems influence the provision of marine ES.

Method We searched for all evidence documenting how changes in structure and functioning of marine ecosystems affect the delivery of ES in academic and grey literature sources. In addition to Scopus, Web of Science, and Google Scholar, we searched 6 online databases from intergovernmental agencies, supranational or national organizations, and NGOs. We screened English-language documents using predefined inclusion criteria on titles, abstracts, and then full texts, without any geographic or temporal limitations. All qualifying literature was coded and metadata were extracted. No formal validity appraisal was undertaken. We identified knowledge clusters and gaps in terms of which ecosystem types, biodiversity components, or ES types have been studied and how these categories are linked.FAO

38 **Review findings** Our searches identified 41 884 articles published since 1968 of which 12 140 were
39 duplicates; 25 747 articles were excluded at the title-screening stage, then 2 774 at the abstract stage.
40 After full-text screening, a total of 653 articles—having met the eligibility criteria—were included in
41 the final database, spanning from 1977 to July 2021. The number of studies was unevenly distributed
42 across geographic boundaries, ecosystem types, ES, and types of pressure.

43 The most studied ecosystems were pelagic ecosystems on continental shelves and intertidal
44 ecosystems, and deep-sea habitats and ice-associated ecosystems were the least studied. Food
45 provision was the major focus of ES articles across all types of marine ecosystem (67%), followed by
46 climate regulation (28%), and recreation and tourism (14 and 13%). Biophysical values were assessed
47 in 98% of the analysed papers, 34% assessed economic values, but only 7% assessed socio-cultural
48 values. Regarding the type of impact on ecosystems, management effects were the most studied,
49 followed by overexploitation and climate change (with increase in seawater temperature being the
50 most commonly assessed climate change pressure). Lastly, the introduction of non-indigenous species
51 and deoxygenation were the least studied.

52 **Conclusions** This systematic map provides, in addition to a database, knowledge gaps and clusters on
53 how marine ecosystem changes impact ES provision. The lack of knowledge is a danger for the
54 sustainability of human actions and knowledge-based nature conservation. The knowledge gaps and
55 clusters highlighted here could guide future research and impact the beneficial development of policy
56 and management practises.

57 **Keywords**

58 *Coastal habitats; Biodiversity; Nature's contribution to people; Spatio-temporal dynamics; Human*
59 *impacts; Management*

60 Background

61 In the context of the current biodiversity erosion crisis, there is an increasingly urgent need to manage
62 anthropogenic activities sustainably to conserve and protect nature's potential to contribute
63 ecosystem services for the benefit of present and future generations [1]. Ecosystem services (ES) and
64 nature's contribution to people (NCP) concepts have gained interest in their ability to highlight our
65 dependency on nature and all the services we extract from it [2–4]. The concept of ES is relatively
66 recent—being introduced in the late 1970s—and has its roots in the recognition that ecosystems
67 provide irreplaceable goods and services [5,6]. It has since been largely popularized by the Millennium
68 Ecosystem Assessment as a way of thinking about the relationships between humans and nature [7].
69 Defined as “the benefits humans obtain from nature” [7], the ES concept helps to produce knowledge
70 to support decisions aimed at promoting nature conservation. The related concept of NCP, defined as
71 “all the contributions, both positive and negative, of living nature to people’s quality of life” [1,2],
72 popularized first by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem
73 Services (IPBES) regional assessments, goes beyond ES by integrating a wider range of specific values
74 and the consideration of negative contributions of nature (also called disservices [8,9]). Specific values
75 defined by IPBES consider the “judgements regarding the importance of nature in particular situations”
76 and differentiate instrumental, intrinsic, and relational values [10].

77 These concepts allow for studying socio-ecological systems, which require rigorous approaches across
78 different scientific disciplines—ecology (e.g., [11,12]), economics (e.g., [13]), anthropology (e.g.,
79 [14,15]), politics (e.g., [16,17]), or geography (e.g., [18])—to analyse and describe the numerous
80 interactions between living components (i.e., humans and non-humans). The ES concept can improve
81 interactions between disciplines and also among scientists, managers, stakeholders, and politicians by
82 redefining the existing debates on the conflicts between development and conservation [19]. The
83 different ES can be divided into three main categories: (1) provisioning services, which are products
84 obtained from ecosystems (e.g., foods, raw materials for industry); (2) regulation and maintenance
85 services, which are benefits obtained from ecosystems (e.g., climate regulation, coastal protection);
86 and (3) cultural services, which are non-material benefits obtained from ecosystems (e.g., recreative
87 activities) [20–23].

88 Marine ecosystems provide a wide range of ES. Several lists are available in the literature such as Bordt
89 and Sander [24], Kermagoret *et al.* [25], Barbier [26], and Mongruel *et al.* [15], generally inspired by
90 the classification proposed in Liqueste *et al.* [22] and Beaumont *et al.* [27]. For instance, based on the
91 Common International Classification for Ecosystem Services (CICES) [28] and Liqueste *et al.* [22], the
92 French platform for the evaluation of ecosystems and ecosystem services listed the ES provided by
93 marine ecosystems [15] as follows: food provision; raw materials from aquaculture; macroalgae
94 production; molecule production; coastal protection; climate regulation; nutrient regulation; pest and
95 disease control; symbolic, emblematic, and aesthetic values; recreation and tourism; landscape
96 amenity; and knowledge production. This study also considered “nursery function” and “maintenance
97 of food webs” in its assessment, even if these are sometimes considered as functions [15] or as
98 regulating services [22]. Although we also included “nursery function” and “maintenance of food
99 webs”, ecological functions, such as primary and secondary production provided by marine ecosystems
100 and sometimes defined as support services, were not included in this review [25,29,30].

101 Marine ecosystems endure numerous direct drivers of change, mainly habitat loss and degradation,
102 overexploitation, pollution, climate change, and introduction of non-indigenous species, all of which
103 threaten the future sustainability of marine and coastal areas [31]. Climate change affects marine
104 ecosystems with different impacts on ES through changes in sea surface temperature, acidification,

105 more extreme events, or sea level rise [32]. The magnitude of the direct drivers may also depend on
106 indirect drivers such as demographic pressure, sociocultural context, economy, technological
107 development, institutions and governance, and conflicts and epidemics. In 2008, a multi-driver analysis
108 showed that no area of the global ocean is unaffected by human influence and that more than 40% of
109 the ocean, mainly in coastal areas (e.g., NE USA, NW Europe, East Asia, Eastern Caribbean) are strongly
110 affected [32]. From 2008 to 2013, “66% of the ocean experienced increases in cumulative human
111 impact [...], especially in tropical, subtropical and coastal regions, while only 13% experienced
112 decreases in response to management measures” [33]. Indeed, threats and pressures sustained in
113 marine ecosystems induce changes that have affected the delivery of marine ES, and negatively
114 impacted human health and well-being, especially indigenous peoples and local communities who
115 depend on fisheries [31]. For example, Selim *et al.* [34] highlighted pathways linking fishing and climate
116 (drivers) to spawning stock biomass and recruitment of three demersal fish species (ecosystem
117 processes) and the consequences for delivery of these fisheries and ultimately on food provision
118 (ecosystem services).

119 In response to growing anthropogenic pressures, marine ecosystems are increasingly included in
120 national and international agendas to counteract the negative impacts of human activities and
121 promote the sustainable use of marine ecosystems (see, for instance, the targets of the Convention on
122 the Biological Diversity or the Sustainable Development Goals of the 2030 Agenda for Sustainable
123 Development adopted by the United Nations). These initiatives are reflected in the implementation of
124 legislation regarding, for example, fisheries management, water quality control, or the establishment
125 of marine protected areas. However, the need to develop effective conservation and protection
126 strategies remains. For instance, marine protected areas involve only about 8% of the marine realm,
127 only partly covering important sites for biodiversity and are not fully ecologically representative, well-
128 connected, or effectively managed [35]. It is therefore crucial to apply rigorous sustainable
129 management practices to help guarantee the delivery of ES and conserve the multiple benefits
130 provided by marine ecosystems that so many people rely on [35,36]. Hence, it is particularly vital to
131 better understand such ecosystems and highlight the related socio-ecological aspects.

132 Liqueste *et al.* [22] identified, defined, and reviewed the marine ES literature and found 145 articles
133 that specifically assessed marine and coastal ES. That review highlighted that, of the numerous ES
134 provided by marine ecosystems, food provision (i.e., fisheries and offshore aquaculture) seems to be
135 by far the most intensively studied marine ES. Furthermore, it revealed that case studies focused on
136 mangroves and coastal wetlands and were mainly concentrated in Europe and North America. In
137 addition, other specific ecosystems are also frequently spotlighted, such as coral reefs, mudflats, and
138 seagrass beds [15]. Also, knowledge on marine ecosystems seems to decrease with distance from the
139 coastline [15]. Only a few articles have explored ES in deep-sea ecosystems [37]. More recently,
140 systematic maps have been published on the ES provided by the ecosystems in the Baltic Sea (Stories
141 *et al.* [38] and Kuhn *et al.* [39]), revealing cultural services as the most assessed ES category. Likewise,
142 food provision and recreation have been significantly studied in the Baltic Sea, in addition to
143 eutrophication mitigation. The primary focus on food provision stems from the fact that some marine
144 species groups are more assessed and studied, such as commercial species and top predator fish stocks
145 [35]. The ES literature has also been reviewed in IPBES reports and demonstrates, for example, that
146 potential/capacity or the supply component are the central foci in many assessments.

147 While there are reviews and meta-analyses on marine ES, none deal with the evidence on how ES
148 delivery is affected by changes in marine ecosystems structure and functioning. The need to consider
149 the temporal dynamics in studies is highlighted [40], but the literature seems to focus on snapshot
150 assessments instead on multi-time assessments in relation to ecological dynamics. Thus, our current

151 map was constructed to focus on the literature assessing the impacts of spatio-temporal dynamics of
152 marine ecosystems on the very ES they provide. In addition, we looked at the drivers of change at the
153 origin of marine ecosystems' dynamics, such as changes in land/sea use, direct exploitation, pollution,
154 climate change, and introduction of non-indigenous species, as well as management effects. We also
155 examined more specifically drivers related to climate change in marine ecosystems with consideration
156 of extreme events (e.g., flood events), sea level rise, warming waters, deoxygenation, or ocean
157 acidification.

158 The heterogeneity of knowledge in marine and coastal ecosystems and their services is a major
159 obstacle to the effective use of scientific results by decision-makers. A systematic map offers the
160 advantage of structuring existing knowledge to produce results that are useful for decision-making.
161 Following the protocol in Campagne et al. [41], we carried out a systematic evidence mapping exercise
162 to highlight the knowledge clusters and knowledge gaps on how changes in the structure and
163 functioning of marine ecosystems affect the provision of marine ES.

164 ***Stakeholder engagement***

165 Producing this systematic map was part of the InDySEM project (Influence of ecological Dynamics on
166 production and demand for marine Ecosystem Services, funded by the French Foundation for Research
167 on Biodiversity-Centre for Biodiversity Synthesis and Analysis (FRB-CESAB)) and was overseen by both
168 a scientific and a methods team. The scientific team was composed of researchers with expertise on
169 marine ecology, economy, and sociology. The scientific team developed and built the project and
170 advised the project leader and the project officer during regular meetings, who validated any
171 adjustments made to the research topic, the PECO elements (Population, Exposure, Comparator,
172 Outcomes), the search strings as well as all the ROSES elements (see below). The methods team was
173 composed of systematic review and data analysis experts, who followed all the Collaboration for
174 Environmental Evidence (CEE) methodological steps for systematic maps. The FRB-CESAB is a research
175 organization with an international scope whose objective is to implement innovative work on the
176 synthesis and analysis of existing data sets in the field of biodiversity.

177 **Objective of the Review**

178 The main goal of this review was to map existing evidence concerning our primary question: **what are**
179 **the impacts of changes in ecosystem structure and functioning on the services that ecosystems**
180 **provide?**

181 In addition, the systematic map summarized the evidence database in terms of the following secondary
182 questions:

183 - What is the existing evidence on how do the spatio-temporal dynamics of marine biodiversity affect
184 ecosystem disservices?

185 - What is the existing evidence on how are marine ecosystem services and disservices linked to natural
186 or anthropogenic drivers of change?

187 Thus, to highlight knowledge gaps on how changes in marine ecosystems affect marine ES, we
188 structured a systematic map according to specific PECO components (Table 1). We focused on changes
189 in biodiversity from the species to the ecosystem level, including functional and structural diversity,
190 and how these changes influence the services provided (i.e., provisioning, regulation, and cultural
191 services). The associated disservices—negative benefits of nature as perceived by humans—were also

192 considered when studied. We focused our systematic map on studies presenting new results of ES
 193 change, thus on papers with quantitative or qualitative data, and excluded narrative analyses or papers
 194 (e.g., policy reports or reviews without new ES values).

195 **Table 1:** Components of the systematic map used in this study

PECO element		Definition(s)
Population	Marine biodiversity (ecosystems and species)	Includes all types of marine ecosystems and the species that they contain
Exposure	Changes in marine biodiversity	All changes at all levels, from species to ecosystem, functional and structural
Comparator	Spatial difference — temporal difference	Articles with data at different place (spatial difference) or data on different time (temporal difference)
Outcomes	Marine ecosystem services (and disservices)	All qualitative or quantitative values of marine ecosystem services and disservices

196 **Methods**

197 The construction of this systematic map followed the methodological guidelines in accordance with
 198 the CEE Guidelines and Standards for Evidence Synthesis [42] and conforms to the RepOrting standards
 199 for Systematic Evidence Syntheses (ROSES) for Systematic Map Reports presented by Haddaway *et al.*
 200 [43] (See Additional file 1 for the ROSES systematic map reports of this study). We followed the same
 201 methodological protocol as that presented in Campagne *et al.* [41].

202 **Search for articles**

203 **Search string**

204 The search string was composed in accordance with the key components of the question representing
 205 Population, Exposure, and Outcomes as planned in the protocol [41] and Table 1. The search string
 206 used on the Web of Science in “exact search” mode is presented in Table 2. The asterisk (*) at the end
 207 of a search term/word was used to accept any variant of a base term. The dollar sign (\$) was used to
 208 accept single or no added characters, useful for retrieving plural and singular forms. Quotation marks
 209 were used to search the exact word order.

210 The search terms used for the substring on ES types included different synonyms for each ES in order
 211 to be as inclusive as possible, inspired by different lists of marine ES based on Mongruel *et al.* [15], the
 212 Global Ocean Accounts Partnership [21] and Liqueste *et al.* [22]. The search terms for the substring on
 213 Exposure, which involves changes in biodiversity (from species to ecosystems) were composed of key
 214 words synonymous to “change”. The search string was tested and constructed in the Web of Science
 215 Core Collection (WOS) to obtain the highest efficiency and the best comprehensiveness related to the
 216 test list (see Additional file 2 for search string construction details and comprehensiveness). Searches
 217 were performed using English terms only. All relevant international literature published in English was
 218 included in this systematic map, including diverse bibliographic documents (e.g., books, journal
 219 articles, theses and technical reports).

220 **Search sources**

221 Publication databases, on-line search engine, and the organizational websites were searched without
222 any time restriction (e.g., since 1788 for Scopus). All searches were undertaken between July and
223 August 2021 (Table 2).

224 **Bibliographic databases**

225 Title, abstract and keywords of the Scopus and WOS publication databases were searched using the
226 search tags "TITLE-ABS-KEY" and "TS", respectively. All databases were accessed with the subscription
227 of the French National Centre for Scientific Research (CNRS).

228 **Search engine**

229 A supplementary search in Google Scholar, with the aid of Publish and Perish [44] software, was used
230 to retrieve additional literature. Google Scholar's use of Boolean characters differs from WOS and
231 Scopus and is limited in terms of the number of characters, and thus search terms [45]. Therefore, we
232 adapted the search string to correspond to what the review team deemed as the most important
233 keywords and used the "keywords" field to search the title, abstract, and body of text with the
234 following keywords: "(marine OR coastal OR ocean) AND (species OR biodiversity OR ecosystem) AND
235 "ecosystem services" AND change". We exported the first 300 search hits, in line with the
236 recommendations by Haddaway *et al.* [45].

237 **Grey literature searches**

238 Six specialist organization websites were searched (cf. Table 4) to collect technical reports with primary
239 data related to our question. For each organizational website, the use of specific keywords with
240 manual-searches varied between website as presented in the methodological protocol (Campagne *et*
241 *al.* [41]) and as listed in Table 2.

242 The keywords used were "marine ecosystem services", which contains the keywords for the Population
243 and the Outcomes components. Adaptation of the keywords used depended on the main topic of the
244 organizational website. For example, because NOAA focuses on marine ecosystems, the search string
245 was only "ecosystem services". For the FAO, the main keywords did not lead to any results, so we
246 focused on one ecosystem service: "fishery". Again, the main keywords did not lead to any results in
247 the IUCN publication websites, so we focused only on "ecosystem service". Other websites were tested
248 such as the Intergovernmental Panel on Climate Change (IPCC) and the IPBES websites. Nevertheless,
249 the main keywords of our search string did not lead to any results. These intergovernmental websites
250 only offered review reports and no records with primary results. A maximum of 50 references was
251 considered for each organizational website.

252

253 **Table 2: Search strings and search hits**

	Name	Search field	Search string	Search hits	Date of search (DD/MM/YYYY)
LITERATURE DATABASES	Web of science	TS	((marine OR coast* OR ocean OR sea OR littoral OR maritime) AND (species OR biodiversity OR ecosystem OR ecological) AND ("ecosystem service\$" OR "contribution to people" OR "ecosystem function\$" OR "ecosystem process" OR "landscape service\$" OR disservice\$ OR "provisioning service\$" OR ((provision OR production OR exploitation) AND (food OR fisher* OR macroalgae\$ OR molecules)) OR "biomass for nutrition" OR "biomass for materials" OR "genetic materials" OR "raw materials" OR "maintain* food webs" OR "life cycle maintenance and habitat protection" OR "habitat provision" OR "nursery function" OR "regulation service\$" OR "climate regulation" OR "carbon sequestration" OR "weather regulation" OR "atmospheric composition and conditions" OR "air quality regulation" OR "coastal protection" OR "water retention" OR "nutrient regulation" OR "nutrient cycling" OR "pathogen regulation" OR "pest and disease control" OR "mediation of waste" OR "mediation of mass" OR "cultural service\$" OR "intellectual interaction" OR "physical interaction" OR "experiential interaction\$" OR tourism OR recreation OR amenity OR aesthetic OR heritage OR symbolic OR "cognitive effect\$" OR "knowledge production" OR education) AND (dynamic\$ OR impact\$ OR effect\$ OR variation\$ OR interaction\$ OR evolution OR change\$)).	17329	20/07/2021
	Scopus	TITLE-ABS-KEY		24051	20/07/2021
ONLINE SEARCH ENGINE	Google Scholar	keywords	(marine OR coastal OR ocean) AND (species OR biodiversity OR ecosystem) AND "ecosystem services" AND change	300	22/07/2021
ORGANIZATIONAL WEBSITES	FAO	Language: "English"	fishery	50	27/08/2021
	UNESCO	Filter: language: "English" - source: "UNESCO" - AuthoCorporate-en-s: "Intergovernmental Oceanographic Commission" - nature of content: "guide" AND "manuals and handbooks"	marine ecosystem service	50	19/08/2021
	UNEP	Filters: "Reports and publications" AND "Publication" AND "Report", "Ecosystems and biodiversity" AND "oceans and seas"	marine ecosystem service	50	19/08/2021
	US NOAA		ecosystem service	15	19/08/2021
	EEA		marine ecosystem service	7	19/08/2021
	IUCN		ecosystem service	32	27/08/2021

254

255 **Estimating the comprehensiveness of the search**

256 The search terms were tested in WOS. The review team compiled a list of 30 articles that we considered
 257 as important and relevant for our respective fields and the research topic. These articles are listed in
 258 Additional file 3. Search terms were modified and refined until these benchmark publications were
 259 retrieved. For example, words related to Population, Outcome and Exposure were progressively added
 260 as described in Additional file 2. In WOS, 25 out of the 30 articles in our test list were retrieved with
 261 the final search terms, with 2 articles were not found due to the search string and 3 out of the 30
 262 articles were not found at all in WOS but only in other literature database. With all the results extracted
 263 (WOS, Scopus and Google Scholar), 29 out of the 30 articles in our test list were retrieved, indicating a
 264 96.7% comprehensiveness (Additional file 3). The only article we did not retrieve was Roessig *et al.*
 265 [46]. We tried different search strings; nevertheless the numbers of documents found with other
 266 search strings retrieving Roessig *et al.* [46] were either unmanageably high or other documents in the

267 test list were not found. The current search string at 96.7% comprehensiveness was assumed to be the
268 best compromise.

269 **Assembling and managing search results**

270 Once the extraction of records from each database and website was completed, we reassembled all
271 records from all the different sources into one spreadsheet file. To do so, records from Scopus, WOS,
272 and Google Scholar were re-exported from Zotero and Mendeley to import the same file types into
273 the R environment for correct merging of records from the different sources and formatting of data
274 columns. Records from organizational websites were manually added in the final Excel files.

275 We removed clear and partial duplicates based on similar DOI and similar titles using R package
276 revtools [47] and the “find_duplicates” function. In addition, we used the “check_duplicates” function
277 in Microsoft Excel software for a double verification.

278 **Article screening and study eligibility criteria**

279 **Screening process**

280 A three-stage filtering process was undertaken in accordance with pre-defined screening and study
281 eligibility criteria [41]. Titles were screened first, followed by abstracts, then full texts.

282 Full texts were sought for all selected abstracts using the journal subscriptions via the CNRS and
283 Sorbonne University. If the articles were not retrievable, requests for full texts were made via
284 ResearchGate (www.researchgate.net), or the authors were contacted directly through ResearchGate
285 or by email. We integrated full texts found or received until 28 February 2022. Unretrievable full texts
286 of accepted abstracts were not screened. Incomplete texts were considered as not found. They are
287 listed in Additional file 4.

288 We applied a conservative approach: titles or abstracts that did not clearly fit the inclusion criteria or
289 did not clearly fit the exclusion criteria (details below in the Eligibility criteria section) were kept for
290 the next eligibility screening stage.

291 To test the consistency of the screening process, Cohen’s kappa coefficient [48] was calculated. But
292 before the statistical tests were run, a training phase was undertaken. The two screeners met to
293 practice, discuss and adapt the eligibility criteria on 100 test titles and then on the abstracts of these
294 accepted test titles. The goal of these meetings was to verify the understanding of the eligibility
295 criteria.

296 The kappa tests were then run on 1 000 titles out of the 41 884 records (2.38%) (due to resource
297 limitations and the considerable number of records within all databases used, it was not possible to
298 run the kappa test on 10% of the titles). Cohen’s kappa coefficient for the title screening stage was
299 0.83. At the abstract screening stage, we tested 402 of the 3 999 titles (10%) selected and Cohen’s
300 kappa coefficient was 0.70. Finally, on 116 full texts of the 1 119 full texts retrieved (10%) Cohen’s
301 kappa coefficient was 0.87. At each screening stage, the reviewers met to discuss all remaining
302 discrepancies.

303 **Eligibility criteria**

304 The selection of records depended on the inclusion and exclusion criteria presented in Table 3. The
 305 inclusion/exclusion decisions were reported at each screening stage. In line with the guideline
 306 recommendations, reasons for exclusion during the full-text screening were also reported (see
 307 Additional file 5).

308 Regarding title screening, only articles with a clear mention of “marine ecosystems” and “ecosystem
 309 services” with the wording of ES or ES-related concepts directly mentioning an ES were accepted (see
 310 list in Liqueste *et al.* [22], or Pr at [20] for a list of marine ES). In the abstract screening process, in
 311 addition to the previous criteria, we considered Exposure and Comparator. If an article fit the inclusion
 312 criteria based on Population, Exposure and Outcome, but not Comparator – (i.e., article on marine
 313 ecosystem and ES but without evidence of spatial or temporal differences), the article was excluded
 314 (Table 2). Because we were targeting primary studies with ES values, we did not consider documents
 315 on methods, reviews or on policy analysis without defined ES values in the studies. The full-text
 316 screening fit the previous criteria and also considered whether qualitative or quantitative ES values of
 317 marine ES and disservices were present. Thus, review papers without ES values or review papers only
 318 with ES values from other papers without new analyses were not included.

319

320 **Table 3: Eligibility criteria to select articles to include in the systematic map**

Criterion	Screening step	Inclusion criteria	Exclusion criteria
<i>Population</i>	Title	Articles whose title deals with biodiversity, i.e., species, habitats, and/or ecosystems in marine environments. Non-exhaustive examples may include open-ocean, continental shelf, coastal areas, seagrass meadows, estuaries, mangroves, coral reefs, etc.	Articles whose title explicitly only refers to terrestrial and/or freshwater biodiversity, species, habitats or ecosystems, i.e., articles regarding exclusively aquatic species and habitats (e.g., lakes, floodplains, rivers, subterranean habitats, etc.) or to terrestrial species and habitats (e.g., forest, agricultural ecosystems, etc.)
<i>Outcomes</i>	Title	Articles dealing with marine ecosystem services (as well as related terms such as “nature’s contributions to people”). (e.g., marine blue sequestration, snorkelling, whale watching) Articles dealing with the marine ecosystem service of food supply in terms of indicators of stock or population size of commercial species (e.g., fishery stock)	Articles dealing solely with function or structure processes and not related to effects on ecosystem services (e.g., primary production, photosynthesis) Studies only addressing species criteria with indicators other than the stock or the population size of the species (e.g., species distribution)
<i>Exposure</i>	Abstract	Any article or study exposing marine biodiversity, i.e., species, habitats, and ecosystems, to a change in structure and/functioning over time caused by an agent of change, i.e., human activity (e.g., direct/overexploitation, land/sea use change, etc.) or a change caused by different spatial area studied	Articles presenting no exposure to a change
<i>Comparator</i>	Abstract	Articles studying changes in ecosystem services through time or space (i.e., temporal or spatial comparisons). This may mean a different study type as detailed in Table 4. Accepted with synchronic comparators (same time, different sites).	Articles only assessing ecosystem services at one time or in one site/area
<i>Temporal period</i>	Abstract	Articles analysing relevant outcomes with data covering periods of at least part of the 20 th century and/or the 21 st century	Articles analysing data covering periods ending before 1900 (e.g., palaeoecology analysis).
<i>Outcomes</i>	Full text	Articles analysing relevant outcomes containing qualitative or quantitative values of marine ecosystem services and disservices	Articles without qualitative or quantitative values of marine ecosystem services and disservices (e.g., narrative review, opinion paper, policy paper without new quantitative or qualitative values defined).

321

322 Articles relating to aquaculture formed a special case in the selection process. The majority of articles
 323 related to aquaculture tested technical improvements to enhance the provision of the service of food
 324 provision and not the effects of changing environmental conditions. Regarding the eligibility criteria
 325 for the full-text screening, most articles on aquaculture were excluded and only articles corresponding
 326 to two contrasting situations were selected: (1) when aquaculture was a driver of change of the marine
 327 ecosystems and affected the delivery of another marine ES (e.g., impact of pollution generated by fish
 328 farming which impact specific ES); (2) when aquaculture was the provisioning service affected by a
 329 driver of change of the marine ecosystem (e.g., oyster farming exposed to eutrophication).

330

331 Study validity assessment

332 The validity of evidence was not assessed in this systematic map, but information was coded regarding
 333 study design elements that may provide some preliminary indication of internal validity. Also,
 334 ‘bibliographic content’ was coded with categories of study, review and meta-analysis. Articles
 335 producing primary data were coded as such. This information is not intended to provide a
 336 comprehensive assessment of study quality, but to highlight details on study type.

337 Deviations from the protocol

338 The protocol [42] was followed. Nevertheless, when we tested the coding strategy (see “Data coding
 339 strategy” section), the protocol classification and categories showed some limitations. They were thus
 340 more precisely defined or adapted if necessary, according to the coding test process. We refined some
 341 categories of metadata and added some new information (i.e., columns) in the evidence base and thus
 342 coded all the information presented in Table 4 (see Additional file 6 for the updated metadata
 343 categories).

344 **Table 4: Metadata (adapted from the protocol in Campagne *et al.* [42]; ES: ecosystem services)**

Item	Description	References	Adaptation from the protocol
Population			
<i>Ecosystem type*</i>	Intertidal rock and other hard substrates; Intertidal sediment; Subtidal rock and other hard substrates; Subtidal sediment; Deep-sea habitats; Pelagic habitats - continental shelf; Pelagic habitats - open sea; Pelagic habitats - estuarine waters; Ice-associated marine habitats + <i>free space for other ecosystem types</i>	Classification EUNIS Niveau 2 - European Commission	“Circalittoral rock and other hard substrates” were integrated in “Subtidal rock and other hard substrates” because it was difficult if not impossible to differentiate these two categories in most articles
<i>Specific ecosystem*</i>	Tidal marsh; Seagrass; Coral reefs; Mangroves; Kelp forests; Beach - dune strip; Estuary + <i>free space for others specific ecosystem types</i>	Mongruel <i>et al.</i> [15]	Addition of “Beach - dune strip”; “Estuary”
<i>Level of biological organization*</i>	The level of biological organization considered in the study: - Species: Species populations (distributions and abundances) or species traits (morphology, physiology, phenology, movement, reproduction); - Community: community composition (community abundance, taxonomic/phylogenetic diversity, trait diversity, interaction diversity); - Ecosystem: functioning and structure	Pereira <i>et al.</i> [41]	We did not code “population”, but “ecosystem” instead because it was more relevant for our map
<i>Characteristics of biodiversity</i>	If any characteristics of biodiversity were assessed in the study, we reported the type of Biodiversity indicator following the definition proposed by Lausch <i>et al.</i> [49]: - Taxonomic: the number of different biotic entities (e.g., individuals, populations, species, communities, ecosystems, landscapes); - Structural: the arrangement and distribution (composition and configuration) of biotic entities (e.g., population structure, community structure and landscape patterns);	Lausch <i>et al.</i> [49]	None

	- Functional: the diversity of functions and processes (species processes, community processes and landscape processes)		
<i>Biodiversity species**</i>	<i>Free space to record the name of species considered in the study, if any</i>		New category of coded names of species studies focused on
Outcomes			
<i>Number of ES per Categories</i>	Number of ES for the following ES categories: Provisioning services; Regulating services; Cultural services; Disservices		None
<i>ES</i>	Food provision; Raw materials; Genetic materials; Water provision; Water purification; Air quality regulation; Coastal protection; Climate regulation; Weather regulation; Nutrient cycling; Habitat provision; Pest and disease control; Symbolic and aesthetic values; Recreation and tourism; Cognitive effects; Educational opportunities (related ES terms would be considered in each ES type) <i>+ free space for other ES and for the name of all ecosystem services and disservices in the study with the name as in the study</i>	Préat [20]	None
<i>ES components*</i>	The ES values defined in the study represent the ES potential/ capacity/ supply; “the provision of a service by a particular ecosystem, irrespective of its actual use. It can be determined for a specified period of time (such as a year) in the present, past, or future.” ([50] page 154) the ES use/flow; “the amount of ES that are actually mobilised in a specific area and time.” ([50] page 155). the ES demand “the need for specific ES by society, particular stakeholder groups or individuals. It depends on several factors such as culturally-dependent desires and needs, availability of alternatives, or means to fulfil these needs. It also covers preferences for specific attributes of a service and relates to risk awareness”. ([50] page 156). (Indication were added if it is preferences/desires; the ES benefits or another form of demand or when the ES demand is not specified)	Following definitions in Burkhard and Maes [50]	We grouped the ES components differently because definitions vary among authors; we grouped components with closed definitions
<i>ES values</i>	The ES values defined in the study are coded following the IPBES Values Assessment Report 2022: - “Economic values are based on individual preferences, reflecting individual needs, wants, perceptions, and worldviews, as well as the scarcities imposed by nature and by the social and economic contexts within which people live”; - Sociocultural valuation methods aim “to value nature and its contributions to people by discovering the psychological, historical, cultural, social, ecological, and political contexts and conditions, as well as the worldviews and social perceptions that shape individually held or commonly shared values”; - “Biophysical approaches assess value based on the intrinsic properties of objects by measuring underlying physical parameters. They generally aim to examine the ecological importance of attributes, qualities, and quantities characterizing nature’s condition and functioning.”	Following definitions in IPBES Values Assessment Report p. 17 [51]	None
Exposure / Comparator			
<i>Scale of study area</i>	Subnational; National; Supranational; Continental; Global; No case study	Liquete <i>et al.</i> [22]	“Local” was integrated in “subnational” because it depended on the size of the study in the article and the country involved
<i>Study country</i>	Country included in the study; global		None
<i>Study ocean locality*</i>	Ocean included in the study based on the case study		New category
<i>Study sea locality*</i>	Sea included in the study based on the case study or NA		New category
<i>Specific location</i>	<i>Free space for the name of the case study site</i>		None
<i>Number of sites</i>	Number of case study sites reported in the study		New category
<i>Temporal scale interval raw data*</i>	Interval of time elapsed between successive temporal replicates of the raw data (i.e., the data used for the analysis in the article, e.g., data used to calibrate a prediction)		Distinguishes information in terms of raw data (which we defined as the data used for the analysis in the article, e.g., data used to calibrate a prediction) and the results data (i.e., the data results of each study, e.g., the results from a prediction model)
<i>Temporal scale duration raw data*</i>	Duration of time elapsed between first and last temporal replicates of the raw data analysis		
<i>Temporal scale interval result data*</i>	Interval of time elapsed between successive temporal replicates of the result data (i.e., the data results of each study, e.g., the results from a prediction model)		
<i>Temporal scale duration result data*</i>	Duration of time elapsed between first and last temporal replicates of the result data analysis		
<i>Time frame*</i>	- Past: data prior to 3 years before the date of publication - Present: data in the last 3 years before publication - Future: data after the publication		None

<i>Time data*</i>	- Observation and descriptive study with measurement of a specific parameter; - Experimentation and demonstrative study with experiments showing causality effects between factors; - Prediction/projection: definition of potential values in the future based on models. Projection is future when a change/pressure happens. Prediction is futures when nothing influences the evolution.	Adapted from Sordello <i>et al.</i> [52]	Addition of “experimentation” and addition of “projection” with “prediction”
<i>Pressure type*</i>	Land/sea use change; Direct/overexploitation; Pollution; Introduction of non-indigenous species; Management effects; Climate change (CC); CC-- extreme events; CC - sea level rise; CC - Warming waters; CC - Deoxygenation; CC - ocean acidification; CC - other pressure <i>+ free space for other pressures</i> (related to climate change, e.g., the impact of El Nino Southern Oscillation);	IPBES [1] and Halpern [32]	We added Climate change pressures adapted from detailed Halpern [32] as it is a specific focus we wanted
<i>Type of management*</i>	Marine protected area; Water quality management; Fishery management		We changed this item to specify the type of management or the presence of a marine protected area
Complementary information			
<i>Type of data*</i>	- Primary data: data was created and not based on other studies; - Quantitative data: empirical or observational data or biophysical or economic indicators; - Qualitative data: data from interviews or public perceptions from questionnaires; - Data variability: when an indicator of the variability is presented in the article	Following Langridge <i>et al.</i> [53]	Added categories
<i>Study design**</i>	- Control-impact design: two or more ecosystems/areas/species with at least one with the driver of change and at least one without the driver of change, both studied at one point in time; - Before-after design: one ecosystem/area/species studied before and after an event (e.g., a new driver of change or a sudden event as an extreme climate event); - Before-after control-impact design: two ecosystems/areas/species; one with the driver of change and one without, both at two time points: before and after the event; - Multiple before-after control-impact design: two or more ecosystems/areas/species: two or more with the driver of change and several without, all at several time points, before and after the event; - Multiple impact design: two or more ecosystems/areas/species with different characteristics (e.g., exposed to different drivers of change) compared at one time point; - Multiple impact design - a temporal series: two or more ecosystems/areas/species with different characteristics over time; - Temporal series during a disturbance: one ecosystem/area/species or several studied over time when exposed to a chronic disturbance; - Temporal series post-disturbance: one ecosystem/area/species or several studied over time post-disturbance; - Correlation analysis: correlations between the magnitude of a driver of change and one or several ecosystems/areas/species characteristics	Adapted from Sordello <i>et al.</i> [52]	New category

345 *Category modified from the protocol Campagne *et al.* [42]

346 **New category; not in the protocol Campagne *et al.* [42]

347

348 Data coding strategy

349 The metadata from all included articles were coded in a standardized data extraction form. The
350 metadata is detailed in a codebook sheet in Additional file 6. For each article, we extracted information
351 on 1) bibliographic information; 2) ecosystem type, specific ecosystem, and biodiversity; 3) ecosystem
352 service; 4) spatial scale of the study, location of the study, temporal scale of the study; 5) driver type,
353 management type; and 6) data type and study design.

354 The coding was undertaken in three steps.

355 First, coding was tested on three articles by three reviewers (SC, LAR, ET) during a face-to-face
356 meeting. This meeting ensured that each reviewer understood the metadata and refined the metadata
357 and its categories when necessary.

358 Secondly, two reviewers (SC, LAR), each separately coded a test sample of 30 articles, and
359 compared their extracted data interpretations. Differences were discussed and new adjustments were
360 made when needed. Note that differences only occurred in terms of the way in which to code
361 metadata and how to deal with ambiguous articles.

362 Finally, SC and LAR coded all 653 articles, with ET cross-checking specific articles identified as
363 difficult to code. We strove to avoid interpreting information in the article, and concentrated on
364 extracting raw information. To verify consistency throughout the whole coding process, LAR coded a
365 sample of 25 articles twice, at the beginning and at the end of the coding process. Cohen's kappa
366 coefficient was 0.99, confirming consistency.

367 **Data mapping method**

368 The database was managed and analysed in Microsoft Excel software using tables and graphs. While
369 many representations were done in Microsoft Excel, we also used MapChart
370 (<https://www.mapchart.net/world.html>) for the world map.

371 Once coding was completed, we checked that our map was a list of publications (i.e., the formats in
372 which authors present their research) all containing only one study unit (i.e., one unique investigation)
373 following James *et al.* [54]. Nevertheless, an article may be classified across several categories of the
374 metadata. For example, an article may involve several ecosystems and/or several ES, but was still one
375 study unit because it was one unique investigation [54]. Consequently, the total number of articles in
376 the different categories of metadata in the results section may be greater than the number of selected
377 articles.

378 The database contained the mention “unknown” if information was not given by the authors, and “NA”
379 if the coding information was not applicable.

380

381 **Review findings**

382 **Review descriptive statistics**

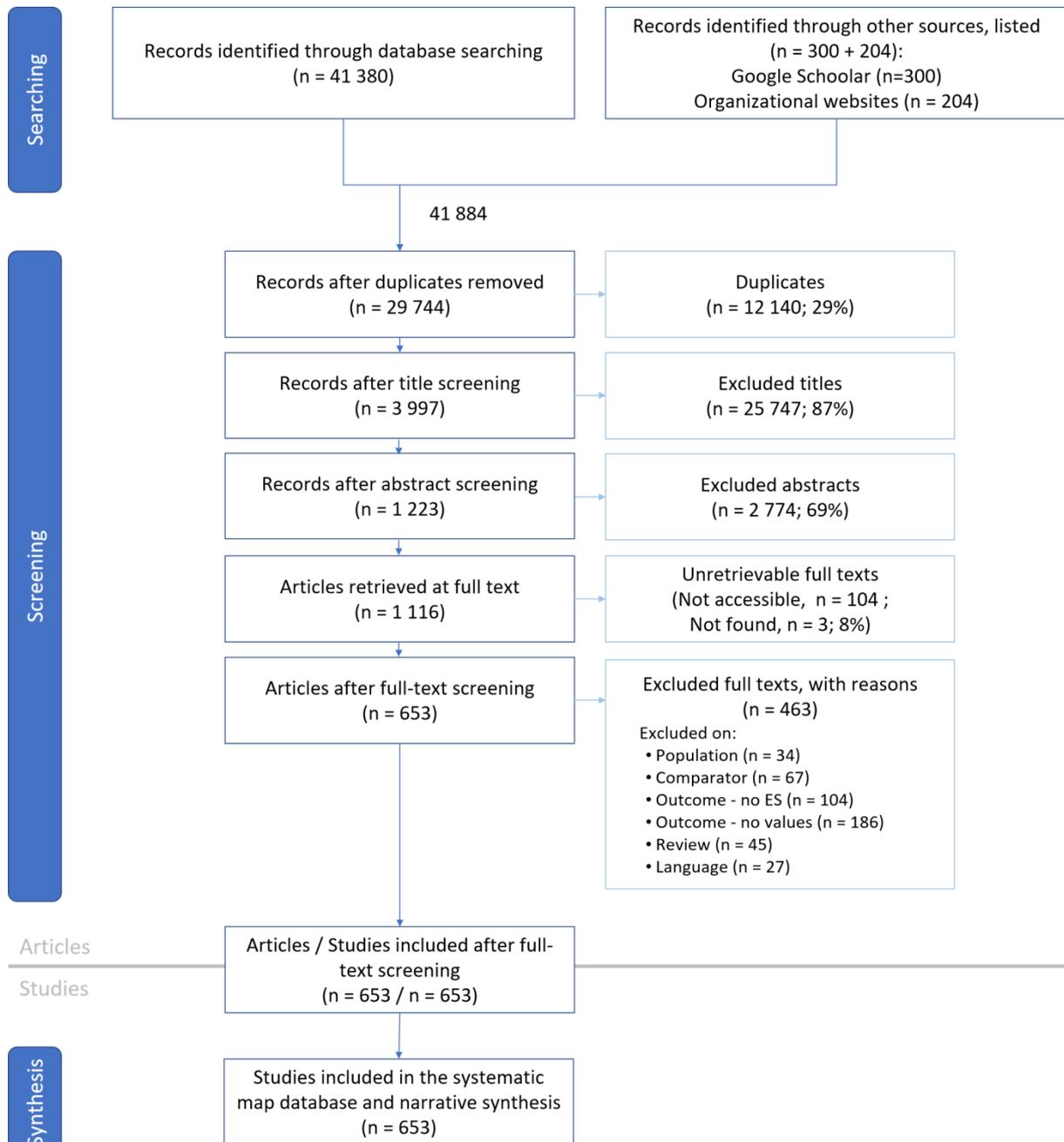
383 The number of records selected at each stage of the review process is presented in Figure 1. A total of
384 41 380 records were identified through database searches, and 504 additional records were identified
385 through Google Scholar and organizational websites. We detected 12 140 duplicate records. The titles
386 and the abstracts were screened separately, resulting in the removal of 25 747 and 2 774 records,
387 respectively. The full texts of 1 116 records were screened; 106 full texts were unretrievable (listed in
388 Additional file 4).

389 Full-text screening led to the exclusion of a further 453 articles (listed in Additional file 5). The main
390 reasons were the lack of ES values in the articles or the lack of ES assessment (cf. eligibility criteria).
391 For instance, even if a title or abstract mentioned an ecosystem service, the object of the assessment
392 was often not about an ecosystem service. Similarly observed by Storie *et al.* [38], several papers
393 mentioned the term “ecosystem services”, but did not mention what kind of services were

394 provided/involved. Other reasons for exclusion were, in the order of the number of articles excluded:
 395 lack of spatial and/or temporal differences (Comparator); review papers either without ES values
 396 altogether, or presenting only existing ES values from other papers without new analyses; missing
 397 marine ecosystem (Population) and full text not in English (“Language”) (Figure 1).

398 Finally, a total of 653 full texts were selected for coding and are listed in Additional file 6.

399



400

401 **Figure 1: ROSES flow chart for the systematic map showing the number of records included at each stage of**
 402 **the review process**

403

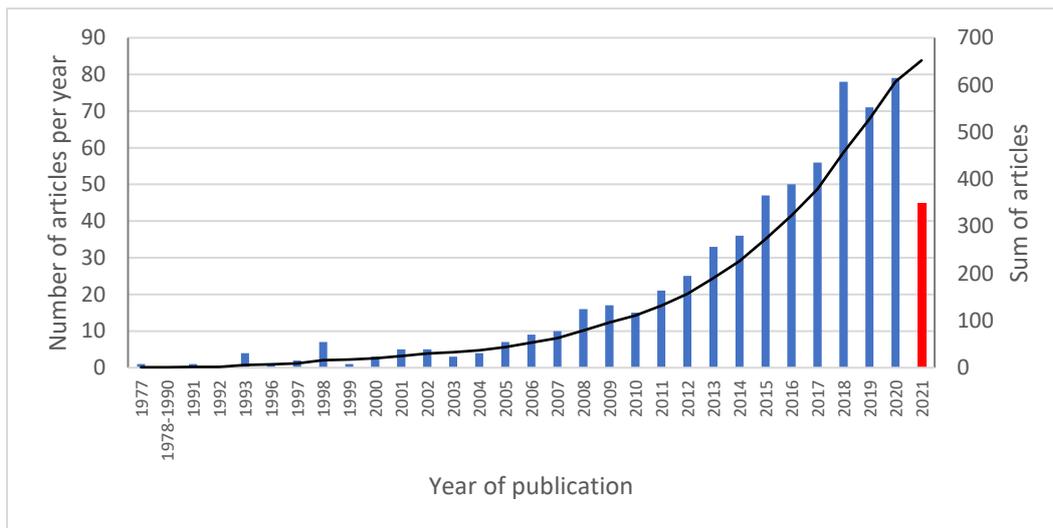
404 **Descriptive information**

405 **1) Bibliographic information**

406 The ultimately selected articles covered a period from January 1977 to July 2021 (date of the records
407 searched) with an increase in the number of articles published during the last 20 years (Figure 2). This
408 trend has been highlighted in many reviews (e.g., [55]), being correlated with the increase of articles
409 published in all fields. A similar pattern was revealed in the temporal evolution of the number of
410 published articles in the 41 380 records identified through database searching (Figure 1 in Additional
411 file 7). The increase in studies on ES has already been reported in McDonough *et al.* [56], noting an
412 increase in the number of articles published each year citing the term “ecosystem services” in the title,
413 keywords or abstracts between 2005 and 2016.

414 Incidentally, all selected records were journal articles, except one that was a technical report. Although
415 we thoroughly searched the grey literature, only one record met all eligibility criteria. In terms of
416 content, four articles were reviews and one article was a discussion paper. No book chapters or other
417 types of content were included in the final database of documents (e.g., meeting abstracts, news,
418 editorials, commentaries, correspondence, communication, etc.).

419



420

421 **Figure 2: Temporal trend of the number of published articles (no selected article was published between**
422 **1978 and 1990), with the number of articles published per year in blue (2021 is shown in red to indicate the**
423 **year is incomplete: literature search was conducted in July) and the black line shows the increase in number**
424 **of articles published.**

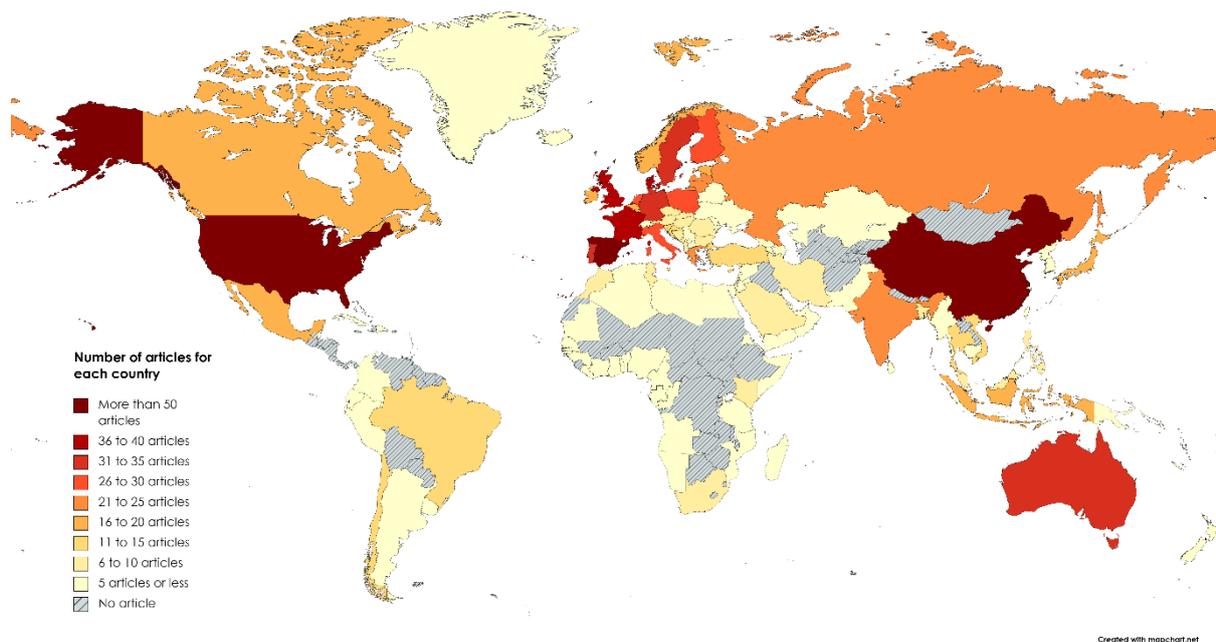
425 The Atlantic Ocean was the most studied ocean (290 articles), followed by the Pacific Ocean (187
426 articles) and the Indian Ocean (107 articles). The Arctic and Antarctic oceans were included in only five
427 and one study, respectively.

428 Study location was coded with the country identified in the articles and related to the study sites
429 presented in the articles. If the article presented a global analysis without a related country, we coded
430 it as “global”. If no study site was mentioned, we coded it as “No case study”. The USA presented the
431 highest number of articles (79 articles), followed by Spain and China (53 and 52 articles, Figure 3). The
432 USA and China were also in the top three countries along with the United Kingdom (UK) for the highest

433 number of published articles (2005–2016) containing the term “ecosystem services” in the
434 McDonough *et al.* [56] analysis and in a review (1998–2017) on water ES (ref. [55]). While the UK was
435 the fifth country in terms of number of articles in our map, Spain seems to actively publish articles on
436 marine ES, particularly in light of our results and compared with those of McDonough *et al.* [56] and
437 Aznar-Sánchez *et al.* [55].

438 In this map, we observed a high number of articles involving North America, Europe, Asia and Australia,
439 but few or none in the countries of South America, Africa, the Middle East and Oceania (except
440 Australia). These results follow a trend similar to the global distribution of valuation articles observed
441 in McDonough *et al.* [56] and more recently in the IPBES Values Assessment reports [10], which showed
442 the highest number of articles to be from Europe, North America, and then Asia.

443 Changes in ES services were analysed mainly at subnational scales, with 61% of the articles (399
444 articles). Only 16% of the articles (104 articles) involved studies at a national scale, 15% (100 articles)
445 at a supranational scale, 2.5% (16 articles) at a continental scale, and 9% (56 articles) were at the global
446 scale. Again, these proportions, in terms of the spatial scale of the analyses, follow a pattern similar to
447 that highlighted in IPBES [10], which showed 72% of subnational-scale articles, 11% at national scale,
448 9% at cross-regional/national scales, and 6% at the global scale. Liqueste *et al.* [22] also showed a
449 relatively high proportion of local (i.e., subnational) marine and coastal studies.



450

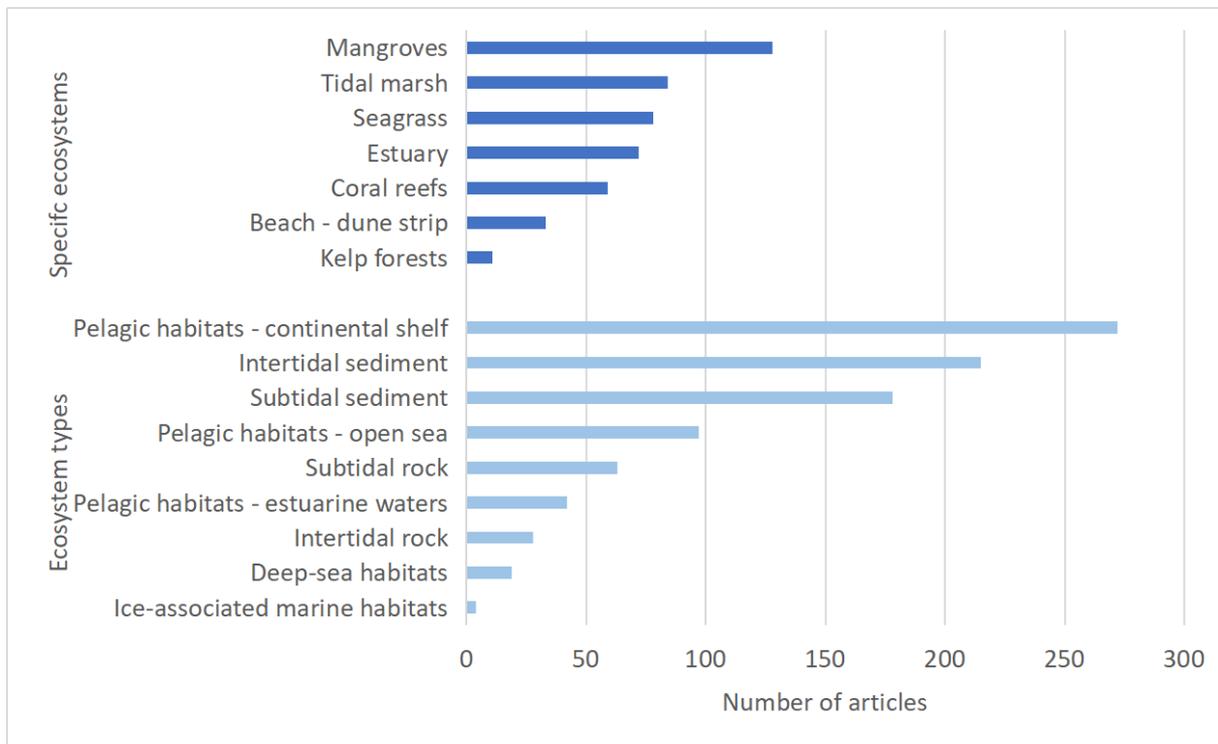
451 **Figure 3: Spatial distribution of the number of articles per country**

452 **2) Population: studied ecosystems and biodiversity indicators**

453 The main ecosystems studied (categories adapted from the “EUNIS level 2 Classification” by the
454 European Commission) were pelagic ecosystems on the continental shelves, and intertidal and subtidal
455 soft-sediment ecosystems (Figure 4). Few articles dealt with intertidal and subtidal hard substrates and
456 the fewest retrieved articles addressed deep-sea ecosystems and ice-associated ecosystems.

457 About half of the articles (49%) focused on specific coastal ecosystems (e.g., mangroves, seagrass)
458 (Figure 4). This focus on specific ecosystems (also called remarkable habitats) has been already

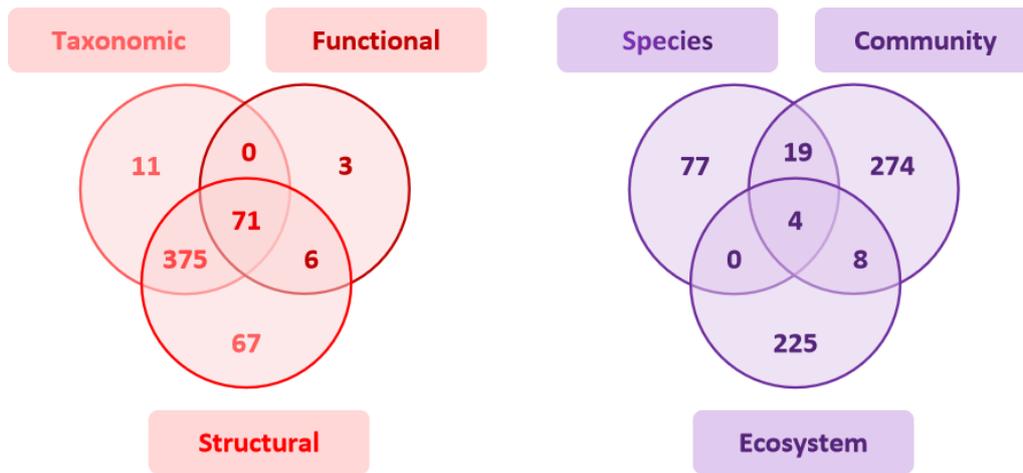
459 highlighted in France [15] and these particular habitats are the subject of disproportionally research
 460 studies (e.g., [57]). In these specific ecosystems, mangroves have received the most attention (19%)
 461 followed by tidal marshes and seagrass meadows (13% and 12%, respectively). Surprisingly, coral reefs
 462 were featured in only 59 articles. Less attention was given to kelp forests, with only 11 articles (2%).



463
 464 **Figure 4: Distribution of articles according to specific marine ecosystems (in dark blue) and ecosystem types**
 465 **(in light blue)**

466 To describe which facet of marine biodiversity was monitored to depict its changes, we coded essential
 467 biodiversity variables (i.e., species, community and ecosystem; cf. Table 4.) [58] and the three essential
 468 characteristics of diversity (i.e., taxonomic diversity, structural diversity and functional diversity) [49],
 469 all detailed in Table 4. Thus, in terms of distribution, community composition [58] was monitored in
 470 301 articles and ecosystem structure in 247 articles, and species' populations were monitored in 89 of
 471 the articles (Figure 5). The structural diversity (i.e., the distribution of biological entities [49]) and the
 472 taxonomic diversity (i.e., the number of different biotic entities like species richness [49]) were the
 473 main characteristics of diversity analysed in 375 articles (Figure 5). Note that not all articles included
 474 marine biodiversity elements, so the total in Table 5 is less than the 653 analysed articles.

475 A qualitative description of the species studied highlights that some charismatic species are often
 476 studied, including exploited fish and shellfish species, such as cod *Gadus morhua*, red mullet *Mullus*
 477 *surmuletus* and Norway lobster *Nephros norvegicus*, and foundation species such as mangrove species
 478 *Avicennia marina* and *Avicennia germinans*, and the seagrass species *Posidonia oceanica* and *Zostera*
 479 *marina*.



480

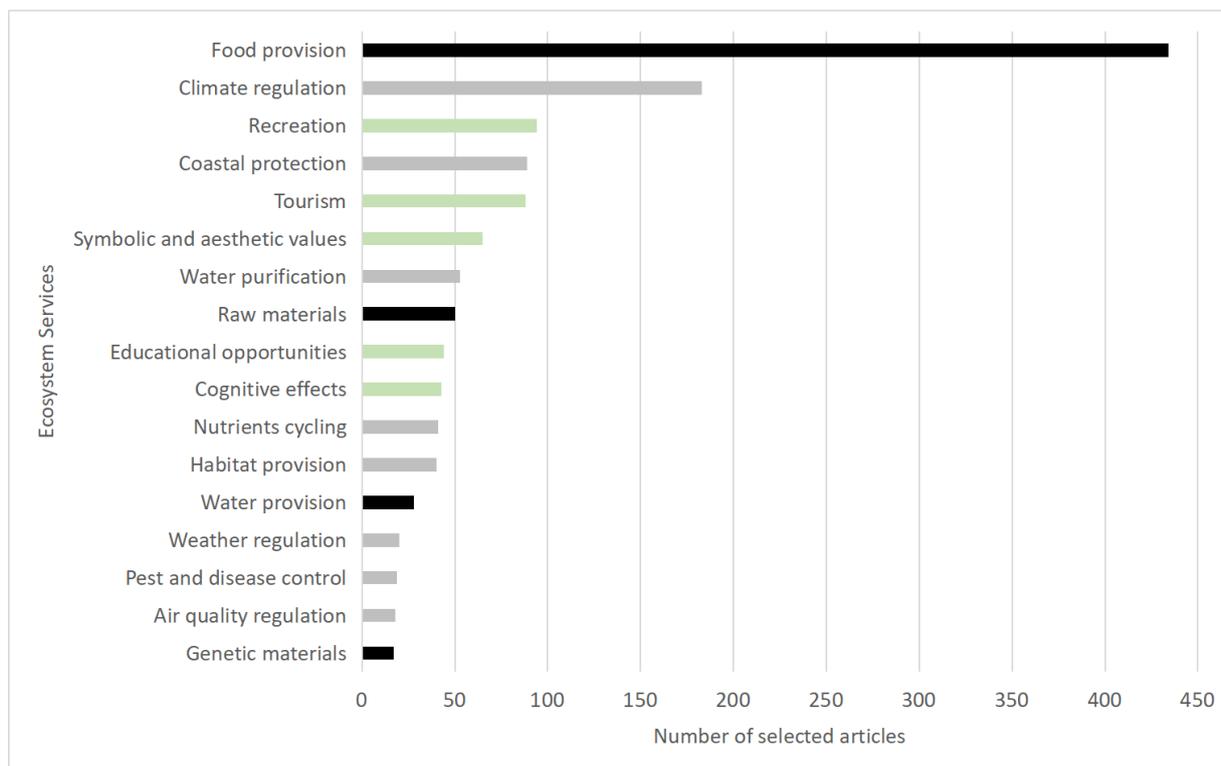
481

482

Figure 5: Number of articles per indicator of marine biodiversity monitored per essential biodiversity variable (left panel) and essential characteristic of diversity (right panel)

483

3) Outcomes: ecosystem services



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Figure 6: Distribution of the number of articles per ecosystem service. Provisioning services are shown in black, regulating services in grey, and cultural services in green.

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Provisioning services were assessed in 68% (447 articles), regulation services in 39% (252 articles) and cultural services in 18% (120 articles) of the articles. The main ES studied was food provision (67%; number of articles in Figure 6) mainly related to fisheries, followed by climate regulation, with 28% of the articles. Recreation and tourism were the subject of 14% and 13% of the articles, respectively. The least analysed ES were pest and disease control, air quality regulation, and genetic materials. Only five articles included disservices (i.e., negative impacts on human well-being; for example, related to the proliferation of harmful species like jellyfish [59]). Over time, the literature has focused mainly on food

494 provision, then progressively covering all the different ES since 2007 (Figure 3 and 4 in Additional file
 495 6).

496 The ES are mainly assessed through the potential, capacity or the supply component (89%; number of
 497 articles in Table 3), followed by use or flow, which were assessed in 45% of the articles. Preferences,
 498 desires, benefits or other forms of demand were assessed in only 8% of the articles. Over time, the
 499 proportion of articles considering ES use or flow varied, stabilizing at around 30% during the last
 500 decade, during which the number of articles has increased (Figure 5 in Additional file 6). While 57% of
 501 the articles assessed only one ES component, 42% assessed two components, which were mainly in a
 502 “supply/use approach”. Only three articles assessed the three ES components simultaneously.

503 In the different ES categories, potential, capacity or supply was assessed in between 94 and 100% of
 504 the articles, except for the ES food provision, in which they were assessed in only 85% of the articles
 505 (Table 5). The ES food provision was assessed through use or flow in 68% of the articles (293 articles),
 506 which is different from all the other ES for which use or flow was only assessed in 20% or less of the
 507 articles (Table 5). The demand component was also heterogeneous, involving more than 20% of the
 508 cultural ES, water purification and air quality regulation, but only 7% and 8% articles on food provision
 509 and climate regulation and 10% of articles on weather regulation and nutrient cycling. All ES showed a
 510 higher proportion of articles on their benefits than on preferences or desires.

511 Following the ES definitions and indicators presented in the articles and their individual definitions, 79%
 512 of the articles analysed only one ecosystem service (516 articles). The number of articles decreased
 513 with the number of ES identified in the articles, with 7% of the articles (47 articles) analysing two ES
 514 and only 7% of the articles (46 articles) analysing more than five ES.

515 **Table 5: Distribution of the number of articles per ecosystem service values and components (cells are**
 516 **shaded according to the high (dark) and low (light) values for each column separately)**

	Total	Food provision	Raw materials	Genetic materials	Water provision	Water purification	Air quality regulation	Coastal protection	Climate regulation	Weather regulation	Nutrients cycling	Habitat provision	Pest and disease control	Symbolic and aesthetic	Recreation	Tourism	Cognitive effects	Educational opportunities
		433	50	17	28	53	18	89	183	20	41	40	19	64	93	87	42	43
Economic	213	155	39	13	18	32	14	49	52	12	17	22	13	42	60	58	29	31
Socio-cultural values	39	28	9	5	6	8	3	8	6	3	2	5	6	14	16	19	10	9
Biophysical	633	419	44	15	24	49	16	82	176	19	39	36	18	53	80	76	36	36
Potential/capacity/supply	583	366	49	16	27	50	17	88	181	20	41	39	18	63	89	85	41	42
Use/flow	297	293	10	2	3	4	3	6	10	1	3	6	1	5	18	17	3	4
All demands	52	30	7	3	4	12	4	13	14	2	4	6	4	15	23	21	12	11
Preferences/desires	18	9	1	1	1	5	1	1	2	0	0	2	2	7	11	10	8	7
Benefits	35	21	6	2	3	8	3	12	11	1	3	4	4	9	13	14	7	6
Other forms of demand	2	2	1	1	1	1	1	1	1	1	1	1	0	1	2	0	0	0

517 The ES were almost always assessed using biophysical values (97% of the articles, Table 5). Economic
518 values of ES were assessed in 33% of the articles. They were measured using socio-cultural values in
519 only 6% of the articles. Over time, the proportion of articles considering ES economic values varied,
520 stabilizing at between 12 and 28% during the last decade, during which the (absolute) number of
521 articles increased (Figure 6 in Additional file 6). The assessment of sociocultural ES values started only
522 in 2006 based on our selection of articles.

523 Biophysical assessments of ES dominated the assessment of ES in the Baltic Sea (47.5% of articles in
524 [39]). The IPBES report [42] showed that 50% of studies are based on a biophysical assessment, 26%
525 on a monetary assessment and 21% on a socio-cultural approach.

526 Biophysical and economic ES values were jointly assessed in 26% of the articles. A small number of
527 articles combined sociocultural and biophysical values (1%) or combined all three assessment methods
528 (28 articles; 4%). Two articles considered sociocultural values alone and no study combined socio-
529 cultural and economic values. We agree with Kuhn *et al.* [46], that “the predominant focus on
530 biophysical research is emphasized by the fact that the vast majority of publications is focused on ES
531 supply, neglecting the demand side and leaving out the societal request for ES”.

532 Although biophysical value was assessed for all types of ES, the economic and socio-cultural values
533 were more common for some specific ES (Table 5). For instance, economic values were frequently
534 assessed (more than 70%) in articles on raw materials, genetic materials, and air quality regulation.
535 Sociocultural values were considered for almost 30% of the ES related to genetic materials and pest
536 and disease control. The economic and socio-cultural values were the least frequently assessed values
537 for the ES climate regulation, food provision, and nutrient cycling.

538 **4) Comparator: spatial and temporal scale**

539 In our map, the spatial scale of the analysis of ES changes was measured using the number of case
540 study sites. For instance, 247 articles involved one site (37% of the articles), 275 articles analysed more
541 than one site (41%) and 187 articles (28%) more than three sites, with a maximum number of sites
542 (536 sites) in a study on coastal tourism under climate change on beaches all over Japan [60].

543 Temporal dynamics were coded with the interval and the time covered by the raw and the results data.
544 While we did not consider articles with data covering periods ending before 1900 (cf. eligibility criteria),
545 data acquisition varied from 1 to 2500 years, e.g., from 500 BC to 2000 in Finney *et al.* [61]. A large
546 majority of articles (83%) covered a period of more than one year (Figure 2 in Additional file 7). The
547 duration of the period studied was longer in the results data, because the raw data were used in
548 simulation models, i.e., for prediction. A total of 170 articles (26%) studied more than one site with
549 data covering more than a year.

550 In terms of the study period, 490 articles (76%) analysed data from the past (i.e., prior to 3 years before
551 the date of publication), and 446 articles (69%) reported the situation in the last 3 years before
552 publication and 146 articles (22%) analysed services in the future (i.e., after the year of publication).

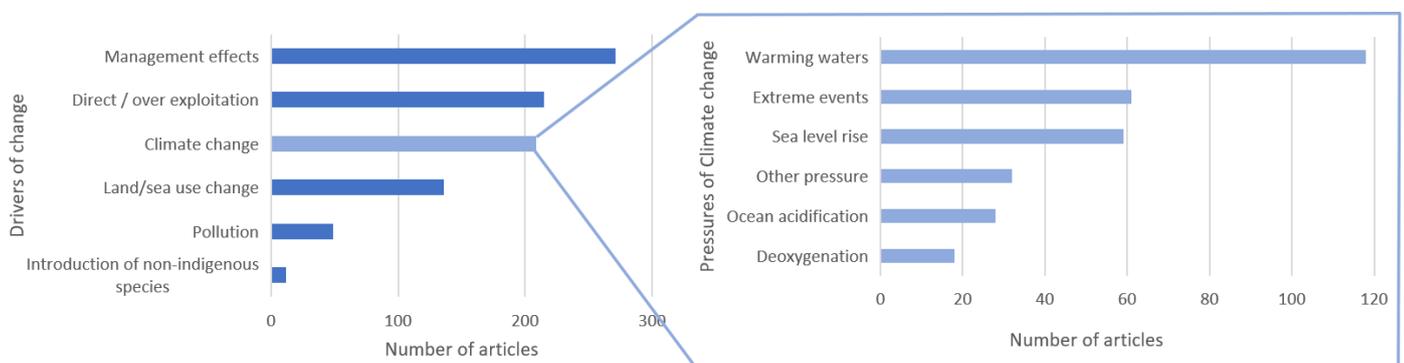
553 **5) Drivers of change**

554 Coastal and marine ecosystems are affected by several drivers of change, which in turn affect the
555 delivery of marine ES [26]. About 60% of global marine ecosystems have been degraded or

556 unsustainably used [49], and the percentage of stocks fished at biologically unsustainable levels has
 557 increased from 10% in 1974 to 34.2% in 2017 [63]. Within the six coded classes of driver types (Figure
 558 7), 48% of the articles (315 articles) identified only one driver and 38% (247) identified more than one
 559 driver, 13% did not identify or mention a driver of change at all. Finally, 57% (376 articles) integrated
 560 data regarding drivers of change into their analyses and 29% (187) integrated data from the ecosystem
 561 condition or processes into their analyses.

562 Within the different coded types of drivers of change, the management effect was the most analysed
 563 driver (41%; Figure 7), followed by direct/overexploitation, analysed in 33% of the articles. Climate
 564 change was analysed in 31% of the articles and land/sea use and change in 21% of the articles. In terms
 565 of climate change pressures, warming waters was the most analysed driver. The introduction of non-
 566 indigenous species and deoxygenation (related to climate change) were the least frequently analysed
 567 pressures.

568 Regarding management, fishery management concerned 32% of the articles, water quality
 569 management 6% and finally marine protected areas, 9%.



571 **Figure 7: Distribution of the number of articles for the types of drivers of change (on the left) with**
 572 **distribution for the pressures related to climate change (on the right). Article can concerned several drivers**
 573 **of change or pressures of climate change.**

574 6) Data and study types

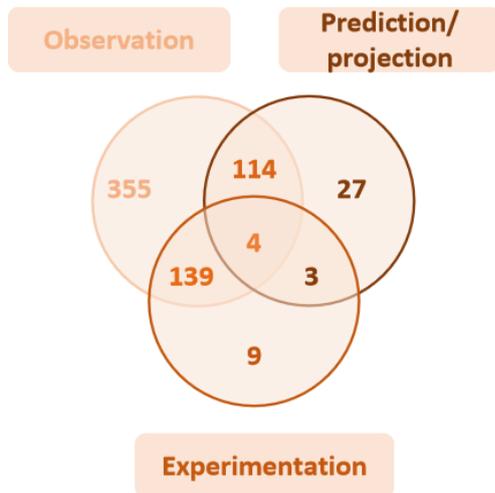
575 Almost all articles were based on quantitative data (98%; 637 articles); qualitative data were exploited
 576 in 5% of the articles. The dominance of quantitative data is also highlighted in Liqueute *et al.* [22],
 577 reporting 56% of quantitative assessments and 10% of qualitative assessments.

578 Within the different ES, qualitative data primarily addressed cultural services, accounting for 13 to 17%
 579 of the articles (Table 1 of Additional file 1). Overall, 55% of all articles presented primary data with the
 580 fewest primary data articles for the food provision and genetic materials ES (respectively 47.8% and
 581 7.1%). With a view to carry out a meta-analysis after the systematic map, the presence of measures of
 582 variability, such as standard errors or standard deviations of ES values, was coded: information on
 583 variability was provided in 57% of the articles. The information on variability was not present in the
 584 same proportions across the ES (Table 1 of Additional file 1): fewer than 24% of the articles on genetic
 585 materials and water provision provided values of variability, but 66% of the articles on climate
 586 regulation did.

587 The data were mostly based on observation and descriptive approaches with measurement of a
 588 specific parameter (90%, 698 articles), representing 100% of the articles on genetic materials, water
 589 provision, air quality regulation, weather regulation, and pest and disease control (Table 1 of Additional

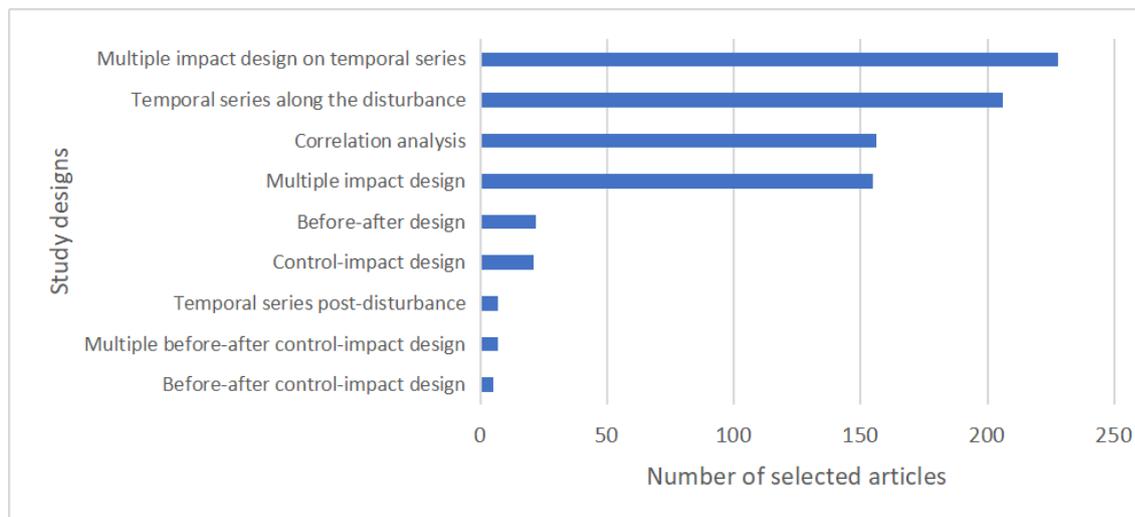
590 file 1). Projection or prediction approaches (definition of potential values in the future based on models;
 591 projection is futures when a change/pressure happens; prediction is futures when nothing influences
 592 the evolution) were used in 22% of the articles (146 articles) and experimentation (experiments
 593 showing causality effects between factors) was used in 23% (153 articles). A mixture of observation,
 594 prediction or projection, and experiment data was reported in four articles. Experimentation alone
 595 was present in 9 articles (Figure 8).

596



597

598 **Figure 8: Number of articles per type of data**



599

600 **Figure 9: Distribution of the number of articles for the types of study design across case studies**

601 The main types of study design were multiple impact design on temporal series, which refers to two
 602 or more ecosystems/areas/species with different characteristics compared over time (35% of the
 603 articles, Figure 9). Temporal series during a disturbance (i.e., one ecosystem/area/species or several
 604 studied over time during a disturbance) followed, with 32% of the articles. A multiple impact design
 605 (i.e., two or more ecosystems/areas/species with different characteristics to compare at one time
 606 point) was used in 24% of the articles. Correlation analysis between drivers and one or several
 607 ecosystems/areas/species was provided in 24% of the articles. The study design with analyses before
 608 and after an event or sudden driver of change were the least studied.

609 Within the different ES, the proportion of the different study types was homogenous with the mean
610 of all ES (Table 1 of Additional file 1), except for pest and disease control, symbolic and aesthetic values,
611 recreation and tourism which were assessed more frequently in studies with a multiple impact design
612 (two or several ecosystems/areas/species with different characteristics to compare at one time).

613 **7) Cross-category analyses**

614 The number and proportion of articles on the different ES showed a similar pattern for the different
615 marine ecosystems, with the intertidal sediment and subtidal sediment ecosystems being the focus of
616 most articles (Table 6). An exception was articles on food provision, which especially involved pelagic
617 habitats on continental shelves. For the specific marine ecosystems, mangroves attracted the most
618 articles examining the various ES. However, estuaries and tidal marshes had proportionally more
619 articles on air quality regulation. Articles on cultural services account for around 20% of the articles on
620 beach - dune strip, mangroves and coral reef.

621

622

623 **Table 6: Distribution of the number of articles per ecosystem service, ecosystem type, and biodiversity**
 624 **component (cells are shaded according to the high (dark) and low (light) values for each column separately)**

		Ecosystem service																	
		Food provision	Raw materials	Genetic materials	Water provision	Water purification	Air quality regulation	Coastal protection	Climate regulation	Weather regulation	Nutrient cycling	Habitat provision	Pest and disease control	Symbolic and aesthetic values	Recreation	Tourism	Cognitive effects	Educational opportunities	
TOTAL		433	50	17	28	53	18	89	183	20	41	40	19	64	93	87	42	43	
Type of ecosystem	Ice-associated marine habitats	4	3	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	
	Deep-sea habitats	19	19	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	
	Intertidal rock and other hard substrates	28	19	3	2	3	3	3	5	4	0	1	4	2	10	12	9	5	5
	Pelagic habitats - estuarine waters	42	32	5	1	2	4	2	6	9	1	2	4	1	5	5	7	3	3
	Subtidal rock and other hard substrates	63	55	1	1	2	2	1	4	4	0	1	3	1	5	10	6	3	4
	Pelagic habitats - open sea	97	96	0	0	0	1	0	0	1	0	0	0	0	2	1	0	0	
	Subtidal sediment	178	106	12	4	6	14	2	28	51	3	10	9	5	18	27	23	14	14
	Intertidal sediment	215	62	23	6	11	20	5	59	126	7	20	17	9	25	30	26	14	13
	Pelagic habitats - continental shelf	272	265	4	2	1	3	0	5	7	0	3	8	2	7	15	21	5	6
	Specific ecosystem	Kelp forests	11	5	1	1	0	1	0	3	4	1	2	2	1	2	4	3	1
Beach - dune strip		33	10	4	2	3	5	2	11	6	1	1	4	4	12	18	17	8	8
Coral reefs		59	44	9	3	3	8	1	16	10	4	3	7	4	12	20	18	10	10
Estuary		72	38	9	3	5	7	4	13	30	3	7	7	4	8	11	10	5	6
Seagrass		78	20	4	2	2	8	0	16	50	2	11	4	3	9	11	9	9	9
Tidal marsh		84	14	8	3	5	9	4	27	54	4	13	6	3	9	10	7	4	4
Mangroves		128	36	17	4	8	14	2	35	82	7	10	11	5	16	19	15	12	11
Biodiversity	Species or population	90	74	1	1	0	1	0	1	9	0	6	4	0	2	4	5	1	1
	Ecosystem	254	64	29	6	13	29	6	65	154	12	26	19	9	34	45	41	25	26
	Community	306	288	7	3	3	7	0	5	14	1	6	9	2	9	18	19	4	5
	Functional	80	59	0	0	0	1	0	4	21	1	4	4	0	1	2	4	1	1
	Taxonomic	465	321	14	4	7	14	1	33	113	4	19	17	2	18	26	31	11	12
Structural	528	363	18	4	8	16	1	44	123	5	24	19	3	20	28	31	13	13	

625

626 **Table 7: Distribution of the number of articles per ecosystem service and type of driver of change (cells are**
 627 **shaded according to the high (dark) and low (light) values for each column separately)**

		Ecosystem services																	
		Food provision	Raw materials	Genetic materials	Water provision	Water purification	Air quality regulation	Coastal protection	Climate regulation	Weather regulation	Nutrient cycling	Habitat provision	Pest and disease control	Symbolic and aesthetic values	Recreation	Tourism	Cognitive effects	Educational opportunities	
Total		433	50	17	28	53	18	89	183	20	41	40	19	64	93	87	42	43	
Driver of change	Introduction of non-indigenous species	12	4	2	0	1	2	1	5	5	1	2	0	2	2	2	2	2	
	Pollution	49	27	7	2	3	7	2	7	19	3	5	5	3	9	14	14	6	7
	Land/sea use change	136	53	28	8	18	29	10	40	71	10	12	22	10	28	36	32	20	20
	Climate Change (CC)	204	141	14	4	10	12	3	43	42	5	16	11	6	15	22	22	9	10
	Direct/overexploitation	215	209	6	3	2	7	0	8	6	3	6	8	3	10	19	19	9	9
	Management effects	271	209	13	7	8	20	2	28	40	6	11	18	9	28	42	47	19	17
	CC - deoxygenation	18	15	0	0	0	0	0	0	2	0	2	0	0	0	1	3	0	0
	CC - ocean acidification	28	24	2	0	1	2	0	4	4	0	1	1	1	3	5	5	3	3
	CC - other pressure	32	24	1	0	1	3	0	4	11	1	2	2	1	3	5	4	3	3
	CC - sea level rise	59	23	8	4	6	5	3	29	19	2	9	4	5	10	11	12	4	4
	CC - extreme events	61	42	7	2	6	4	1	24	5	2	4	6	3	6	8	7	3	3
	CC - warming waters	118	77	5	2	3	7	2	12	28	2	5	9	2	7	10	14	4	4

628
 629 The coded biodiversity indicators showed similar patterns within the ES (Table 6). Ecosystem structure
 630 was the most monitored biodiversity indicator across all articles on different ES, except for food
 631 provision which was particularly studied in terms of community composition. Structural diversity and
 632 taxonomic diversity [49] showed similar patterns within the different ES. Functional diversity, which is
 633 the diversity of functions or functional traits, was generally the least studied across all ES.

634 The heat map on Table 7 demonstrates that 48% of the articles on food provision studied the impacts
 635 of management effects and/or direct/overexploitation. For the other ecosystems, the impacts of
 636 land/sea use change were most studied, involving 37 to 64% of studies depending of the ES, ranging
 637 from 18 out of 28 articles on water purification to 36 out of 87 articles on recreation. Nutrient cycling
 638 and coastal protection were relatively more frequently studied in relation to climate change impacts
 639 (39 and 48%). Regarding the specific climate change-related pressures, warming waters and sea level
 640 rise were the focus of most articles, with extreme events supplanting either of these top two pressures
 641 or coming in at a close third place for the articles on raw materials, water provision, coastal protection
 642 and pest and disease control (Table 7).
 643

644 **Comparison with other evidence syntheses**

645 To our knowledge, no other systematic map has been published on the evidence of how ecosystem
 646 service delivery is affected by changes in marine ecosystem structure and functioning. Nevertheless,
 647 evidence syntheses published on related subjects were used to compare our map results. The final

648 number of analysed articles (653) is close to that reported for maps on the impact of agroforestry on
 649 ES and human well-being in high-income countries [64] and on the analysis of publication trends on
 650 water ES [55], but higher than other evidence syntheses on related subjects (Table 8). Our number of
 651 articles is low compared with the review of the overall ES literature [65], i.e., not restricted to marine
 652 ecosystems and their dynamics.

653 We analysed more articles than Liqueete *et al.* [22], likely due to the publication date range: we
 654 considered all articles up to July 2021 and Liqueete *et al.* considered articles only up to 2012. Our
 655 selection of articles from this 8-year interval contains 496 articles. Thus, our database up to 2012
 656 contains 157 articles, a figure close to the 145 articles considered in Liqueete *et al.*

657

658 **Table 8: Comparing other evidence syntheses to our current map. (WOS: Web of Science)**

Citation	Scope of review	Nature of synthesis	Search databases	No. of other literature sources	Publication date range of included articles	No. of included articles
<i>Our systematic map</i>	Impact of changes in marine ecosystem structure and functioning on ecosystem service delivery	systematic map	3 (WOS, Scopus, Google Scholar)	6	1977 to 2021 (July)	653
Castle <i>et al.</i> 2022 [64]	Impacts of agroforestry on ecosystem services and human well-being in high-income countries	systematic map	5 (WOS, Scopus, EBSCO: Agricola, Econlit, CAB Abstracts and Global Health, AGRIS)	24	1990 to 2020 (June)	632
Inácio <i>et al.</i> 2022 [65]	Mapping lake ecosystem services	systematic review	3 (WOS, Scopus, Google Scholar)	0	2000 to 2021	30
Storie <i>et al.</i> 2021 [38]	Impact of Baltic Sea ecosystems on human health and well-being	systematic map	17	7	1975 to 2020	67
Aznar-Sánchez <i>et al.</i> 2019 [55]	The worldwide research trends on water ecosystem services	bibliometric analysis	2 (WOS and Scopus)	0	1998 to 2017	782
McDonough <i>et al.</i> 2017 [56]	Analysis of publication trends in ecosystem services research	bibliometric analysis	4 (Scopus, WOS; CABI: CAB Abstracts, and Environmental Sciences and Pollution Management)	0	2005 to 2016	Approximately 3000
Liqueete <i>et al.</i> 2013 [22]	Current status and future prospects for the assessment of marine and coastal ecosystem services	systematic review	1 (SciVerse Scopus)	0	1823 to 2012	145

659 **Limitations of the map**

660 **Limitations in searching**

661 The search string and the articles accepted were only in English. Like for most of the maps or reviews,
 662 this restriction biased the distribution of the articles, with around 30% of the articles coming from
 663 English-speaking countries, as reported in Collins *et al.* [66]. Integrating an additional language (e.g.,
 664 French or Spanish) would have increased the range of the map, but also introduced other potential
 665 biases by focusing on some countries at the expense of others; an exhaustive search should ideally
 666 include all or the mainly used languages around the world but we did not have the resources or the
 667 time to integrate additional searches in other languages.

668 While the searches obviously depend on the search terms and the databases used, we adopted a
 669 comprehensive approach to limit this dependency.

670 **Limitations in screening**

671 The kappa coefficient at the title screening step was calculated on only 2.38% instead of 10% of titles
672 given the high number of records (29 744 records) screened at the title step. Due to resource and time
673 limitations, we chose to screen 1001 records by two screeners. The CEE recommends pilot testing on
674 10%, which is considered as the necessary proportion to thoroughly test and ensure that criteria are
675 correctly defined so that no relevant evidence is missed during screening. Although we were not able
676 to abide by this guideline, we carried out a thorough training phrase and applied a conservative
677 approach during all screening steps. In addition, we chose to apply relatively strict criteria at the
678 abstract screening stage, based on the absence of the Comparators item. This pragmatic decision was
679 taken in light of the very large volume of literature and limited human resources. We conducted a
680 posteriori crosscheck checking if abstracts have information about the Comparator (e.g., information
681 of ES change), which confirmed in principle that abstracts provided the required information.

682

683 **Limitations in coding**

684 The test of the coding procedure highlighted some limits of the coding categories of the protocol [41],
685 such as the difficulty of differentiating a “local” scale of analysis from a “subnational” scale, depending
686 on the size of the study and the country involved. To overcome this limit, we grouped these two levels
687 into a single level (“subnational”) in our analysis. All improvements on the categories coded are
688 detailed in Table 4.

689 Coding was generally strictly based on the data in the article, but the EUNIS ecosystem classification
690 and the ES classification were coded based on interpretation of the information in the articles. When
691 difficulties were encountered, the reviewers held discussions and reached decisions together. If the
692 same hesitations or difficulty in coding came up more than once, we strove to find overall solutions to
693 apply across the board and maintain coding consistency throughout the analysis.

694

695 **Conclusions**

696 This map highlights knowledge clusters and gaps on the impacts of the spatio-temporal dynamics of
697 marine ecosystems and biodiversity on the ecosystem services they provide. A high number of records
698 was identified in our search (29 744 records without the duplicates) with 2.3% (653) selected for the
699 systematic map. This low number of mapped articles can be linked to the frequent use of keywords
700 relating to ES for articles covering very different subjects, a point also highlighted in [38] and [67].

701 We focused on the ES affected by marine ecosystem dynamics, but our map’s results show that 9 years
702 after the well-cited Liqueste *et al.* [22] article, similar knowledge clusters and gaps in the marine and
703 coastal ecosystems remain. Nevertheless, some efforts can be highlighted, such as the recent increase
704 in the number of articles on the different values of ES, e.g., ES benefits and preferences.

705 Our systematic map combines a large amount of information on ecosystems, ES with their values and
706 components, types of temporal and spatial dynamics, drivers of change, study type and data type.
707 Compared with other reviews on marine ES, we introduced new information on marine ES literature,
708 such as the type of study design and the type of temporal and spatial dynamics.

709 **Implications for future research**

710 Marine ecosystems receive much less attention than terrestrial ecosystems in ES research [37,68]. In
711 our review of the literature on ES affected by marine ecosystem dynamics, we highlighted differences
712 among articles within the marine ecosystems and the marine ES, revealing different levels of interest
713 and knowledge.

714 The proportion of articles within the different ES categories in this systematic map with 68% of
715 provisioning services, 39% of articles on regulation services and 18% on cultural services differ studies
716 on other studies. Systematic maps on marine and coastal ES in the Baltic Sea showed different patterns,
717 with cultural services as the most assessed ES categories [38,39]. Studies on ES provided by lake
718 ecosystems [65] and on terrestrial ecosystems [69–72] reported that regulation services were the most
719 assessed. Nevertheless, the knowledge gap on marine cultural services has already been highlighted
720 [73,74] as well as the focus of cultural ES research on land-based assessments [75] which can generally
721 be related to the difficulties identifying and appraising intangible attributes [73], such as aesthetic,
722 symbolic, and bequest values [73]. Also, methods to quantify indicators of cultural services generally
723 only capture a discrete, snapshot value, for lack of measures of changes over time [73], and therefore
724 do not include the dynamics of the marine ecosystems. Recreation and tourism are the most studied
725 cultural services, likely due to their socio-economic importance and the fact they are easier to assess
726 and quantify [73,76]. Even though the importance of recreation and tourism is unquestionable, other
727 cultural services need to be considered more extensively and assessed [73,76]. The dominance of
728 potential/capacity or the supply component (90%, 599 articles) was also observed in Kuhn et al. [39],
729 Inácio et al. [65] and IPBES [10].

730 Food provision was the most studied marine ES, particularly for fisheries. Our results were influenced
731 by the high proportion of articles on food provision (i.e., fisheries), which is an important ecosystem
732 service that marine ecosystems provide, having high economic importance for humans. Some marine
733 species groups are more frequently assessed and studied such as commercial species and top predator
734 fish stocks [30]. Regarding tourism or recreation, our screening process retrieved literature on the
735 impact of tourism and/or recreation activities on the ecosystems, which we excluded as out of scope.
736 Furthermore, the existing ES analyses have not integrated how the impact of tourism and/or recreation
737 activities on the ecosystems also affects all ES as well as the tourism and/or recreation activities
738 themselves, thus shaping the sustainability of these activities. For example, Apps *et al.* [77] studied
739 how scuba diving can impact the behaviour of the grey nurse shark and Harriott *et al.* [78] studied
740 recreational diving and its impact in marine protected areas in Eastern Australia. However, neither of
741 these studies explored how these impacts affected the sustainability of the recreational activities as a
742 feedback loop.

743 Knowledge on marine ecosystems decreases with distance from the coastline, as previously shown in
744 [79]. Knowledge clusters are concentrated in the pelagic ecosystems on continental shelves and
745 intertidal and subtidal soft-sediment ecosystems, and less attention has been given to deep-sea
746 ecosystems [37,80] and ice-associated marine ecosystems [81]. The relatively low volume of ES
747 literature for these latter two ecosystems can be explained by their relatively less accessible habitats.
748 They may also be ecosystems that—by nature—provide fewer ES in terms of diversity and in quantity
749 compared with other marine or terrestrial ecosystems. Deep-sea research incurs high costs, difficulties
750 and risks associated with the ecosystem characteristics [82]. However, deep-sea ecosystems are
751 growing centres of interest for extracting mineral resources [83] and, although some studies have
752 analysed the potential impact of mining on deep-sea biodiversity, research efforts also need to be

753 directed at estimating the potential impact of human activities on their ecological conditions and
754 ecosystem service provisions. Recent publications have addressed the impacts of deep-sea mining on
755 microbial ES [83] and how to incorporate ES into the environmental management of deep-seabed
756 mining [84]. Articles on deep-sea ES highlight many ecosystem “functions” and “support services” such
757 as habitat provision and nutrient cycling [82]. Mangroves are the most studied specific ecosystem,
758 followed by tidal marshes and seagrass meadows, also highlighted by [15], and kelp forests are the
759 least studied. As shown in Jacquemont *et al.* [85], the capacity to provide ES and the volume of papers
760 are not related to the global surface area of the habitat. For instance, in contrast to soft-sediment
761 habitats, mangrove ecosystems provide a high quantity of ES per unit area and have been intensely
762 studied, even though they represent a small surface area on the globe [85]. Among specific ecosystems,
763 macroalgae have received little attention, but current focus is turning to kelp forests in light of the
764 growing interest in blue carbon [86].

765 Most drivers of change directly affect the ecosystem status and functioning and therefore its ability to
766 provide ES, but management effects may either consist in reducing the pressures or even the very
767 provision for some ES. When effective, management is expected to lead to positive results regarding
768 ecosystem preservation and sustainable ES consumption. Across the different types of drivers of
769 change, management effects, followed by direct/overexploitation and climate change, are the most
770 studied. IPBES [87] has shown that the highest relative impact of direct drivers on the marine realm
771 based in terms of essential biodiversity variables is direct exploitation (management effects are not a
772 category of direct anthropogenic drivers in IPBES), followed by land/sea use change and then climate
773 change. Therefore, the pattern of knowledge clusters closely reflects the relative impacts of the drivers
774 of change. The introduction of non-indigenous species and pollution have the lowest relative impact
775 on the marine realm [87], but it is nevertheless important to grow knowledge on their impact on
776 marine ES given their increasing frequency [68]. The need to develop the knowledge base on the
777 efficiency of management actions in marine ecosystems has been highlighted [15]. Management
778 effects have the highest number of articles within the types of drivers of change so that the database
779 of our systematic map could be used to analyse management efficiency.

780
781 Time-series study designs are common, but control-impact and/or before-after designs are the least
782 implemented study designs. This discrepancy can be attributed to the spatial scales at which ES are
783 provided and affected by the drivers of change on marine ecosystems. With regard to the questions
784 raised in our study, the establishment of long-term time series is better suited to the study of ES than
785 the development of experimental approaches or control-impact and before-after study designs. For
786 example, it is difficult to design experiments to follow the responses of fisheries to climate change or
787 overexploitation; in contrast, time-series analyses and prediction or projection are more suitable and
788 more frequently implemented. One interesting perspective is to extend the scope of the systematic
789 map to the feedback loop of ES variation on other ES and on human demand. For example, drivers of
790 change impact marine ES, which affect ES uses, which in turn also affect their sustainability. In addition,
791 the multifunctionality and the bundles of services are not sufficiently studied [15] and have only been
792 rarely studied in marine realm.

793 This systematic map confirms hypotheses and results on marine ES knowledge presented throughout
794 this paper, although our systematic map focuses on marine ES affected by marine ecosystem dynamics.
795 The database presents detailed information on the knowledge within the ES and ecosystems
796 categories, thereby identifying very specific knowledge gaps for future research. The database can thus

797 be used as a source of articles for a meta-analysis on related topics. As for future prospects for the
798 systematic map defined here, we agree with Collins *et al.* [66] on the interest to explore the use of
799 computer algorithms to construct and update the maps, particularly in light of the high and increasing
800 number of articles to search, screen and code in the systematic map process.

801

802 **Implications for policy/management**

803 The ES concept is increasingly used and implemented in policy and management tools, because it is
804 known to increase the consideration of nature and its contributions to people into land or marine
805 planning [68]. This concept is increasingly cited in international and national regulations and policies,
806 but its implementation is challenging, requiring further solid scientific knowledge [68]. Indeed,
807 *“[f]uture efforts should be aimed at developing solid evidence linking decisions to the anthropogenic*
808 *impacts on ecosystems and generated services and, as a consequence, to human well-being; working*
809 *with leaders in governments, businesses, and civil society to develop and provide knowledge and tools*
810 *to effectively integrate ecosystem services into decision-making processes; and reforming policies and*
811 *institutions, and building capacities to better align with private, short-term goals and with societal,*
812 *long-term goals”* [68].

813 The lack of knowledge is a danger for the sustainability of human actions and knowledge-based nature
814 conservation. The knowledge gaps and clusters highlighted here have an impact on the beneficial
815 development of policy and management practises. For example, limited evidence on the efficiency of
816 management actions in marine ecosystems has been highlighted [15,73]. Given that management
817 effects have the highest number of articles among the types of drivers of change coded, the database
818 of this systematic map could be used to analyse management efficiency further. While management
819 actions concerned many fisheries regulations now more regulation are applied. Marine protected
820 areas (MPAs) are a key tool increasingly used for marine protection and conservation [67,88].
821 Nevertheless, the number of articles on MPAs in the map is low, despite the growing number of articles
822 over the last 10 years. Studies on MPAs primarily assess the biological responses of their
823 implementation, with less emphasis on the impact of ES delivery (but see the recent review of the ES,
824 societal goods, and benefits of MPAs [67]). There is a need to grow knowledge on the efficiency of
825 MPAs and other conservation actions to better guide their implementation depending on the context,
826 desired level of protection, and conservation targets [68].

827 The consideration of the plurality of nature’s value is absolutely essential to cultivate a sustainable and
828 equitable future, as recommended by the latest IPBES report [10]. Nevertheless, the economic and
829 socio-cultural values of marine ES are still poorly known and have generated less interest. As funders
830 and/or government authorities, decision-makers can push for more transdisciplinary science and
831 research at the science-policy interface as well as for the participation of different types of decision-
832 makers in research. They can also advocate more studies on the desired and preferred ES that are
833 poorly studied. For example, beach – dune strips present one of the lowest numbers of articles even
834 though they are ecosystems of high importance for local economies through the many recreational
835 and tourist activities they afford and for mitigating numerous anthropic pressures. These conflicts of
836 use have wide political implications and are largely exposed to climate change.

837

838 **Declarations**

839 • **Ethics approval and consent to participate**

840 Not applicable

841 • **Consent for publication**

842 Not applicable

843 • **Availability of data and materials**

844 Datasets produced by the systematic map are available as supplementary material.

845 • **Competing interests**

846 The authors declare that they have no competing interests. The systematic map contains articles of
847 which the authors of the systematic map are authors or co-authors. These articles were screened or
848 coded using the exact same process as all the other articles of the systematic map. The articles selected
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858 All authors contributed to the conception and the design of the systematic map. CSC was the major
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861 ET, JC and RM provided comments on the manuscript. All authors read and approved the final
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875 **Additional Files**

876 **Additional file 1: ROSES for systematic map reports**

877 **Additional file 2: Search strings and comprehensiveness**

878 **Additional file 3: Test list**

879 **Additional file 4: List of unobtained full texts**

880 **Additional file 5: Articles rejected during the full-text screening process**

881 **Additional file 6: Systematic map database - List of all selected articles with their codes**

882 **Additional file 7: Additional figures and table**

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