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European Broad-Scale Seabed Habitat Maps Support Implementation of Ecosystem-Based Management

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Abstract

We have analyzed the development of "Broad-Scale Seabed Habitat Maps" (BSHM) and their potential use in a European context with regard to the EU Marine Strategy Framework Directive (MSFD) implementation, MPA designation and network assessment as well as other applications of BSHMs. The analyses are anchored in BSHMs developed by a series of interlinked EU projects (e.g. UKSeaMap, BALANCE, MESH, Mesh Atlantic, EUSeaMap 2012, and EUSeaMap 2016) and all maps are based on environmental data. Some EU Member States have used BSHMs as part of their MSFD Initial Assessments published in 2012. However, we conclude that BSHMs are a prerequisite for another key MSFD activity, *i.e.* mapping of potentially cumulative effects of multiple human stressors. Further, BSHMs seem to play a growing role with regard to evidence-based assessments of MPAs. With the upcoming second round of MSFD Initial Assessments due in 2018, including assessment of potentially cumulative pressures, there seems to be an increasing need for more BSHMs nationally, regionally and on a European scale.

Keywords

Benthic Habitats, Mapping, Ecosystem-Based Management, Marine Strategy Framework Directive, Marine Protected Areas (MPA)

1. Introduction

There is a growing pressure on marine ecosystems from human activities, glo-

bally, regionally and nationally [1]. All countries are, according to the UN Rio Convention [2], obliged to understand and preserve their biological diversity. In order to make informed decisions, managers and policy makers need information (e.g. data and maps) on marine species, populations and habitats and the multiple human stressors affecting these. In our understanding, a critical prerequisite for decision making and informed management is the availability of information, e.g. Broad-Scale Seabed Habitat Maps (BSHM; Table 1 includes a description of abbreviations and acronyms used) based on full-coverage environmental data.

The concept of mapping seabed habitats using marine environmental data was originally framed by [3] and subsequently put in practice by [4] for Canadian waters. Considering that mapping benthic animal and plant communities over extensive areas (*i.e.* at a national, regional or even continental scale) by direct sampling is impractical due to excessive costs, the authors advocated the use of enduring and recurrent seabed environmental (*i.e.* geological and oceanographic) factors as proxies for benthic communities. Their mapping approach consisted of 1) classifying the geological and oceanographic spatial data layers into ecologically-relevant broad categories (e.g. light penetration into "photic" or "aphotic"; exposure to water motion into "exposed" or "sheltered") based on a

Table 1. List of abbreviations and acronyms used in this article.

Abbreviation	Explanation
BALANCE	Baltic Sea Management—Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning
BSHM	Broad-scale Seabed Habitat Map
CPIA	Cumulative Pressure and Impact Assessment
EBM	Ecosystem-Based Management
EEZ	Exclusive Economic Zone
EMODnet	European Marine Observation and Data Network
EU	European Union
EUNIS	European Nature Information System
GES	Good Environmental Status
GIS	Geographical Information System
HELCOM	Helsinki Convention (http://www.helcom.fi/)
JNCC	Joint Nature Conservation Committee
MESH	Mapping European Seabed Habitats
MPA	Marine Protected Area
MS	Member State (of the European Union)
MSFD	Marine Strategy Framework Directive
OSPAR	OSPAR Convention (https://www.ospar.org/)
RSC	Regional Seas Conventions
UN	United Nations

hierarchical classification, and 2) overlaying via GIS techniques the layers classified in order to produce a map of what they defined as benthic "seascapes" (e.g. "Photic-Exposed-Gravel"). This pioneering study has since inspired many initiatives worldwide (for a review, see [5] [6]).

In Europe, the concept was first tested by the Joint Nature Conservation Committee (JNCC) within the framework of the Irish Sea Pilot project, which produced so-called marine landscape maps for this regional sea [7] [8]. Subsequently, the JNCC extended this cartography to the entire United Kingdom seas in the UKSeaMap project [9].

On an international level, two European projects simultaneously tested and applied this approach: BALANCE (2005-2007), and MESH (2004-2008). BALANCE produced a first generation of marine landscape maps for the Baltic Sea region including the Kattegat [10]. MESH developed a prototype BSHM for North-West Europe, for which efforts were made to adapt the method to the marine section of the EUNIS (European Nature Information System) habitat hierarchical classification scheme version 04.05, widely used across Europe by managers and scientists [11]. This EUNIS-compliant MESH approach gave a strong impetus to initiatives of broad-scale habitat mapping across Europe. First the EUSeaMap project (2009-2012) harmonized the MESH seabed habitat maps with those of the BALANCE project, and extended the method to a new region, the western Mediterranean basin [12]. The MeshAtlantic project (2010-2013) then extended this cartography to four extensive areas around Ireland, the Bay of Biscay, the Iberian Peninsula and the Azores Islands [6]. In addition, national initiatives also applied the MESH method to smaller areas with improved resolution; in France [13] and in the United Kingdom [14].

Further, the Seabed Habitat lot in the second phase of EMODnet (2013-2016) built upon this progress in the formation of EUSeaMap 2016. The aim of this project was to update the areas that had been mapped within the framework of EUSeaMap and MeshAtlantic by integrating new geological and oceanographic datasets with improved accuracy, and to undertake the mapping of areas that had not yet been covered, namely the Norwegian Sea, the Canary Islands, the Adriatic Sea, the Central and Eastern Mediterranean and the Black Sea. As a result, EUSeaMap 2016 has achieved a pan-European seabed habitat cartography first initiated by the Irish Sea Pilot, which has gradually led to a comprehensive coverage of the distribution of seabed habitats across Europe.

The lessons learned from the above introduced projects and activities, in combination with a growing use of the key products, *i.e.* BSHMs, have motivated us to synthesize how the BSHMs have been used in the context of 1) the implementation of the MSFD, especially with regard to the MSFD Initial Assessment, 2) the designation and assessment of Marine Protected Area (MPA) networks, and 3) other types of use. Hence, our objective has been to analyse and evaluate usage of BSHMs in exercises that assess pressures and state (MSFD assessment) as well as responses (spatial measures such as MPAs)—or in other words, the use of the maps in the context of Ecosystem-Based Management (EBM).

EBM (noun) is by [15] defined as: "an integrated approach to management of human activities that considers the entire ecosystem, including humans with the goal of maintaining an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need". An important element in regard to EBM is the term "ecosystem" (noun), which is "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit", cf. the UN Convention on Biological Diversity. EBM differs from approaches that focus on a single species, sector, activity or concern; it considers the cumulative impacts of different sectors. Specifically, EBM: 1) emphasizes the protection of ecosystem structure, functioning, and key processes; 2) focuses on a specific ecosystem and the range of activities affecting it; 3) explicitly accounts for the interconnectedness within systems, recognizing the importance of interactions between many target species or key services and other non-target species; 4) acknowledges interconnectivity among systems, such as between air, land and sea; and 5) integrates ecological, social, economic, and institutional perspectives, recognizing their strong interdependences [15] [16]. Hence, EBM is about acknowledging linkages between ecosystems and human societies, economies and institutional systems [17].

2. Method

Our analyses of the use of BSHMs are rooted in two approaches, the first being a specific survey developed to review the use of BSHMs in European Union Member States' (MSs): 1) MSFD assessments and 2) MPA designation and network assessments. The second approach involves comprehensive literature reviews on the use of BSHMs in 1) MPA designation and network assessments, and 2) evaluations of the potential impacts of multiple human pressures. The methods are described in the following sections.

2.1. Data Collection through a Survey Regarding the Use of BSHMs in MSFD and MPA Designation and Network Assessments

A survey was carried out with the objective of gathering information on the usage of BSHMs in assessment and reporting in relation to MSFD and MPA assessments as described in [18] and is summarized in the following sections:

The survey (provided as Supplementary Information S1) was divided into four parts: 1) MSFD Initial Assessment (7 questions), 2) next MSFD assessment and MSFD indicators development (8 questions), 3) MPA evaluations (11 questions) and 4) profile of the respondent (3 questions). Respondents were given the option to skip a section (Parts 1, 2 and 3 only) if they were not involved in that part of work, by answering "no" to the first question of each section. Part 1 of the survey included four questions aimed at understanding whether a BSHM was available for the country (or part of the country) and used in the EU Member State's 2012 MSFD Initial Assessments (as per Art. 8 of MSFD).

The surveys allowed respondents to provide comments and specify which, if

any, maps were used. Information regarding the availability and downloads of BSHMs produced by the MESH, BALANCE, MESH Atlantic, EUSeaMap and EMODnet Seabed Habitats projects is summarized as Supplementary Information S2. In Part 2 similar questions were asked about the likely use of BSHMs for the next MSFD Initial Assessment, to be prepared for 2018. Two optional questions were included with the aim of gathering examples of use of BSHMs for the purpose of MSFD Good Environmental Status (GES) determination and monitoring, as some countries are in the process of developing indicators (as per Art. 10 of MSFD). Part 3 focused on the use of BSHMs for MPA site selection and in network assessments. Respondents could provide further details on the BSHMs used, the types of assessment carried out and the geographic scale of the analysis. The contact details of the respondent and the country assessed were collected in Part 4. Contact details were used if further clarification on answers was required.

The survey was sent to the members of the Marine Expert Group (established under the EU Nature Directives) and the Marine Strategy Co-ordination Group comprising 23 EU MSs having jurisdiction of marine waters. Members of both groups were given the option to forward the survey to national experts, if necessary. The survey was thus directed at a total of 141 experts, representing an average of 6.1 respondents per MS. A notification email was sent to the contacts providing the online link to the survey, explaining the reasons for the survey and defining the BSHM concept. The survey was kept open for four weeks and a reminder was sent to non-respondents ten days after the first email.

For countries with more than one respondent, the information was aggregated together to analyze the answers on a country level. Where some answers were in disagreement we selected the positive answers, for example, if one respondent answered "no" and another "yes" to the same question, we used the "yes" answer. This maximized the level of detail for each question asked. In some cases, further clarification on answers was requested to the respondent. This occurred, for example, when the type of habitat map used could not be considered as a BSHM as per the definition given in the introduction to the survey.

2.2. Literature Review on the Use of BHSMs in Regional MPA Network Assessment

Technical reports produced within the framework of regional initiatives were queried with an internet-specific search, directed at Regional Sea Conventions (RSCs) and international project portals, so as to identify MPA-related network assessments dealing with seabed habitats. These reports were screened to identify the MPA assessments that were carried out at a marine regional/sub-regional scale with the support of BSHMs.

Each report was synthesized with regard to: year of assessment, marine geographic region object of assessment, name and typology of the BSHMs considered, and a brief summary on the aspects for which the habitat map was used in the MPA assessment. Further, the bibliography of each analyzed RSC report on MPA network assessments was screened to identify other existing region-

al/sub-regional/national assessments having used BSHMs within MPA-related assessments. In such cases, national assessment reports were also analyzed in the same manner as the RSC reports.

2.3. Literature Review on the Use of BHSMs in Multiple Pressure Analysis

Further, we evaluated the use of BSHMs in the context of cumulative pressure and impact assessments (CPIA), which is an activity that EU MSs are required to carry out in the context of the MSFD. CPIA rely on three types of data/information, *i.e.* 1) spatial distribution of human stressors, 2) spatial information on ecosystem components and 3) a stressor- and ecosystem component-specific sensitivity weight [1] [19]. To date, only few European CPIA studies are published in scientific literature, but a recent review by [20] has identified 25 national, regional or pan-European studies. We scrutinized these with the aim of singling out those which included BSHMs.

3. Results

Eighty-five people answered the survey in early 2016; of these 53 completed it. Of those 53 respondents 36 were contacted directly by us, 13 were forwarded the link to the survey and four did not specify how they received it.

3.1. Use of BSHMs in MSFD Assessments

In part 1 of the survey, regarding the use of BSHMs in the 2012 MSFD Initial Assessments, we received answers from 17 (74%) of the 23 EU Members States (MSs) having jurisdiction of marine waters. Nine (53%) of the 17 MSs that responded were aware of a BSHM that existed for their waters, seven (41%) were not aware, whilst one (6%) was unsure. All of those MSs that had an available map used it. These results suggest that at least 39% (nine) of all 23 MSs used a BSHM for the 2012 MSFD Initial Assessment. This figure is conservative and could be slightly higher as we did not receive an answer for six of the MSs. When we consider the nine MSs that used a BSHM for their first MSFD assessment, the BSHM was in four of the cases an output of an international project (BALANCE, EUSeaMap, MESH or MeshAtlantic). Three of the MSs used maps derived from national mapping programmes and one from both national and international projects (Table 2).

In part 2 of the survey, respondents were asked whether they are or will be involved in the 2018 MSFD Article 17 reporting for benthic habitats or in the development of indicators of environmental status for benthic habitats that will inform this reporting. Respondents from 19 (83%) out of 23 MSs answered that they are (or will be) involved, while three (13%) were unsure and one said "no". In all but one of the 19 MSs respondents were aware that a BSHM will be available. Of these, nine (50%) were aware of a BSHM from an international project, three (17%) were aware of national BSHMs, two (11%) were aware of BSHMs

Table 2. Awareness of availability, and usage, of BSHMs in past and future MSFD Assessments. Where there were multiple respondents from a single MS, a "yes" took precedence, followed by a "no".

Response	2012 MSFD Initial Assessment		2018 MSFD Assessment	
	1.2 Was a BSHM available…in 2012?	1.4 Did you use a BSHM map to inform your 2012 MSFD reporting on Initial Assessments?	2.2 Will a BSHM be available…?	2.4 Is it likely that a BSHM will be used to assess benthic habitats indicators as part of the 2018 MSFD Article?
1) BSHM available	9	9	18	14
a) from international project (s)	4	4	9	8
b) from national project (s)	3	3	3	1
c) from national and international projects	1	1	2	1
d) from unsure origin	1	1	4	4
2) No BSHM available	7	N/A	0	N/A
3) Unsure of BSHM availability	1	N/A	1	N/A
4) No response	6	N/A	4	N/A

from both national and international projects, and four (22%) were unsure.

Of the 18 MSs aware of a BSHM, 14 (78%) were planning to use it in the 2018 MSFD Assessment, the rest were unsure. When related to all 23 EU MSs, this value corresponds to 61%, however this is a conservative figure as some experts were unsure of their involvement and one MS did not provide any answer at all (Figure 2). Of the 14 MSs that are likely to use a BSHM in 2018, all except for two provided more detailed information on the use of the BSHM in indicator development. Specifically they were asked about the type and the spatial coverage of the indicators. Indicators were grouped according to the MSFD Criterion they belong to (as defined in [21]) and summarized according to the geographic scale at which the assessment was likely to take place (Figure 1).

In most cases BSHMs are likely to be applied to the development/assessment of the following criteria: Physical Damage (Index 6.1, 28% of answers), Habitat Distribution (Index 1.4, 25%), Habitat Extent (Index 1.5, 15%), and Habitat Condition (Index 1.6, 8%). All answers specifying regional assessments were given by MSs within the OSPAR region. When asked whether a BSHM will be used for other MSFD-related purposes (other than MSFD assessments/reporting and MPA assessment), experts from 19 MSs replied; 6 of these with a positive answer. Some of the responses specified the purpose, which included: 1) integrated management of human activities in the coastal waters (choice of location
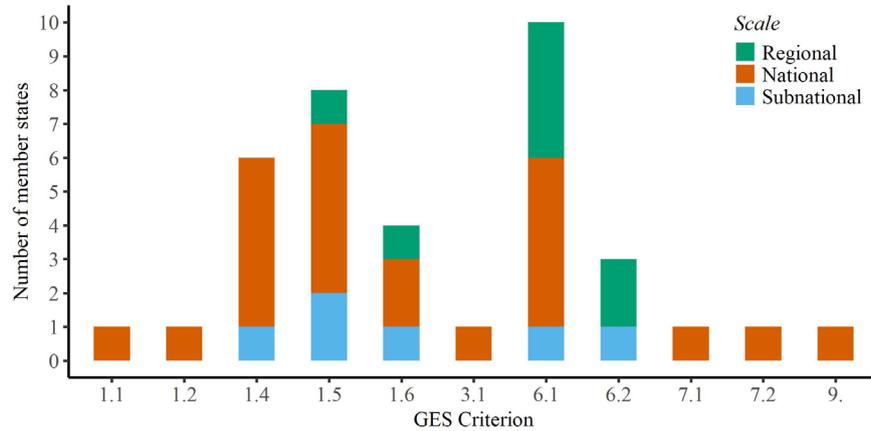
Figure 1. Summary of MS intentions for using BSHMs to assess various GES criteria. Results are divided into the spatial scale of each assessment and relate to the following survey questions: "2.5a Please specify which indicator (s) are likely to be assessed using a BSSHM" and "2.5b. For each indicator assessment… please specify the likely geographical coverage?" where the criteria are: 1.1 Species distribution, 1.2 Population size, 1.4 Habitat distribution, 1.5 Habitat extent, 1.6 Habitat condition, 3.1 Level of pressure of the fishing activity, 6.1 Physical damage, having regard to substrate characteristics, 6.2 Condition of benthic community, 7.1 Spatial characterisation of permanent alterations, 7.2 Impact of permanent hydrographical changes and 9. Contaminants.

of sea cages for aquaculture, placement of pipelines), 2) location of e.g. threatened and/or declining habitats, red listed biotopes, for Environmental Impact Assessments and Natura 2000, 3) mapping and assessment of goods and services provided by benthic habitats, 4) assessment of pressures on benthic habitats produced by human activities and 5) marine spatial planning.
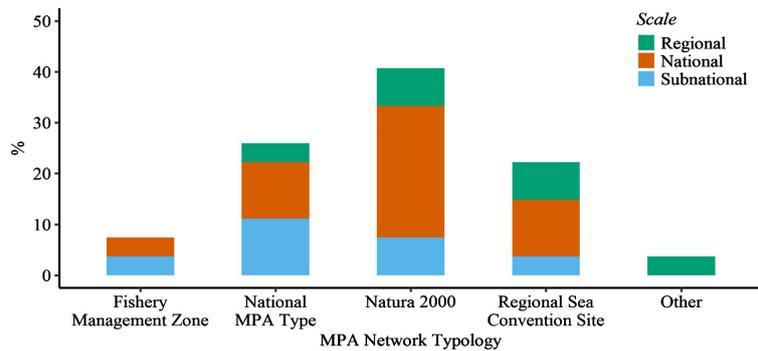
3.2. Use of BSHMs for MPA Designation and Network Assessments

In part 3 of the survey, the respondents who declared involvement in MPA-related processes belonged to 21 (91%) of the 23 MSs having jurisdiction of marine waters. Of these 2 (9.5%) declared that they were not aware of the availability of a BSHM for their country while 4 (19%) were not sure. In circumstances where respondents were aware of the availability of a BSHM this was used for both designation/site selection and other network assessments in at least 12 (55%) MSs (Table 3).
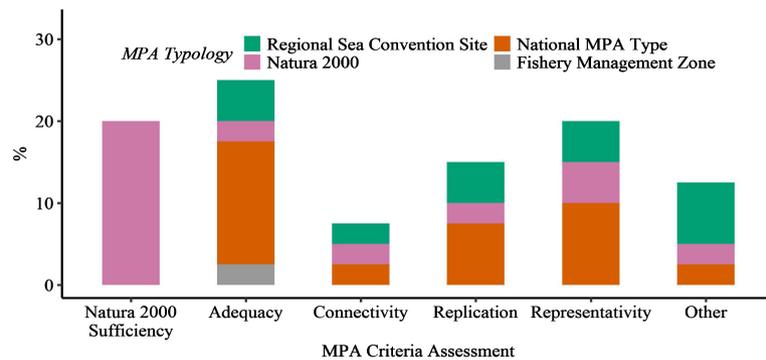
Detailed information on BSHM use and designation/site selection was collected for 11 of these 12 MSs (85%). More specifically it appears as though BSHMs were used mostly for Natura 2000, followed by National MPA and RSC site designation/selection purposes (Figure 2(a)). Detailed information on use of BSHMs in MPA network assessments was reported for 10 of the 12 MSs (83%). Figure 2(b) indicates the different percentage of use of BSHMs per MPA network assessment criterion according to MPA type. BSHMs were used for all assessment criteria. However, apart from the evident use of BSHMs in assessing the sufficiency of Natura 2000 sites, the criteria for which BSHMs are mostly used are adequacy and representativity. Assessments of network adequacy and

Table 3. Awareness of availability, and usage, of BSHMs in MPA designation/site selection and network assessments. Where there were multiple respondents from a single MS, a "yes" took precedence, followed by a "no".
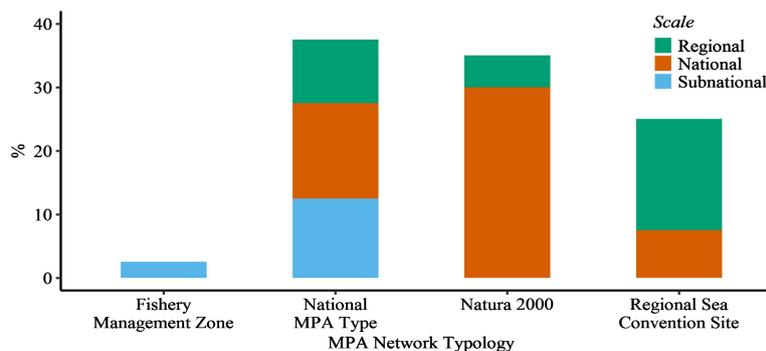
Response	3.2 Is a BSHM available…?	3.3 Was/is a BSHM used for MPA designation/site selection processes?	3.5 Was/is a BSHM used for MPA network assessments?
Yes	18	13	12
No	2	6	6
Unsure	1	2	2
No response	2	2	2

(a)

(b)

(c)

Figure 2. Use of BSHMs in MPA designation. (a) shows the use (percentage) of BSHM in site designation/site selection per network typology and geographic scale; (b) shows the use of BHMS in MPA assessments per criterion and network typology; (c) shows the use of BHMS in MPA assessments per network typology and geographic scale.

representativity seem to be centered most on national MPA network evaluations. Reported use of BSHMs at sub-national level is limited to national MPA network and fishery management zone assessments. On the other hand, BSHMs are reported as being used mostly for national assessments of Natura 2000 and national MPA networks. They are also most often used for RSC MPA assessments at a regional level (Figure 2(c)).

3.3. Literature Review on the Use of BSHMs in MPA Designation and Network Assessments

A synthesis of the contents and references of the technical reports involving MPA network assessments is provided in Table 4.

In the Baltic Sea two BSHMs have been used since 2009 to assess the MPA network at a basin-wide scale (BALANCE 2007 marine landscape map and the EUSeaMap 2015 interim draft Baltic Sea map). In the Atlantic region, the EU-SeaMap 2012 BSHM was first used in 2013 to assess the MPA network within OSPAR regions II and III. Specific assessments were conducted in the Channel Islands area to assess the UK and French MPAs. In 2014, the EUSeaMap 2012 BSHM integrated with UK field survey data, was used to assess the network in the UK continental shelf waters and the same map was used in 2015 to assess the network in the Celtic Seas. In the Mediterranean, the EUSeaMap 2012 BSHM was used within the framework of that project, to assess the network within the Western Mediterranean EU countries in terms of the coverage of the broad-scale habitats covered by the network. At a basin-wide scale the EUSeaMap 2012 Western Mediterranean map was integrated with a proxy BSHM for the Eastern Mediterranean constructed by intersecting bathymetric data and sediment maps. The latter was used to assess the MPA network across the entire Mediterranean Sea.

BSHMs have been used to assess the percentage cover of specific habitats in the network (representativity and adequacy) in all the analyzed reports, followed by the degree of replication of specific habitats, which is performed in most of the identified reports. The connectivity (sometimes referred to as proximity) criterion has been evaluated in the Baltic and Atlantic regions and sub-regions.

3.4. Literature Review on the Use of BHSMs in Multiple Pressure Analysis

25 out of the 40 cumulative impact assessment studies reviewed by [20] are European. Two of these ([19] and [32]) have included data layers representing BSHMS in their analyses of the potential impacts of the effects of multiple human stressors. In the study covering the Baltic Sea, BSHMs constitute 57% (8 out of 14; 6 out of 8 originated for BALANCE) of the ecosystem component data layers [19]. In a similar study in the eastern parts of the North Sea, BSHMs accounted for 38% (10 out of 26; 8 out of 10 originated from EUSeaMap) of the ecosystem component data layers.

In an ongoing Danish study of potential cumulative effects, where the objective

Table 4. Synthesis of BSHM use in MPA network assessments.

Year	Area	Map used	Subhead	Reference
2009	Baltic Sea	BALANCE 2007 marine landscape map [10]	Benthic marine landscape habitat surface area cover (representatives), number of patches (replication), and distance between selected merged benthic marine landscapes (connectivity) occurring within the Baltic MPA network.	[22]
2010	Baltic Sea	BALANCE 2007 marine landscape map [10]	Percentage surface area cover of marine landscape habitats (representativity); number of landscape habitat replicates (replication) and distance between habitat patches (connectivity) contained within the MPA network.	[23]
2015	Baltic Sea	EUSeaMap [12]. Interim draft Baltic Sea Broad-Scale Predictive Habitat Map.	Percentage surface area cover of marine landscape habitats (representativity); number of landscape habitat patch replicates (replication) and distance between habitat patches (connectivity). Distance between selected and merged benthic habitat types (connectivity) contained within the MPA network.	[24]
2013	OSPAR Dinter II and III regions	EUSeaMap [12] at EUNIS level 3	Broad-scale habitat surface area coverage (representativity), number of habitat type replicates (replication), % coverage of habitat type (adequacy) and distance between habitat types (connectivity) contained within the MPA network.	[25]
2013	French and UK Channel island	EUSeaMap [12] at EUNIS level 3	Percentage surface area of broad scale habitat types (rep-resentativity) contained within the MPAs contained in the OSPAR database.	[26]
2014	French and UK Channel island	EUSeaMap EUNIS level 3 broad scale habitats [12], which was downloaded from the MESH (Mapping European Sea-bed Habitats) website (http://www.searchmesh.net/default.aspx)	Number of replicates of ten habitats (replication), size distribution of habitat patches (viability), total area of habitat patches (adequacy) contained within the Channel island MPAs and geographical distance among habitat patches and MPAs (connectivity).	[27]
2014	UK continental shelf waters	UKSeaMap combined map draft version (v0.2) which integrates EUSeaMap broad-scale habitats and field survey data (http://jncc.defra.gov.uk/page-6655#EUNIScombined).	Number of EUNIS level 3 broad-scale habitats (replication), surface area coverage of habitats (representation), site proximity of EUNIS level 2 habitats (proximity).	[28]
2014	UK continental shelf waters	EUSeaMap model of seabed habitats (2012 version22) and a draft version (dated 18th November 2013) of the EUNIS level 3 seabed habitat map integrating data originating from maps from UK field surveys and the EUSeaMap model (called the "UKSeaMap Combined Map").	Number of each broad scale habitat feature present in each depth band/energy layer (OSPAR representatively principle), surface area computation of each EUNIS Level 3 habitat occurring in each Charting Progress 2 region (OSPAR features principle), distance between habitat types occurring within MPAs (OSPAR connectivity principle).	[29]
2015	Celtic Seas	EUSeaMap [12]; JNCC UKSeaMap	Broad-scale habitat maps were used to assess % of broad scale habitat surface area cover (adequacy), size distribution of broad-scale habitat patches (Viability), and distance between broad scale habitats (connectivity) contained within network.	[30]

Continued

2011	Western Mediterranean	EUSeaMap ([1])	Percentage coverage of each broad-scale habitat occurring within the Western Mediterranean EC country MPA network (representativity).	[12]
2012	Mediterranean Sea	EUSeaMap [12] for the western Mediterranean and a proxy broad scale habitat map constructed for the remainder of the Mediterranean.	Percentage cover of the generated proxy broad scale benthic habitats contained within the MPA network (representativity), percentage cover of three priority habitats provided in the EUSeaMap broad-scale map for the western Mediterranean was also assessed.	[31]

is not only to map these but also to study the relative importance of key groups of human stressors along a land-sea gradient, BSHMs account for 17% (8 out of 47) of the ecosystem component data layers (unpublished data).

4. Discussion

The results of our online survey suggest that at least 9 of the 23 EU MSs used a BSHM in the first MSFD assessment in 2012. This could be partially explained by the fact that in 2012 the marine waters of 5 (Cyprus, Bulgaria, Greece, Malta and Romania) out of 23 EU MSs were not included at all in the BSHM delivery provided by the EMODnet programme or other international projects because coverage of all European waters was only reached with the EMODnet 2016 delivery. As the quality of BSHM increases and the availability of the maps becomes more well known, a higher percentage of MSs (over 61%) are likely to use a BSHM in future MSFD assessment or indicator development. These figures are conservative, as we were not able to receive an answer for all MSs. It also emerged that at the time of the survey some MSs were still unsure about the next MSFD reporting or had not yet decided to confirm the assignment of the same experts who led the 2012 assessment.

Results indicate that over 60% of the EU MSs are likely to use a BSHM produced by an international project in their next MSFD reporting or indicator development (Table 2) on its own (50%) or in combination with maps from national mapping projects (11%). Percentages were slightly lower amongst users of BSHM in the first MSFD assessment, when 55% of the BSHM were derived from only international projects (40%: EUSeaMap 2012, Balance, MESH or MeshAtlantic), or in combination with BSHMs from national mapping programmes (11%). It is important to note that since 2016, and for the next MSFD assessment, the regional BSHM map available from international initiatives is going to be a single harmonized BSHM for all EU seas (EUSeaMap 2016, produced by the EMODnet Seabed Habitat consortium).

OSPAR Contracting Parties are working towards the development of common indicators for benthic habitats. An example is the development of the so-called BH3 indicator or "Extent of Physical Damage to special and predominant habitats", which is the reason for the high number of responses regarding the use of

BSHM in regional assessments for this criterion. The development of this common indicator has been led by marine experts from the United Kingdom and Germany. This indicator will help evaluate to what extent the integrity of the seafloor and associated ecology is being damaged by anthropogenic activity using a combination of sensitivity assessments and exposure to pressures. The work combines the distribution and sensitivity of habitat components using a BSHM and the distribution and intensity of human activities and pressures that cause physical damage, such as mobile bottom gear fisheries, sediment extraction and offshore constructions. The method involves using the EUSeaMap 2016 BSHM in combination with habitat maps from surveys from all OSPAR Contracting Parties.

The survey respondents can be considered fully knowledgeable of MPA-related assessments in the EU MSs, however only 65% of these indicated that BSHMs are used for site selection/MPA assessment processes in their respective countries. This response could be attributed to various factors: the current non-exhaustive spatial coverage of BSHMs across European seas, the possible limited application of BSHM to specific processes required for thorough MPA designation/network assessment etc. Until now BSHMs have been mainly used for Natura 2000 site assessments because of the nature of the marine habitats listed in Annex I of the Habitats Directive (92/43/EEC). In fact, these are, except for *Posidonia oceanica* meadows, very generic and thus characterized by a variety of assemblages/communities contained in broad-scale habitats. Moreover, BSHMs appear mostly used for representativity/adequacy assessments linked to the evaluation of Natura 2000 network sufficiency at national/regional scale, a process anticipated by the Directive since its inception in the 1990s. A similar consideration can be drawn for the RSC MPA assessments that are run at regional scale under the direction of the RSC secretariats. The MPA criteria that most benefit from the map availability are those linked to the percent cover of the broad-scale habitats within the network. Exhaustive coverage of BSHMs for all European seas will allow a more thorough assessment of the network.

From the survey, it emerges that some users of BSHM are planning to use the maps for other MSFD-related purposes, including marine spatial planning and benthic habitat ecosystem service assessments (Mediterranean Sea).

It has been suggested by [33] to concentrating effort in collating existing data, extracting maximum value from it through "reuse" or new interpretations, and using BSHMs (such as MESH or UKSeaMap) for marine spatial planning purposes. BSHMs have been used as data sources during the creation of the UKs first marine plan, which was finalized in 2013 for the East of England inshore and offshore area. EUSeaMap biological zones and energy map layers were combined with a local seabed substrate model to create a new map of broad-scale habitats in this area, where more-detailed habitat maps were not available [34]. The same approach was used for the latest Marine Plans in the South of England [35].

An effort to provide a first assessment of benthic ecosystem services on the Atlantic-European scale has been completed in the context of the "Mapping and Assessment of Ecosystems and their Services" (MAES) programme, the European Biodiversity Strategy and the implementation of the MSFD, by [36]. The authors provide maps of the provision of ecosystem services and general spatial distribution patterns, and concluded that "benthic habitats provide a diverse set of ecosystem services, with the food provision and biodiversity maintenance services more extensively represented". Crucial information for this work were harmonized maps, using a single classification system of the distribution of habitats providing the ecosystem services, and covering the full areas of all European EEZ areas in the North Atlantic. The authors used MeshAtlantic and EU-SeaMap 2012 EUNIS BSHMs.

The MSFD also requires the development of monitoring programmes to measure progress towards GES for marine habitats, and a BSHM could be used in strategic planning and prioritization of monitoring activities, for example. The use of BSHMs combined with habitat maps from surveys as best available evidence of the distribution of benthic habitat at broad scale (*i.e.* EUSeaMap 2016 in combination with benthic habitat maps from surveys), is suggested in the UK to begin to develop habitat monitoring options at UK-wide scale, as part of The UK Marine Biodiversity Monitoring Research and Development Programme [37]. The maps can be used to prioritize areas to be monitored, based on a risk assessment approach. The habitat maps can be overlain with maps of human pressures in order to develop sampling designs that focus monitoring effort on those habitats most at risk from human activities.

Our study has revealed that parts of the work related to MSFD on mapping and assessing potential cumulative impacts of multiple human stressors required access to regional BSHMs (Baltic Sea: see [19]; North Sea: see [32]). The methods on which these assessments are based originates from [1], where pressure data is combined with information on ecosystem components and pressure-specific sensitivity. These studies rely to a relative large extent on BSHMs from BALANCE and EUSeaMap and would probably not have been as successful without these maps. Further, we are aware of ongoing activities updating the Baltic study and aiming at a provisional pan-European assessment of potential cumulative pressures and impacts in Europeans seas, where both rely on the produced BSHMs (EUSeaMap).

5. Conclusions and Perspectives

In Europe, BSHMs are evidently widely used for multiple purposes in regard to MSFD assessments and MPA network assessments. Our analysis has revealed: 1) BSHMs have been applied for MSFD and MPA assessment purposes in all regions of Europe, *i.e.* the Baltic Sea, Black Sea, Mediterranean Sea and north-east Atlantic including the North Sea, 2) a majority of EU Member States are aware of the existence of BSHMs, 3) 39% of the 23 coastal EU Member States have ap-

plied BSHMs in the first MSFD assessment in 2012, and 4) regional BSHMs are of particular use in broad-scale cross-border assessments, which are required by the MSFD.

The wider spatial coverage obtained with the EUSeaMap 2016 BSHMs will in our understanding fill a gap as benthic habitat maps have partly been discounted in national, regional and pan-European assessments of the state of the sea and will greatly support the future 2018 MSFD assessments. Likewise, RSCs (*i.e.* Barcelona Convention, Black Sea Convention, HELCOM, OSPAR), when assessing status and trends within their respective convention areas can improve from having a predominantly benthic focus to hopefully considering the entire ecosystem cf. the definition of ecosystem-based management. There are already now indications that EMODnet-developed BSHMs are integral parts of regional assessments, e.g. the HELCOM HOLAS II activity, where BSHM is an important data product strengthening the final output. Hence, we expect a trickle-down effect, where BSHMs or HOLAS II-based products will be integral parts of the MSFD Initial Assessment to be produced by Baltic EU MSs. Further, the MSFD requires MSs to characterize cumulative pressures and impacts. From the studies in the Baltic Sea and North Sea we conclude access to BSHMs might be a prerequisite for these endeavors.

The need for data and maps informing decisions and implementation of the EU MSFD and other EBM-based policies and strategies (e.g. the EU Water Framework Directive and the HELCOM Baltic Sea Action Plan) will drive the further development of pan-European marine spatial data both in terms of broad-scale and finer scale benthic habitats. Geographical gaps, quality and especially spatial resolution of BSHMs are likely to be improved in the coming years and these will thus attain growing usage in supporting EBM and informed decisions.

Acknowledgements

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