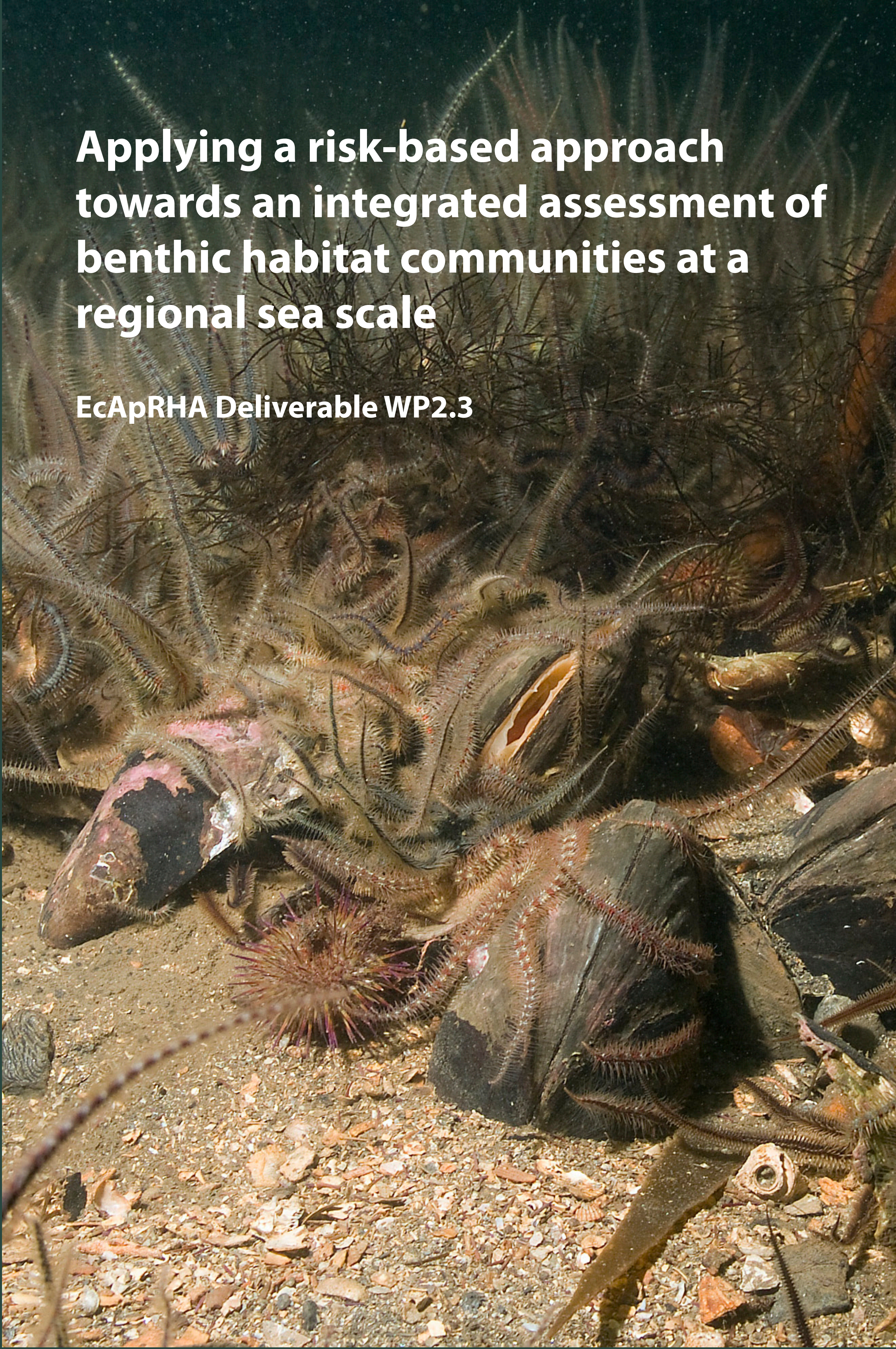
Applying a risk-based approach towards an integrated assessment of benthic habitat communities at a regional sea scale

EcApRHA Deliverable WP2.3



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Contents

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EcApRHA

The EcApRHA project (Applying an Ecosystem Approach to (sub) Regional Habitat Assessment) aims to address gaps in the development of biodiversity indicators for the OSPAR Regions. In particular, the project aims to overcome challenges in the development of indicators relating to the MSFD (Marine Strategy Framework Directive 56/2008/EU), such as Descriptor D1 (Biodiversity), D4 (Food webs) and D6 (Seafloor integrity), and to deliver an action plan to OSPAR that will enable monitoring and assessment at the (sub) regional scale, to contribute to OSPAR Intermediate Assessment 2017.

Indicators related to the benthic and pelagic habitats, as well as food webs, are investigated within the project at different levels (from data to indicator; from indicator to habitat assessment; from habitat to ecosystem assessment).

Acknowledgment

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Executive Summary

The Marine Strategy Framework Directive (MSFD) aims to implement an integrated ecosystem-based approach, to manage anthropogenic pressures on the marine environment focusing on 11 Descriptors within European Union marine waters. To meet the MSFD's aim, numerous indicators have been developed to help determine their ecological status. To forward an ecosystem-based approach and undertake an assessment of the status of our ecosystems at sub-regional seas scale, integration of these indicators and across descriptors is required. A method to quantify how much pressure different ecosystem components can resist before changing state also needs to be quantified to implement appropriate management measure.

Through work developed within the European co-funded 'Ecosystem Approach to (sub) Regional Habitat Assessments' (EcApRHA) project, in conjunction with the development of indicators within the OSPAR regional seas convention, we propose an integrated cyclical approach to assess the state of the seabed and benthic communities. The method developed integrates indicators relating biodiversity (D1) and seafloor integrity (D6) descriptors in a cyclical process, with implications on other descriptors (e.g. commercial fish and shellfish (D3), food webs (D4) and eutrophication (D5)).

The proposed method links the different indicators together, so that *in situ* monitoring and assessment data can influence and update modelled benthic habitat maps, sensitivity and anthropogenic disturbance assessments. In addition, by collecting benthic data in areas with a gradient of anthropogenic pressure, analysis of the effects of the different pressure types on specific benthic habitat types can be analysed. Hence, quantitative feedback can be provided to set thresholds and thus advise on management measures. This integrated cyclical approach to determine the state of the seabed is based on data collected through monitoring methods, and can be applied to other areas of marine ecosystem assessment. Due to information which is currently missing on pristine reference areas, and uncertainties with regard to setting baselines, the proposed method is recommended to be adopted to assess the condition of benthic habitats.

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Acronyms

BH1	Typical species composition
BH2	Condition of benthic habitat communities
BH3	Physical damage of predominant and special habitats
BH4	Area habitat loss
CEMP	Coordinated Environmental Monitoring Programme
D1	Descriptor 1: Biodiversity
D3	Descriptor 3: Commercial fish and shellfish
D4	Descriptor 4: Food webs
D5	Descriptor 5: Eutrophication
EIA	Environmental Impact Assessments
GES	Good Environmental Status
EcApRHA	Ecosystem Approach to (sub) Regional Habitat Assessments’
EcoQ	Ecological Quality Status
EQR	Ecological Quality Ratio
EU	European Union
EUNIS	The European Nature Information System
MMI	Multi-Metric Index
MPA	Marine protected Area
MSFD	The EU Marine Strategy Framework Directive (2008/56/EC)
OSPAR	The (Oslo-Paris) Convention for the Protection of the Marine Environment of the North-East Atlantic
PERMANOVA	Permutation Analysis Of Variance
SIMPER	SIMilarity PERcentages
TS	Typical Species
VMS	Vessel Monitoring Systems
WFD	Water Framework Directive

1 Background

The Marine Strategy Framework Directive (MSFD; Directive 2008/56/EC) aims to implement an integrated ecosystem-based approach in order to manage anthropogenic activities and achieve Good Environmental Status (GES) by 2020 (CEC, 2008). OSPAR is the mechanism by which 15 Governments and the EU cooperate to protect the marine environment of the North-East Atlantic. As such it provides the mechanism to help its Contracting Parties, who are also EU Member States to cooperate in achieving their obligations of regional coherence under the MSFD. To help encompass an ecosystem view of the marine environment under the MSFD, 11 descriptors are described (CEC, 2008) ranging from maintaining biodiversity, managing commercially exploited fish and shellfish, to minimising eutrophication and contaminants. These 11 descriptors are each made up of numerous indicators through which reporting by member states is required.

Multiple indicators enable responses to anthropogenic pressures to be analysed more widely and provide a better understanding of their responses on benthic communities (Bremner et al. 2006, de Juan et al. 2009). However, individual analysis of the indicators does not resolve the issue of how to undertake an ecosystem based assessments of the marine environment. In addition, gaps in information required to carry out assessment of the marine environment still exist (Borja et al. 2013, Bertram et al. 2014). Overarching knowledge gaps include: lack of pristine reference areas or values to compare condition related indicators against and set baselines; varying spatial scales and methodologies for which data is collected by Member States for the different indicators; and a cohesive holistic approach to assess different aspects of the marine environment accurately (Borja et al. 2014).

One increasingly popular and necessary method to undertake an integrative and more ecosystem based assessments of the marine environment is through Multi-Metric index (MMI) tools (Borja et al. 2012, Schoolmaster et al. 2012). MMI tools enable the state of the marine environment to be monitored and assessed through the use of various metrics to derive at a single index from impacts caused by anthropogenic disturbance (Hering et al. 2006, Schoolmaster et al. 2012). MMI tools are commonly used to provide a simple measure of the state of the marine environment for policy decisions such as Good Ecological Status within the Water Framework Directive (WFD; 2000/60/EC) (Hering et al. 2006, Schoolmaster et al. 2012). Various indicators from different MSFD descriptors can therefore potentially be used to assess the state of the marine environment into a single value (Borja et al. 2016).

Numerous integrated indicator tools have been developed in recent decades (reviewed by Borja et al. (2016)). However, these tools have similar problems which consists of lack of reference areas or levels to assess baselines, and how to assess thresholds (Borja et al. 2012, Elliott et al. 2017). Additionally, trying to synthesise many aspects of the marine environment into a single unit can be problematic and lead to loss of information which accurately reflects the complex nature of the marine environment (Borja et al. 2014, Villnäs et al. 2015). Further, most MMI assessment tools use indicators, which are measured and assessed at varying levels of confidence and spatial scales, adding an additional level of uncertainty. Other problems MMI tools can have include how to weight the different anthropogenic pressure indicators appropriately, and problems with double counting which can lead to additional imbalance or bias of certain indicators (Borja et al. 2014, Villnäs et al. 2015).

Borja et al. (2012) and Hill et al. (2012) review and evaluate a number of approaches, which can be used to set a reference condition. These approaches include the use of existing areas, historical information, modelled reference condition, to the adoption of expert judgement. The preferred method is the use an existing reference area, however such sites are often lacking (Borja et al. 2012). Furthermore, there is insufficient knowledge on the effect of anthropogenic activities on condition related indicators, in terms of recovery, which inhibits the use of such reference areas. Use of historic data faces similar challenges, supplementary to problems when temporal changes are not considered (Borja et al. 2012). Modelling approaches to set reference condition are thought to not be sufficiently developed due to lack of data and knowledge to build and validate such models (Hering et al. 2010, Borja et al. 2010, 2012, Rombouts et al. 2013). As far as the authors are aware, to date (January 2017) use of modelling approaches still remains a knowledge gap. Expert judgement has been suggested as the only pragmatic way to determine reference condition, although it can lack sufficient data to make confident assessments and can lead to shifting baselines (Pauly 1995, Mee et al. 2008, Borja et al. 2012). Use of least damaged areas may be an alternative in the absence of reference condition (Coates et al. 2007). Borja and Tunberg (2011) and van Loon et al. (2015) use 99th percentile of biotic index data for the whole dataset (as an extreme value). However, if insufficient samples are used, or if the sampling design is not representative of the assessed area (both for benthic habitats and pressure exposure), the percentiles may provide erroneous values (OSPAR. In Prep.b). Use of the percentile method should also undertake pre-calibration to cross validate the values (OSPAR. In Prep.b).

1.1 The EcApRHA Project

The EU co-financed EcApRHA project specifically focuses on supporting OSPAR Countries in the development of regional methodologies in the North-East Atlantic to assess indicators relating to D1 (biodiversity), D4 (food webs) and D6 (seafloor integrity) and to contribute to OSPAR Intermediate Assessment for 2017 (OSPAR, 2016b). The EcApRHA project also focuses on working towards integrating indicators under these descriptors. The OSPAR Intermediate Assessment is proposed for use by North-East Atlantic EU Member States as part of the obligation to report against the MSFD. To develop indicators under these three descriptors the EcApRHA project is split into three indicator related work packages: Pelagic habitats; Benthic habitats; and Food webs, which feed into the final work package - Ecosystem perspectives. To ensure support to the MSFD requirements of regional coherence, the EcApRHA project is embedded in work being forwarded within OSPAR.

1.2 Aim and structure of the report

One of the aims of the EcApRHA project is to progress methods to undertake an integrated assessment of indicators. The aim of this report is to develop an integrated approach to assess benthic descriptors under D1 and D6 in the absence of information on pristine reference areas.

This report firstly provides an overview of each of the OSPAR benthic indicators, highlighting some problematic issues and knowledge gaps facing the use of the indicator. The process for benthic habitat integrated assessment is then described. A glossary is also provided outlining definitions for the terms used within this document to support clarity.

2 Key issue 1 - From data to indicators

The following section outlines in brief the indicators being developed under work package 2 (Benthic habitats) and highlights current problems with assessment of these indicators. Note, the indicators under work package 2 have been developed in close collaboration with the relevant OSPAR technical subsidiary body (refer to OSPAR (In Prep.a - e) for more detail).

2.1 Typical species composition (BH1)

The indicator 'Typical species composition' refers to species which are vulnerable to changes in anthropogenic pressure. Considering the EU Habitats Directive (Directive 92/43/EEC) which relates the status of conservation of the habitats and the long-term survival of typical species (TS; CEC, 1992), the aim of the indicator is to measure changes in the proportion of typical species within different EUNIS[1] level habitat types when a disturbance occurs, compared to reference conditions. Specific species are not possible to outline since this will change depending on the geographic region and benthic habitat type.

The criterion for typical species composition was tested on the following methods of analysis:

- TS1 - Structural habitat-forming species (or autogenic ecosystem engineers as defined by Jones et al. (1994)).
- TS2 - Species contributing to intra- habitat types (within the same benthic habitat type) similarity identified through SIMilarity PERcentages (SIMPER) analysis.
- TS3 - Species contributing to inter-group (between different groups) dissimilarity between samples of the same benthic habitat with different exposure to disturbance using SIMPER analysis.
- TS4 - Sensitive species based on biological traits analysis (Bremner et al. 2006, de Juan & Demestre 2012). The biological traits considered include: size, longevity, motility, attachment, benthic position, flexibility, fragility and feeding habits.
- TS5 - Species whose relative frequency of occurrence is more than 1% where no or least anthropogenic pressures are registered.
- TS6 - Species whose relative frequency of occurrence is more than 3% where no or least anthropogenic pressures are registered.
- TS7 - Sensitive species based on biological traits analysis contributing to intra- habitat type similarity identified through SIMPER analysis (this typical species is an amalgamation of TS2 and TS4 with an increased percentage similarity).
- TS8 - Sensitive species based on biological traits analysis whose relative frequency of occurrence is more than 1%.
- TS9 - Species contributing to intra-habitat type similarity identified through SIMPER analysis or species whose relative frequency of occurrence was greater than 3% where no or least pressures were registered.

[1] The European Nature Information System (EUNIS, http://eunis.eea.europa.eu/) is a system to classify habitat types according to the resolution of benthic habitat data. The numbering of levels, used within this document refers to EUNIS version 2016. An updated classification of EUNIS levels is planned for 2017.

- TS10 - Sensitive species based on biological traits analysis contributing to intra- habitat type similarity identified through SIMPER analysis or whose relative frequency of occurrence was less than 1%. This typical species is an amalgamation of all of the above options.

Detailed analysis of each typical species method demonstrated TS10 as the most appropriate methods to reflect changes in the proportion of typical species in the presence of anthropogenic pressures (OSPAR, In Prep.a). The latter is as a result of significant negative correlations between an increase in physical and chemical disturbance and the percentage of typical species for the tested benthic habitats.

To detect changes in typical species from anthropogenic pressures, data must be collected in areas where no anthropogenic pressures occur or in least damaged areas. From testing of the indicator, significant changes in the typical species composition were detected using different benthic habitat EUNIS levels (from level 3 to level 5). This demonstrates the indicators adaptability to detect anthropogenic pressure changes at different scales and levels of detail. More detailed methods describing the process to select typical species can be found within OSPAR (In Prep.a).

Following testing BH1 using three different case studies and three different methods (refer to OSPAR (In Prep.a)), key shortcomings identified include the lack of control areas or pristine reference areas where benthic habitats have not been exposed to anthropogenic pressures. To help overcome problems relating to the lack of pristine reference areas to compare samples against, data were collected along a gradient of anthropogenic pressures including pressure extreme. Using this method, changes in typical species composition in varying habitat EUNIS level types were detected (OSPAR, In Prep.a). Although data analysed demonstrated a significant decrease in the proportion of typical species in some benthic habitats as fishing or pollution increased, it is recommended that this indicator is tested in more areas to strengthen results.

2.2 Condition of benthic habitat communities (BH2)

BH2 aims to assess the condition of benthic habitat communities. To undertake an assessment of this indicator various metrics can be used depending on the anthropogenic pressure type. These include:

- Measures of biological diversity (e.g. Shannon, Simpson and Margalef (Magurran 2004, Jost 2006)).
- Sensitivity metrics (e.g. Multivariate AZTI Marine Biotic Index (Borja et al. 2000) and Hurlbert's et al. (1971) ES_{50}).
- Biological traits metric (e.g. Infaunal Trophic Index and fuzzy correspondence analysis (Word et al. 1979, Bremner et al. 2003, 2006)).
- Multivariate community composition changes (e.g. Bray-Curtis similarity index and PERMANOVA (Beals 1984, Anderson et al. 2008)).

Analysing changes in these metrics with varying levels of anthropogenic pressure, enables the condition of benthic habitat communities to be assessed. To undertake assessment of BH2, sites should be monitored along a gradient of anthropogenic pressure from areas of minimal disturbance to heavily impacted areas, to see whether the anthropogenic pressure has an effect on the condition of the benthic habitat (Elliott et al. In Review, OSPAR, In Prep.b). The latter therefore means that information on pristine reference areas is not prerequisite and less optimal methods such as use modelled reference areas or expert judgement can be avoided (Borja et al. 2012, Elliott et al. In Review).

Data collection for BH2 analysis should be carried out within the same habitat EUNIS level 5 type (defined at biological community level). Sampling within the same EUNIS level 5 habitat type, enables environmental variation to be minimised, since EUNIS level 5 habitats take into account a range of environmental and biological variables upon classification. It is advised that analysis is undertaken on an anthropogenic pressure by EUNIS level 5 habitat, to enable the effects of individual pressures on a particular benthic habitat type to be analysed, and thus introduce relevant quantitatively derived management measures where applicable.

To obtain a single assessment result from the different metrics used to assess the condition of benthic habitats, MMI tools are frequently used (Hering et al. 2006, Schoolmaster et al. 2012, Borja et al. 2014). To use MMI tools, metrics should be normalised following data exploration (Zuur et al. 2010). The resulting unifying figure provides an Ecological Quality Ratio (EQR) value. EQR's are then categorised into Ecological Quality Status (EcoQ) ranges which provides a target range in which a benthic habitat is classified according to its condition and from which baselines are set defining the limit between a habitat in GES or not (OSPAR, In Prep.b). Through undertaken analysis of the condition or EQR of benthic habitats at EUNIS level 5, with increasing anthropogenic pressure, the detection of a change in the resistance (the ability of a benthic habitat to tolerate a pressure without changing its characteristics) of a particular habitat type should be possible (**Figure 1;** Elliott et al. In Review). BH2 has been tested out on several case studies including the southern North Sea project (OSPAR. In Prep.c) and sedimentation pressures within German coastal waters (OSPAR. In Prep.c). Furthermore, cross border applications of MMIs on benthic invertebrates and macro-algae for coastal regions have been assessed within the scope of the WFD assessments (OSPAR. In Prep.c).

Factors affecting assessment of BH2 include: identifying a pristine reference condition or sufficiently least damaged areas; accessing biological and anthropogenic pressure data on different and sufficiently fine scale; and the detection of pressures on benthic habitats from environmental variability. To help overcome problems relating to the lack of pristine reference areas to compare samples against, data should be collected along a gradient of anthropogenic pressures including pressure extreme (Elliott et al. In Review, OSPAR, In Prep.b; **Figure 3.i**). To reduce environmental variability causing difficulties in distinguishing pressure effects, samples should be collected in similar biogeographic areas, with minimal environmental variation. Following the latter, environmental variation should be analysed (Elliott et al. In Review), in addition to working with as high resolution a data as possible (i.e. EUNIS level 5 habitat types and raw anthropogenic pressure data). A coordinated or joint, cross-border nested scale (from site to regional scale) monitoring program, assessing individual anthropogenic pressures on specific benthic habitat, would help improve understanding of quantitative pressure-state relationships (Elliott et al. In Review, OSPAR, In Prep.b).

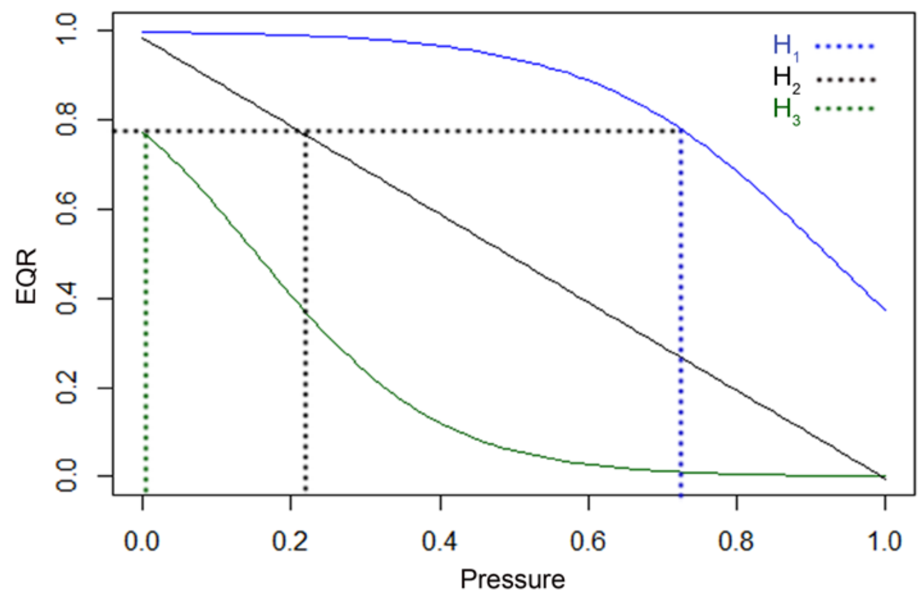

Figure 1: Hypothetical pressure-state relationships on a particular benthic habitat per anthropogenic pressure type. H_1 to H_3 refer to different hypothetical EUNIS level 5 habitat types. The dashed line indicates a proposed threshold pressure value that can be exerted on a specific habitat type over a period of time before the benthic habitat deteriorates in condition (Graph from Elliott et al. In Review).

2.3 Physical damage of predominant and special habitats (BH3)

BH3 assesses the extent and level of disturbance on benthic habitats caused by physical damage anthropogenic pressures. At present (January 2017), this indicator focusses on impacts from bottom-trawling fishing activities and specifically vessels in excess of 12 m, given such activities are cited as one of the most important anthropogenic activities affecting the marine ecosystem (Jennings & Kaiser 1998, Halpern et al. 2008). Only vessels of 12 m or larger have been considered since these vessels are equipped with Vessel Monitoring Systems (VMS) enabling the area of the potential pressure exerted by the vessel to be calculated.

BH3 is assessed by collecting data on both benthic habitat and anthropogenic activities (**Figure 2.b**). The distribution and intensity of mobile bottom gear fisheries are based on swept area ratios (SAR) of surface and sub-surface (sediment penetration ≥ 2 cm) abrasion for fishing vessels of > 12 m within 0.05° x 0.05° grids (also known as c-squares) (Eigaard et al. 2016, OSPAR, In Prep.d). The SAR is the width of fishing gear (in metres) multiplied by the average vessel speed (in knots) and the time fished. The distribution of anthropogenic pressures is based on calculations of exposure within a year and across an MSFD cycle of six years (Anon, 2015, OSPAR. In Prep.d). The EUNIS habitats are mapped at different levels of detail, from level 3 physical habitats to level 5 biological communities, according to data available, and then aggregated to EUNIS level 3 where more detail is provided (**Figure 2.a**).

The sensitivities of benthic habitats (EUNIS level 3 to 5) are based on resistance and resilience (recoverability of the habitat /characteristic species in years) in relation to a defined intensity of anthropogenic pressure (OSPAR, In Prep.d, Tyler-Walters et al. 2001; **Figure 2.c**). The sensitivity is assessed at species, community or EUNIS level 3 habitats, depending on what benthic habitat mapping information is available within each grid cell. Benthic habitat maps and sensitivity assessments are assigned confidence levels based on the type of information used (e.g. ground-truthed data, percent of ground-truthed data, modelled maps, to best available evidence and expert judgement- refer to OSPAR, In Prep.d; **Figure 2.f**).

A matrix combining the intensity or exposure of anthropogenic pressure (per pressure type) and benthic habitat sensitivity (per EUNIS level 3 habitat type) supports the classification of disturbance. Disturbance distribution are then categorised from none to very high (ten categories) (**Figure 2.e**), and the distribution of categories is shown on disturbance maps (**Figure 2.d**). The disturbance maps for surface and subsurface abrasion are then combined by selecting for each of the cells the highest disturbance category from the two maps. The final outputs of this modelled assessment are levels of disturbance per benthic habitat type across a region. These levels of disturbance are amalgamated into a Physical Damage Index value for each benthic habitat. During indicator development a formula for calculating this index was tested and found not to deliver satisfactory results to capture temporal changes in fisheries pressures. Further work is required to test and make this index operational.

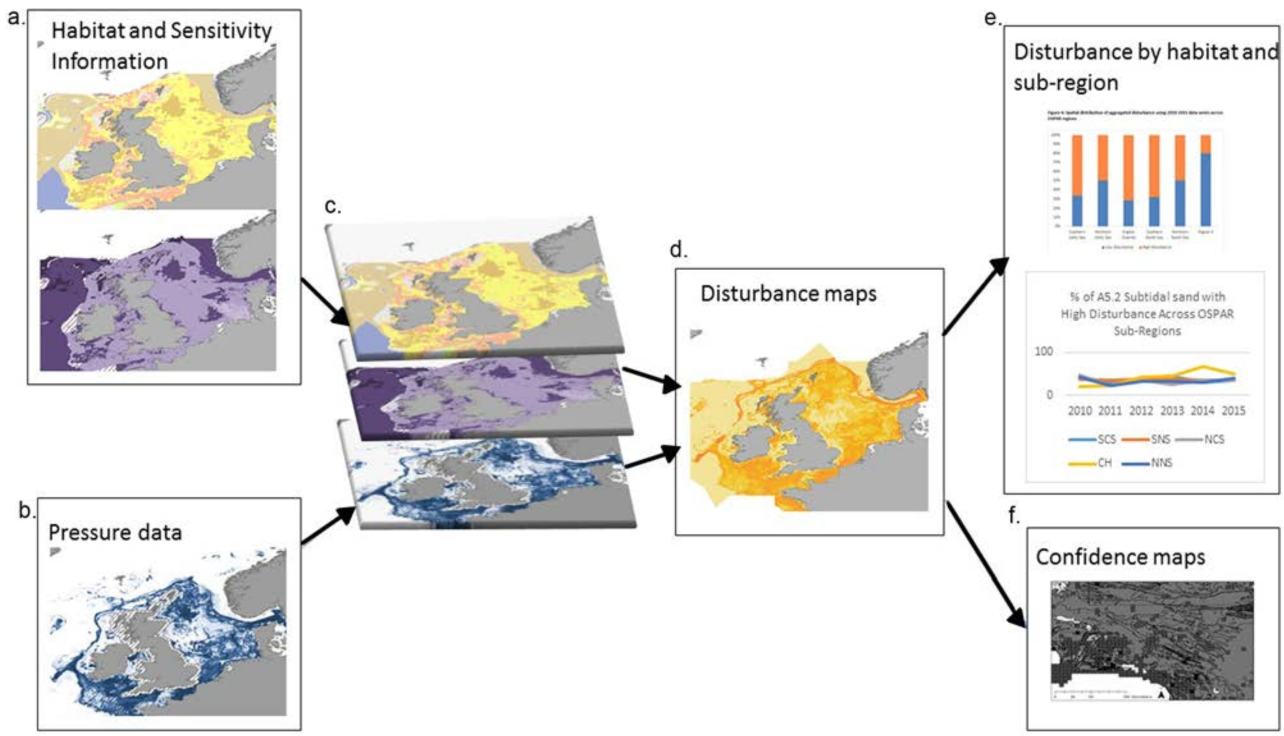

Figure 2. Conceptual overview of BH3 showing the different components required for analysis.

An assessment has been undertaken for OSPAR Region II (Greater North Sea) and Region III (Celtic Seas), and a partial assessment for Region IV (Bay of Biscay and Iberian Coast) has been undertaken due to lack of benthic habitat data. During the next indicator assessment cycle the method for this indicator will be improved from semi-quantitative/categorical to a more quantitative approach. In order to do that the following knowledge gaps need to be addressed:

- Data on extent and distribution of benthic habitats and their sensitivities. Additional information from benthic species collected during surveys will be used to improve the quality of the results, and to improve the evidence available on the distribution of sensitivity information across the regions.

- Currently a limited pressure data set on the distribution of fisheries is used. Moreover, due to different approaches to extract data from the national databases it is expected that some data are missing or potentially misallocated. A gap also exists around the activities of smaller vessels (< 12 m) fishing mostly in coastal waters that are not equipped with a VMS recorder. Information on other activities causing physical damage (e.g. sand extraction, offshore construction activities) will also be included as the indicator is further refined. Due to the different nature of the anthropogenic pressures (e.g. selective extraction, abrasion and changes in siltation), for each of these physical damage pressures a separate disturbance matrix is required in order to explore how to take into account multiple pressure in the assessment.
- The scale of fishing pressure and the matrix underpinning disturbance categories need to be evaluated using experimental and field studies in order to improve evidence on the pressure-state relationships as per within BH1 and BH2.
- A method to evaluate historical damage needs to be developed, as the indicator currently does not take account of the benthic fishing activity which has occurred prior to 2010. In some areas benthic habitats may have already lost sensitive features due to ongoing anthropogenic pressures. In order to improve the assessment and to take account benthic habitats deteriorated in the past, a reference state of the habitats could be included in future iterations.
- Based on the levels of disturbance per benthic habitat type across the region a 'Physical Damage Index' will be further tested and developed to calculate a value for each benthic habitat or geographical area.

2.4 Area habitat loss (BH4)

BH4 is being developed to assess the proportion of the area of benthic habitats that is permanently or for a long-lasting period lost due to anthropogenic pressures. The metric for this indicator is the surface area of lost benthic habitat. The assessment of benthic habitat extent may be based on mapping of abiotic parameters (e.g. sediment, depth range) and biotic parameters (key species, benthic habitat-forming species, communities) or by modelling the extent of the EUNIS level 3, 4 or 5 habitats. Each benthic habitat is then attributed a specific sensitivity to the various types of anthropogenic pressures causing loss of extent. Many human activities causing benthic habitat loss require licensing procedures and Environmental Impact Assessments (EIAs) (e.g. wind farm constructions, sediment extraction, etc.). When available, EIAs enable the extent and intensity (e.g. duration and/or frequency of a pressure, amount of sediment extracted) of the pressures to be determined. The activity footprint (extent and intensity of pressures) is then combined with the extent and sensitivity of benthic habitats in order to assess the extent of permanently lost area for each habitat.

At present two national concepts exist for the assessment of benthic habitat loss, which have been developed within German and the UK (Bioconsult, 2013, Strong 2016). In principle, both concepts assess activities and pressures in a similar way: benthic habitat maps are required; the sensitivity of habitats is assessed; and finally pressures and sensitivities are combined to produce a value for the potential impact on the benthic habitat. Differences that still have to be discussed arise from the following issues:

- How to assess the extent of benthic habitats: assessment of the potential (predicted) extent or the actual extent of habitats?
- Which benthic habitat types shall be assessed (EUNIS level 3 to 5 and Special habitats)?
- Which anthropogenic pressure types to include (i.e. physical loss and/or habitat loss)?
- How to consider irreversible changes at a community scale given this can lead to irreversible loss at EUNIS level 5?

A common approach for the OSPAR maritime area is being developed (OSPAR. In Prep.e).

3 Key issue 2 - From indicators to habitat assessment - An integrated approach to assess benthic habitats

To date indicators have largely been analysed and tested as separate components (refer Coordinated Environmental Monitoring Programme – CEMP, indicator guidelines, OSPAR In Prep.a - e). Albeit, they were developed coherently and are highly interlinked and complement one another. It should also be noted that the described indicators are also affected by uncertainties with regard to existing conditions of benthic habitats, and the reference conditions of those different habitats. From BH1, BH2 and BH3[2], we propose an integrated method to assess benthic habitats to reduce duplication of survey effort, and optimise monitoring requirements by ensuring that the different indicators feed into one another, and strengthen confidence in the overall assessment.

3.1 Benthic habitat integrated process overview

To undertake this integrative cyclical assessment, the methodologies of the individual benthic habitat indicators are used and linked together. The latter enables a quantitative feedback loop to be created so that monitoring data can feed into and update benthic habitat maps, in addition to sensitivity and disturbance calculations. Such a process also facilitates quantitatively derived management measures to be put in place. **Figure 3** and below outlines the process to undertake this integrated benthic habitat indicator quantitative assessment:

- Information on anthropogenic activities (**Figure 3.a)** are collected and spatially analysed according to the anthropogenic pressures they exert on the marine environment (**Figure 3.b**; BH3).
- Ground-truth sampling (**Figure 3.c**) helps to classify EUNIS level 5 and Special habitats, and create benthic habitat prediction models (EUNIS level 3 and Special and biogenic habitats; **Figure 3.d**). Predictive and ground-truthed data provide the data to build benthic habitat maps (EUNIS level 3 to 5) of ranging confidence (**Figure 3.e**; BH3), and help analyse BH1.
- Information on benthic habitat (EUNIS levels 3 to 5) (**Figure 3.e**) and benthic data (BH1 and BH2) resistance and resilience per anthropogenic pressure types, are then used to build a map of habitats sensitivities (**Figure 3.f**; BH3) (EUNIS level 3 to 5) of ranging confidence.

[2] Since BH4 is at early stages of development and a common OSPAR approach has not yet been agreed upon, it has not been included in the benthic habitat integrated assessment.

- These anthropogenic pressure and benthic habitat sensitivities data layers (**Figure 3.b and f**) are combined using disturbance matrices of pressure intensity versus sensitivity (**Figure 3.g**; BH3) per habitat (EUNIS level 3 to 5) and pressure type.
- Each habitat type (EUNIS level 3 and Special habitats) mapped across the region are categorised according to their sensitivity and the intensity of anthropogenic pressure being undertaken within the area to produce a Disturbance distribution map (**Figure 3.h**; BH3).
- The benthic habitat disturbance map (**Figure 3.h**) can then facilitate benthic habitat monitoring and assessment programs (**Figure 3.i**; BH1; BH2) to be adapted per pressure and EUNIS level 5 habitat type, to collect data in areas with a gradient of anthropogenic pressure from highly impacted to reference areas, or in the absence of, least damaged areas.
- From *in situ* monitoring and assessment (**Figure 3.i**) of benthic habitats (EUNIS level 5), in combination with fine scale data on anthropogenic pressures, the condition of benthic habitats (EUNIS level 5), can be statistically quantified through pressure-state changes (**Figure 3.j**; BH1 and BH2). The latter will enable quantitative baselines for disturbance to be set, based upon changes in EQR of EUNIS level 5 benthic habitats with increasing pressure.
- These more quantitatively derived EQR thresholds (**Figure 3.j**) can then feed back and refine benthic habitat maps and habitat sensitivity assessments (EUNIS level 3 to 5; **Figure 3.d** to **f**), and benthic habitat disturbance matrix (**Figure 3.g**). Which in turn can also be used to influence into disturbance distribution assessments and maps (**Figure 3.h**), with increased confidence in disturbance values.

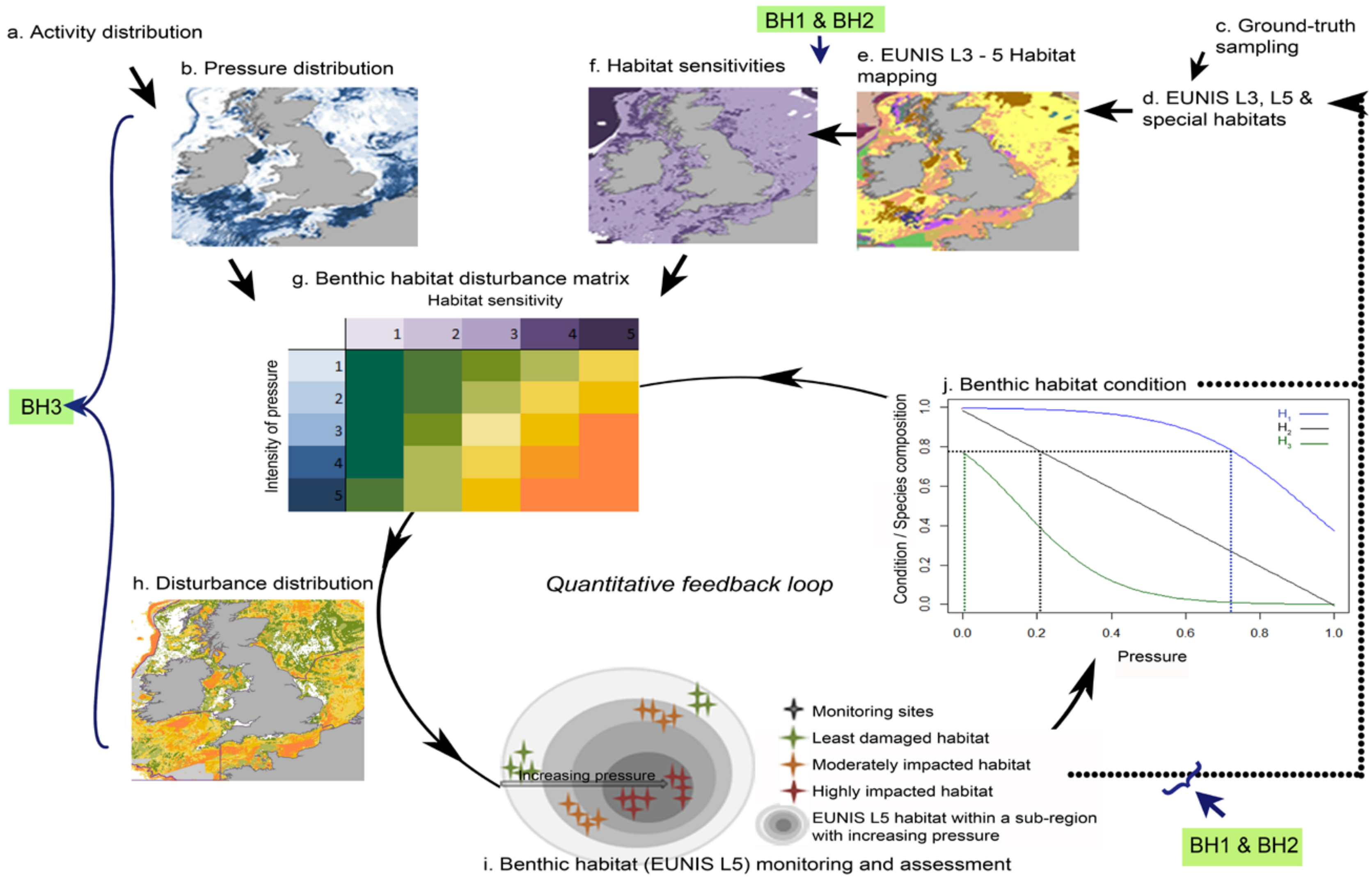

Figure 3: Overarching conceptual approach for an integrated assessment of benthic habitat indicators on a (sub) regional scale.

Through the benthic habitat integration process, data requirements for the three indicators can be classified into three main categories. These data requirements comprise of a) site specific benthos monitoring data, b) Benthic habitat data, and c) data relating to anthropogenic pressures (**Figure 4**). To support the description of the integration of benthic habitat indicators (**Figure 3**), **Figure 4** illustrates a simplified overview linking the type of data required for benthic habitat integrated assessment and how they support the assessment of each indicator. Within **Figure 4**:

- **Benthos monitoring data** (**Figure 4.a**) refers to the collection of data on benthic macro-fauna and macro-flora and communities in addition to metadata containing information on the geographical location, depth, time the data was collected, etc. Standardised methods used to collect benthic data are prerequisite to assess the cross institutional and cross border comparability of quantitative information on benthic species (OSPAR In Prep.a - b).
- **Benthic habitat data** (**Figure 4.b**) provides information on seabed type classified according to EUNIS levels. Benthic habitat maps can be produced at different spatial resolutions depending on methods used (e.g. ground-truthed sampling, acoustic mapping to use of modelling techniques) (Kenny et al. 2003, Diaz et al. 2004). Benthic habitat data also comprise of information on environmental variables (e.g. depth, exposure sediment type, etc.) used to classify (Brown et al. 2011) and model habitat within the scope of different national and international classification systems (OSPAR In Prep.d).
- **Anthropogenic pressure data** (**Figure 4.c**) provides information on the extent and intensity of pressures exerted by anthropogenic activities on the seabed. Anthropogenic pressure data can also be acquired at different spatial scales. For example, 0.05^{o} x 0.05^{o} grids can be used for spatial quantification of fishing pressure at sub-regional scale (ICES, 2015, OSPAR, In Prep.d) whereas site specific data can be acquired to address finer scale fishing, dumping and disposal action pressure data (OSPAR, In Prep.a - d).

Figure 4 illustrates the link between each of these data types and how they are important for the calculation of BH1, BH2 and BH3. The three corners of the triangle link since:

- Benthos monitoring data (**Figure 4.a**) help classify benthic habitat types (**Figure 4.b**), provides the spatial location; and help make predictive habitat maps (BH3). Benthos monitoring data also enables the identification of communities (BH2) and typical species (BH1) within EUNIS level 5 habitats. The latter is then used to assess reference conditions (BH1 and BH2).
- Benthic habitat (**Figure 4.b**) and anthropogenic pressure data (**Figure 4.c**) is required for BH3 sensitivity analysis and mapping, and evaluating and mapping the extent of disturbance per benthic habitat type (also refer to **Figure 3.g and h**).
- Through benthos monitoring (**Figure 4.a**) and anthropogenic pressure data (**Figure 4.c**), assessing quantitative pressure-state relationships along a gradient are possible (BH1 and BH2; **Figure 3.j**). Areas with least damaged can be distinguished to verify habitat specific communities (BH2), typical species (BH1) and their sensitivities (**Figure 3.e and h**). The extent of disturbance can also be validated (BH3; **Figure 3.g and h**).

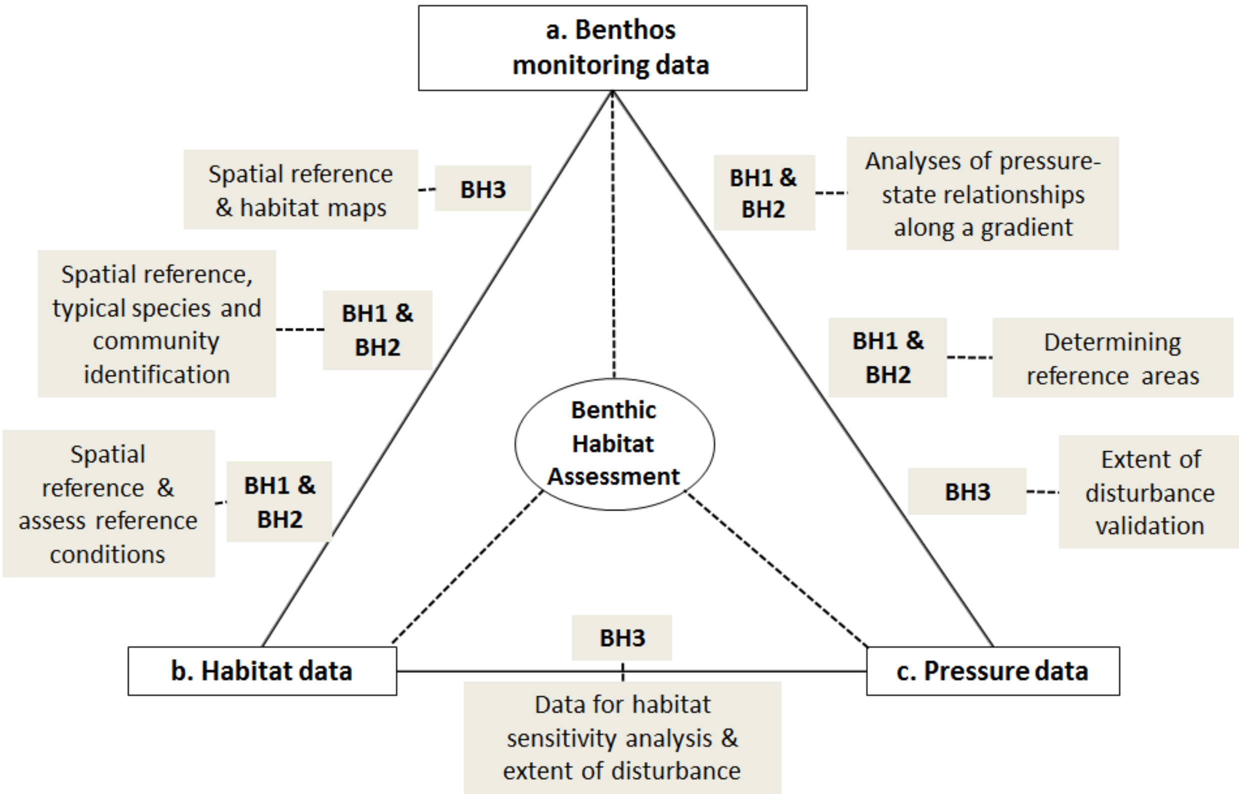

Figure 4. Data flow requirements for benthic habitat integrated assessment.

4 Discussion

The proposed integrative cyclical approach uses information and methods from the different benthic indicators, within the different MSFD descriptors, in a cohesive approach so that they can inform and influence one another and provide a more complete assessment of benthic habitats. The process enables more efficient use of monitoring requirements by collecting data for several indicators as opposed to independent methods for each indicator. Results also enable updated monitoring and assessment data to be built upon to strengthen benthic habitat community assessments through its integrated cyclical approach. The quantitative pressure-state analysis facilitates the identification of threshold tipping points to advise on anthropogenic activity management measures. The proposed method is different from usual integrated assessments, since it does not rely on an MMI tool to assess the state of the marine environment, but draws from the processes of the different indicators to evaluate the state of a benthic habitat within a particular region. This method therefore avoids problems of double counting, varying spatial scales, weighting of the various indicators, and problems with assessing thresholds which exist within current MMI integrated assessment methods (Borja et al. 2013, Berg et al. 2015).

The proposed method relies on the availability of benthic habitat (EUNIS level 4 to 5 and special habitats) and anthropogenic pressure (extent, frequency and intensity) data to undertake assessment. The method also relies on the need for a gradient of anthropogenic pressures including pressure extremes to be able to detect changes in benthic habitat communities. The gradient of pressures is therefore used as a proxy for the lack of information that currently exists on pristine reference areas for most benthic EUNIS level 4 to 5 habitats. Within this approach, sufficiently least damaged areas must be selected during monitoring and assessment and compared to the same EUNIS level 4 to 5 habitat with varying anthropogenic pressures (Elliott et al. In Review).

Ideally pristine reference conditions are required to set baselines for full-recovery potential of each habitat. However with centuries of anthropogenic pressure taking place and only relatively recently detailed benthic habitat and activity mapping taking place, identification of such pristine reference areas are few and far between. Pristine conditions can help discern the behaviour and ecology of marine ecosystems and avoid shifting baselines where least damaged sites are considered as reference areas (Pauly 1995, Josefson et al. 2009). With time (depending on the benthic habitat type), Marine Protected Areas (MPAs) could be used to create long-term low-pressure areas as a proxy for reference areas if strict management measures (e.g. no-take area) were implemented to ensure no damaging activities occurred within the MPA, and adequate benthic monitoring is in place (Van Hoey et al. 2010, Elliott et al. In Review). It should however be noted that presently, long-term recovery of benthic habitats is not well understood due to lack of long-term anthropogenic demersal pressure and benthic data (Kaiser et al. 2006, Foden et al. 2011).

To further improve the process, links with other descriptors could be included such as with Descriptor 4 (food webs), where many vertebrates (e.g. demersal fish and birds) depend on benthic species for food resources and refuge (Nordström et al. 2015, Arroyo et al, 2017, Elliott et al. In Press). A deterioration in benthic habitat quality from increased anthropogenic pressure has been linked to changes in trophic levels of demersal communities (Arroyo et al, 2017). Links with Descriptor 3 (commercial species) could also be made through linking benthic habitat quality and benthic anthropogenic pressures to commercially important demersal fish habitats (Elliott et al. In Press). In addition, the proposed method can help inform on assessment and monitoring requirements for special habitats, as those listed under the Habitat Directive or Regional Sea Conventions, even if specific objectives and management measures (e.g. thresholds) may differ.

To incorporate a more ecosystem perspective, effects of co-occurring or multiple anthropogenic pressures on benthic habitats should be explored (Halpern et al. 2008a, Foden et al. 2011, OSPAR, In Prep.f). The latter, would however lead to difficulties in distinguishing the effects of individual anthropogenic pressure types on benthic habitat and therefore difficulty in setting management measures (Giakoumi et al. 2015). As part of OSPAR Intermediate Assessment 2017, an ecosystem assessment outlook is being developed through cumulative effect assessments of OSPAR common indicators (Elliott et al, 2017, OSPAR, In Prep.f). The latter approach could be applied to benthic habitat integration to help provide a wider understanding of individual and cumulative effects or otherwise known as co-occurring pressure (Elliott et al, 2017).

Due to limited and difficulties in accessing long-term and extended spatial coverage datasets, full testing of this integrated cyclical approach has not yet been undertaken. Future work should focus on identifying established datasets, for example from WFD assessments and marine research and industries (e.g. through EIAs). Testing the approach would identify where data-access issues exist, and ensure standardised monitoring methods are used to support cross-institutional and cross-border comparability of benthic information within regional seas. Analysis of the individual indicators has been undertaken within OSPAR regional seas area. However, the proposed methodology could be trialled and applied to other regional seas such as the Mediterranean and the Baltic Sea supporting cross-region coherence, and further developing an ecosystem-based approach for benthic habitats assessment.

Annex 1 - Glossary of technical terms outlined within this document

Term	Description	Source
Anthropogenic Pressures	The mechanism through which a human activity causes an effect on any part of the ecosystem and may change the environmental state or condition of that part of the ecosystem over a given period of time. A pressure can be of physical, chemical or biological nature.	Foden et al. 2011, Goodsir et al. 2015, Oesterwind et al. 2016
Baseline	The qualitative or quantitative description of the state a habitat type against which subsequent values of state are compared. A baseline condition can be set at different levels (e.g. pristine, least damaged, or to be maintained in its current state) according to the management objective for that particular habitat.	OSPAR 2012, Elliott et al. In Review
Benthic habitat	The place where benthic species occupy. Characterised by the physico-chemical (e.g. sediment, depth, salinity, temperature, etc.) and biological conditions (fauna, flora, algae). Benthic habitats may comprise of one or several biological communities depending on the European Nature Information System (EUNIS) habitat classification level. EUNIS is a system to classify benthic habitats on different scales. The higher the level, the more detail and sub-types of habitats are included.	Davies et al, 2004, Elliott et al. 2016
Coastal waters	Marine waters, the seabed and subsoil on the landward side of a line, every point of which is at a distance of one nautical mile on the seaward side from the nearest point of the baseline from which the breadth of territorial waters is measured.	CEC.2000, 2008
Criteria	A particular aspect of biodiversity that requires their status to be assessed e.g. population size.	OSPAR 2012
Cumulative effects or co-occurring pressures	The size and location of multiple anthropogenic pressures, which overlap in an area or on a habitat. These pressures may be additive, synergetic or antagonistic. This term is therefore also referred to as co-occurring to avoid this confusion.	Foden et al. 2011, Judd et al. 2015
Descriptor	Qualitative features which are used to assess GES. 11 are described within the MSFD, three of which (Biological diversity, seafloor integrity and food webs) relate to the EcApRHA project.	CEC. 2008
Ecological Quality Ratio	Refers to a standardised index (between 0 and 1) used to assess biological indicators against reference conditions for a specific area.	Borja et al. 2004, 2007, Borja and Rodríguez 2010,

		Tett et al. 2013
Ecosystem	An ecosystem consists of biotic (community of organisms) and abiotic (physical, chemical and biogeochemical) features, processes and interactions in a defined space at a given time.	Dauvin et al. 2008, Curtin and Prellezo 2010
Ecosystem approach	The comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity.	OSPAR, 2016d
Good Environmental Status	Refers to the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations.	CEC. 2008
Ground-truth	*In situ* sampling to verify a benthic habitat type or its condition	EMODnet 2016
Indicator	Are distinct features that help quantify descriptors outlined within the MSFD.	CEC. 2008
Integrated approach	The combining of information from different (scientific) indicators into one higher-level indicator or to criterion-level, or the combining of information from two or more criteria to descriptor level or to an alternative grouping of criteria (e.g. for an ecosystem component, or for a grouping of criteria below descriptor level).	Borja et al. 2014
Least damaged habitats or condition	The state of a habitat that may have been subject to some anthropogenic impacts or disturbance, but whose structure and functions are not adversely modified. The latter will need a certain level of expert judgment. However, through exploring anthropogenic pressure-state relationships, it will be possible to determine whether the least damaged habitat's structure and function are not adversely modified.	Elliott et al. In Review.
Metadata	The data helping to define or to understand other data. For example, date of sampling and geographical location of a station which is associated with biological data such as species abundance and environmental data such as	FGDC Content Standard for Digital Geospatial Metadata

	substrate characteristics.	Workbook, Ver2.0, May 1, 2000 within OSPAR. In Prep.d
Monitoring	The different observatory methods to survey species, habitats, ecosystems, etc. in time.	Schmitt et al. 1996
Multi-Metric Index tool	A quantitative monitoring and assessment tool to undertake an integrative assessment of the marine environment or part of. The tool combines measures of the status of the marine environment into a single unit.	Schoolmaster et al. 2012
Predominant species and habitat	Habitat category referred to in Table 1 of Annex III to the Directive. Widely occurring and broadly defined habitat types (e.g. shelf sublittoral sand or mud) that are typically not covered by other legislation (see 'Special habitat types').	OSPAR 2012
Pristine reference state/ condition/ area	The mean value or the ranges of values which define a pristine or best environmental state which has not been subject to anthropogenic impacts or only minor disturbance has been undertaken in the area.	CEC. 2008, Borja et al. 2010
Region	The MSFD derestriction is split into four marine regions (Baltic sea, the North East Atlantic Ocean, the Mediterranean Sea and the Black Sea) to facilitate implementation of the Directive, taking into account hydrological, oceanographic and biogeographic features.	CEC. 2008
Sensitivity	The ability of a habitat to tolerate pressure and the time the habitat needs to recover following removal of the pressure.	Aish et al. In Review.
Special habitat	Habitat which have a specific management concern, especially those recognised or identified under Community legislation (the Habitats Directive and the Birds Directive) or international conventions as being of special scientific or biodiversity interest.	CEC. 2008
Sub-region	An area within EU regional seas which has similar range of benthic habitats and oceanic conditions. Within OSPAR's mandate, the North East Atlantic Ocean, this includes the Celtic seas, Greater North Sea, Bay of Biscay and the Iberian Coast, Macaronesian biogeographic region.	CEC. 2008
Threshold	For management purposes, thresholds are used as the value or range of values to describe the quality of a particular habitat before it changes state from	Samhouri et al. 2010, OSPAR, 2012

	increased pressure.	
Vessel Monitoring System (VMS)	VMS is a general term to describe a satellite communications system used to monitor fishing activities. The system is based on electronic devices (transceivers), which are installed on board vessels and automatically send data to a shore-based "satellite" monitoring system. VMS provides monitoring agencies with accurate locations of where fishing vessels are and where they were at periodic time intervals. The position information can be provided to the monitoring agency in near real time (less than 30 minutes), regardless of the location of the vessel.	NOAA fisheries glossary 2006, FAO, 2016

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