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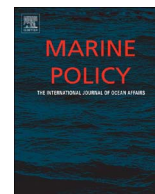
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## Integrating benthic habitat indicators: Working towards an ecosystem approach

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### ABSTRACT

The Marine Strategy Framework Directive (MSFD) requires an ecosystem-based approach to assess the state of Europe's seas. To date, assessment is carried out on an indicator by indicator basis. Integration of indicators is required to undertake a more holistic assessment of the state of the marine environment. Here, an integrated approach to assess benthic habitats is proposed. Within this conceptual method, four OSPAR benthic habitat indicators relating to biodiversity (D1) and sea-floor integrity (D6) descriptors are linked together. For the integration, benthos, environmental and anthropogenic pressure data are required. State indicators are assessed along a gradient of pressure to facilitate threshold values to be quantified and provide advice on management measures. The method also includes a feedback system whereby best available evidence on benthos, its sensitivity and disturbance assessments can be replaced with ground-truthed data. The proposed method can be expanded to include other related indicators under the different descriptors (e.g. commercial fish and shellfish (D3), food webs (D4) and eutrophication (D5)) where relevant. The concept is a first step towards integration of benthic indicators and could be applied to monitoring requirements under other Directives such as the Habitat or Water Framework Directive.

### 1. Introduction

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) of the marine environment by 2020 [1]. To achieve an ecosystem view of the marine environment under the MSFD, 11 descriptors are described [1] ranging from maintaining biodiversity (D1), marine food webs (D4), sea-floor integrity (D6), to minimising eutrophication (D5) and contaminants (D9). These descriptors are each made up of numerous criteria through which reporting by Member States is required [2].

Multiple indicators enable responses to anthropogenic pressures to be analysed more widely and provide a better understanding of their responses on benthic communities [3–5]. However, due to the complex nature of the marine environment, there is some overlap between indicators used to report on the different descriptors and criteria, and the MSFD's first reporting cycle has been criticised for its poor coherence

(e.g. [6–8]). Gaps in information required to carry out assessment of the marine environment also exist [6,9]. Overarching knowledge gaps include: lack of pristine reference areas, or values to compare state related indicators against to set baselines; varying spatial scales; and a holistic approach to assess different aspects of the marine ecosystem [10].

One increasingly popular method to undertake integrative and ecosystem based assessment of the marine environment is through Multi-Metric Index (MMI) tools [11,12]. MMI tools enable the state of the marine environment to be monitored and assessed through the use of various metrics to derive a single value caused by anthropogenic pressures [11,13]. 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 (GES) within the Water Framework Directive (WFD; 2000/60/EC) [11,13].

Numerous integrated indicator tools have been developed in recent decades (reviewed by [14]). However, these tools suffer from the lack of pristine reference areas or levels to assess baselines and disturbance

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**Table 1**  
OSPAR benthic habitat indicator summary.

Indicator	Aim	Measurement unit
Typical species composition (BH1)	To measure changes in the proportion of typical species within different benthic habitats when a physical or chemical disturbance occurs, compared to pristine reference or least damaged conditions.	Percentage change.
The condition of benthic communities (BH2)	To measure changes in the condition of benthic communities' through biological diversity indices (e.g. Shannon-Wiener or Margalef), biological traits indices (e.g. Infaunal Trophic Index, fuzzy correspondence analysis) or multivariate community composition changes, along a gradient of anthropogenic pressure.	Ecological Quality Ratio (the ratio of the value of the indicator for the considered habitat benthic community against that of a least damaged community).
The extent of physical damage of benthic broad habitat types (BH3)	To assess the extent and degree of potential physical disturbance on benthic broad-scale habitats caused by anthropogenic pressures by combining data on anthropogenic activities with the sensitivities of underlying benthic habitats mapped.	Square kilometre and percentage of benthic broad-scale habitat disturbed.
The area of habitat loss (BH4)	To assess the proportion of the area of benthic habitats that are permanently, or for a long-lasting period lost due to anthropogenic pressures.	Square kilometre and percentage of habitat lost.
The size-frequency distribution (BH5)	To assess the effects from physical disturbance or hypoxia on bivalves or other sensitive benthic species.	Number or biomass of individuals per size class <sup>a</sup> .

<sup>a</sup> Note: within the OSPAR region the method for BH5 has not yet been developed and its unit may be subject to change.

gradients against [12]. Additionally, trying to synthesise many aspects of the marine environment into a single value leads to loss of information, thus only approximately reflecting the complex nature of marine systems [10,15]. 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 difficulties when using MMI tools include, uncertainties in how to weight the different pressure indicators appropriately, and redundancy problems with double counting which can lead to imbalance or bias of certain indicators [10,15].

The aim of this paper is to develop a quantitative integrated method to assess GES of benthic habitats, using benthic habitat indicators under descriptor 1 (biodiversity) and descriptor 6 (sea-floor integrity), with potential implications on other descriptors. To assess GES of benthic habitats, a brief overview of the different types of integration methods is outlined. The OSPAR (Convention for the Protection of the Marine Environment of the Northeast Atlantic) benthic habitat indicators are summarised. The conceptual method on how to integrate these indicators in terms of process and data type is then described. To avoid confusion in terminology, key terms used in this paper are aligned with MSFD and OSPAR language (refer to [Supplementary Material](#)).

## 2. Integration of indicators

Various methods exist to integrate indicators and undertake a global assessment of the marine environment as reviewed by Borja et al. (2014) [10]. MMI tools are more commonly used methods for integration (e.g. [14]). The assessment of cumulative or co-occurring pressures is also frequently used to undertake global assessment of the marine environment (e.g. [16–18]). Quantitative cumulative assessments do not currently incorporate individual indicators and descriptors under the MSFD [19]. The use of more complex modelling techniques such as End to end and Ecopath with Ecosim [20] can also be used. Such models are however, rarely used for larger scale benthic management decisions due to their difficulties in addressing seafloor integrity [20], and the large amount of data required to validate these models. The WFD uses the 'One Out, All Out' (OOAO) approach with regard to the integrated assessment of biological indices. The OOAO approach has, nonetheless been considered erroneous and overly precautionary [6,21]. No specific rule has so far been agreed by European Member States for the MSFD [6]. Integrated ecosystem approaches are currently under development in OSPAR [19].

## 3. Methodology

### 3.1. OSPAR benthic habitat indicators

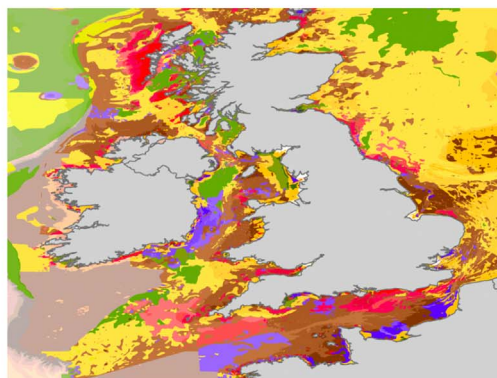
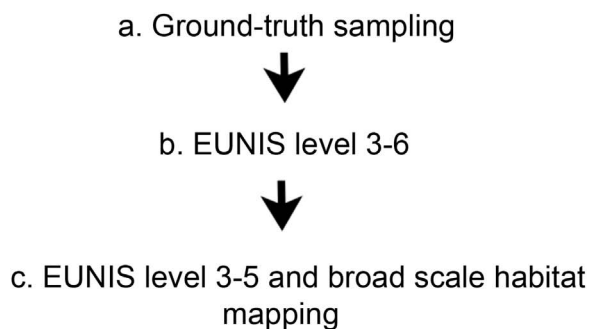
Under the OSPAR regional seas convention, five benthic habitat indicators have been proposed. These include: Typical species composition (BH1); Condition of benthic communities (BH2); Extent of physical damage of benthic broad habitat types (BH3); Area of habitat loss (BH4); and Size-frequency distribution of bivalve or other indicator species (BH5) [2,5,22].<sup>1</sup> The overarching aims of these indicators are summarised within [Table 1](#). To undertake an integrative cyclical assessment, the methodologies of the individual benthic indicators are used and linked together through a quantitative feedback loop. All five indicators rely on three main data types:

1. Benthos data comprising of species inhabiting particular seabed types and the seabed itself;
2. Environmental data (e.g. depth, salinity, wave exposure, sediment type) used to classify and model the benthic habitats according to the hierarchical levels of the European Nature Information System (EUNIS) levels alongside benthos data [23]; and
3. Anthropogenic pressure data (e.g. abrasion, siltation, physical disturbance, nutrient enrichment, etc.) [24].

### 3.2. Benthos and seabed data

Ground-truth sampling from benthic monitoring and assessment, and environmental data are required to identify typical species (BH1) and benthic communities (BH2) occurring at a site scale (100's of meters to 10's of kilometres). Various methods exist to collect benthos data (e.g. cores, visual imagery techniques, trawl surveys, etc.) [25]. Each method has advantages and disadvantages which should be taken into consideration (refer to [26]). If sufficient data are available, broad-scale and biogenic habitat can be predicted and mapped using this benthos data with the support of environmental data ([Fig. 1a-c](#)). Using best available evidence on species and benthic habitat sensitivities (by combining resistance and resilience characteristics) for defined anthropogenic pressures, broad-scale sensitivity maps are created ([Fig. 1d](#); BH3; [27,28]). Best available evidence is based on the confidence of sensitivity assessments and the underlying source of benthic data which

<sup>1</sup> Precise methods for the benthic indicators described are currently being developed under the OSPAR convention and should be publically available by the beginning of 2018 ([www.ospar.org/work-areas/bdc/ecapra/cemp-reports](http://www.ospar.org/work-areas/bdc/ecapra/cemp-reports) and <https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/biodiversity-status/>).



d. Benthic habitat sensitivity

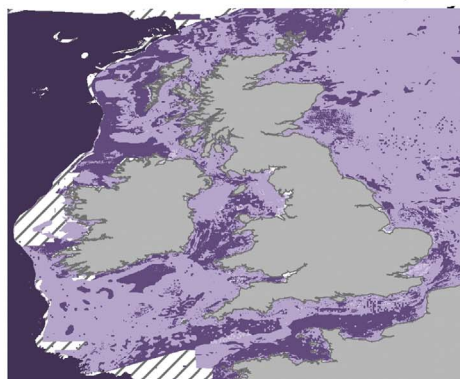


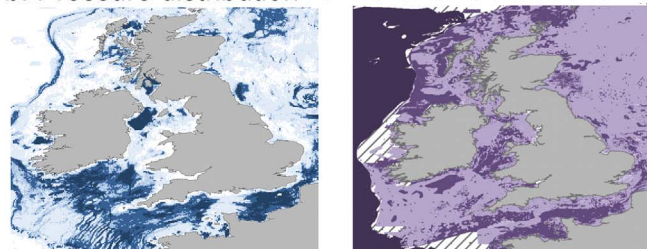
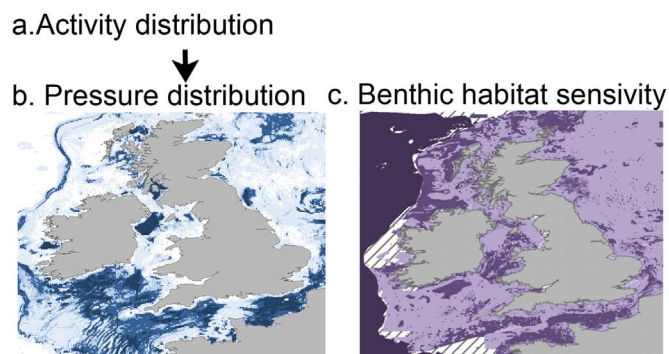
Fig. 1. Mapping benthic habitats and their sensitivity. Benthos data (a) is used to classify EUNIS level 3–5 habitat benthic habitat seabed types (b) and predict broad-scale benthic habitats (c). Broad-scale habitat sensitivities to anthropogenic pressures, are then mapped using best available evidence (d).

are assessed in accordance to the information used to make assessments [24]. For example, information on the sensitivity of species and benthic habitats may be derived from ground-truthed data (high confidence), percent of ground-truthed data, modelled maps, and expert judgement (low confidence) [29].

### 3.3. Pressure data

Information on anthropogenic activities (Fig. 2a) are collected and analysed according to the spatial and temporal pressures they exert on the marine environment (Fig. 2b). To map pressures exerted on benthos, the extent and intensity (i.e. concentration, duration and/or frequency) of the pressures are required. The precise method to assess pressure will depend on the anthropogenic activity [24]. Eastwood et al. (2007) [30] provides details of assessing common activity- pressure relationships.

Through methods outlined within BH3, information on the intensity



d. Benthic habitat disturbance matrix

Intensity of pressure	Habitat sensitivity					Disturbance categories
	1	2	3	4	5	
1	1	2	3	4	6	1
2	1	2	4	6	7	2
3	1	3	5	7	9	3
4	1	4	6	8	9	4
5	2	4	7	9	9	5

e. Disturbance distribution

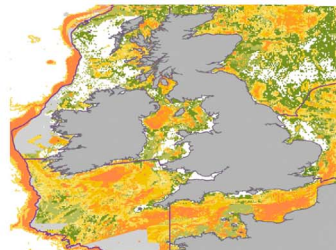


Fig. 2. Steps required to assess disturbance from anthropogenic activities. Anthropogenic activity data (a) is collected to map pressures (b). Benthic habitat sensitivity assessments (c) are then used in combination with the pressure data to assess and map disturbance using categories ranging from 1 to 9, with 9 representing 100% disturbance (d-e).

of the pressure (Fig. 2b) within the area the activity takes place, alongside the habitat sensitivity (Fig. 2c) is combined using a disturbance matrix (Fig. 2d) and categorised from no disturbance (0) to high disturbance (9), per benthic habitat and pressure type. The matrix uses Eq. (1), and is weighted so that low sensitivity benthic habitats are less affected by pressure and high sensitivity habitat types are more affected by pressure. Values from the disturbance matrix are then applied to spatially crossed pressure and sensitivity layers to produce a disturbance distribution map (Fig. 2e; BH3).

$$D = b + \frac{ab}{\bar{b}} \tag{1}$$

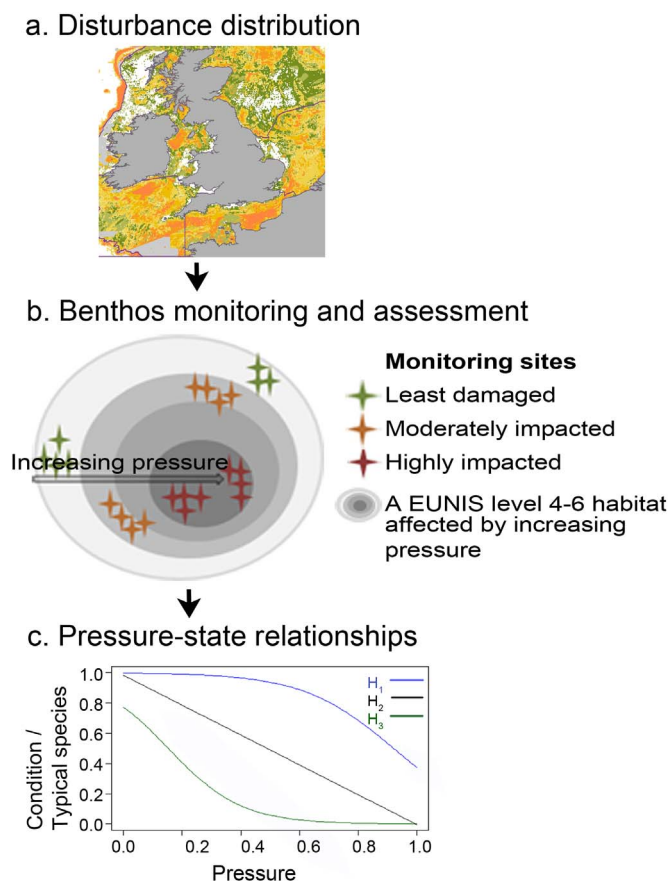
Where  $D$  is the disturbance score,  $b$  is sensitivity,  $a$  is pressure and  $\bar{b}$  is the average of the sensitivity categories.

The area of benthic habitat lost (BH4) can also be calculated from modelled benthic habitat sensitivity maps (Fig. 2c) and disturbance maps (Fig. 2e). From the disturbance map, the extent of disturbance is calculated for each assessed benthic habitat and pressure type of the pre-defined assessment area (e.g. sub-regional sea). Refer to [31,32] for more information.

### 3.4. Measuring along a gradient of pressure

Benthic habitat disturbance maps (Fig. 3a) from BH3 can facilitate monitoring and assessment programs (Fig. 3b) carried out within BH1 and BH2 by identifying areas with variations of pressure intensities. To





**Fig. 3.** Steps required to understand pressure-state relationships. Disturbance distribution data (a) help identify sampling stations for monitoring and assessment (b). Sampling within the same habitat benthic community or typical species composition, along a gradient of pressures helps understand its condition (c). Graph c. represents hypothetical pressure-state relationship of a particular condition state indicator from an increasing pressure type.  $H_1$  to  $H_3$  refers to the hypothetical responses a benthic habitat community or typical species might have with increasing pressure.

Adapted from [33].

assess benthos condition by the related state indicators (e.g. BH1 and BH2), benthos data is collected along a gradient of anthropogenic pressure at a site scale from highly impacted to pristine reference areas, or in the absence of, least damaged areas (Fig. 3b) [33]. The condition of the benthic habitats and its communities are assessed by exploring changes with increasing pressure (Fig. 3c). BH5, size frequency distribution of bivalves or other indicator species, could equally be used by exploring changes in their values along a gradient of pressure within a particular site.

To determine what species are considered typical for BH1, a combination of measures (e.g. frequency of occurrence and SIMilarity PERcentages of least impacted areas [34], and sensitive species based on biological traits analysis [4,35], or on pollution sensitivity groups [36,37]) can be used. For BH2, sampling is undertaken at EUNIS level 4–6 (biological community level). The latter enables the effect from environmental variation to be minimised since EUNIS level 4–6 habitats take into account a range of environmental and biological variables upon classification [23].

In areas of minimal gradients of pressure, environmental data should be included in the model to distinguish the difference between natural disturbance and pressure [33,38]. For areas with high natural variation, more sensitive condition measures may be required (e.g. by using a broader set of typical species for BH1, and MMIs based on Shannon-Wiener for BH2) [39–41]. Specific spatial scales used to assess pressure-state changes will be dependent on the benthic community or typical species extent, and the extent of the pressure exerted on the

benthic habitat. Within Fig. 3c, the curves reflect hypothetical responses of a benthic community or typical species composition to increasing anthropogenic pressure [33]. Non-linear and linear relationships with increasing pressure may also be observed [16,40,42]. Samhuri et al. (2010) [43], describe different pressure-state responses which are likely to be observed.

### 3.5. The feedback loop

Using the quantitatively derived pressure-state changes (Fig. 3c), it will be possible to determine thresholds at which a specific benthic habitat type deteriorates with increasing pressure (Fig. 4j). The threshold will be possible to identify by examining the point at which the derivative of the pressure-state relationship is observed to significantly shift [40,43]. The quantitatively derived thresholds (Fig. 4j) can then feedback and refine the modelled benthic habitat maps and best available evidence sensitivity assessments (Fig. 4d–f). The thresholds can then update the disturbance calculations (Fig. 4g–h.), increasing the confidence in disturbance values estimated.

## 4. Discussion

With a growing human population causing greater pressures on our marine ecosystems, managing human activities is imperative for the goods and services humans depend upon [44,45]. To date, a transparent, holistic method to assess the state of the marine environment under the MSFD has not been achieved. The proposed method is a first step towards integrating indicators. The method improves upon expert judgement and helps provide advice on management measures from quantitatively derived baselines and thresholds.

The method links different benthic indicators together cohesively so that the methods and results from the individual indicators can inform and influence one another, allowing feedback between indicators and thus avoiding loss of information. This enables transparency of indicator analyses throughout integration. Double counting is avoided since the indicators methods have been used to feed into one another rather than duplicating assessment. The approach also allows flexibility so that appropriate indices for BH1 and BH2 are selected according to the stressor type and area of assessment, as advised by Rice et al. (2012) [5].

Advantages of using MMI tools is that they provide a single value for a potentially large area which policy makers and managers can act upon [13,41]. This method draws from the processes of the different benthic indicators to evaluate the state of the benthic habitats and its communities within a particular region. Problems with varying spatial scales, which can make it difficult to quantify the effects of pressure on the marine environment [30,46,47] are minimised since the indicators are analysed on a site scale of relevance to the area of the benthic habitat and pressure type [25].

One of the major problems with assessing baselines with which to evaluate ecosystem components against, is the lack of information that exists on pristine reference areas as a result of centuries of anthropogenic pressure [11,19]. Gradients of anthropogenic pressures are increasingly used to investigate pressure-state relationships in the absence of such pristine reference areas (e.g. [25,33,48]). With the growing information on anthropogenic pressures and improved statistical methods to analyse their effects, the spatial resolution to analyse pressures has dramatically improved, facilitating the detection of such pressure gradients (e.g. [49]). It can be difficult to distinguish pressure gradients from environmental variability. However including environmental variables in statistical models can help [33,50]. The use of flexible spatial scales (according to the size of the benthic habitat and extent of the pressure), can also facilitate the identification of gradients in pressure [25,33]. More sensitive measures to assess pressure-state relationships can equally be used [41,51].

When identifying pressure gradients, the potential of shifting

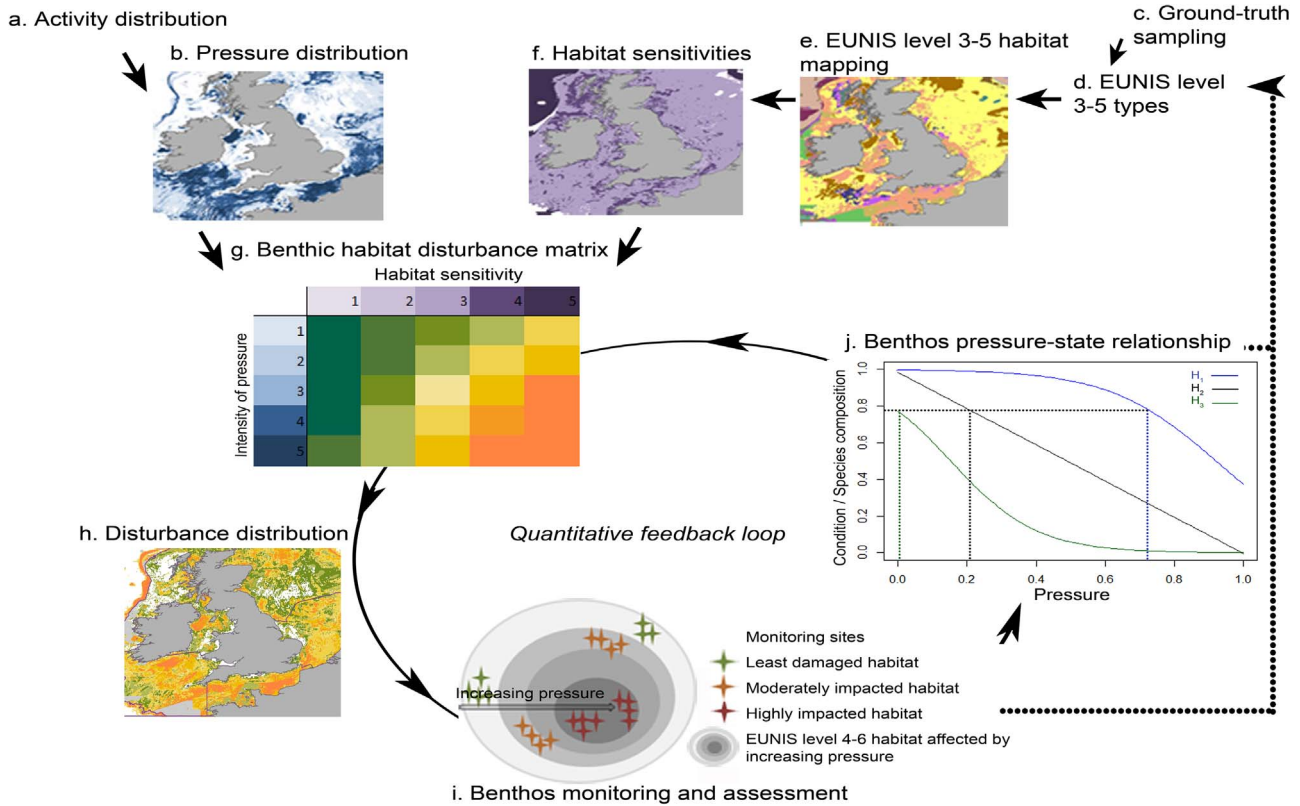


Fig. 4. Overarching conceptual approach for an integrated assessment of benthic habitat indicators at a sub-regional scale, bringing together Figs. 1–3, to highlight the feedback of information gathered across indicator assessment and to provide increased confidence in benthic indicator assessment.

baselines where least damaged sites are considered as reference areas can occur [52,53]. Borja et al. (2012), review a number of approaches which can be used to set a reference condition (e.g. use of percentiles as extreme values, modelling techniques, use of historical data etc.), each has advantages and disadvantages [12]. With time (depending on the benthic habitat type), fully protected Marine Protected Areas (MPAs) could be used as a proxy for reference areas [52]. Adequate management and monitoring would need to be implemented to ensure no damaging activities occurred within the MPA and to track potential recovery [25,33,52]. However, at present, due to the lack of reference areas and adequate monitoring, long-term recovery of benthic habitats is not well understood [18,54].

An additional benefit of analysing the effects of individual pressures along a gradient is that quantitative baselines can be identified to inform management measures for the area in question. Such quantitatively derived management measures would thus avoid expert judgement which is currently used to assess benthos sensitivity to pressures [13,24,28]. Analysing benthic indicators along a gradient was initially selected by the European Commission [5]. Josefson et al. (2009) successfully used pollution pressure gradients to identify thresholds and assess faunal structure in western Scandinavia, under the WFD [40]. Similar work has also been undertaken by ICES (2016) whereby gradients of fishing intensity were used to assess the state of benthic habitats [48].

The current method of OSPAR benthic indicator assessment largely relies on expert judgement given the lack of information on the distribution of benthic habitats and their sensitivity to pressure [24,28]. The cyclical approach developed here, enables new ground-truth data and quantitative results from pressure-state relationships to feedback and inform individual indicator assessments. The process here also facilitates more efficient use of monitoring requirements by collecting data for several indicators as opposed to independent methods for each indicator. The proposed method could equally help inform assessment

and monitoring requirements for the Habitat Directive (92/43/EEC), WFD, and MSFD, given each Directive requires wide scale monitoring and quantitative assessment to identify thresholds. Depending on benthic habitat and pressure types to be assessed, similar and co-ordinated monitoring could be implemented to inform each of the Directives specific assessments [33].

#### 4.1. Developing the integrated approach

To improve the process, links with other descriptors could be included such as with descriptor 4 (food webs) and descriptor 3 (commercial fish and shellfish), where many other species (demersal fish, cephalopods, birds, etc.) depend on benthic species for food resources and refuge [55–57]. Arroyo et al. (2016) linked deteriorations in benthic habitat quality from increased anthropogenic pressure to changes in trophic levels of demersal communities [57]. Links with descriptor 3 (commercial species) could also be incorporated by linking changes in benthic habitat quality from increasing anthropogenic pressures to commercially important demersal fish habitats [56,58].

In some ecosystems, other pressures than fishing have a key role in benthic structure and function. For example, in intertidal and infralittoral benthic communities, the structure and composition of species are affected by eutrophication (e.g. [59,60]) and chemical pollution (e.g. [61]). This integrated approach could therefore be expanded to allow the assessment of impacts relating to descriptors 5 (Eutrophication) and 8 (Contaminants). To assess the effect of eutrophication or contaminant pressure gradients (e.g. nutrient enrichment, contamination, etc.), descriptor 5 and 8 benthic state related indicators would need to be used (e.g. [15,40,62]).

The effects of cumulative anthropogenic pressures on benthic habitats should equally be explored given cumulative pressures are commonly found within the marine environment [16–18]. Analysing cumulative pressures along a gradient could, however lead to

difficulties in distinguishing the effects of individual anthropogenic pressure types on benthic habitat and therefore difficulty in setting management measures [63]. Understanding cumulative effects are important given cumulative impacts can affect the marine environment in different ways (e.g. cumulative, accumulative, additive etc.) [16]. Various studies have forwarded the understanding of cumulative impacts (e.g. [16–18]). However, quantitative methods to integrate the different indicators in areas where cumulative pressures exist have not yet been developed [19].

## 5. Conclusion

The proposed method outlined here is a first step towards integrating benthic indicators in a transparent quantitative manner to inform management measures. Analyses of the individual indicators have been undertaken within the OSPAR regional seas area. Future work should focus on identifying established datasets to test the integrative approach and incorporate indicators from other descriptors. This methodology could further be trialled and adapted to other regional seas such as the Mediterranean and the Baltic Sea, supporting cross-region coherence and an ecosystem-based assessment of benthic habitats at European scale.

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## Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at <http://dx.doi.org/10.1016/j.marpol.2018.01.003>.

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