EU request to advise on methods for assessing adverse effects on seabed habitats

Advice summary

ICES advises on the suitability and shortcomings of different indicators and indicator methods for assessments of adverse effects on seabed habitats. The indicators are specifically evaluated for MSFD D6C3 and D6C5 assessments of (sub)regions and broad habitat types (BHTs). Performance is evaluated in gradient studies or relative performance ranking. Suitability is evaluated in terms of associated habitat properties, output type and scale, and potential use for setting ecologically-meaningful and quantitative thresholds.

Regional assessments would ultimately best be carried out by applying different indicators in a complementary manner. Systematic screening of indicators that cover different aspects of seabed habitat condition and benthic community properties may improve change detection as well as accuracy and confidence in assessments of human pressures. State-based and pressure-based assessment methods would be best implemented simultaneously, sequentially and/or iteratively to maximize operationality across regional, national, and local scales.

ICES was unable to estimate and advise on robust quality threshold values. Appropriate thresholds for seabed habitat need to be relevant to the management aims (achieving GES), informed by ecological principles, and be ecologically meaningful, habitat-specific, and preferably derived from the objective analysis of ecological data, with uncertainty estimation.

ICES advises on the main components of a framework and a stepwise approach to evaluating methods that assess the state of seabed habitats and the effects of human pressures.

Current sampling effort and design is unlikely to provide an empirically-based, representative picture of seabed habitat status (state-based indicators) at the whole regional scale required for MSFD/D6 assessments. Guidance should be developed for strategic sampling that will facilitate data standardization between countries and ensure ground-truthing of analytical assessment outcomes (from pressure-based methods) in areas of extrapolations with high uncertainty.

Request

DG ENV requests ICES to advise on methods to assess adverse effects on seabed habitats. In particular, the advice should include:

- *i)* *A detailed review of indicators used, or under development, by Regional Sea Conventions, Member States and ICES, for assessing the state/condition of seabed habitats suitable for MSFD assessments. The indicators considered can also include peer-reviewed indicators which have large-scale application.*
- *ii)* *Advise, using a set of agreed criteria, on a common framework to evaluate methods to assess benthic risk (model) and state (data) indicators, with respective threshold values [could be clearer].*
- *iii)* *A targeted benthic data call (via TG Seabed), in order for ICES to evaluate the performance of selected (reviewed) benthic risk and state indicators, in relation to their ability to assess the state/condition of seabed habitats and adverse effects from specified pressures.*
- *iv)* *Advice on threshold values to assess the quality of seabed habitats.*
- *v)* *Advice on the suitability and shortcomings of both risk and state indicators for MSFD assessment purposes at national and regional scales.*

Elaboration on the advice

Suitability and shortcomings of selected indicator methods

The suitability and applicability of seabed habitat quality indicators and indicator assessment methods currently operational in EU waters are summarized in Table 1. ICES notes that several indicators are currently specific to certain BHTs and/or (sub)regions and remain to be tested and validated for application at MSFD-scale. However, in the short term, high levels of regional coverage will only be achieved with pressure-based indicators. Limitations in terms of applicability of the state-based indicators are in most cases related to data availability, as opposed to the indicator methods themselves.

In the short term, high levels of regional coverage will only be achieved with pressure-based indicators. Most pressure-based indicator methods that provide good coverage of BHTs are mainly associated with physical abrasion from bottom trawling. ICES previously advised that the development of indicators that respond to other types of pressures (in addition to trawling abrasion) will more effectively support assessment of D6 (ICES, 2019), the limitation at present being the broad-scale availability of robust pressure gradients datasets.

ICES advises that no single indicator or assessment method detected changes in response to all human pressures and/or showed a similar response across regions. Ultimately the assessment of D6 would best be carried out using a set of complementary indicators, each associated with specific biological and ecological habitat properties. Systematic screening of multiple indicators will maximize accuracy and transparency in the assessment of seabed habitat changes in response to human pressures.

State-based and pressure-based assessment methods would best be applied in a complementary manner to inform regional-scale assessments. The former can be applied locally to detect changes in habitat condition and to ground-truth broad-scale predictions derived from pressure-based analytical models; the latter can be used to attribute changes in habitat state to specific pressures. Both types of methods can be implemented simultaneously, sequentially and/or iteratively to maximize operationality across regional, national and local scales and ensure that different aspects of seabed ecosystems are being monitored and different human pressures tracked in assessments of adverse effects.

Four state-based indicator groups showing clear patterns of association in response to pressure gradients can be used to inform the selection of an appropriate set of indicators covering different aspects of seabed habitat condition and benthic community properties for use in MSFD/BHT-scale assessments. Not all correlated indicator methods showed the same sensitivity to these pressure gradients.

Options for establishing quality thresholds

Quality thresholds are needed to distinguish habitats in GES from those that are adversely affected. ICES was unable to estimate and advise on robust quality threshold values. The scientific underpinning to establishing thresholds is under development, and guidance is provided on available methods for defining thresholds (ICES, 2022a).

Appropriate thresholds need to be relevant to the management aims (achieving GES) and informed by ecological principles. They must also be ecologically meaningful, habitat-specific, and preferably derived from the objective analysis of ecological data, with uncertainty estimation. To retain ecological meaning, threshold values need to be defined for each indicator.

ICES identifies five ecologically-motivated methods for setting quality thresholds. From these the ‘natural variation’ and ‘maintaining function’ approaches define an ecologically meaningful state and can be used to estimate thresholds quantitatively from data. Other methods relying on pressure–state relationships (tipping point, detectable change, and distance to degradation) need to be informed by a range of data from low to high-pressure conditions, and/or the availability of recovery time-series.

A ‘natural variation’ approach is a most promising, quantitative, objective, and repeatable method to define an ecologically meaningful state which can be used to establish thresholds. The method is not applicable to all indicators and requires long time-series from undisturbed or low-pressure locations. There is a pathway towards making this approach operational through the use of meta-analysis.

Table 1 Overview of currently operational indicator methods, including suitability, applicability, and performance as evaluated in gradient studies or relative performance ranking. Suitability is evaluated in terms of current BHT coverage, associated habitat properties, output type and scale, and potential use for setting ecologically-meaningful and quantitative thresholds. Indicator potential scale of applicability over the short term (< one year) is defined either as a percentage of EU ecoregions corresponding to currently applicable/covered BHTs, as specified national EEZ/subregion in the Mediterranean and Black Sea or distinguished as existing substantial scientific work (yes), could be easily estimated (yes[9]) or would need considerable work to estimate (no). All information was synthesized from ICES (2022a, 2022b, 2022c, 2022d).

Indicator method	Indicator	State (S) or pressure (P) basis	Current BHT coverage (within regions where method is available)	Output scale	Indicator potential scale of applicability in short term (1 year)						Main pressure	Performance in gradient studies	Relative performance in ranking	Habitat properties[10]	Continuous (C) or ordinal (O) outputs	Ability to derive ecologically meaningful and quantitative threshold
					North Sea	Baltic Sea	Celtic Seas	Bay of Bis. and Iberian Coast[1]	Med. Sea	Black Sea						
Pressure-based state (modelled/expert judgement)																
PD2	Biomass	P	Soft sediment BHTs excl. abyssal and, in some regions, bathyal sediments	Grid cell and habitat level	85–90	> 95	55–65[2]	5–15[3]	Greece (ISCM, LS), Italy (AS, ISCM)[4]	-	Fishing abrasion	n/a	Inconclusive	Size structure of species	C	Yes
L1	L1	P	Soft sediment BHTs excl. abyssal and, in some regions, bathyal sediments	Grid cell and habitat level	85–90	> 95	55–65[2]	5–15[3]	-	-	Fishing abrasion	n/a	Inconclusive	Absence of particularly sensitive or fragile species	C	Yes
BH3	BH3 distur-bance index	P	All BHTs	Grid cell and habitat level	> 95	0	> 95	> 95	-	-	Fishing abrasion	n/a	Inconclusive	Absence of particularly sensitive or fragile species	O	No
CumI	CumI	P	All BHTs	Grid cell and habitat level	0	100	0	0	-	-	Organic enrichment, pollution, fishing abrasion	n/a	Inconclusive	Absence of particularly sensitive or fragile species	O	No
Pressure-based state (pressure–state relationship from local data + statistical model)																
SoS	SoS	P + S	Soft-sediment BHTs excl. abyssal	Grid cell and habitat level	0	0	0	5–15[3]	Italy (AS)[5]	-	Fishing abrasion	Highly responsive	Inconclusive	Relative abundance of species, absence of particularly sensitive or fragile species	C	Yes

Indicator method	Indicator	State (S) or pressure (P) basis	Current BHT coverage (within regions where method is available)	Output scale	Indicator potential scale of applicability in short term (1 year)						Main pressure	Performance in gradient studies	Relative performance in ranking	Habitat properties[10]	Continuous (C) or ordinal (O) outputs	Ability to derive ecologically meaningful and quantitative threshold
					North Sea	Baltic Sea	Celtic Seas	Bay of Bis. and Iberian Coast[1]	Med. Sea	Black Sea						
TDIs	pTDI, TDI, mT,mT DI	P + S	Habitats assessed at EUNIS level 4[7]	Grid cell and habitat level	35–45[7]	0	0	0	France (WMS)[6]	-	Fishing abrasion	Non responsive	Not examined	Absence of particularly sensitive or fragile species	C	Yes
L2	Median longevity	P + S	Soft sediment BHTs excl. abyssal and bathyal sediments	Grid cell andhabitat level	85–90	0	0	0	-	-	Fishing abrasion	Responsive	Inconclusive	Absence of particularly sensitive or fragile species	C	Yes
State (+ upscaling to BHT)																
D_M'	D_M'	S	Soft-sediment BHTs excl. abyssal and bathyal sediments	Sampling locations and habitat level	75–85	0	0	0	-	-	Organic enrichment, pollution, fishing abrasion	Responsive	Inconclusive	Species compositio n	C	Yes
State (reflect change to specific pressure)																
BENTIX	BENTIX	S	Not upscaled to BHT	Sampling locations	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Yes	Yes	Organic enrichment, pollution	Non responsive	n/a	Absence of particularly sensitive or fragile species	C	Yes
DKI	DKI	S	Not upscaled to BHT	Sampling locations	Yes	Yes	Yes[9]	Yes[9]	Yes[9]	No	Organic enrichment, hypoxia	Non responsive	n/a	Species composition, relative abundance of species, absence of particularly sensitive or fragile species	C	Yes
M-AMBI	M-AMBI	S	Not upscaled to BHT	Sampling locations	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Organic enrichment, pollution, fishing abrasion	Responsive	n/a	Species composition, absence of particularly sensitive or fragile species	C	Yes
Long-lived fraction	Long-lived fraction	S	Not upscaled to BHT	Sampling locations	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Yes[9]	No	Fishing abrasion	Highly responsive	n/a	Absence of particularly sensitive or fragile species	C	Yes

Indicator method	Indicator	State (S) or pressure (P) basis	Current BHT coverage (within regions where method is available)	Output scale	Indicator potential scale of applicability in short term (1 year)						Main pressure	Performance in gradient studies	Relative performance in ranking	Habitat properties[10]	Continuous (C) or ordinal (O) outputs	Ability to derive ecologically meaningful and quantitative threshold
					North Sea	Baltic Sea	Celtic Seas	Bay of Bis. and Iberian Coast[1]	Med. Sea	Black Sea						
BQI	BQI	S	Not upscaled to BHT	Sampling locations	No	Yes	No	No	No	No	Organic enrichment, hypoxia, fishing abrasion	Not examined	n/a	Species composition, relative abundance of species, absence of particularly sensitive or fragile species	C	Yes
State (potentially responsive to the full range of pressures)																
Species richness	Species richness	S	Not upscaled to BHT	Sampling locations	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Not specified	Non responsive	n/a	Species compositio n	C	Yes
Biomass	Biomass	S	Not upscaled to BHT	Sampling locations	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Not specified	Highly responsive	n/a	General	C	Yes
Abun-dance	Abun-dance	S	Not upscaled to BHT	Sampling locations	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Not specified	Non responsive	n/a	General	C	Yes
Shanno n index	Shanno n index	S	Not upscaled to BHT	Sampling locations	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Not specified	Responsive	n/a	Species compositio n, relative abundance of species	C	Yes
Inverse Simpson	Inverse Simpson	S	Not upscaled to BHT	Sampling locations	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Yes[9]	Not specified	Responsive	n/a	Species compositio n, relative abundance of species	C	Yes

[1] Almost 70% of ecoregion is classified as abyssal sediment.
[2] Area specified is UK EEZ and Irish Sea.
[3] Soft sediments in northern Iberian region and parts of Bay of Biscay (excluding abyssal sediment; ICES, 2022a).
[4] Limited applicability below 100 m in the Mediterranean and Black Sea and for epifaunal data. ISCM = Ionian Sea and the Central Mediterranean Sea, AS = Adriatic Sea, LS = Aegean-Levantine Sea.
[5] AS = Adriatic Sea.
[6] WMS = Western Mediterranean Sea.
[7] A5.38, A5.39, A5.46, A5.47, A5.15, A5.25/26, A5.27, A5.37, A5.14.
[8] Southern North Sea and English Channel.
[9] State-based indicator values are available in all regions for at least some BHTs and/or coastal waterbodies (in this case, according to WFD national sampling schemes).
[10] Properties of benthic habitats referred to in Descriptor 6 of Commission Decision (EU) 2017/848 (EC, 2017). For some indicators, the most aligned habitat property remains open for further interpretation.

Common framework to evaluate assessment methods

ICES advises on the main components of a framework and a stepwise approach to evaluating methods to assess the state of seabed habitats and the effects of human pressures. The main components include two sets of criteria to evaluate the suitability of indicators and thresholds (tables A3 and A4 in annexes 3 and 4, respectively); a common dataset covering gradients of varying pressures intensity (from relatively undisturbed to adversely affected); and guidance as provided in this advice along with two workshop reports (ICES, 2022a, 2022c).

The following stepwise approach is proposed to evaluate methods:

1. selection of candidate indicators considering data availability, the scale of application, BHTs, pressures, and theoretical links to biotic structure and ecological function;
2. screening of selected indicators and associated threshold methods for their suitability for assessing GES under MSFD Descriptor 6 against established criteria (tables A3 and A4 in annexes 3 and 4);
3. empirical testing of the specificity, sensitivity and/or responsiveness of state-based indicators and indicator methods within and between BHTs over gradients of pressure intensity using a representative common dataset,
4. evaluation of pressure-based indicators and indicator methods by comparing sensitivity and impact rankings between BHTs and subdivision (or EEZ); and
5. application of guidance on the determination of threshold values (ICES, 2022a).

Suggestions

ICES suggests that the gradient study dataset (common dataset) be developed further and used to test the performance of newly developed indicators. Outcomes from pressure-based indicator methods should be continued to be compared, especially where they overlap within a region, to determine whether these assessments currently find the same BHTs most at risk from human pressures.

In addition to quality and extent, connectivity is another important property for determining GES and recovery of seabed habitats. Where indicators for the spatial coherence, configuration, and/or connectivity of habitat patches of good quality exist, thresholds for what can be considered good should be investigated and developed in future. Hydrodynamic and biophysical models can inform connectivity metric estimation among habitat patches within a region and/or habitat networks. The definition of connectivity quality criteria will need to consider source-sink and metapopulation dynamics, demographic theory based on life-history traits for sensitive species, and the role of habitat fragmentation for maintaining benthic ecosystem functions between viable subpopulations.

ICES suggests developing and applying indicators linked to functional habitat properties, especially those to inform the absence of species providing a key function. Biological traits may be used to strengthen the links between existing indicators and function.

The sensitivity of assessment outcomes to a range of threshold values should be evaluated to better inform the definition of quality, extent, and configuration thresholds for MSFD assessment purposes.

Basis of the advice

Background

Many assessment methods are used to generate the indicators catalogued in an ICES Technical Service (ICES, 2022b). Scales of applications of the methods range from EU-wide to regional and local/subregional. The assessment methods can broadly be classified into two different types distinguished by the data used to calculate the indicator at the point of implementation (Figure 1).

The first type of assessment methods are based on sampling data and generate **state-based indicators**. The benthic state in a defined area is evaluated using empirical observations, typically long-term monitoring data. These sample-derived methods vary in their assumptions, structures, and processing, and the resulting indicators focus on different components/properties of the benthic community and ecosystem (Table 1). Sample-derived methods and state-based indicators may further include measures of species sensitivities to specific pressures allowing for more specific pressure–impact evaluation.

The second type of assessment methods generate **pressure-based indicators**. These methods predict benthic state from pressure and community/habitat sensitivity information. They are either built on expert judgement and sensitivity/pressure overlap calculations, which produce ordinal outputs – or on mechanistic models or statistical predictions of pressure–state relationships, which produce continuous quantitative outputs (with or without uncertainty). Such pressure-derived assessments are often applicable to large geographic areas, and the model-based approach can be used to predict the impact to unsampled areas at various spatial scales, depending on input data resolution. This is achievable because data on pressure is often more readily available and has greater geographic coverage than data on benthic fauna. Most pressure-based assessments estimate a single indicator; however, some can estimate multiple indicators within the same model. Note that previous ICES advice (ICES, 2017) focused on the definition of pressure indicators in relation to bottom-contact fishing footprint.

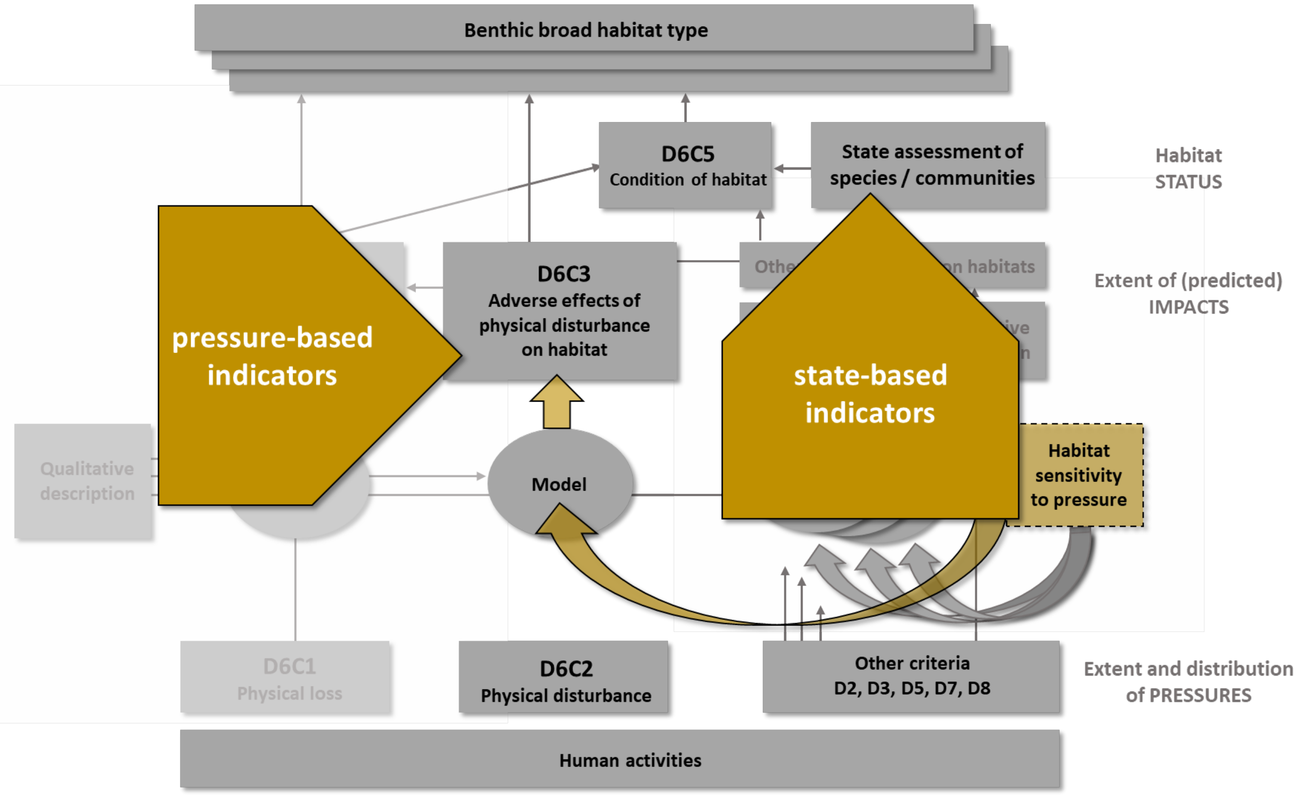

Figure 1 Diagram adapted from Figure 5.7-1 of the European Commission's Article 8 MSFD Assessment Guidance (EC, 2022), showing where pressure-based and state-based indicators are currently most suitable for assessing MSFD Descriptor 6. The diagram onto which indicators are overlain shows the levels and methods of integration for benthic habitats and seabed integrity under D1 and D6, as agreed by EU's TG Seabed. Details on currently operational pressure-based and state-based indicators are provided in Table 1.

Results and conclusions

Suitability and shortcomings of selected indicator methods

Characteristics of the benthic habitat quality indicators considered in performance evaluation are summarized in Annex 4 in ICES (2022c). A summary of the main elements emerging from the comparative assessment of indicator methods is provided in tables 1 and A1 of this advice.

Pressure-based indicators that produce ordinal or continuous quantitative outputs are in a state of readiness that provides 95% or more of the area covered by all BHTs in some of the example regions (Table 1). Relatively high coverage of the

North Sea can be achieved with two pressure-based indicators that rely on local data and statistical models, or one state-based indicator; such coverage, however, is not achievable in the short term in other example regions. The pressure-based assessment methods that provide wide regional coverage are largely applicable to soft-sediment BHTs. They are not yet widely tested for application to rock or biogenic reef BHTs or, in most cases, to abyssal or bathyal BHTs. The proportional extent of these habitat types in some regions partly explains differences in the overall coverage for pressure-based indicators (e.g. in the Bay of Biscay and Iberian Coast ecoregion, abyssal BHTs account for approximately 70% of the total region).

Fishing abrasion is the predominant physical pressure on benthic habitats in EU ecoregions (ICES, 2019). Mean response to trawling across all trawl gradients showed that most indicators declined at high trawl intensity relative to low trawl intensity (ICES, 2022c). This decline was significant in some state-based indicators, including biomass, richness, fraction long-lived, median longevity, SoS, D_M', Shannon Index, and Inverse Simpson. Indicators developed using selected sensitivity traits to trawling disturbance (SoS and fraction long-lived) showed a stronger response to increasing trawling pressure, together with biomass. The TDI indicators showed limited or no response to trawling. No state-based indicators showed a consistent response within all individual locations/trawl gradients. Not all indicators could be estimated for all studies due to missing biomass data and/or information on species' sensitivity classification.

Four groups of state-based indicators showed clear patterns of association in their response to pressure gradients: 1) indicators with a diversity component or based on diversity measurements; 2) the TDI indicators; 3) indicators based on the most sensitive or longer-lived species; and 4) the AMBI and BENTIX indicators (ICES, 2022c). Such groups were consistent when considering all locations/datasets vs. only datasets where all indicators could be estimated.

Comparisons of ranked scores for indicators estimated using pressure-based assessment methods showed differences in sensitivity outputs and some consistency in impact outputs among BHTs in the areas considered. In the North Iberian Atlantic and the North Sea SoS, PD2, L1 and BH3 all identified 'offshore circalittoral mud' as the broad habitat type most impacted by physical abrasion pressure. Different outcomes reflect differences in method design, measured components, and data availability and resolution in each region.

Options for establishing thresholds

The scoring of selected methods and approaches for setting thresholds against a revised set of criteria for threshold suitability for MSFD assessment purposes resulted in a clear separation of favoured and less-favoured methods (ICES, 2022a). Preferred methods identified an ecological transition from a good to a degraded state, estimated thresholds quantitatively with uncertainty, and were able to define habitat- (and region-) specific thresholds.

Quality thresholds define at what value (or range of values) of an indicator the local quality can be considered 'good'. Extent thresholds define what fraction of the area of a benthic habitat needs to be achieving the quality threshold for the entire habitat to be considered in GES.

Among the methods examined for setting extent thresholds (Figure A2, Annex 2), the 'avoid collapse' and 'trade-off' approaches were identified as promising. The 'avoid collapse' method defines a minimal extent needed to maintain full reproductive potential of benthic species. Operationalizing this approach would require estimating the relationship between population size and recruitment for the type of species that occur in a BHT, which can be challenging especially in deep-water habitats/communities where recruitment processes are poorly known. The 'trade-off' approach is a spatial management tool aimed at achieving a balance between habitat quality and socio-economic benefits from human activities. This approach can be used to explore extent thresholds from both societal and bioecological viewpoints. ICES explored the consequences of a range of areal extent thresholds in previous advice (ICES, 2021).

A worked example of how quality and extent thresholds can be estimated and combined to evaluate GES of seabed habitats is provided in ICES (2022a) This example uses the 'natural variation' and 'avoid collapse' methods to calculate a quality and extent threshold, respectively, for the PD2 indicator. Beyond this worked example, ICES was unable to estimate quality thresholds at this time.

Methods

The methods used in the generation of this advice are detailed in ICES (2022a) and ICES (2022c). Approximately 600 indicators were considered and information was compiled on the most current operational indicators (ICES, 2022b). Two sets of criteria were revised and adapted in order to evaluate the suitability of indicators and thresholds, respectively, for MSFD assessment purposes. Both sets of criteria are included in tables A3 and A4 in annexes 3 and 4 of this advice.

For performance evaluation, 17 benthic datasets were compiled to evaluate the specificity, sensitivity, and/or responsiveness of different indicator methods to a range of pressure gradients. These included 14 datasets over gradients of commercial bottom-trawling intensity, two over gradients of eutrophication, and one over a pollution gradient. Each dataset consisted of data on abundance and biomass per benthic species, from which state-based indicator values were estimated. The combined dataset covered a range of locations with variations in seabed depth and sediment type. The datasets were used to evaluate change and complementarity in benthic indicator values along the different pressure gradients and to determine which indicators are most responsive to the relevant disturbance.

Details of the methods used for setting thresholds are described in the worked examples contained in ICES (2022a) and ICES (2022c).

Sources of uncertainty and limitations

ICES recognizes that there is a high degree of uncertainty in the available data. Annual benthic sampling across the EU is sporadic – lacking spatial and temporal coverage – and may be difficult to standardize between countries with respect to taxonomic resolution and accuracy as well as sampling design and methods. State-based assessments will come with higher uncertainty in data-limited regions and in areas of model extrapolation (areas of prediction outside the range of the data).

About half of the indicator methods considered were developed for a specific region, and their methodology had to be adjusted for application to other geographic areas. This created limitations and uncertainty in the testing of indicator performance.

Properties of benthic habitats referred to in Descriptor 6 Criterion C3 (D6C3) of Commission Decision (EU) 2017/848 (EC, 2017) include ‘species composition’, ‘relative abundance’ of species, ‘absence of particularly sensitive or fragile species’, absence of ‘species providing a key function’ and ‘size structure of species’. An important gap associated with this advice is the paucity of indicators for habitat properties other than ‘absence of particularly sensitive or fragile species’ and the fact that none of the indicators examined was specifically linked to ‘species providing a key function”.

The gradient datasets covered a substantial range of regions, habitats, and depth zones, yet most studies were taken from relatively shallow and sandy habitats in the Greater North Sea. Future work on gradient studies could be extended to other areas to expand both the range of habitats and the depth coverage.

The comparative analysis of multiple indicators can result in differences in community composition that seem to be related to the assessed pressure, while in fact, the pressure gradient varies with environmental conditions and/or targets specific areas with a particular community composition. This may produce confounding effects, where the apparent effect of the human pressure is masked or amplified by underlying environmental gradients.

Additional information

This advice only applies to broad habitat types (BHTs) that are listed in Table 2 of Commission Decision (EU) 2017/848 (EC 2017); other habitat types (OHTs) have not been considered. The Decision says that OHTs may be selected by Member States, through regional or subregional cooperation, and also include additional habitat types – according to the criteria laid down under ‘specifications for the selection of species and habitats’ – and which may include habitat types listed under Directive 92/43/EEC or international agreements such as Regional Sea Conventions.

The common dataset developed in support of this advice and used to examine indicator performance along pressure gradients is available upon request by contacting ICES Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT).

The pressure-based outputs of PD2 and L1 are available via https://github.com/ices-eg/WKTRADE3. Other pressure-based outputs will need to be requested from the data providers (e.g. OSPAR and HELCOM).

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Annex 1

Table A1 Suitability and shortcomings of benthic indicator methods evaluated by ICES, grouped by link to EU Commission Decision 2017/848 Descriptor 6 (seabed integrity).

Predominantly link to 2017/848 Descriptor 6: D6C5		
Habitat quality indicator: condition of benthic habitats		
Indicator method	Suitability	Shortcomings
Multivariate AZTI Marine Biotic Index (M-AMBI)	- able to disentangle community changes resulting from variation along environmental gradients from those resulting from human disturbance - evidence of successful applications to coastal waters and gradients of organic enrichment and oxygen depletion.	- applications to date are restricted to infauna and grab samples - needs to be evaluated for other bathymetric zones (offshore), habitat types and pressures - responds to eutrophication and pollution gradient rather than trawling - ICES meta-analysis output showed no significant effect of trawling on the mean response - depth-specific and/or habitat-specific reference conditions and thresholds should be further tested and evaluated
Danish Quality Index (DKI)	- developed for use in poly- to euhaline benthic environments characterized by relatively high species diversity, further developed to fit low salinity and low diversity environments - developed to measure benthic macrofauna 'quality', in response to any disturbance gradient	- complicated computation which requires normalization - restricted to grab samples (soft bottom habitats) and assessment of whole waterbodies - response to pressure and/or management actions is slow - describes the overall status of an area but not proportion of a specific habitat type - ICES meta-analysis output showed no significant effect of trawling on the mean response
Relative Margalef Diversity (D_M') (OSPAR BH2b)	- widely used for a variety of human activities (bottom trawling, organic enrichment, inorganic pollutants) - sufficiently sensitive to distinguish quality differences for a range of pressure levels - assessment results are easy to communicate in terms of diversity	- high taxonomic expertise required - confidence in assessment results depends on the reliability of distinguishing no- or low-pressure areas to estimate reference levels - indicator responds to any type of pressure and does not specifically indicate the type of pressure at stake - reliability of scaling and aggregation of results highly dependent on representativity of monitoring
BENTIX	- tested along a gradient of organic enrichment and the long-term trends of decline or recovery of the community health in response to dumping - Successfully applied for the classification of ecological quality of coastal waters in the Eastern Mediterranean over a wide variety of habitat types against various pressures	- high taxonomic expertise is required - still to be tested in offshore bathymetric zones; depth-specific or habitat-specific reference conditions and thresholds should be tested and evaluated - did not show a significant mean reduction in response to trawling in ICES meta-analyses - mostly adequated for Mediterranean waters - organic enrichment is currently the only pressure assessed

Predominantly link to 2017/848 Descriptor 6: D6C3		
Habitat quality indicator: impact of physical disturbance on benthic habitats		
Indicator method	Suitability	Shortcomings
Population Dynamic 2 (PD2)	- strong rooting in general concepts of population dynamics and the fact that it is a single indicator summarizing impact across the entire benthic community - the biomass component of the PD2 method is a proxy for ecosystem (functioning) processes; for example, nutrient cycling or energy flow through foodwebs - uncertainty estimates can be generated	- approach requires estimates of the longevity of all species in a community which is not known for many deep-living species - the current implementation assumes an equilibrium between benthic state and trawling (benthos is adapted to certain level to a certain continuous trawling frequency), but when large changes in trawling pressures occur this may not be accurate. Dynamic implementation of the logistic model may be more appropriate in that case - mainly relevant to trawling impacts (has been used to map impacts of hypoxia in the Baltic Sea) - requires macrobenthic biomass data/longevity from undisturbed areas (which can be hard to find for all BHTs) - still to be tested for use/extrapolation to other regional seas
Sentinels of the Seabed (SoS; OSPAR BH1) Fraction of sensitive species	- potentially applicable with regards to any type of disturbance (physical or chemical), and then highly specific for the type of disturbance - highly sensitive in distinguishing reduced quality from good (reference) quality situations in the relative low-pressure range (i.e. by use of most sensitive species) - could be used as an early warning to detect a decrease in the most sensitive species	- definition of sensitive species may leave room for different interpretations - need for reference (no- or low-pressure) areas and known (single) pressure gradients to identify sentinel species - sentinel species are not necessarily indicative to distinguish quality changes under poor quality conditions (sensitive species might be absent)
Trawling Disturbance Index (TDIs: TDI, mTDI and pTDI)	- empirically-based state indicator, strong link between species traits and trawling/abrasion pressure - particularly applicable to benthic epi-/megafauna of the soft-bottoms - epi-/megafauna dataset already available for large parts of the continental shelves at European scale (e.g. based on the IBTS fisheries surveys network)	- definition of some traits (e.g. ‘fragility’) may leave room for different interpretations - ‘feeding mode’ trait is not directly selected by the gear and is a correlated trait - variability of disturbance at intermediate levels of trawling was less evident - log- relationships between sensitivity groups are scientifically unfounded - mT indicator introduces criteria (protection status) independent of trawling pressure, which makes it less specific to the pressure and difficult to interpret - ICES meta-analysis showed no significant mean reduction in response to trawling and conflicting results within case studies - trawling Intensity is the only pressure assessed

Reduction in median community longevity (L2) and fraction of long-lived species.	- current applications utilize benthic data from boxcore and grab samples to estimate the effects of trawling on longevity biomass composition - relationship between trawling intensity and longevity distribution allow for changes in the indicator values over time, regional and broad-scale habitat scales - uncertainty in habitat-specific biomass longevity relationship confidence intervals are estimated on model prediction of fixed effects	- determination of longevity may leave room for different interpretations - data demanding if benthos sampling is not within the range of habitat variables included within model variables - trawling intensity is the only pressure assessed - statistical method; with reduced statistical power due to mismatch of trawling and benthos temporal sampling range - indicator shows a wide variation across grid cells trawled that reflect the variation in bed shear stress
Fraction of community biomass that is affected by trawling during its lifespan (L1)	- can be implemented in all areas with PD and/or L2 information	- outcome is theoretical value and cannot be evaluated with empirical data - no mechanistic relationship between pressure and impact - trawling intensity is the only pressure assessed
Pressure-based approaches linking predominantly to 2017/848 Descriptor 6: D6C3		
Habitat quality indicator: impact of physical disturbance on benthic habitats		
Indicator method	Suitability	Shortcomings
Cumulative Impact from physical pressures on benthic biotopes (CumI)	- applicable to all major and relevant physical pressure gradients - method uses (partly) pressure-specific sensitivities - method uses exact extent of pressures when known and not only approximations with rasters/grids - evaluates both intensity and frequency of pressures when data are available - works in both data-rich and data-limited areas - method identifies (functional) loss as a consequence of multiple cumulative pressures	- high computational demands due to the use of vector data (polygons) - sensitivity values are summarizing a community while the actual sensitivity is species-based - definition of some sensitivity may leave room for different interpretations - difficult to aggregate the ordinal output scale with other indicators expressed on a continuous quantitative scale. - outcome is theoretical value and cannot be evaluated with empirical data
Extent of physical disturbance to benthic habitats (BH3)	- BH3 can calculate disturbance at a range of spatial resolutions - BH3 can be particularly useful for assessing large sea areas where currently only limited data are available - BH3 currently assesses physical disturbance from bottom-contact fishing and aggregate extraction but can be adapted to new human activities where data are available	- habitat damage and modification, which took place before the period 2010–2015 are not explicitly considered - assessments influenced by the availability and resolution of input data: pressure data (e.g. VMS C-squares); sensitivity information and habitat map resolution - assessments can be process and data-heavy, requiring high levels of computing power when running analyses at the scale of the Northeast Atlantic (e.g. due to complexity of detailed habitat maps) - difficult to aggregate the ordinal scale with other indicators which are using a continuous quantitative scale - outcome is theoretical value and cannot be evaluated with empirical data

Annex 2

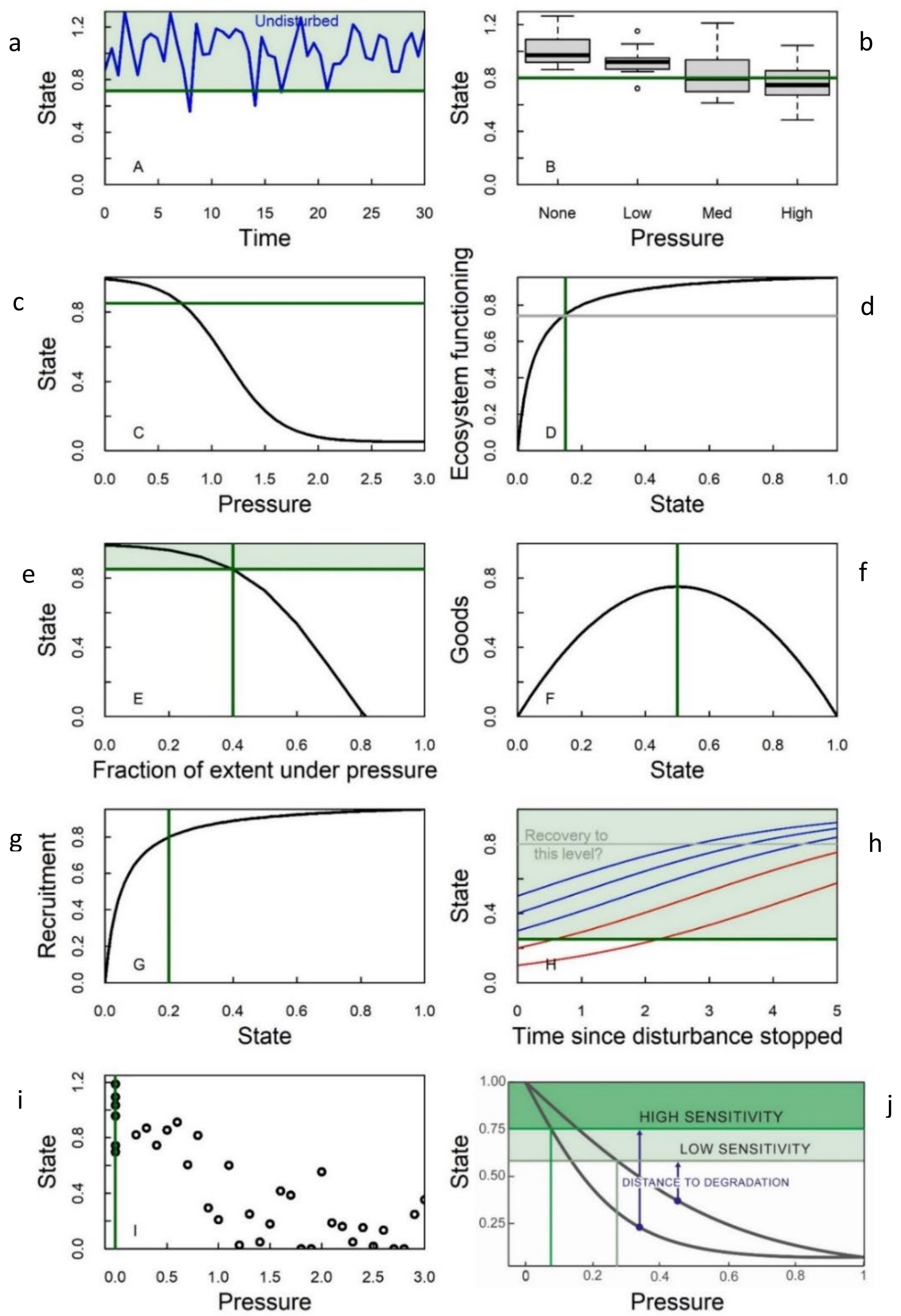

Figure A2 Illustrative examples of methods and approaches considered by ICES to derive thresholds. In each panel, the solid green line indicates a threshold between a good and a degraded state, and the green polygon indicates a possible GES region (where present). Grey lines indicate other reference values used to derive the threshold. Panel a) natural variation: good state is within the range of pressure-free variation; b) detectable change: good state is at or above the level that is statistically detectable from the baseline; c) tipping point: breakpoint in statistical relationship between state and pressure; d) maintain function: state that maintains ecosystem function at levels without pressure; e) trade-off: point at which the increase in conservation benefits decreases relative to the delivery of goods; f) maximizing goods: state that maximizes the number of goods from a human use perspective; g) avoid collapse: state that maintains reproductive output; h) recovery possible: state that would allow recovery within a specified time once the pressure is removed; i) zero pressure: any level of pressure results in a degraded state; and j) distance to degradation. State where the slope is 45 degrees plus a fraction of the distance to 1 depending on habitat sensitivity. See ICES (2022a) for additional details and information on each method.

Annex 3

Table A3 Criteria and guidance for evaluating indicators. Revised based on work carried out by the ICES Working Group on the Ecosystem Effects of Fishing Activities (WGECO; ICES, 2012) and used by the Working Group on the Ecosystem Effects of Fishing Activities (WGBIODIV; ICES, 2013) to evaluate the performance of indicators to support implementation of the MSFD at subregional and regional scale. The 16 criteria are grouped into five main categories, and the principle characteristic of each indicator's performance examined by each criterion is given. Further information is available in ICES (2022a).

Criterion no.	Category	Characteristic	Criterion
1	Type of indicator	State- or pressure-based	Is the indicator a pressure-based indicator or an appropriate state-based indicator?
2	Quality of underlying data	Existing and ongoing data	Indicators must be supported by current or planned monitoring programmes that provide the data necessary to derive the indicator. Ideal monitoring programmes should have a time-series capable of supporting baselines and reference point settings. Data should be collected on multiple sequential occasions using consistent protocols, which account for spatial and temporal heterogeneity.
3	Quality of underlying data	Indicators should be concrete	Indicators should ideally be easily and accurately determined using technically feasible and quality-assured methods and have high signal-to-noise ratio, i.e. there is little variance in the calculation of the indicator, either from natural variability or sampling variability.
4	Quality of underlying data	Quantitative vs. qualitative	Quantitative measurements are preferred over qualitative, categorical measurements, which in turn are preferred over expert opinions and professional judgments.
5	Quality of underlying data	Relevant spatial and gear coverage	Data should be derived from a representative proportion of the MSFD subregion (in terms of ecological and pressure gradients), at appropriate spatial resolution and sampling design, to which the indicator will apply.
6	Quality of underlying data	Reflects changes in ecosystem component that are caused by variation in any specified manageable pressures	This should include if the indicator is capable of including different gears with different impacts on habitats or species if this is relevant to the indicator and its application.
6a	Quality of underlying data	Reflects changes in ecosystem component that are caused by variation in any specified manageable pressures	The indicator reflects change in the state of an ecological component that is caused by specific significant manageable pressures (e.g. fishing mortality, habitat destruction). The indicator should therefore respond sensitively to particular changes in pressures. The response should be unambiguous and in a predictable direction, based on theoretical or empirical knowledge, thus reflecting the effect of change in pressures on the ecosystem component in question. Ideally the pressure–state relationship should be defined under both the disturbance and recovery phases.
7	Management	Relevant to MSFD management targets GES at criterion level	Details how specific the indicator is to the driver(s) of concern and whether the effects of one driver can be disentangled from other drivers. This criterion is not scored.
8	Management	Relevant to management measures	Clear targets that meet appropriate thresholds (absolute values or trend directions) for the indicator can be specified that reflect management objectives, such as achieving GES.
9	Management	Comprehensible	Indicator links directly to management response whether or not immediately operational. The relationship between human activity and resulting pressure on the ecological component is clearly understood.
10	Management	Established indicator	Indicators should be interpretable and explainable in a way that is easily understandable by policy-makers and other non-scientists (e.g. stakeholders) alike, and the consequences of variation in the indicator should be easy to communicate.

Criterion no.	Category	Characteristic	Criterion
11	Management	Cost-effectiveness	Indicators used in established management frameworks (e.g. EcoQO indicators) are preferred over novel indicators that perform the same role. Internationally used indicators should have preference over indicators used only at a national level.
12	Management	Early warning	Sampling, measuring, processing, analysing indicator data, and reporting assessment outcomes should make effective use of limited financial resources.
13	Conceptual	Scientific credibility	Indicators that signal potential future change in an ecosystem attribute before actual harm is indicated are advantageous. These could facilitate preventive management, which could be less costly than restorative management.
14	Conceptual	Metric relevance to MSFD criteria	Scientific, peer-reviewed findings should underpin the assertion that the indicator provides a true representation of variation in the ecosystem attribute in question. Meets FAIR data criteria.
15	Conceptual	Cross-application	For D6, metrics should fit the indicator criteria stated in the 2017 MSFD Decision document (EC, 2017).
16	Indicator suites	Indicator correlation	Metrics that are applicable to more than one MSFD descriptor are preferable; e.g. BH3 -> D1 benthic habitat and D6.

Annex 4

Table A4 Criteria and guidance for evaluating thresholds. Revised based on work carried out by the ICES Working Group on the Ecosystem Effects of Fishing Activities (WGECO) in 2013 (ICES, 2013b) to evaluate the performance of thresholds to support the implementation of the MSFD at subregional and regional scale. The 12 criteria are grouped into two main categories, the principle characteristic and evaluation criteria of each threshold's performance examined by each criterion are given. Further information is available in ICES (2022a)

Criterion no.	Category	Characteristic	Evaluation criterion	Criterion
1	Overall evaluation	Method of derivation	Approach to define threshold given	Rationale and methodological approach to define threshold should be given
2	Management evaluation	Framework consistency	Threshold consistency	Thresholds should not conflict across indicators within MSFD or with international policy frameworks
3	Management evaluation	Regional consistency	Level of regional coordination	Threshold should be coordinated on relevant regional scale for shared regions and subregions
4	Management evaluation	Framework consistency	Preference for established thresholds	Thresholds already accepted and used by wider society as reliable and meaningful should be preferred over novel thresholds that perform the same role
5	Scientific evaluation	State of ecosystem	Integrity	To what level of integrity threshold refers (e.g. sustainable use)
6	Scientific evaluation	State of ecosystem	Adaptability of threshold	The threshold should be assigned/allowed to change with (a) refined analyses and models of the indicator time-series, and/or (b) change in ecosystem information
7	Scientific evaluation	Data quality	Uncertainty in threshold estimates	The statistical method used for thresholds setting should provide upper and lower confidence limits
8	Scientific evaluation	Data quality	Derivation of threshold	Threshold should be based on analytical models and ecological theory. Empirical derivation based on time-series or baseline data is preferred over expert judgement
9	Scientific evaluation	Data quality	Spatial extent (range)	Threshold should be based on data for the region for which is being applied and for the same spatial scale
10	Societal evaluation	Societal acceptance	Cross-sectoral integration	Thresholds should be informed by and subject to cross-sectoral public consultation to include social economic and ecological implications of targets for society
11	Societal evaluation	Societal acceptance	Ease of understanding	Rationale for the threshold should be easily understandable by policy-makers and other non-scientists alike, and clear to communicate
12	Management evaluation	Ecologically meaningful	GES good/degraded	Threshold should identify the separation between good and degraded environmental status based on established ecological principles and analysis