WORKING GROUP ON THE ECOSYSTEM EFFECTS OF FISHING ACTIVITIES (WGECO)

VOLUME 2 | ISSUE 26

ICES SCIENTIFIC REPORTS

RAPPORTS SCIENTIFIQUES DU CIEM

ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA

CIEM COUNSEIL INTERNATIONAL POUR L'EXPLORATION DE LA MER

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H.C. Andersens Boulevard 44-46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

ISSN number: 2618-1371 I

ICES Scientific Reports

Volume 2 | Issue 26

WORKING GROUP ON THE ECOSYSTEM EFFECTS OF FISHING ACTIVITIES (WGECO)

Recommended format for purpose of citation:

ICES. 2020. Working Group on the Ecosystem Effects of Fishing Activities (WGECO).
ICES Scientific Reports. 2:26. 43 pp. http://doi.org/10.17895/ices.pub.6005

Editors

Brian Smith• Tobias van Kooten

Authors

Anna Rindorf • Brian Smith • Chris Lynam • David Reid • Elena Eriksen • Ellen Kenchington • Fatima Borges • GerJan Piet • Jeremy Collie • Maurice Clarke • Murray Thompson • Stefán Áki Ragnarson • Tobias van Kooten

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

Contents

i Executive summary

Due to the COVID-19 outbreak and the resulting travel restrictions, WGECO was conducted entirely by remote meetings in 2020. This strongly limited the amount of work which could be done, and reduced attendance as well. As a result, in consultation with ACOM leader-ship, it was agreed that only Tors D and E would be taken up this year. WGECO decided to keep all other ToRs for 2021 and not add any new ones.

In a 'bottom-up' approach, WGECO compiled a list of candidate indicators for use in the ICES Ecosystem Overviews (EOs; ToR d.). These were mostly indicators which were scored earlier for their applicability for the EOs by WKFOOI, WKBIODIV and WGECO (including those in the 2018 WGECO report). A new scoring system for operationality was set up, based on the criteria for uptake in the EOs (as provided by ACOM/Henn Ojaveer), and the indicators were scored. This yielded a number of indicators which were both applicable and near-operational (table 1). The status and steps towards final operationalization were briefly discussed, and recommendations made towards operationalizing.

In addition, WGECO started to work towards a 'top-down' approach to identify the indica-tors required based on the linkage diagrams presented in the EOs. The approach taken is to compile a complete set of categories under each activity/pressure/state, and then decide which categories require indicators.

Ultimately, the combined of bottom-up and top-down approach should yield a framework for prioritizing the operationalization of available indicators on the basis both the invest-ment needed to do so, the indicator quality and the added value for the EOs and FOs (ICES Fisheries Overviews).

WGECO reviewed a WKEUVME workflow document offering advice options to protect vulnerable marine ecosystems (VME) while considering restrictions on fishing activities in NE Atlantic waters (ToR e). The workflow document was in response to the European Commission's request to ICES to deliver "advice on the list of areas where VMEs are known to occur or are likely to occur and on the existing deep-sea fishing areas (ref. (EU)2016/2336)". WGECO agrees the workflow provides necessary steps to propose regula-tory options to managers for protecting VMEs. The workflow can also be improved, and WGECO's review summarizes major comments to point out sections of the workflow where improvements could occur. These include: 1). applying a more conventional risk-assessment framework to the workflow, 2). providing details regarding Species Distribution Models, decision support tools, and their application, 3). providing clarity on VME confidence and the intended precautionary approach, and 4). developing concrete management actions for closed area selection to fully inform trade-off analysis. Additional comments were made considering the presentation of trade-offs to managers for selecting different closed areas, considering previous ICES work and advice relevant to the workflow and deep-sea access regulation, and how the workflow can accommodate future data updates to ensure data are fully documented and adhere to ICES data standards.

ii Expert group information

Expert group name	Working Group on Ecosystem Effects of Fishing Activities (WGECO)
Expert group cycle	Annual
Year cycle started	2020
Reporting year in cycle	1/1
Chair(s)	Tobias van Kooten, Netherlands
	Brian Smith, USA
Meeting venue(s) and dates	31 March – 7 April 2020, by correspondence (13 participants)

1 Tor d: Prioritize indicators (one or more than one) from a set of indicators from current and earlier work by WGECO or its participants (including particularly those from ToR d of WGECO 2018), which can be estimated on a routine basis and are applicable across several ecoregions. For each prioritised indicator, supply a short explanatory text for justification of the prioritization, identify the required steps to operationalize their use in the ICES fisheries and/or ecosystem overviews, and outline how WGECO or ICES can support their implementation over the next three years.

1.1 Approach

For the selection process of what should be considered the preferred indicators for inclusion in the Ecosystem overviews we applied two perspectives:

- a bottom-up perspective where we started with an inventory of existing indicators and applied existing indicator selection criteria (adopted from previous evaluations e.g. WKFOOWI, WKBIODIV, WGECO) as well as new criteria (from the requirements of the Ecosystem overviews)
- a top-down perspective where we started from the categories of human activities, pressures and ecosystem components as they occur in the ecosystem overviews' linkage frameworks and which identify the aspects or sub-components of each of those categories that could/should be represented by the indicators.

Ultimately the aim is to bring these two perspectives together in order to provide this prioritization of indicators for each of the categories of human activities, pressures and ecosystem components and whatever aspects, further detail or sub-components deemed most relevant.

The work done under this ToR is a first step in a 3-year process, in which we aim to set up a framework to prioritize the development of indicators (by WGECO or others) based on both operational and ecological suitability.

1.1 Bottom-up scoring of indicators

1.1.1 Compilation of indicators and existing classification

The indicators scored were selected based on how close to being operational they were perceived to be. This meant including indicators first evaluated by ICES WKFOOWI (ICES, 2014) and WGBIODIV (ICES, 2015), which were then further compiled and evaluated by WGECO (ICES 2017a). WGECO (ICES 2018) also evaluated a range of further, potentially valuable ecosystem indicators for which full methodology had yet to be developed and propose methodologies and data sources. These included: Total mortality, Productivity of key predators, Primary production required to support fisheries, Guild level biomass, Total biomass of small fish, Pelagic-to-demersal ratio, and Benthic indicators. Benthic indicators were evaluated by WKBENTH (ICES 2017b) and reviewed by WGECO in 2017 (ICES 2017b).

Criteria for the evaluation were worked out by WGECO and WGBIODIV. These allowed an appreciation of both the "effectiveness" of each indicator and its potential to be used operationally. In this report, each indicator was scored against two qualities: 'Appropriate' and 'Operational'. The criteria 'Appropriate' was based on previous scoring from ICES working groups and workshops (WKFOOWI, WGBIODIV, WGECO). If more than one working group had scored an indicator, the results from the group where most participants participated in the scoring was used (WKFOOWI chosen over WGBIODIV, WGBIODIV over WGECO).

Some additional indicators were evaluated and given a preliminary score (Table 1). These will be further evaluated in 2021 along with others derived from a literature search or were not scored as the focus of the group was on completing scores of 'Operational' indicators.

1.1.2 Scoring procedure

The score for 'Operational' indicates the degree to which an indicator is technically suitable for inclusion in the ecosystem overview. It was derived on the basis of the criteria for inclusion in the Ecosystem Overiews, as described in the document 'EO pipeline process DRAFT-1', provided to WGECO by Henn Ojaveer, the ACOM member tasked with overseeing the development of the ecosystem overviews. This document defines seven criteria, of which five were used:

1. Is based on mature, peer-reviewed science.
2. Is connected to an expert group which can be asked to provide periodic updates.
3. Is applicable for (almost) all ICES ecoregions.
4. Is based on quality-assured data which will be available in the future.
5. Is based only on open-source analysis software and on data which can be publicly shared (TAF compliance).

Two further criteria from that document were deemed less relevant in relation to the degree to which an indicator is operational. These were 'supports the role of the ecosystem overviews' and 'is of interest to the ICES client commission(s) and/or stakeholders'. These are outside the scope of 'operational' and hence of this score.

1.2 Results

The result of the scoring for 'Appropriate' and 'Operational' is given in table 2 along with any barriers to being directly operational identified.

1.3 Discussion of (selected) individual indicators

18 indicators were evaluated by WGECO to be close to operational. However, a number of these still have decisions that need to be made before the indicators are fully operational. WGECO identified the following issues.

For indicators including aspects of guilds (Guild level biomass from surveys, Guild level biomass from e.g. stock assessment models), an agreed method and a resulting list of species/ages to guilds in each area is needed. WGECO considered that this could be achieved by **requesting WGSAM, WKOISS, WGBIODIV or WGECO to peer review an existing method based on stomach content analyses** (Thompson *et al in press*). **WGECO recommends ACOM leadership and Secretariat dealing with FOs and EOs to ask the appropriate working group to take this up.**

The indicators related to food abundance and natural mortality (Mean weight at age of piscivorous fish, Mean weight at age of planktivorous fish, Total mortality (M+F)) require **allocation of species to guilds and definition of relevant age groups**. For planktivorous fish, a preliminary evaluation has been completed by Shephard *et al* 2014, and **this method can be used directly**.

Size based indicators were generally operational (LFI, Mean length of surveyed community, Size composition in fish communities (TyL)), though **case specific technical details must be presented and peer reviewed and plug-in code must be supplied. WGECO recommends to ACOM leadership and Secretariat dealing with FOs and EOs to ask WGBIODIV to take this up.**

Indicators which required information on life history characteristics such as asymptotic length or maximum length (Mean maximum length, species sensitivity, Pelagic-to-demersal ratio) would require an updated peer reviewed database of life history traits for all areas. The data required for benthic indicators based on traits is already under development in WGFBIT, while a starting point for fish could be the data published in Rindorf *et al*. (in press) and other data previously published by WGECO or WGBIODIV. In addition to life history traits, it would be useful to have a clear species-specific allocation to the fish groups mentioned under D1 biodiversity of the MSFD (pelagic, demersal, deep water and coastal) along with a group for diadromous species, as these species are of relevance to e.g. the habitat directive. **WGECO suggests to ACOM leadership and Secretariat dealing with FOs and EOs to ask that WGBIODIV reviews and supplements the life history trait list in 2021 and that this list is subsequently published as a publicly available ICES database.**

Indicators of development and pressure on individual species require **an overview of which of the species ICES already advises on (to avoid potentially conflicting advice) and R-code to estimate abundance from surveys for other species to be fully operational**. Pressure indicators may be difficult to obtain for species where total catches are poorly determined (e.g. species with a high discard rate in historic data) and **species for which reliable catch data can be obtained should be identified by groups familiar with these issues (WGEF, WGCATCH and an additional group for bony fish)**. **WGECO recommends to ACOM leadership and Secretariat dealing with FOs and EOs to ask the appropriate working groups to take this up.**

There are several plankton, marine mammals, seabirds and benthic communities where the **criteria for operationality may be better evaluated by other working groups e.g. using the WGECO criteria (WGPME, WGBYC, JWGSEABIRD, WGFBIT)**. **WGECO recommends to ACOM leadership and Secretariat dealing with FOs and Eos to ask the appropriate working groups to take this up.**

WGECO discussed that satellite image based primary productivity, which is widely used, should ideally be first validated with in situ information before it is used as a primary productivity indicator.

1.4 Recently proposed indicators to be considered by WGECO in the future

Here we summarize a small selected set of papers, from a non-exhaustive review, discussing indicators and thresholds that are worth considering for development and possible inclusion in ICES Overviews in future.

Since the last time that WGECO addressed the topic of possible additional indicators (ICES 2018), there have been a number of papers published on the topic of evaluating indicators against a set of evaluation criteria in a similar fashion. Bundy *et al* (2018) looked at a wide range of indicators covering Biodiversity, Ecosystem Structure and Functioning, Ecosystem Stability and Resistance to Perturbations, Resource Potential, and Fishing Pressure. Their screening criteria were: Public awareness, Coordination and tractability, Theoretical basis, Measurability, Specificity, Sensitivity, Responsiveness, and Non-redundancy, so broadly similar to those used by WGBIODIV, WKFOOWI & WGECO.

Within the categories above, they identified: Total Landings and total fishing pressure; Mean Trophic Level; LFI; Biomass of gadoids; Community Condition, Biomass of the piscivore guild; Landings and biomass of skates and of flatfish; Total biomass; Heip’s evenness, Margalef Richness; Diversity of target species Landings; and fishing pressure on Clupeoids. Many of these have been included in the indicators evaluated by WGECO, or very similar ones, but some are not and may be useful to examine more closely.

A second study (Fu *et al* 2019) and based on the Indiseas project, identified and evaluated a different series of possible candidate indicators. The indicators proposed were largely focused on indicators of trophic level, and the biomass associated with them. As such they may be complimentary to some of the trophic level or guild level indicators evaluated in this WGECO report, but as with the Bundy *et al* (2018) evaluation, have established methods and appropriate data sources. As with the guild level indicators WGECO evaluated, the main issue for operational use would be the definition and standardization of the quantification of trophic level.

The main indicators proposed were: Biomass to catch ratio, Proportion of predatory fish, Mean intrinsic vulnerability, Mean lifespan, Trophic level of catch, Trophic level of catch with variable TL, Marine trophic index, Mean trophic level of community, Biomass of all surveyed species, Biomass of high-trophic-level species, Biomass of low-tophic-level species, Ratio of htl biomass to total biomass, Ratio of ltl biomass to total biomass, Ratio of ltl biomass to htl biomass.

A similar trophic level approach is described by Pranovi *et al* (2020). Here the aim is to develop an indicator based on Biomass accumulation across TLs. This would have the same methodological and data support as in Fu *et al* (2019) but may be less prone to issues of identifying discrete trophic levels.

A possibly related approach but not focused on trophic levels was proposed by Thorson *et al* (2018). This approach calculates the "Portfolio effect and this is described by the authors as follows. "*Decades of research suggest that biological complexity can reduce the variance over time of an ecosystem service relative to the variance of each individual component. This is often termed the 'portfolio effect' (PE), analogous to how a portfolio of financial investments can be used to decrease variance in economic performance in a collection of assets for a given expected rate of return. The PE is strongest when the ecological 'assets' are negatively correlated over time, termed 'asynchrony', and the PE decreases as the assets become more positively correlated with one another, termed 'synchrony'. For example, maintaining PE via preserving different components of populations or communities can improve economic outcomes in fishing communities by decreasing resource variability and allowing top consumers stable access to food. This represents a feasible step towards ecosystem-based resource management."*

The paper offers methods to calculate PE, however the evaluation is based on a model system, and raises the question of whether suitable data are available in the field. This would obviously impact the operational possibilities. The indicators are also likely to be complex to communicate with a wider audience.

WGECO has evaluated benthic indicators in previous reports and evaluated those developed by WKBENTH, and these will be evaluated further by WGFBIT. Two recent papers also suggest additional valuable approaches. Hiddink *et al* (2020) evaluated many benthic indicators of fishing impact, but conclude on proposing just two: whole-community numbers of individuals and their biomass. Both performed well on the evaluation criteria. However, in common with many benthic state indicators they could not be considered as operational at present, principally because the data collection needed to calculate them is expensive and time consuming to collect from surveys. The main benefits of these indicators were that they do not involve a lot of taxonomic identification to be calculated, they represent better value to cost and they also perform better than the more taxonomically specific indicators.

In related work, Elliot *et al* (2018) proposed a method to integrate benthic indicators to provide a more holistic, single indicator linked to the MSFD etc. The approach uses four OSPAR benthic habitat indicators relating to biodiversity (D1) and sea-floor integrity (D6) which are linked together. The integration requires benthos, environmental and anthropogenic pressure data. The principle value of this indicator is the holistic aspect, where a single, synthetic indicator can be used in place of a range of variables, thus improving communication and suitability for an Ecosystem overview. The approach has promise, but would need a formal evaluation and understanding of its operationality.

Pelagic ecosystem indicators remain one of the Cinderella subjects in this field. Some indicators were proposed by Shepherd *et al* (2014), and evaluated by WGECO. A new study that has evaluated and selected pelagic indicators is presented in Otto *et al* (2018). This uses both fish and zooplankton indicators. The fish indicators are broadly the same as in this report, the zooplankton ones are more novel, and comprise: Total zooplankton abundance; Mean size; Ratio cladoceran to copepod; Copepod biomass; Microphagous mesozooplankton biomass; Ratio total zooplankton biomass to total phytoplankton biomass. Interestingly, the indicators performed differently in different basins in the Baltic. The methods for these indicators are available, however, suitable data may not be available in all areas. The operationality of the method should also be evaluated. The differential results across the different basins raise the question of how generically applicable these indicators may be.

Link and Watson (2019) presented an approach to define Ecosystem Overfishing (EOF) and determine thresholds for indicators to avoid the risk of reaching tipping points. Ecosystem Overfishing is considered the point at which total catch relative to ecosystem production will exceed suitable limits (i.e. the level of fish production that is removed through fishing is greater than that that can be supplied by natural primary production at the base of the food web).

In the past, a range of modelled indicators have been suggested to monitor the ecosystem impacts of change in primary production (PP), such as the primary production required to support fisheries (PPR) (Pauly and Christensen 1995). However, PPR indicators have not yet been applied in a management context and WGECO 2018 scored them poorly since "the data are not yet available to support the assumptions of specific values of TE", where TE=transfer efficiency. Nevertheless, previous studies such as Watson *et al*. (2014) have considered the PP in relation to fisheries using satellite data to estimate PP, assumed values of TE and literature values for trophic level. Watson *et al*. (2014) indicated that during the 1970s and 1980s, the fisheries in the North Sea were taking more biomass from the ecosystem than could have been replaced annually through PP (Figure 1). Subsequent declines in fisheries yield during the 1990s brought the fishing catches below the level at which the system could begin to recover.

Link and Watson (2019) proposed the following 3 simple indicators that are based on the same principle of trophic transfer but do not require estimates of transfer efficiency or trophic level:

1. The 'Ryther index', total catch presented on a unit area basis for an ecosystem [t km^{-2}].
2. The 'Fogarty index', the ratio of total catches to total primary productivity in an ecosystem.
3. The 'Friedland index', the ratio of total catches to chlorophyll in an ecosystem (as a proxy for 2).

Currently, the ICES Fisheries Overviews provide the total landings per marine ecosystem without reference to sustainable levels or limits due to ecosystem production. Link and Watson (2019) note as WGECO do, that such an approach should ideally be based on total catch rather than landings only data. However, the Link and Watson (2019) approach provides useful first estimates of these limits for total landings when based on the area of the ecosystem as a proxy for potential ecosystem production (as in the Ryther index). The Ryther index is the simplest of the three indicators, and assumes that the potential ecosystem production does not change over time. However, nutrient reductions (which may be achieved to reduce eutrophication of coastal waters) and climate change effects can also lead to change in the primary production available to higher trophic levels. To capture change in potential ecosystem production through simple metrics, Link and Watson propose the Fogarty and Friedland indices. However, the Fogarty and Friedland indices are ratios that require data on the plankton for the denominator for which there is currently no agreed methodology for monitoring (OSPAR 2017). So, further improvements to data collection, analyses and biogeochemical modelling would be useful here (Lynam *et al* 2016). Watson *et al* (2014) demonstrated how these concepts can be used to further our understanding of how change in the PP available in the ecosystem supports the fisheries catch. In their preliminary study, they found that catch in the North Sea declined to acceptable levels, below the available PP, in the years 2001-2005 (Figure 1). However, this was based on a single estimate of average PP for the period 1998–2007. Clearly PP changes from year to year and potential declines in PP would lead to increases in the Fogarty and Friedland Ratios in addition to PPR.

Link and Watson (2019) have suggested that thresholds for the Ryther and Fogarty indicators can be determined to avoid ecosystem overfishing (EOF), given the carrying capacity limits to production of fish communities. The threshold should be set where the total yield (commercial catch) leads to a depletion rate that is greater than the rate of renewal achievable by the ecosystem. They suggest that the

Ryther index for total catch should be on the order of 0.3 to 1.1 t km^{-2} year^{-1} or practically not to exceed (NTE) ~1 t km^{-2} year^{-1}, with an extreme limit NTE 3 t km^{-2} year^{-1} above which point a tipping point may occur. They also expect system-wide MSYs to be of the order of 1 to 3 t km^{-2} year^{-1}. To be precautionary, they propose a Ryther index threshold of ~1 t km^{-2} year^{-1} to delineate EOF but they note that this may be too low. Notably the Ryther index, calculated using official landings for ICES area 4 only, has not reached the lower threshold level of 1 in the available time series back to 1950 (Figure 2). In contrast, the higher thresholds beyond which extreme events may occur (3 t km^{-2}) is consistent with our general understanding of the system. Link and Watson (2019) also suggested a Fogarty ratio (of catch relative to net PP) >1‰ is an indication of probable EOF (and thus the same 1‰ value for the Friedland index) and values >2.5‰ suggesting ecosystems are at risk of breaching catastrophic tipping points.

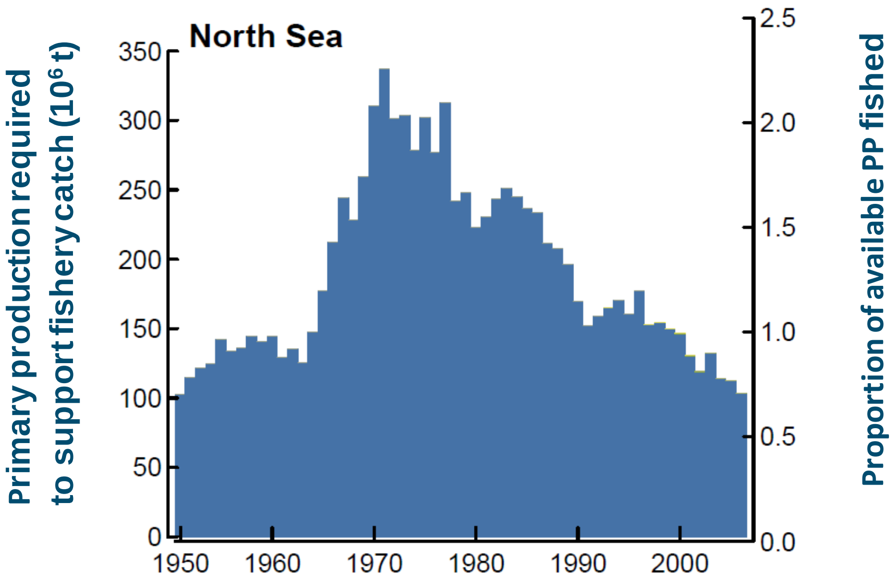

Figure 1. The primary production required to support fisheries catch (i.e. an estimate of the primary production that would have been fed into the system to create a biomass of fish equal to the landed catch, left axis) and its ratio to available PP (right axis). Figure reproduced from Watson *et al*. (2014). The PP required to support the fishery is determined from the trophic level of the catch, a transfer efficiency of 10% between trophic levels and a 9:1 conversion rate of wet weight to carbon following Pauly and Christensen (1995). The proportion of available PP fished (right axis) is the ratio of the primary production required to support fisheries catch divided by a single satellite derived estimate of average PP for the period 1998–2007. Trophic level estimates were taken from FishBase (www.fishbase.org) for fishes and SeaLifeBase (www.sealifebase.org) for invertebrates.

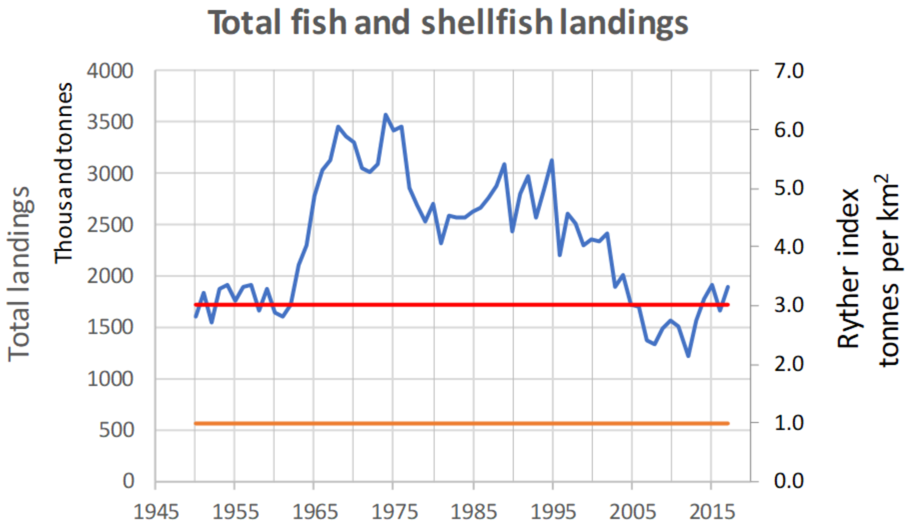

Figure 2: Ryther index based on ICES statistics on the total landings from the North Sea (area 4 only), data from the historical nominal catches database pre-2008 and data for the more recent years the Official nominal catches database) and the Ryther index (right axis) i.e. tonnage relative to sea area, where the North Sea is taken to be 570,000 km^2, showing the upper extreme limit (red) and lower limit (orange) to the expected MSY range (Link and Watson 2019).

Data sources

Official Nominal Catches 2006-2017. Source: Eurostat/ICES data compilation of catch statistics - ICES 2019, Copenhagen. Format: Archived dataset in .xlsx and .csv formats. Version: 16-09-2019

Historical Nominal Catches 1950-2010. Source: Eurostat/ICES database on catch statistics - ICES 2011, Copenhagen. Format: Archived dataset in .xls and .csv format. Version 26-06-2019

The deep sea is the largest ecosystem on Earth and extends into EU waters. However, many of the indicators for measuring Good Environmental Status (GES) under the Marine Strategy Framework Directive (MSFD) have been developed and tested using data from shallow shelf seas. The slowdown of many biological and chemical processes, including growth rate, that occurs in the deep-sea may complicate interpretation of indicator response to pressures and establishment of thresholds. Further, data availability for deep-sea areas can be limited, restricting the suite of indicators that can be measured (Orejas *et al*. submitted); Teixeira *et al*. (2016) noted that the number of marine biodiversity indicators assessed decreased noticeably from shallow to deep waters. The EU Horizon 2020 project ATLAS[1] reviewed the GES descriptors and their relevance to deep-sea benthic ecosystems and demersal fish species within EU waters (Kazanidis *et al*. submitted). Based on data availability, data quality and expert judgement, 24 indicators (3 for D1 Biodiversity is maintained; 5 for D3 The population of commercial fish species is healthy; 14 for D6 The sea floor integrity ensures functioning of the ecosystem; 2 for D10 Marine litter does not cause harm) were used in the assessment of nine deep-sea case study areas, their habitats and ecosystem components. Ten of those indicators were new ones proposed specifically to assess the status of deep-sea ecosystems. The IDEM project[2] also tested the implementation of the MSFD in the deep Mediterranean Sea examining indicators across all of the 11 descriptors and commenting on their performance (Danovaro *et al*. 2020). WGECO proposes to consider the recently proposed indicators

---

[1] ATLAS is a European Horizon 2020 project "A transatlantic assessment and deep-water ecosystem-based spatial management plan for Europe" grant agreement No 678760.

[2] IDEM is a DG Environment project "Implementation of the MSFD to the deep Mediterranean Sea" grant agreement No 11.0661/2017/750680/SUB/ENV.C2.

of these projects and others in the future and to consider the issues that arise when applying such indicators to the deep sea.

1.5 Top-down approach: Indicators required based on EO linkage diagrams

In addition to the selection process of what should be considered the best indicators, here referred to as a bottom-up perspective we also developed and applied a top-down perspective where we started from the categories of human activities, pressures and ecosystem components as they occur in the ecosystem overviews' linkage frameworks and identified which aspects, further detail or sub-components of each of those categories could/should be represented by the indicators. Ultimately the aim is to match these two perspectives in order to develop an overview where the preferred indicators are given for each of the categories of human activities, pressures and ecosystem components and whatever aspects, further detail or sub-components deemed most relevant.

To further develop this top-down perspective we worked from an improved and more comprehensive typology of categories of human activities, pressures and ecosystem components and added for each of the categories the aspects, further detail or sub-components that could, or possibly should, be considered when illustrating e.g. the extent of a specific activity, the magnitude of a pressure or the state of an ecosystem component.

The more comprehensive typology of categories of human activities, pressures and ecosystem components was developed in the H2020 AQUACROSS project, a follow-up of the ODEMM project on which the initial typology was based. To add the further detail, we considered the requirements of policy documents such as the MSFD but also those of the wider audience with an interest in the ecosystem overviews, e.g. business, NGOs or society at large. An example (see Table 5) of how these perspectives lead to the choice of a specific sub-category, i.e. elasmobranchs, of, in this case, fish illustrates how we intend this process to work. Elasmobranchs are not specifically mentioned in the MSFD but fall in the other MSFD fish sub-categories such as coastal fish or demersal fish. Most of the different elasmobranch species would be considered sensitive species based on their life-history characteristics and as such one or more of these species could be selected as indicator species. For practical purposes (different elasmobranch species are often not distinguished in commercial catches) or communication purposes (Conservation NGOs often focus on this group) it could therefore be relevant to provide an indicator that represents this group of fish.

In this chapter we provide separate tables for the human activities, pressures and ecosystem components. Because of the limited availability of experts, we focussed for the human activities table 3 only on fisheries and aquaculture leaving the other activities for subsequent years also pending the decision of what should be considered within the remit of WGECO: only effects of fishing or the ecosystem effects of ALL activities.

As the emphasis of the bottom-up indicator selection process was on pressure (P) and state (S) indicators (see table 2) we also focussed primarily on developing the tables for pressures (table 4) and state, i.e. ecosystem components (table 5). For now, we therefore maintained the "Specific Primary Activity" in Table 3 as it occurred in Borgwardt *et al* (2018). Clearly a more in-depth discussion is needed on what the most appropriate level of detail, i.e. metiers, is.

As for the human activities we focussed for the pressure table principally on the fisheries-induced pressures but did consider all ecosystem components. Where possible (or needed) we provided suggestions for more detailed smaller sub-categories that can help select indicators or identify possible gaps not covered by existing indicators. Our reason for adding this detail is that these simple categories provide a comprehensive overview of the whole ecosystem and how the main activities and their pressures impact the state of the ecosystem components. These simple categories cannot show all the, often ecosystem-specific, detail that falls under these categories. For example, to illustrate the effects of fishing on marine mammals the broad category fishing is useless as it may primarily be the fixed nets causing most of the bycatch. Similarly, the impact of fishing on the seafloor habitats can be better illustrated by showing the activity of the benthic trawls. In the case of pressures, there is a marked difference between lost fishing gear, i.e. ghostnets, causing mortality through entanglement and other fishing litter, e.g. dolly-rope, which likely cause less mortality (via ingestion) but levels are largely unknown.

Finally, there may be considerable differences between the state of the fish community represented in terms of its size structure or some aspect of species composition (e.g. sensitive species) and whether this is shown for the demersal fish assemblage or the pelagic fish assemblage. Note that these sub-categories are not mutually exclusive as commercial fish may also be demersal or pelagic fish and as such size structure of the demersal fish assemblage may include commercial species as well as elasmobranchs. In table 5 we also distinguished between different sub-categories and the type of metrics to be used. For example, biomass may apply to all fish, or commercial versus non-commercial species or any other subset of the fish community. Species/ trait composition involves any proportional metric such as the typical biodiversity metrics in terms of species (e.g. Hill's N1, N2), but also functional or genetic biodiversity. And, again, such metric may be applied to the whole fish community or any other subset of the fish community.

Table 3. Typology Economic activities and their primary activities distinguishing broad activity types and more specific activities. Adopted from Borgwardt *et al* (2018)

Type	Specific Primary Activity
Aquaculture	Ex-situ (on land) aquaculture (water abstraction, waste discharge)
	Fin-fish - operational (waste products, anti-fouling, predator control, disease and disease control, infrastructure effects on local hydrography, escapees, litter, anchoring/mooring of boats)
	Fin-fish - set-up (atmospheric emissions for transport of brood stock/juveniles, interaction with seafloor during set-up of infrastructure, loss of gear)
	Freshwater Aquaculture
	Freshwater Aquaculture - fish ponds in the riparian zone
	Macro-algae - operational (waste products, anti-fouling, predator control, disease and disease control, infrastructure effects on local hydrography, litter, anchoring/mooring of boats)
	Macro-algae - set-up (atmospheric emissions from boats (certain species), trampling (certain species), interaction with seafloor, removal of habitat-structuring species, loss of gear)
	Shellfish - operational (waste products, anti-fouling, predator control, disease and disease control, infrastructure effects on local hydrography, litter, anchoring/mooring of boats)
	Shellfish - setup (atmospheric emissions from boats, interaction with seafloor when dredging for brood stock, loss of gear, litter)
Fishing	Benthic trawl and artisanal fishing
	Benthic trawls and dredges - general (anti-fouling, ballast water, litter, lost gear)
	Benthic trawls and dredges - mooring/anchoring (interaction with seafloor)
	Benthic trawls and dredges - operations (interaction with seafloor, catch, bycatch, waste products)
	Benthic trawls and dredges - steaming (atmospheric emissions, collisions)
	Commercial fisheries freshwater - operations (catch, bycatch, disturbance)

Type	Specific Primary Activity
	Commercial pike fishing with gill nets - general (litter, lost gear, antifoulants)
	Commercial pike fishing with gill nets - operational (catch, bycatch, waste products)
	Commercial pike fishing with gill nets - set up/recovery (interaction with lake bed, steaming, atmospheric emissions, collisions)
	Demersal fishing
	Long-line pelagic - general (anti-fouling, ballast water, litter, lost gear, waste products)
	Long-line pelagic - mooring/anchoring (interaction with seafloor)
	Long-line pelagic - operations (catch, bycatch, waste products)
	Long-line pelagic - steaming (atmospheric emissions, collisions)
	Long-line pelagic (including steaming, operations, mooring/anchoring)
	Nets (fixed/set/gillnets/other nets/lines) - general (litter, lost gear, antifoulants)
	Nets (fixed/set/gillnets/other nets/lines) - general (litter, lost gear, antifoulants, steaming, waste products)
	Nets (fixed/set/gillnets/other nets/lines) - operational (catch, bycatch)
	Nets (fixed/set/gillnets/other nets/lines) - operational (catch, bycatch, waste products)
	Nets (fixed/set/gillnets/other nets/lines) - set up/recovery (interaction with seafloor)
	Nets (fixed/set/gillnets/other nets/lines) - set up/recovery (interaction with seafloor, atmospheric emissions)
	Pelagic trawls
	Pelagic trawls - general (anti-fouling, ballast water, litter, lost gear)
	Pelagic trawls - general (anti-fouling, ballast water, litter, lost gear, waste products)
	Pelagic trawls - mooring/anchoring (interaction with seafloor)
	Pelagic trawls - operations (catch, bycatch)
	Pelagic trawls - operations (catch, bycatch, waste products)
	Pelagic trawls - steaming (atmospheric emissions, collisions)
	Potting/creeling - general (litter, lost gear)
	Potting/creeling - general (litter, lost gear, waste products)
	Potting/creeling - operational (catch, bycatch)
	Potting/creeling - operational (catch, bycatch, waste products)
	Potting/creeling - set up/recovery (interaction with seafloor)
	Suction/hydraulic dredges - general (anti-fouling, ballast water, litter, lost gear)
	Suction/hydraulic dredges - mooring/anchoring (interaction with seafloor)

Type	Specific Primary Activity
	Suction/hydraulic dredges - operations (interaction with seafloor, catch, bycatch, waste products)
	Suction/hydraulic dredges - steaming (atmospheric emissions, collisions)

Table 4. Typology human-induced pressures distinguishing broad pressure types and more specific pressures. Adopted from Borgwardt *et al* (2018)

Type	Pressure	Further detail
Biological disturbance	Extraction of flora and/or fauna	Extraction of a specific ecosystem component
	Introduction of genetically modified species	Introduction of a specific ecosystem component
	Introduction of Microbial pathogens	Introduction of a specific ecosystem component
	Introduction of non-indigenous species	Introduction of a specific ecosystem component
	Translocations of species (native or non-native)	Translocation of a specific ecosystem component
Chemical changes, chemicals and other pollutants	Changes in input of organic matter	
	Introduction of Non-synthetic compounds	CO_2 emission
	Introduction of Radionuclides	
	Introduction of Radionuclides	
	Introduction of Synthetic compounds	
	Litter	Entanglement
		Ingestion
	N&P Enrichment	
	pH changes	
	Salinity changes	
Energy	Electromagnetic changes	
	Input of light	
	Noise (Underwater and Other)	
	Thermal changes	
Exogenous/Unmanaged processes	Change in wave exposure (climate change, large-scale)	
	Emergence regime change (climate change, large-scale)	
	Geomorphological change (e.g. due to tectonic events)	

Type	Pressure	Further detail
	pH changes (climate change, large-scale)	
	Precipitation regime change (climate change, large-scale)	
	Salinity change (climate change, large-scale)	
	Thermal change (climate change, large-scale)	
	Water flow rate changes (climate change, large-scale)	
Physical change	Abrasion/Damage	
	Artificialisation of habitat	
	Barrier to species movement	
	Change of habitat structure/morphology	
	Changes in Siltation	
	Changes in wave exposure	
	Death or Injury by Collision	
	Disturbance (visual) of species	
	Emergence Regime Changes	
	Selective Extraction of non-living resources: substrate e.g. gravel	
	Smothering	
	Total Habitat Loss	
	Water abstraction	
	Water flow rate changes	

Table 5. Typology for biota of ecosystem components distinguishing specific relevant subcomponents.

	Ecosystem components	Specific level 1			Metrics
Structure	Marine mammals	Cetaceans	Baleen whales	Species	Numbers Biomass Reproduction Area occupied
			Deep-diving toothed cetaceans		
			Small toothed ceta-ceans		
		Seals			
	Seabirds	Wading feeders			Numbers Biomass Reproduction
		Surface feeders			
		Water column feeders			
		Benthic feeders			
		Grazing feeders			
	Fish	Commercial fish	Species	Size structure	Numbers Biomass Size structure Species-/traits composition
			Population age/size structure	Species com-position	
		Non-commercial fish Non-target fish	Pelagic		
			Demersal		
			Elasmobranchs		
			Migratory fish, e.g. di-adromous, anadro-mous		

	Ecosystem components	Specific level 1			Metrics
			Coastal		
			Deep-sea		
	Cephalopods	Coastal/shelf cephalopods			Numbers Biomass
		Deep-sea cephalopods			
	Reptiles	Turtles			Numbers
	Seabed habitats including benthic communities	Commercial shellfish			Numbers Biomass Extent
		Benthic Infauna			
		Benthic Epifauna			
		Physical habitats	MSFD predominant or broad habitat types	EUNIS	
	Water column habitats including plankton communities	Phytoplankton			Numbers Biomass Extent
		Zooplankton			
		Physical habitats	MSFD predominant or broad habitat types	EUNIS	
Functioning	Foodweb	Trophic guilds			Relative abundance ion terms of species/size/traits: within and between guilds Productivity

These sub-categories are therefore intended to guide the selection of indicators (what aspects or sub-categories are worth considering) help limit the amount of indicator put forward and hence avoid duplication (we do not need many different indicators that represent the same aspect/sub-category) without restricting the process (e.g. allowing more than one metric/indicator for the same sub-category if deemed necessary).

A first outcome of this exercise was the identification of two clear gaps in the existing indicators: reptiles and cephalopods were not covered. This also illustrates that the relevance of certain (sub-)categories is ecosystem-specific as reptiles are not relevant in e.g. the North Sea or Baltic Sea.

1.6 Revisiting the inventory: which indicators contribute most to EO requirements?

In the next two years of which this ToR will be part of WGECO's work, we aim to combine the two approaches (bottom up and top down) for which we have set the stage here. By conducting the 'bottom up' prioritization we compile an inventory of well-developed and well-performing indicators which (can be made to) adhere to the operational standards of the Ecosystem Overviews. Using the 'top down' approach we define what is most needed to make the Ecosystem Overviews better reflect the state of each ecosystem.

By reconciling these approaches, we expect to distill the best available indicators, but also highlight where (for which ecosystem states) good indicators are missing or underdeveloped. It will also allow us to suggest further development of specific indicators because they are promising candidates for specific underdeveloped aspects of the Ecosystem Overviews.

In the context of selecting indicators for the Ecosystem Overviews, it is also important to consider the various types of indicators. In the next years, WGECO will discuss this, and particularly the distinction between strategic indicators (or surveillance indicators) and tactical indicators (which are used in management plans).

1.7 References

Bundy, A., *et al*. (2019). "Scrupulous proxies: Defining and applying a rigorous framework for the selection and evaluation of a suite of ecological indicators." Ecological Indicators 104: 737-754.

Danovaro, R., E. Fanelli, M. Canals, T. Ciuffardi, M. C. Fabri, M. Taviani, M. Argyrou, E. Azzurro, S. Bianchelli, A. Cantafaro, L. Carugati, C. Corinaldesi, W. P. de Haan, A. Dell'Anno, J. Evans, F. Foglini, B. Galil, M. Gianni, M. Goren, S. Greco, J. Grimalt, Q. Güell-Bujons, A. Jadaud, L. Knittweis, J. L. Lopez, A. Sanchez-Vidal, P. J. Schembri, P. Snelgrove, S. Vaz, L. Angeletti, M. Barsanti, J. A. Borg, M. Bosso, A. Brind'Amour, G. Castellan, F. Conte, I. Delbono, F. Galgani, G. Morgana, S. Prato, A. Schirone, E. Soldevila. (2020). Towards a marine strategy for the deep Mediterranean Sea: analysis of current ecological status, Marine Policy 112, 103781, 10.1016/j.marpol.2019.103781.

Elliott, S. A. M., *et al*. (2018). "Integrating benthic habitat indicators: Working towards an ecosystem approach." Marine Policy 90: 88-94.

Fu, C., *et al*. (2019). "Making ecological indicators management ready: Assessing the specificity, sensitivity, and threshold response of ecological indicators." Ecological Indicators 105: 16-28.

Hiddink, J. G., *et al*. (2020). "Selection of indicators for assessing and managing the impacts of bottom trawling on seabed habitats." Journal of Applied Ecology.

Link, J.S. and Watson, R.A. 2019. Global ecosystem overfishing: Clear delineation within real limits to production. Science Advances, 5(6): eaav0474. https://doi.org/10.1126/sciadv.aav0474

Lynam, C.P., Uusitalo, L., Patrício, J., Piroddi, C., Queirós, A.M., *et al*. (2016) Uses of Innovative Modeling Tools within the Implementation of the Marine Strategy Framework Directive. Front. Mar.Sci.3:182. https://doi.org/10.3389/fmars.2016.00182

OSPAR 2017. Pilot Assessment of Production of Phytoplankton. Intermediate Assessment 2017. Available at: https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/biodiversity-status/fish-and-food-webs/phytoplankton-production/

Otto, S. A., *et al*. (2018). "A quantitative framework for selecting and validating food web indicators." Ecological Indicators 84: 619–631.

Pauly, D. and Christensen, V. 1995. Primary production required to sustain global fisheries. Nature, 374, 255–257.

Pranovi, F., *et al*. (2020). "Cumulative biomass curves describe past and present conditions of Large Marine Ecosystems." Global Change Biology 26(2): 786-797.

Shephard, S., *et al*. (2014). "Assessing the state of pelagic fish communities within an ecosystem approach and the European Marine Strategy Framework Directive." ICES Journal of Marine Science 71(7): 1572–1585.

Thompson, M.S.A., Pontalier, H., Spence, M., Pinnegar, J.K., Greenstreet, S., Moriarty, M., Hélaouët, P. and Lynam C.P. In press A feeding guild indicator to assess environmental change impacts on marine ecosystem structure and functioning. Journal of Applied Ecology *in press.*

Thorson, J. T., *et al*. (2018). "Spatial heterogeneity contributes more to portfolio effects than species variability in bottom-associated marine fishes." Proceedings of the Royal Society B: Biological Sciences 285(1888).

Watson, R., D. Zeller and D. Pauly. 2014. Primary productivity demands of global fisheries. Fish and Fisheries 15, 231–241. https://doi.org/10.1111/faf.12013

1.2 Tables

Table 1. Indicators preliminarily scored for appropriateness by WGECO in 2017 or 2020. Note that scores are based on less than 3 persons and hence should not be considered final.

	Publication reference	Attributes			Avalability of underlying data (Measurable)				Quality of underlying data (Sensitivity) (Responsive)			Conceptual (Theoretical Basis)			Communication (Concrete) (PubleAware)	Management (Measureable) (Sensitivity) (Responsive)			
Recommended ranking: 0 = no, 1 = somewhat, 2 = very much;		State and pressure 'box'	State Pressure, Impact	Useful for other MSFD Descriptors (Note which Descriptor)	Existing and ongoing data	Quantitative	Relevant spatial coverage	Relevant temporal coverage	Indicators should be technically rigorous (tangible)	Reflects changes in ecosystem component that are caused by variation in any specified manageable pressures	Magnitude, direction and variance of indicator estimable	Scientific credibility	Associated with Key processes	UnAmbiguous	Comprehensible	Relevant to management	[MSFD] management thresholds (targets) estimable	Cost-effectiveness	Appropriateness score/max score
WKFOOWI Selection Criteria number			1	14	2	4	5a	5b	3a	6a	3b	10 and 13	6b		9	8	7	11	
(note scores from WGBIODIV2013 are the average of 3/4 people, ***scores for criteria 2/5/3/6*** *were scaled by x0.667 since WGBIODIV scored out of 3 not 2 as in WKFOOWI,*																			
Name of candidate indicator																			
Long SB1	WGECO 2017	Benthos	I	1/D6	1	2	1	1	2	1	1	1	1	2	1	1	0.5	0	0.55
Long SB2	WGECO 2017	Benthos	I	1/D6	1	2	1	1	2	1	1	1	1	2	1	1	0.5	0	0.55
Long LL1	WGECO 2017	Benthos	I	1/D6	1	2	1	1	2	1	1	1	1	2	1	1	0.5	0	0.55
Long LL2	WGECO 2017	Benthos	I	1/D6	1	2	1	1	2	1	1	1	1	2	1	1	0.5	0	0.55
PD1	WGECO 2017	Benthos	I	1/D6	1	2	1	1	2	1	1	1	1	2	1	1	0.5	0	0.55
PD2	WGECO 2017	Benthos	I	1/D6	1	2	1	1	2	1	1	1	1	2	1	1	0.5	0	0.55
Sensitive fish individual state indicator	Rindorf et al. In press, WGECO 2020	Fish	S	Some species may occur under D3, most under D1	*2*	*2*			*2*	*2*		*2*	*2*	*2*		*2*	*2*	*2*	1.00
Sensitive fish individual pressure indicator (catch/state from Rindorf et al. or F)	Rindorf et al. In press combined with estimates of catch or from assessment models (e.g. ling, thornback ray, spurdog), WGECO 2020	Selective extraction of species	P	Some species may occur under D3, most under D1	*2*	*2*			*2*	*2*		*2*	*2*	*2*		*2*	*2*	*2*	1.00
'Ryther index' [total catch presented on a unit area basis for an ecosystem]	Link, J.S. and Watson, R.A. 2019, WGECO 2020	Selective extraction of species	P	D1/3/4	*2*	*2*	*2*	*2*	*2*	*2*		*2*	*2*	2	*2*	*2*	*2*	*2*	1.00
Fogarty index' [the ratio of total catches to total primary productivity in an ecosystem]	Link, J.S. and Watson, R.A. 2019, WGECO 2020	Selective extraction of species	I	D1/3/4	*0*	*2*	*0*	*0*	*2*	*2*		*2*	*2*	1	*2*	*2*	*2*	*2*	0.73
'Friedland index' [the ratio of total catches to chlorophyll in an ecosystem as a proxy for Fogarty Index]	Link, J.S. and Watson, R.A. 2019, WGECO 2020	Selective extraction of species	I	D1/3/4	*0*	*2*	*0*	*0*	*2*	*2*		*2*	*2*	1	*2*	*2*	*2*	*2*	0.73
Fishery selection pattern	Brunel and Piet 2013	Selective extraction of species	P	D1/3					*2*	0		*2*	*2*	2	*2*	*2*	*2*	*2*	0.89

Table 2. 'Operational' scoring. Ranking: 0 = no, 1 = somewhat, 2 = yes; Dark grey background indicates operational ratings scored by less than 3 persons and hence highly uncertain. Italics indicate 'appropriate' ratings scored by less than 3 persons and hence highly uncertain. These should be revisited in future WGECO meetings. Light grey indicates indicators with less than 75% rating in the 'operational' criteria. Indicators are sorted according to preliminary operational score.

Name of candidate indicator	Publication reference	State and pressure 'box'	State, Pressure, Impact	Is based on mature, peer-reviewed science	Is connected to an expert group which can be asked to provide periodic updates	Is applicable for (almost) all ICES ecoregions	Is based on quality-assured data which will be available in the future	Is based only on open-source analysis software and on data which can be publicly shared (TAF compliance)	Operational score/max	Appropriate score/max	Number of persons scoring	Comments
Guild level biomass from surveys	WKFOOWI; Thompson *et al* in press; Garrison & Link, 2000 a, b	Food webs	S	1.75	2	2	1.75	2	0.95	0.79	4	Requires agreed allocation of species and age to guild. If this is available, operational in all areas following review of estimation method and R-code
LFI	WKFOOWI	Food webs	S	1.8	1.6	1.8	2	2	0.92	0.96	5	Unclear if R-code is available
Mean maximum length of demersal fish and elasmobranchs	OSPAR 2017d; also Bell *et al* 2018, WGBIODIV 2013	Fish	S	1.75	1.75	1.75	1.75	2	0.90	0.78	4	Requires agreed estimates of maximum length. Can be calculated by surveys or from Stock Assessment data
Sensitive fish individual state indicator	Rindorf *et al*. In press, WGECO 2019, 2020	Fish	S	1.75	1.5	2	1.75	1.75	0.88	*1.00*	4	Agreed species list requires life history data. Assessed stocks acan be derived directly rom ICES. Other stocks can be based on agreed indices from surveys and associated R-code

Name of candidate indicator	Publication reference	State and pressure 'box'	State, Pressure, Impact	Is based on mature, peer-reviewed science	Is connected to an expert group which can be asked to provide periodic updates	Is applicable for (almost) all ICES ecoregions	Is based on quality-assured data which will be available in the future	Is based only on open-source analysis software and on data which can be publicly shared (TAF compliance)	Operational score/max	Appropriate score/max	Number of persons scoring	Comments
Total biomass of small fish	WKFOOWI	Food webs	S	1.4	1.25	2	1.75	2	0.84	0.89	5	Requires agreed allocation of species and ages to small/large. With this operational in all areas based on assessments. Potentially 'good' is linked to not having reduced productivity of higher trophic levels. Unclear if it is an indicator of bottom up effects, recruitment failure or of food available to larger things. If there is a decline, it is a signal to investigate for which reason. Lacks some development of specific details (use assessment or surveys, what is the limit size below which fish are small, are there species that are excluded)
Guild level biomass from e.g. stock assessment models	WKFOOWI	Food webs	S	1.5	1.6	1.8	2	1.8	0.87	0.96	4	Requires agreed allocation of species and age to guild. If this is available, operational in all areas based on assessments

Name of candidate indicator	Publication reference	State and pressure 'box'	State, Pressure, Impact	Is based on mature, peer-reviewed science	Is connected to an expert group which can be asked to provide periodic updates	Is applicable for (almost) all ICES ecoregions	Is based on quality-assured data which will be available in the future	Is based only on open-source analysis software and on data which can be publicly shared (TAF compliance)	Operational score/max	Appropriate score/max	Number of persons scoring	Comments
Production of phytoplankton	OSPAR 2017/WGBIODIV 2013	Productivity/Food webs	S	1.67	1.5	2	1.5	2	0.87	0.78	3	Unclear to WGECO If phytoplankton data are available, whether code to estimate indicator is available and which group would be responsible for updating the indicator.
Sensitive fish aggregate indicator	Greenstreet *et al* 2012, WGBIODIV 2013	Fish	S	1.67	1	2	1.67	2	0.83	1.00	3	Operational. Requires R-code
Mean length of surveyed community	WKFOOWI	Food webs	S	1.5	1	2	1.75	2	0.83	0.86	4	Operational. Requires R-code
Size composition in fish communities (TyL)	OSPAR 2017	Food webs	S	1.5	1.5	1.75	1.5	2	0.83	0.82	4	Operational. Requires R-code.
Pelagic-to-demersal ratio	WKFOOWI	Food webs	S	1.2	1.25	1.8	2	2	0.83	0.82	5	Requires agreed allocation of species and ages to pelagic/demersal. With this operational in all areas based on assessments. Unclear what the indicator would say

Name of candidate indicator	Publication reference	State and pressure 'box'	State, Pressure, Impact	Is based on mature, peer-reviewed science	Is connected to an expert group which can be asked to provide periodic updates	Is applicable for (almost) all ICES ecoregions	Is based on quality-assured data which will be available in the future	Is based only on open-source analysis software and on data which can be publicly shared (TAF compliance)	Operational score/max	Appropriate score/max	Number of persons scoring	Comments
												about the ecosystem and what would be considered 'good'. Therefore not necessarily high priority
Total mortality (M+F)	WKFOOWI	Food webs	P?	1.67	1.5	1	2	2	0.82	0.75	3	Immediately operational in North Sea and Baltic Sea
Mean weight at age piscivorous fish	WKFOOWI	Food webs	S	1.25	1.25	2	1.75	1.75	0.80	0.82	4	Requires agreed allocation of species and age to guild. If this is available, operational in all areas based on assessments. Requires R-code.
Mean weight at age planktivorous fish	Shephard *et al* 2014, ranking assumed equal to WKFOOWI parallel for predator fish	Food webs	S	1.33	1.33	2	1.67	1.67	0.80	0.82	3	Requires agreed allocation of species and age to planktivorous fish. For a start, the species and ages included in Shephard *et al* 2014 can be used and the indicator is the operational in North Sea and Celtic Seas based on assessments. Requires R-code.
Plankton biomass and/or abundance	OSPAR 2017, WGBIODIV 2013	Plankton	S	1.5	1.5	1.75	1.25	1.75	0.78	0.61	4	Unclear to WGECO for which areas plankton data are available annually, whether code to estimate indicator is available and which group would be responsible for updating the indicator.

Name of candidate indicator	Publication reference	State and pressure 'box'	State, Pressure, Impact	Is based on mature, peer-reviewed science	Is connected to an expert group which can be asked to provide periodic updates	Is applicable for (almost) all ICES ecoregions	Is based on quality-assured data which will be available in the future	Is based only on open-source analysis software and on data which can be publicly shared (TAF compliance)	Operational score/max	Appropriate score/max	Number of persons scoring	Comments
Sensitive fish individual pressure indicator (catch/state from Rindorf *et al.* or F)	Rindorf *et al*. In press combined with estimates of catch or from assessment models (e.g. ling, thornback ray, spurdog), WGECO 2019, 2020	Selective extraction of species	P	1	1.33	1.67	1.67	2	0.77	*1.00*	3	Agreed species list requires life history data. Assessed stocks can be derived directly from ICES. Other stocks can be based on agreed indices from surveys, catch data from relevant WGs and associated R-code
Breeding success of seabirds	WKFOOWI	Seabirds		1.75	1.75	1.5	1.33	1.33	0.77	0.86	4	JWGBIRD to update this
Primary Production required to support fisheries	WKFOOWI	Food webs	S? I	1.5	1	1.67	1.33	2	0.75	0.71	4	Peer reviewed, agreed, trophic transfer efficiency is needed for all species.
Changes in average trophic level of ma-	OSPAR 2017, WGBIODIV 2013	Food webs	S	1.75	1.25	1.75	1	1.25	0.70	0.61	4	Peer reviewed, agreed, trophic level is needed for all species and ages.

Name of candidate indicator	Publication reference	State and pressure 'box'	State, Pressure, Impact	Is based on mature, peer-reviewed science	Is connected to an expert group which can be asked to provide periodic updates	Is applicable for (almost) all ICES ecoregions	Is based on quality-assured data which will be available in the future	Is based only on open-source analysis software and on data which can be publicly shared (TAF compliance)	Operational score/max	Appropriate score/max	Number of persons scoring	Comments
rine predators (cf MTI)												
Reproductive success of marine birds in relation to food availability	OSPAR 2017/WGBIODIV 2013	Food webs	S	1.25	1.25	1.5	1.33	1	0.63	0.69	4	JWGBIRD to update this
Total mortality (equilibrium production/biomass)	WKFOOWI	Food webs	P?	1.33	1.5	1.5	1.5	0	0.58	0.75	3	
Annual breeding success of kittiwake	OSPAR 2017/WGBIODIV 2013	Seabirds	S	1.25	1.75	0.33	1	1	0.53	0.75	4	Limited geographic scope, a special case of the general indicator in the row above
Ecological Network Analysis indicator (e.g. trophic efficiency, flow diversity)	OSPAR 2017, WGBIODIV 2013	Food webs	S	1.5	0	2	0.33	0.67	0.45	0.40	4	Unclear which specific indicator is referred to here.

Name of candidate indicator	Publication reference	State and pressure 'box'	State, Pressure, Impact	Is based on mature, peer-reviewed science	Is connected to an expert group which can be asked to provide periodic updates	Is applicable for (almost) all ICES ecoregions	Is based on quality-assured data which will be available in the future	Is based only on open-source analysis software and on data which can be publicly shared (TAF compliance)	Operational score/ max	Appropriate score/max	Number of persons scoring	Comments
Productivity of key predators	WKFOOWI	Food webs	S	0.5	0	2	0.5	1	0.40	0.71	2	Need to identify key predators and measures of productivity. If based on mean weight at age and/or recruitment, operational following definition of key predators for assessed stocks
'Ryther index' [total catch presented on a unit area basis for an ecosystem]	Link, J.S. and Watson, R.A. 2019, WGECO 2020	Selective extraction of species	P	2	2	2	2	2	1.00	*1.00*	1	Total catch already given in Overviews
Fogarty index' [the ratio of total catches to total primary productivity in an ecosystem]	Link, J.S. and Watson, R.A. 2019, WGECO 2020	Selective extraction of species	I	2	0	2	0	0	0.40	*0.73*	1	Dependent on PP time-series, a PP plot only currently given in Overviews
'Friedland index' [the ratio of total catches	Link, J.S. and Watson, R.A. 2019,	Selective extraction of species	I	2	1	2	1	1	0.70	*0.73*	2	Dependent on Chlo time-series, can be determined by ERSEM/satellites

Name of candidate indicator	Publication reference	State and pressure 'box'	State, Pressure, Impact	Is based on mature, peer-reviewed science	Is connected to an expert group which can be asked to provide periodic updates	Is applicable for (almost) all ICES ecoregions	Is based on quality-assured data which will be available in the future	Is based only on open-source analysis software and on data which can be publicly shared (TAF compliance)	Operational score/max	Appropriate score/max	Number of persons scoring	Comments
to chlorophyll in an ecosystem as a proxy for Fogarty Index]	WGECO 2020											
Fishery selection pattern	Brunel and Piet 2013	Selective extraction of species	P	2	1	2	2	1	0.80	*0.89*	2	
By-catch rates of Chondrichthyes	OSPAR 2017, WGBIODIV 2013	Fish	P	1	2	2	1	0	0.60	0.52	1	International bycatch data required. Identical to sensitive species catch/abundance?
Changes of plankton functional types (life form) index Ratio	OSPAR 2017, WGBIODIV 2013	Plankton	S	1	1.5	1.5	1	1.5	0.65	0.54	2	
Change of plankton functional types (life form) index	OSPAR 2017, WGBIODIV 2013	Food webs	S	2	1.5	2	2	2	0.95	0.54	2	

Name of candidate indicator	Publication reference	State and pressure 'box'	State, Pressure, Impact	Is based on mature, peer-reviewed science	Is connected to an expert group which can be asked to provide periodic updates	Is applicable for (almost) all ICES ecoregions	Is based on quality-assured data which will be available in the future	Is based only on open-source analysis software and on data which can be publicly shared (TAF compliance)	Operational score/ max	Appropriate score/max	Number of persons scoring	Comments
Ratio [specific to Food webs]												
Changes in biodiversity index (s)	OSPAR 2017, WGBIODIV 2013	Plankton	S	1.5	1.67	2	1	2	0.82	0.44	2	
Biomass, species composition and spatial distribution of zooplankton	OSPAR 2017, WGBIODIV 2013	Food webs	S	2	2	2	0.5	1	0.75	0.57	2	
Changes in average faunal biomass per trophic level	OSPAR 2017, WGBIODIV 2013	Food webs	S	2	0	2	0	0	0.40	0.64	1	
Distributional range and pattern of grey and harbour seal haul-	OSPAR 2017, WGBIODIV 2013	Marine Mammals	S	2	2	2	2	2	1.00	0.67	1	

Name of candidate indicator	Publication reference	State and pressure 'box'	State, Pressure, Impact	Is based on mature, peer-reviewed science	Is connected to an expert group which can be asked to provide periodic updates	Is applicable for (almost) all ICES ecoregions	Is based on quality-assured data which will be available in the future	Is based only on open-source analysis software and on data which can be publicly shared (TAF compliance)	Operational score/ max	Appropriate score/max	Number of persons scoring	Comments
outs and breeding colonies												
Distributional range and pattern of cetaceans species regularly present	OSPAR 2017, WGBIODIV 2013	Marine Mammals	S	1.5	1.5	1	1	1.5	0.65	0.61	2	
Abundance of grey and harbour seal at haul-out sites	OSPAR 2017, WGBIODIV 2013	Marine Mammals	S	2	1.5	2	1.5	1.5	0.85	0.70	2	
Abundance at the relevant temporal scale of cetacean species regularly present	OSPAR 2017, WGBIODIV 2013	Marine Mammals	S	2	2	2	2	2	1.00	0.67	1	

Name of candidate indicator	Publication reference	State and pressure 'box'	State, Pressure, Impact	Is based on mature, peer-reviewed science	Is connected to an expert group which can be asked to provide periodic updates	Is applicable for (almost) all ICES ecoregions	Is based on quality-assured data which will be available in the future	Is based only on open-source analysis software and on data which can be publicly shared (TAF compliance)	Operational score/max	Appropriate score/max	Number of persons scoring	Comments
Harbour seal and Grey seal pup production	OSPAR 2017, WGBIODIV 2013	Marine Mammals	S	1.5	1.5	1	1	1.5	0.65	0.74	2	
Numbers of individuals within species being bycaught in relation to population	OSPAR 2017, WGBIODIV 2013	Marine Mammals	S	2	2	2	2	2	1.00	0.41	1	
Species-specific trends in relative abundance of non-breeding and breeding marine bird species	OSPAR 2017, WGBIODIV 2013	Seabirds	S	2	2	2	2	2	1.00	0.80	1	
Non-native/invasive mammal presence on is-	OSPAR 2017, WGBIODIV 2013	Seabirds	P	2	2	2	2	2	1.00	0.31	1	

Name of candidate indicator	Publication reference	State and pressure 'box'	State, Pressure, Impact	Is based on mature, peer-reviewed science	Is connected to an expert group which can be asked to provide periodic updates	Is applicable for (almost) all ICES ecoregions	Is based on quality-assured data which will be available in the future	Is based only on open-source analysis software and on data which can be publicly shared (TAF compliance)	Operational score/ max	Appropriate score/max	Number of persons scoring	Comments
land seabird colonies												
Mortality of marine birds from fishing (bycatch) and aquaculture	OSPAR 2017, WGBIODIV 2013	Seabirds	I	2	2	2	2	2	1.00	0.26	1	
Distributional pattern of breeding and non-breeding marine birds	OSPAR 2017, WGBIODIV 2013	Seabirds	S	1	2	2	2	2	0.90	0.65	1	

2 ToR e: Review WKEUVME workflow document to set regulatory options for protecting VME (vulnerable marine ecosystems) and ensuring fishing according to the European Union's deep-sea access regulation.

2.1 General remarks

WGECO was asked to review a workflow document for the delivery of advice options and their ability to protect vulnerable marine ecosystems (VME) while considering restrictions on fishing activities based on the 2009-2011 fishing footprint of NE Atlantic waters. The workflow document is a working document that will feed into the workshop WKEUVME. The workshop meetings of WKEUVME will provide the underlying technical work for ICES to respond to the European Commission's request to deliver "**advice on the list of areas where VMEs are known to occur or are likely to occur and on the existing deep-sea fishing areas (ref. (EU)2016/2336)**".

Specific tasks for WGECO to consider for the review included:

1. Suggest alternative options (if relevant) and/or improvements to the proposed workflow supported by relevant scientific literature. Does the workflow provide a set of technical criteria that can be used to propose a set of regulatory area options to managers?
2. Provide scientific input on how to analyse/present to managers the associated trade-offs between different areas selected. Can the trade-off analysis be used to prioritize 1) a list of areas where VMEs are known or are likely to occur, and 2) the existing deep-sea fishing areas (i.e. footprint 2009 to 2011)?
3. Consider previous ICES work and/or advice that may be relevant to the workflow related to the deep-sea access regulation.
4. Consider how the workflow can accommodate future updates of the assessment based on ICES VME and VMS data and data calls; consider whether the workflow can best conform to the ICES FAIR principles that data is fully documented.

2.2 Task 1. Suggest alternative options (if relevant) and/or improvements to the proposed workflow supported by relevant scientific literature. Does the workflow provide a set of technical criteria that can be used to propose a set of regulatory area options to managers?

WGECO agrees the workflow provides a set of steps that can be used to propose regulatory options to managers for setting up protections for VME. Two major strengths of the proposed workflow include: the best available data are being used, and the process for providing advice is inclusive and independent (neutral or nonbiased). However, we believe the workflow can be improved and have summarized major comments to point out sections of the workflow where and how improvements could be made. For the workflow to be accepted and implemented, it needs to be as clear as possible. Supporting references were included when applicable.

Major comments

Section 2 Workflow for the delivery of advice options and their potential to protect VMEs versus restrictions on fishing activities within the 2009-2011 fishing footprint.

The workflow comprises four steps:

1. VME presence
2. Fishing patterns
3. Precautionary Approach
4. Delineate Closed Areas

Steps 1 and 2 are part of risk assessment, while 3 and 4 are risk management. In Figure 2, we think that Steps 1 and 2 lead to 3, which leads to Step 4. For example, if the decision is risk prone (not precautionary) Step 1 wouldn't lead straight to Step 4. WGECO suggests revising Fig. 2 in a more conventional risk-assessment framework (see Figure 5.1 in NRC 2002).

Section 3 Data layers to address Step 1 of the workflow.

Absence of evidence is not evidence of absence with regard to VME presence. The areas without direct VME observations (termed "VME habitat") and VME evidence (termed "VME indicators") may also contain VMEs. WGECO notes the importance of this understanding for the formulation of the Precautionary Approach. The use of the VME categories in the report appears to be inconsistent. WGECO recommends WKEUVME to adhere to the VME terminology used by WGDEC (ICES 2019a). As an example, in Table 1, "VME database" refers to VME records that have a high degree of confidence, but in ICES 2019a, these were categorized as "VME habitat".

Section 3.1 Areas where Vulnerable Marine Ecosystem (VME) are known or likely to occur.

Text regarding species distribution models (SDM) is vague (lines 132+). The general discussion is useful, but specific models and their appropriateness were not discussed. How can workflow and a greater understanding for trade-offs occur without specifics if these models were to be used as planned? The understanding is that SDM review and selection will occur with a future workshop, but WGECO stresses the need for this process to occur in the near term. Although the data derived from SDMs will be given higher precautionary status, the areas identified will likely be of greater concern for stakeholders, have lower confidence in the spatial extent of VME, and warrant extraordinary support in order to implement regulatory options. The challenges presented in Table 5 (comments below) can be addressed with such tools, using real data that allow decision makers to select optimal areas for protection by exploring trade-offs between conservation objectives and the resource use.

Similarly, modelled habitat data as output from SDMs were unavailable at this stage. WKEUVME needs to be aware of inherent biases with this approach (e.g. inclusion/exclusion of data, model parameterization), and be able to account for them.

The precautionary approach (i.e. the new dimension added to the discussed measures in WKREG [ICES, 2019b]; lines 153+) is acceptable, but there appears to be much ambiguity in confidence of low-medium-high VME presence and in determination of data quality. What differentiates low and medium, and medium and high? Something more concrete should be developed or if available, presented so that managers and stakeholders clearly know what will result from these data rather than waiting to hear this area will be closed/not closed. It is suspected that stakeholders may wait to divulge any opinions about specific areas of interest unless it is clear a closure will occur due to VME proximity. WKEUVME acknowledges the ambiguity of these categories (line 332) and plans to discuss them at an upcoming meeting. WGECO asserts the need to clarify to the best extent possible differences between these categories prior to manager/stakeholder engagement. Furthermore, it is not clear how the attributes "data quality" and "confidence of VME presence" differ. As an example, it is hard to foresee VME data of poor quality to have high confidence in VME presence.

Figure 3 is confusing. It appears to be a mix of a number of concepts (relation between degree of precaution and data quality, and data products). The axes are disorienting and do not seem to align; thus, it is hard to visualize the connection between A/B and C in this figure. WGECO recommends that the A and B panels be removed and that panel C be replotted as data layers stacked vertically. This perspective is important because the data layers are cumulative, not independent

For 2009–2011 fishing data, the workflow document acknowledges these data may not accurately reflect historic impacts (lines 257–258). It is of concern that if left unknown, these historic fishing areas may become desirable following implementation of closed areas (fishing displacement) and may overlap with unobserved VME habitat. It is also possible that new fishing areas may develop as a result of fishing displacement (acknowledged in lines 308+) and it is worthwhile to note WKEUVME is actively considering this consequence. With regulatory checks limiting fishing outside of the existing footprint (Regulation 2016/2336 Article 8; e.g. requirement of impact assessment to protect VME habitat in new or historic fishing grounds) it should be a priority of the proposed workflow to reduce inefficiencies in granting access to stakeholders where appropriate.

Section 4.1.4 What are the main fisheries (and gears) affecting the bottom and potentially impacting VMEs in the 400 – 800 m depth?

Use of gear other than mobile bottom trawls (i.e. pelagic trawls on seamounts) can have benthic impacts (see McConnaughey *et al*. 2020) and is worth including/examining for fishery/VME overlap. Additionally, for future considerations, the pelagic habitat above seamounts with localized communities is also particularly vulnerable to fishing (Ramirez-Llodra *et al*. 2011). The workflow document acknowledges a need to measure fishing intensity of other gears that may impact benthic habitat but is currently unable to develop SAR for non-bottom gear (lines 295+). It is acceptable to know that WGSFD is in the process of developing such methods. WGECO stresses and supports WKEUVME's need to include all possible gears with impact to the benthos to ensure any ongoing fishing (400-800 m) outside of the existing mobile bottom fishing gear specified is not ignored.

Fig. 8. Categories of fishing pressure. Note that fishing effort within a C-square is patchy so parts of a C-square will have a much higher SAR. Within a C-square, the distribution of effort at smaller scales (e.g. 1km^2, would follow something like a negative binomial distribution). The consequence is that within a C-square there is a range of unfished to heavily fished habitat.

The Trawling Best Practices group defined VME taxa as those with a critical trawling intensity of F=0.35, defined as Fcrit = R/d = 0.35, where R is the recovery rate and d the depletion rate per tow. E.g. if R=0.1, d=~0.3; R=0.2, d=~0.6. These recovery rates correspond to taxa with longevities of 25 and 50 years. F is equivalent to the swept area ratio, providing a link between fishing pressure and vulnerability.

Line 325: Most of the region is either fished or unfished. Can there be a third option? This statement seems unnecessary.

Section 4.2 Overlap between VMEs and Fishing

If the C-square is the resolution at which fishing effort data are collected, is it really possible to fine-tune the decisions on whether or not all or part of the C-square could remain open (Step 4.2)?

Table 4 seems to mix precaution with VME data quality, which is confusing. What is meant by most? More than half? We advise adding clarity here to maintain proposed workflow.

Section 4.3 Possible Management Actions for Protecting VMEs

Table 5 has separate columns for Confidence of VME and Degree of Precaution, which is appropriate. But the actions need to become more concrete for an actual trade-off analysis (see Task 2 below). How many closed areas? How big a closed area? Which countries and fleets are affected, what VME species are protected?

Section 5.1 Implementing buffer zones

Buffers around closed areas offer added insurance of minimizing illegal fishing; however, they have been shown to have variable effectiveness given their objectives (to allow some fishing vs to prevent illegal fishing; see Pérez-Ruzafa *et al*. [2017] and references therein). In the workflow, buffer zones of approximately 1 km and 1.5 km were proposed for flat seabed (line 436). This seems minimal and possibly insufficient relative to C-square size as other areas have imposed 3.7 km to minimize illegal fishing effects for research purposes (e.g. Link *et al*. 2005; Smith *et al*. 2013). Variable buffer sizes by depth may also prove difficult for fishers to navigate. For seabed with geomorphological features (line 438+), no buffer was deemed necessary which seems to be in contrast to the objectives and advice (ICES 2018a). As referenced in the workflow document, ICES (2013) suggests the proposed buffer plan is acceptable for ICES, but provides no basis for the specified buffer size.

In 2018, ICES (2018a) advised that buffers are required in all cases and that the buffer around VME closures should have a width of at least twice the water depth. It will be important that ICES is not seen to change its advice on buffers without a clear basis, but this basis seems unclear.

For the implementation of buffers, it wasn't clear how they would be applied (by partial C-square or other scale?). As an example, are VMEs with a buffer area enclosed within a C-square or do they stand on their own? In the latter scenario, there would be two types of area closures, buffer areas and C-squares. One would assume that C-squares would thus include records of VME indicators which have no accurate position. If the boundary of the buffer area does go beyond the boundary of the C-square, would that square be assigned as having a VME?

2.3 Task 2. Provide scientific input on how to analyse/present to managers the associated trade-offs between different areas selected. Can the trade-off analysis be used to prioritize 1) a list of areas where VMEs are known or are likely to occur, and 2) on the existing deep-sea fishing areas (i.e. footprint 2009 to 2011)?

Garcia (1996) defined the **precautionary approach** as "a set of agreed cost-effective measures and actions, including future courses of action, which ensures prudent foresight, reduces or avoids risk to the resources, the environment, and the people, to the extent possible, taking explicitly into account existing uncertainties and the potential consequences of being wrong." Application of the precautionary approach is appropriate for VMEs given the large uncertainties associated with their distributions, and the vulnerability, longevity, and growth rates of VME taxa. However, the degree of precaution should not be conflated with data quality because these are two different steps in the risk analysis. Evaluating data quality is part of risk assessment, whereas deciding the degree of precaution is part of risk management.

Table 5 provides a conceptual starting point for trade-off analysis in that it contains some of the elements required for risk assessment: a set of actions, measures of fishing intensity, confidence of VME presence, and degree of precaution applied in decision making. But this table is too vague for actual trade-off analysis (e.g. "Consider Closed Area" is really inaction). The actions need to be more concrete, as discussed in the next paragraph. It is helpful to have a small number of proposed actions (~5), ranging from no action (status quo) to actions with larger closed areas or number of closed areas. Having a finite set of actions helps to focus discussion, after which the actions can be modified or amended. To convert Table 5 to a decision table, the Actions would be columns and the rows would be the consequences of each action, including the amount of VME protected and the fisheries impacted (e.g. Fig. 5b in Fulton *et al*. 2015).

To be more concrete, the actions need to specify the number of C-squares closed (as polygons) as in Figure 13, which provides a hypothetical data product. To fully inform trade-off analysis, the ancillary information required for each C-square inside a closed area includes, which VME species are present (with degree of confidence), which countries, fleets and métiers fish in that area, and what was the average revenue during a reference time period? Given these metrics, a decision support tool (DST; e.g. MARXAN) could be used to identify combinations of C-squares that provide "least-cost solutions" (Collie *et al*. 2013). While the result of an algorithm is unlikely to become the chosen action, it helps to quantify the trade-offs and for stakeholders to specify their degree of precaution (risk aversion). The ICES spatial tool could be extended to become a dynamic DST.

Software-based DSTs, e.g. MARXAN and Zonation, are very useful to explore and evaluate trade-offs during the spatial prioritization process, weighing different resource needs and conservation objectives. WGECO believes it is important to develop an interactive web-based platform which would allow decision makers and scientists to explore the outcomes of a range of various management actions using DSTs. This tool would incorporate data obtained in the WKEUVME workflow, such as maps of VME occurrence with associated degree of confidence (ranging from real data to outputs from species distribution models) and fishing effort. The analysis would be carried out open source, similar to the current TAFs[3] established at ICES. Fully integrating DSTs into the WKEUVME workflow would thus facilitate the decision-making process.

2.4 Task 3. Consider previous ICES work and/or advice that may be relevant to the workflow related to the deep-sea access regulation.

The EU enacted new legislation on regulating access to deep-sea fisheries in 2016 (EU) 2016/2336). This builds on a previous regulation (EU 734/2008). The main provisions of the Regulations are as follows:

- Its terms refer to specified "bottom" gears in EU waters. Bottom gears include bottom trawls, dredges, bottom-set gillnets, bottom-set longlines, pots and traps (Regulation 734/2008 Article 1);
- The Regulations apply to fisheries with bottom gears operating at depths of > 400 metres (Regulation 2016/2336 Article 9);
- Deep sea fishing authorizations to use any bottom gears may normally be granted only for fishing activities within the areas that were fished with bottom gears during the pe-

[3]http://ices.dk/marine-data/assessment-tools/Pages/transparent-assessment-framework.aspx

riod 2009-2011 (the fisheries "footprint"). Outside of the fisheries footprint, deep-sea fishing authorizations to use any bottom gears may be granted only if an impact assessment demonstrates that the protection of VMEs will not be compromised (Regulation 2016/2336 Article 8);

- Bottom trawling at depths >800 metres is prohibited in all areas (inside and outside the footprint) (Regulation 2016/2336 Article 9);
- Implementing acts to establish a list of areas where VMEs are known to occur or are likely to occur should have been drawn up by 13 January 2018 in order to prevent significant adverse impacts of VMEs in those areas (Regulation 2016/2336 Article 9). The list of areas is subject to annual review.

Two important aspects of the 2016 regulation are outstanding, namely the establishment of a list of areas where vulnerable marine ecosystems (VMEs) are known to occur or are likely to occur and the determination of the existing deep-sea fishing areas, the so-called "fishing footprint". ICES was asked to gather data and information to help determine the two aspects. ICES informed the Commission of its capacity to produce a complete technical service by the end of 2019 leading to final advice in 2020. This service would form the basis for the Commission to adopt the implementing regulation fixing the fishing footprint and the list of VME locations.

The process to begin the technical service, started with an ICES workshop (WKREG, ICES, 2019b). The workshop reviewed the data and information on the fishing footprint (2009-2011) and the location of VMEs, and considered a potential tool for supporting transparent decision making in future. The strengths and weaknesses of this decision support tool were identified along with identified summary of the information content required for implementation. The group also outlined a framework whereby a range of closed area options could be given to managers and stakeholders to consider under different protection and management scenarios, to facilitate future decision making.

Previous advice and technical work

In 2018, ICES provided advice in response to an EU request on the deep-sea bottom fisheries footprint, for depths of 200 m and greater, based on VMS and logbook data for the years 2009–2011 (ICES, 2018a). This footprint is missing information from some fleets as some data were not supplied to ICES. ICES also advises on where this footprint is bisected by the 800 m depth contour, below which bottom trawling shall not be permitted under the EU deep-sea access regulation (EU) 2016/2336. This advice was based on incomplete data. This advice was the first use by ICES of a prototype decision support tool (ICES, 2018b). Spanish data (in EU waters) and some other countries (outside EU waters) were completely absent from the initial 2018 footprint advice.

Also in 2018, ICES provided an updated Technical Service (ICES, 2018c) to the EU as follow-up to the above advice. The new information included some data for Spanish and Portuguese vessels with VMS <15m for 2009–2011. Interactive maps showing the fisheries pressure and VME presence were provided with a number of selectable layers to aid in the interpretation of the ICES advice and implementation process of the deep-sea access regulation. The issue of "islands" or squares with no fishing effort surrounded by those with effort was addressed by providing options.

In addressing this request ICES noted that the fisheries footprint referred only to vessels using bottom gears at depths >400 metres. Vessels using pelagic gears or vessels operating in depths < 400 metres are excluded from the footprint, even though they may have some impact on VMEs. Moreover, since the use of all bottom gears are prohibited outside the fisheries footprint, ICES assumed that the request to identify known or likely VME areas refers only to VME areas within the fisheries footprint. This interpretation could be problematic if there will be future applications to fish outside the footprint. This may not be a problem if such requests supply evidence of absence of VMEs. However, absence of evidence should not be construed as evidence of absence.

Also it is difficult to closely describe the bottom-fisheries footprint for different depth bands. For example, to select C-squares where bottom fishing is occurring > 800 m the 800 m depth contour can be, in most cases, delineated easily. However, some C-square grid cells would inevitably be crossed by the contour line, and parts of the grid square that were transacted may thus be misclassified. This results in spatial overestimating of fishing pressure at the regional scale. C-squares, where fishing occurred in areas ≥800 m depth were displayed as the fishing activity footprint.

In 2019 ICES produced an updated Technical Service (ICES 2019c) comprising maps with the deep-sea (≥ 800 m depth) fishing footprint for all bottom-contacting gears, and a set of coordinates for the three largest deep-sea fishing areas. ICES also provided a list of areas where VMEs either occur or are likely to occur, with a set of coordinates for the three largest VME areas in the Northeast Atlantic. In addition to static PDF maps, interactive maps showing the same information with a number of selectable layers were provided to the European Commission. Furthermore, ICES provided the data to the European Commission, as .csv files, the full coordinates of all 2009–2011 deep-sea fishing areas, and also of areas where VMEs occur or are likely to occur. Certain datasets are missing. For instance, pelagic trawls are known to interact with the bottom in some cases, but these are not included.

Decision Support Tools and associated work

As stated above, ICES presented a method (ICES, 2018b) to identify VMEs in relation to fishing, that may be used as a basis for implementing the habitat protection aspects of regulation EU 2016/2336. This approach is a simple method of presenting fishing footprint by C-square in relation to current knowledge of VME presence (not absence because extent of zero values is unknown). The strength of the tool is that it allows visualisation of the two main data sets (VMS/SAR and VME) available to ICES. These are the only available data at present to answer the EU request. The tool is thus a pragmatic approach to the problem. The weakness of the tool is that it does not provide a robust decision support framework for managers/stakeholders to deliberate on a set of closures by way of trading off the various competing parameters of concern.

Because it is unknown which areas do have VMEs present, any closures within the 2009-2011 footprint could displace effort into hitherto unfished areas within the footprint. An additional concern is that the proposed workflow may not be future proof to applications to fish outside the footprint. According to the regulation, such applications should be accompanied by studies to show no impact on VMEs. There is a danger that the absence of evidence of VMEs illustrated in the current ICES (2018b) spatial tool, could be misconstrued as evidence of absence.

The approach taken by ICES has been not to present the fisheries activity by country/gear type etc. This functionality could be implemented for decision support if managers or stakeholders need to know which fleets are impacted by a proposed closure.

Habitat modelling

Currently the ICES VME advice is based on two types of information only:

- VME habitat data, which refers to high quality visual records from e.g. UWTV surveys
- VME indicator data, which refers to other records of VMEs, from e.g. by-catch in survey trawls.

This type of information is included in the ICES VME weighting algorithm. At present, marine habitat modelling is not used to predict VME presence in an operational advice context. The ICES Working Group on Deep Sea Ecology (WG with responsibility for VME mapping) and the Working Group on Marine Habitat Mapping are planning a joint approach to this issue. However, work is at an early stage. The approach outlined in the workflow document is a pragmatic first step in the process of answering the advisory requirements of the deep-sea access regulation. However, for the future, modelling of VME likelihood is required. This is particularly the case to identify areas of likely non-occurrence of VMEs.

2.5 Task 4. Consider how the workflow can accommodate future updates of the assessment based on ICES VME and VMS data and data calls; consider whether the workflow can best conform to the ICES FAIR principles that data is fully documented.

ICES has produced extensive general guidelines with respect to best practices of data management (ICES 2019d). These centre on the FAIR principles that ensure the data are:

Findable (through documentation and metadata)

Accessible (through clarity on licensing, formats, and the data policy)

Interoperable (through extended use of shared reference systems and services)

Reusable (by having known data quality and good documentation).

ICES has also prepared more specific guidelines on collection and extraction of data and analyses that could be relevant to the WKEUVME workflow, such as VME and VMS data. Annually, ICES sends out data calls to the member states to request new data on VME occurrences. These data are stored in a central database maintained by WGDEC. Specific guidelines were produced that describe the scope, rationale and technical details of the VME data call and use of the data (e.g. ICES 2020a). Comparable guidelines were provided for annual VMS data calls (e.g. ICES 2020b). ICES has also produced specific guidelines for data management and analysis of VMS data (e.g. ICES 2019e). Specific guidelines can also be prepared in response to Special Request Advice for a single assessment process. As an example, ICES (2019f) describes the data management workflow for specific tasks related to the seafloor integrity indicator.

ICES has also developed Transparent Assessment Frameworks (TAFs), which are online open resource of ICES stock assessments for each assessment year. In these frameworks, data can be fed in from the ICES database or other sources which allow a range of analysis to be carried out and the assessment data, methods, and results available online. Such open frameworks make the data, methods and results from stock assessments easy to locate, explore, and re-analyze. All R-code used for analysis is stored centrally (GitHub) and thus the reproducibility of analysis can be ensured.

WGECO suggests to operationalize the WKEUVME workflow, it should adopt the FAIR principles. We recommend that the data management of the workflow should be open source and reproducible, using methodology and approaches similar to the TAFs. Such data management structure would provide the essential platform to ensure accommodation of future data updates and reproducibility with respect to data analyses. As an example, the outputs from species distribution models are likely to be of greater importance in assessment work in coming years, and these outputs should be fully supported by regular data calls and have specific workflows. As stated above under Task 2, WGECO recommends developing an interactive web-based platform where Decision Support Tools are used to explore the various consequences of a range of proposed management actions.

2.6 References

Collie, J.S., W.L. Adamowicz, M.W. Beck, B. Craig, T.E. Essington, D. Fluharty, J. Rice, and J.N. Sanchirico. 2013. Marine spatial planning in practice. Estuarine, Coastal and Shelf Science 117:1-11.

Fulton, E.A., Bax, N.J., Bustamente, R.H., Dambacher, J.M., Dichmont, C. *et al*. 2015. Modelling marine protected areas: insights and hurdles. Philosophical Transactions of the Royal Society B. 370: 20140278.

Garcia, S.M. 1996. Precautionary approach to fisheries. Part 2: scientific papers. Prepared for the Technical Consultation on the Precautionary Approach to Capture Fisheries (Including Species Introductions). Lysekil, Sweden, 6–13 June 1995. FAO Fisheries Technical Paper. No. 350, Part 2. Rome, FAO. 1996. 210p.

ICES 2013. General Advice. Evaluation of the appropriateness of buffer zones. Special request Advice June 2013, 1.5.5.2 ICES Advice Book 1, 2 pp.

ICES. 2018a. Advice on locations and likely locations of VMEs in EU waters of the NE Atlantic, and the fishing footprint of 2009–2011. *In* Report of the ICES Advisory Committee, 2018. ICES Advice 2018, sr.2018.10. 12 pp. https://doi.org/10.17895/ices.pub.4429.

ICES. 2018b. Documentation of the processing, review and production of data products for ACOM's Vulnerable Marine Ecosystems Advice Drafting Group (ADGVME), 14 June 2018, Copenhagen, Denmark. DOI: https://doi.org/10.17895/ices.pub.4430.

ICES. 2018c. EU request to provide a further technical service to aid in the interpretation of ICES advice on locations and likely locations of VMEs in EU waters of the NE Atlantic, and the fishing footprint of 2009–2011 (sr.2018.10). *In* Report of the ICES Advisory Committee, 2018. ICES Advice 2018, sr.2018.28. 10 pp. https://doi.org/10.17895/ices.pub.4645.

ICES 2019a. ICES/NAFO Joint Working Group on Deep-water Ecology (WGDEC). ICES Scientific Reports. 1:56. 119pp.http://doi.org/10.17895/ices.pub.5567

ICES 2019b. Stakeholder workshop to disseminate the ICES deep-sea access regulation technical service, and scope the required steps for regulatory purposes (WKREG). ICES Scientific Reports. 1:ISS NO. 31 pp. http://doi.org/10.17895/ices.pub.5636

ICES 2019c. EU request to provide an update on the list of areas where VMEs are known to, or likely to occur, and on the existing deep-sea fishing areas for 2009–2011. In Report of the ICES Advisory Committee, 2019. ICES Advice 2019, sr.2019.19. 14 pp. https://doi.org/10.17895/ices.advice.5597

ICES 2019d. ICES User Handbook: Best practice for Data Management. 12pp. http://doi.org/10.17895/ices.pub.4889

ICES 2019e. Guidelines for the VMSdatacall_proposedWorkflow.r. (ver. 2, 5 February 2019). http://doi.org/10.17895/ices.pub.4705

ICES 2019f. EU request to advise on a seafloor assessment process for physical loss (D6C1, D6C4) and physical disturbance (D6C2) on benthic habitats. ICES Special Request AdviceEU ecoregions. Published 5 December 2019

https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2019/Special_Requests/eu.2019.25.pdf

ICES 2020a New information on Vulnerable Marine Ecosystems (VME) in the North Atlantic from ICES member countries. Our Ref: H.4/NH/ACB/LS/av30 January2020

https://www.ices.dk/sites/pub/Publication%20Reports/Data%20calls/data-call.2020.WGDEC_VME_data.pdf

ICES 2020b. Data call: VMS/Log book data for fishing activities in the North East Atlantic and Baltic Sea for the provision of ICES advice on the spatial distribution and impact of fisheries 2009 to 2019.

H.4/NH/AB/av. 5 February 2020. https://www.ices.dk/sites/pub/Publication%20Reports/Data%20calls/datacall.2020.VMS_LogBook_data.pdf

Link, J., Almeida, F., Valentine, P., Auster, P., Reid, R., and Vitaliano, J. 2005. The effects of area closures on Georges Bank. In: Barnes PW, Thomas JP (eds) Benthic habitats and the

effects of fishing. American Fisheries Society Symposium 41. American Fish Society, Bethesda, MD, p 345–368.

McConnaughey, R.A., Hiddink, J.G., Jennings, S., Pitcher, C.R., Kaiser, M.J., Suuronen, P., Sciberras, M., Rijnsdorp, A.D., Collie, J.S., Mazor, T., Amoroso, R.O., Parma, A.M., and Hilborn, R. 2020. Choosing best practices for managing impacts of trawl fishing on seabed habitats and biota. Fish and Fisheries, 21:319–337.

National Research Council. 2002. Effects of trawling and dredging on seafloor habitat. National Academy Press, Washington, D.C. 126 pp.

Pérez-Ruzafa, A., Garcia-Charton, J.A., and Marcos, C. 2017. North East Atlantic vs. Mediterranean Marine Protected Areas as Fisheries Management Tool. Frontiers in Marine Science, 4:245.

Ramirez-Llodra, E., Tyler, P.A., Baker, M.C., Aksel Bergstad, O., Clark, M.R., Escobar, E., Levin, L.A., Menot, L., Rowden, A.A., Smith, C.R., and Van Dover, C.L. 2011. Man and the last great wilderness: Human impact on the deep sea. PLOS One, 6: e22588.

Regulation (EC) No 734/2008 of 15 July 2008 on the protection of vulnerable marine ecosystems in the high seas from the adverse impacts of bottom fishing gears.

Regulation (EU) 2016/2336 of the European Parliament and of the Council of 14 December 2016 establishing specific conditions for fishing for deep-sea stocks in the north-east Atlantic and provisions for fishing in international waters of the north-east Atlantic and repealing Council Regulation (EC) No 2347/2002.

Smith, B.E., Collie, J.S., and Lengyel, N.L. 2013. Effects of chronic bottom fishing on the benthic epifauna and diets of demersal fishes on northern Georges Bank. Marine Ecology Progress Series, 472:199–217.

Annex 1: List of participants

Name	Institute	Country	E-mail
Anna Rindorf	DTU Aqua - National Institute of Aquatic Resources	Denmark	ar@aqua.dtu.dk
Brian Smith *Chair*	NOAA Fisheries Woods Hole	USA	Brian.smith@noaa.gov
Chris Lynam	Centre for Environment, Fisheries and Aquaculture Science Lowestoft Laboratory	UK	chris.lynam@cefas.co.uk
David Reid	Marine Institute Rinville	Ireland	David.Reid@Marine.ie
Elena Eriksen	Institute of Marine Research	Norway	elena.eriksen@hi.no
Ellen Kenchington	Fisheries and Oceans Canada Bedford Institute of Oceanography	Canada	Ellen.kenchington@dfo-mpo.gc.ca
Fatima Borges	Portuguese Institute of Sea and Atmosphere	Portugal	mfborges@ipma.pt
GerJan Piet	Wageningen University	Netherlands	gerjan.piet@wur.nl
Jeremy Collie	University of Rhode Island, Graduate School of Oceanography	USA	jcollie@uri.edu
Maurice Clarke	Marine Institute Rinville	Ireland	Maurice.Clarke@marine.ie
Murray Thompson	Centre for Environment, Fisheries and Aquaculture Science Lowestoft Laboratory	UK	murray.thompson@cefas.co.uk
Stefán Áki Ragnarsson	Marine Research Institute of Iceland	Iceland	steara@hafro.is
Tobias van Kooten *Chair*	Wageningen University	Netherlands	tobias.vankooten@wur.nl

Annex 2: Resolutions

2019/OT/HAPISG05 The **Working Group on the Ecosystem Effects of Fishing Activities (WGECO),** chaired by Tobias van Kooten, NL and Brian Smith, USA, will meet by correspondence, 31 March–7 April 2020 to:

a) Investigate the ecological consequences of stock rebuilding, with particular emphasis on benthivorous fish and invertebrates.

1) Make first-order estimates of predation pressure on benthos;
2) Examine evidence of food limitation and density-dependent growth;
3) Compare the footprints of trawling to the footprints of predation pressure on benthos.

b) Apply spatial distribution indicators to survey data (fish and benthos) across marine ecosystems. Analyse temporal trends in spatial indicators in relation to potential drivers and pressures (e.g. climate change, abundance changes).

c) Conduct a "reality check" and horizon scanning survey within WGECO. The aim is to develop a consensus view of the major emerging issues in relation to fisheries and ecosystems, and on which WGECO could focus future work. WGECO members will provide a list of emerging issues (horizon scanning), that would benefit from scrutiny by WGECO. This list will be collated and used as material for a plenary discussion, and with the aim of producing a perspectives paper in the ICES JMS or Fish and Fisheries.

d) Prioritize indicators (one or more than one) from a set of indicators from current and earlier work by WGECO or its participants (including particularly those from ToR d of WGECO 2018), which can be estimated on a routine basis and are applicable across several ecoregions. For each prioritised indicator, supply a short explanatory text for justification of the prioritization, identify the required steps to operationalize their use in the ICES fisheries and/or ecosystem overviews, and outline how WGECO or ICES can support their implementation over the next three years.

e) WGECO to review a working document describing a workflow to be used by WKEUVME to propose a set of regulatory area options ensuring VME (vulnerable marine ecosystems) protection and fishing in line with EU's deep-sea access regulation. Suggest alternative options (if relevant) and/or improvements to the proposed workflow supported by relevant scientific literature. The review should also provide scientific input on the associated trade-offs between the different regulatory area options, with respect to how area closures will ensure VME protection and how the closures will affect fisheries (e.g. spatial footprint and intensity of bottom fishing). The review should be done in the context of the established ICES VME and VMS (vessel monitoring system) / logbook data (respective data calls) that serve as the required input to operationalize the workflow and any subsequent updates.

WGECO will report by 30 April for the attention of ACOM.

Supporting Information

Priority	The current activities of this Group will enable ICES to respond to advice requests from member countries. Consequently these activities are considered to have a very high priority. It will also lead ICES into issues related to the ecosystem affects of fisheries, especially with

	regard to the application of the Precautionary Approach. Consequently, these activities are considered to have a very high priority.
Scientific justification	Term of Reference a) Many stocks are rebuilding and will likely have higher abundance and biomass than we have seen in recent times. This in turn will likely have effects through trophic interactions both up and down the foodweb. At ICES, WGECO and WGSAM have been tasked previously with similar ToRs. WGECO will investigate the potential consequences of stock recovery of benthivorous fish and invertebrates, their ensuing risks for fish stock management and the use of MSFD indicators. It is hypothesized that a large increase in benthivorous fish will have an impact on benthic productivity and biodiversity. This ToR requires data on the spatial distribution of benthivorous predators, their prey consumption rates and diet composition. It also requires data on the abundance and production of benthic faunal. This ToR links to ToR c. Term of Reference b) WGECO has traditionally had a leading role in developing and testing indicators, and their use for provision of advice. The work of this ToR facilitates operationalization of these indicators, by identifying data sources, refining, evaluating their strengths and weaknesses and gaps in indicator availability. Indicators that are evaluated to be promising will be applied to fish and benthic invertebrates species in the ICES region. Term of Reference c) The ICES Strategic Plan seeks to incorporate a wider range of scientific knowledge into advice to inform decision-makers and society about the state of our seas and oceans, the consequences of human use, and option for conservatoin and mangement. This ToR will allow WGECO to contribute strongly to the development of future ICES strategy. We intend to seek input across the national and disciplinary range of WGECO members, many of whom are operating at a high level in the field and in the home institutes. We aim to publish the results of this initiative as a perspective paper in one of the key journals, and this will be available to inform future progress for this important and centrally positioned Expert Group. Term of Reference d) WGECO has over consecutive years (e.g. 2016, 2017 and 2018) proposed and reviewed indicators. For ICES producing a set of quantative indicators linked to exsiting data, that can be estimated on a routine basis and are applicable across several ecoregions is of high priority. Given the overaching role of the group, WGECO is in a good position to provide steer in term of a priority set of indicators using criteria (see e.g. Rice and Rochet 2005 or WGBIODIV 2015 on OSPAR indicators). This TOR also offers WGECO or ICES the opportunity to work in a structured fashion over a 3 year period towards operationalizing a set of prioritized indicators for use in ICES advice products, namely for the ICES fisheries and/or ecosystem overviews. Term of Reference e) During their previous meeting at ICES HQ (8–16 April 2019) WGECO provided initial input on an EU DGMARE request to ICES relating to the EU's Deep Sea Access Regulations. The suggested ACOM approved process (phase 1 and phase 2) is designed to ensure ICES's scientific integrity while at the same time ensuring required dialogue with the managers so that what ICES can offer (in terms of data, VMEs and VMS) can contribute towards the deep sea access regulation for regulatory purposes. WGECO offered to provide further scientific input during their 2020 meeting as a review of the workflow and the set of criteria to propose a set of regulatory area options to managers. More specifically to provide scientific input on the associated trade-offs between different areas selected (an integral part of Phase 2). As such, WGECO is tasked to review a working document describing a workflow to be used by WKEUVME to come up with a set of regulatory area options using available ICES data. Specifically, WGECO is tasked to: • review the working document to provide input on whether the suggested workflow to identify regulatory areas options is suited for management purposes, and, in line with previous ICES work related to the deep-sea access regulation;

	• suggest alternative options (if relevant) and/or improvements to the proposed workflow supported by relevant scientific literature • provide scientific input on how to best estimate for each of the regulatory area options, how area closures will ensure VME protection and how the closures will affect fisheries (e.g. spatial footprint and intensity of bottom fishing). • consider how the workflow can accommodate future updates of the assessment based on ICES VME and VMS data and data calls; • consider whether the workflow can best conform to the ICES FAIR principles that data is fully documented

Resource requirements	The research programmes which provide the main input to this group are already underway, and resources are already committed. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants	The Group is normally attended by some 20–25 members and guests.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to advisory committees	There are no current direct linkages with the advisory committees.
Linkages to other committees or groups	There is a very close working relationship with the groups of the Fisheries Technology Committee, JWGBIRD, BEWG, WGBIODIV, WGBYC, WGFBIT and WGSAM.
Linkages to other organizations	OSPAR, HELCOM