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Report of the Workshop on guidance on how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats (WKFBI)

31 May–1 June 2016

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Executive summary

The Workshop on guidance on how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats (WKFBI), chaired by Adriaan Rijnsdorp (the Netherlands), met at ICES Headquarters on 31 May1 June 2016. The Workshop was attended by 28 participants from 10 countries, including representatives from various ICES Working Groups, two representatives from the fishing industry and one from DG Environment. The task of the workshop was to evaluate the information that is required to assess the state of seabed habitats (high resolution data on the trawling intensity by métier, maps of seabed habitats, information on the sensitivity of seabed habitats for bottom-trawling pressure) and prepare a guidance document on how fishing pressure can be used to develop indicators of the state of seabed habitats.

The workshop was prepared by a group of experts and chairs from WGDEC Working Group on Deep-water Ecology, BEWG Benthos Ecology Working Group, WGMHM Working Group on Marine Habitat Mapping, WGSFD Working Group on Spatial Fisheries Data, and supported by an ICES professional officer to organize the required building blocks and carry out the subsequent impact analysis required for WKFBI. In addition to evaluating material prepared by ICES Working Groups, the WKFBI compared a selection of similar approaches developed within European-funded projects (BENTHIS) and regional seas conventions (BH3).

Maps of trawling intensities (surface and subsurface abrasion), based on VMS and logbook data taking account of the differences in the footprint across métiers, are presented for surface and subsurface abrasion from all bottom-trawl métiers, as well as for the main fishing gears separately (otter trawl, demersal seine, beam trawl, dredge). Maps cover the European seas ranging from the Iberian peninsula in the south to the Norwegian Sea in the north and the Baltic Sea in the east at a resolution of 0.5° by 0.5° (c-square). A unified habitat map for the entire study area was generated based on the 2016 interim EMODNET maps.

Habitat sensitivity was estimated using the categorical approach developed in the UK (MB0102). Sensitivity depends on the **resistance** of the receptor (species or habitat feature) and the ability of the receptor to recover (**resilience**). For each habitat resistance and resilience was estimated of a selection of key and characterizing species based on scientific evidence by experts. Because the sensitivity scoring used the MB0102 benchmark of medium physical pressure which is not related to a specific trawling intensity, trawling intensity classes were arbitrarily set. The sensitivity scoring for the shelf habitats (0-200m) was carried out by BEWG, the scoring for the deep-sea habitats was done by WGDEC. Because of the lack of data on deep-sea habitats, in particular the occurrence of biogenic habitats, WGDEC adopted a precautionary approach and classified all deep-sea habitats as highly sensitive. For the shelf habitats, habitat sensitivity increased from low to medium for surface abrasion to medium to high for subsurface abrasion. Pilot maps with the surface and subsurface abrasion were generated based on the categorical approach and compared to maps of trawling impact estimated using the mechaniztic approach developed by FP7-project BENTHIS providing an impact score on a continuous scale.

All results of the different analyses should be considered preliminary. The purpose of the impact analysis exercise for WKFBI was to go through all stages of the process in order to detect potential problems and evaluate and compare the strength and weaknesses of the various approaches. One inherent challenge with the expert judgement

approach considered is that it is difficult to interpret the differences in trawling impact in quantitative terms as both sensitivity and trawling intensity are categorical. Methods such as developed in BENTHIS provide a quantitative estimate of the impact on a continuous scale. These methods, however, are still under development and the uncertainty of the impact estimates have not been determined nor has the sensitivity of the methods been investigated. The quantitative methods do provide a promising approach to derive the scientific basis to assess the impact of trawling on the state of the seabed. The first results presented in this report are already useful to relate the class-boundaries used in the categorical method with the estimated impact based on the approaches relating longevity and the population dynamics to the respective trawling intensity.

All methods explored in this report provide estimates of the trawling impact on the benthic community at the level of the grid cell. In addition to pressure indicators such as the trawling footprint (surface area or proportion of a management unit or habitat) trawled, or the indicator for the degree of aggregation (such as the proportion of the footprint where 90% of the total fishing effort occurs), the estimates of trawling impact can be aggregated to a metric that reflects the trawling impact or seabed integrity at the level of the habitat or management area.

By applying a methodology that develops matrices of habitat sensitivity in relation with trawling pressure allows a consistent assessment of the relative impact of bottom trawling across different habitats taking account of the estimated trawling intensities of the surface and subsurface seabed. Applying the same classification criteria over time means that changes in trawling impact can be assessed. If a benchmark has been set, for instance in terms of the surface area of a particular habitat or management area that is impacted less than a predefined level, changes in trawling impact can be compared to the benchmark (both in space and time). Scientific effort is needed to further investigate possible benchmark and threshold settings for an appropriate assessment.

An inherent challenge is how to deal with impact across consecutive years. If an area is trawled its subsequent sensitivity will change, i.e. if a previously disturbed site is trawled again it may be impacted less (vulnerable species/habitats have not yet recovered) and can therefore be viewed as more resilient to additional trawling disturbance. Similarly a challenge will be to interpret the implications of the heterogeneity in trawling and its effect on habitat fragmentation on the recovery, which will depend on the amount of undisturbed communities in neighbouring areas acting as sources of new recruitment to disturbed areas.

In the context of MSFD purposes there is first a need to assess whether there is impact (from the pressure, Article 8 assessment). Only later, following a decision to reduce that impact, will there be a need to consider possible management options such as intensity of trawling, productivity of the area and habitat recovery times.

Definitions in the context of WKFBI

Pressure:

The physical abrasion of the seabed by bottom-contacting fishing gears. The pressure is expressed as the ratio between the sum of the area swept by the fishing gear (with components having a surface or subsurface penetration) per year and the total area of the site (swept-area ratio - SAR).

Sensitivity:

The intolerance of a species or habitat to damage from an external factor and the time taken for its subsequent recovery.

Resistance:

The ability of a receptor to tolerate a pressure without changing its character

Recoverability (or resilience):

The time that a receptor needs to recover from a pressure, once that pressure has been alleviated

Impact:

The effects (or consequences) of a pressure on an ecosystem component. The impact is determined by both exposure and sensitivity to a pressure.

Indicator:

A characteristic of a benthic habitat that can provide information on ecological structure and function

1 Introduction

Member countries and Regional Sea Conventions (RSCs) are developing indicators of impacts on benthic habitats from anthropogenic activities, particularly bottom-trawling, for Marine Strategy Framework Directive (MSFD) purposes (D1 biodiversity and D6 seabed integrity). EU projects are also developing approaches across European seas (including the Mediterranean and Black Sea). As part of this process, ICES has provided bottom fishing pressure maps using VMS and logbook data to OSPAR and HELCOM. The next challenge for the process of developing indicators is to interpret what these fishing pressure maps mean in terms of impact on benthic habitats and their utility in management.

The EU (DG ENV) have requested advice from ICES on "guidance on how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats". In preparation of this Advice the ICES Benthic Ecology Working GroupBEWG, Working Group on Marine Habitat Mapping - WGMHM, Working Group on Deep-water EcologyWGDEC and Working Group on Spatial Fisheries DataWGSFD have been tasked to work on this in early 2016 and provide input to an open workshop on "guidance on how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats (WKFBI)". In addition to evaluating material prepared by ICES Working Groups, the WKFBI will also compare similar approaches on assessing benthic impact of fishing developed within European-funded projects and regional seas conventions.

The workshop aims to produce "principles and good practices" to be used at a regional scale when operationalizing similar indicators to be used to assess the impact of fishing to the seabed. This will provide a foundation for exploration of the environmental benefits, impacts and trade-offs for fisheries. WKFBI outcome include:

a) An evaluation of a scoring processes for sensitivity of habitats, which should also include rules on:

   i. How to scale-up sensitivity to a regular grid cell (here: c-square resolution of 0.05o x 0.05o)

   ii. How to treat variation in habitat type when evaluating sensitivity within a grid cell (c-square resolution of 0.05o x 0.05o)

   iii. How to interpolate and/or extrapolate information on sensitivity when habitat data are missing

b) Evaluation of information on sensitivity of the benthic community of the various seabed habitats that ensures habitat maps for sensitivity can be produced for at least one demonstration area of NW European waters (MSFD region/subregion).

c) An evaluation of impact maps that combine the benthic information on sensitivity and fishing pressure maps (fishing abrasion, weight and value of landed catch), taking into account differences in benthic impact of the various fishing gears / métiers.

d) Evaluate and synthesis findings (a-c, above) aimed at tangible use of indicators of the state of the seabed in relation to fishing pressure.

e) Prepare a guidance on how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats, including "principles and good practices" when regionally operationalizing indicators to assess the impact of fishing to the seabed.

In preparation for the workshop a method was considered for the interpretation of pressure maps of fishing intensity to an assessment of the state of seabed habitats. This was done to ensure that at the coming workshop both substance and conceptual discussions will take place.

The mechanism through which fishing has an effect on any part of the ecosystem is called pressure. The resulting disturbance or stress exerted by the pressure depends on temporal frequency, spatial extent and intensity of the activity. The effects (or consequences) of a pressure depend on the sensitivity of the habitat. Sensitivity can be defined as the ability of the habitats or species to withstand the pressure (i.e. resistance) and the ability to recover from the pressure (i.e. recoverability). The effects (or consequences) of a pressure on an ecosystem component are defined as its impact. It is thus important to be aware of the methods used to characterize the exposure of benthic habitats to bottom fishing pressures (Chapter 2), and the sensitivity of these habitats to fishing pressures (Chapter 3 and 4), in order to understand which habitats are likely to be impacted and the extend of the impact (Chapter 5).

The following steps were taken in preparation of the workshop:

1) Acquire a habitat map covering as much of the MSFD region as possible. The thematic classes of the habitat map need to be aligned or cross-referenced to the classes used in the sensitivity assessment without significant gaps.
2) Acquire sensitivity information for each thematic class of habitat to surface/subsurface abrasion. Habitat map polygons are then attributed with the sensitivity code.
3) Acquire surface/subsurface abrasion layers (pressures from fishing activity) for the MSFD assessment area. Clip layers to match the habitat map coverage.
4) Combine (intersect/raster calculator/map algebra) the attributed habitat map with the abrasion layers. Use a combination matrix (categorical attribution of pressure and sensitivity) to combine sensitivity and pressure to calculate impact.
5) Map the impact of fishing on benthic habitat.
6) Extract summary statistics/indicators from the impact map. Produce a confidence assessment for the map and summary statistics.

2 Fishing Pressuremethods and results

2.1 Introduction

Spatial fisheries data are essential to understand interactions between fisheries and the ecosystem and thus have become a key issue in European maritime policies. In order to describe the spatial and temporal distribution of fishing activities – and simultaneously considering their characteristic ecological footprint – the Working Group on Spatial Fisheries Data (WGSFD) uses data from the Vessel monitoring system (VMS) and fisheries logbook data provided by participating countries. In the past a high amount of effort was spent to data compilation, quality control and harmonization. As part of the ongoing OSPAR requests in 20142016 the group revised and improved the method proposed under BH3 to assess Swept-area Ratio within c-squares using VMS and logbook data for the calculation of surface and subsurface pressure layers. The group defined best practices and workflows in R for data analysis and data call submission, and developed indices, e.g. representing fishing intensity on different spatial scales which is now part of the BH3 technical specifications for the calculations of fishing pressures.

Benthic habitats are mainly influenced by mobile bottom contacting gears (Kaiser *et al.*, 2006), which are e.g. beam trawls, demersal otter trawls and dredges. To quantify the direct impact of fishing on the seabed the penetration depth as well as the swept-area, i.e. the area covered by the specific gear needs to be estimated. Spatially and temporally resolved maps of fishing pressure, in combination with the respective sensitivity estimates of a fished habitat, then gives us the opportunity to provide information on the potential effects of fishing on benthic habitats. This year WGSFD met in Brest, France on 17th20th May 2016. As part of their ToRs, the group produced updated fishing abrasion pressure maps used for the here applied WKFBI approach.

2.2 Methods to estimate trawling intensity

To do the requested work, WGSFD decided to deliver a spatially resolved index of fishing intensity for mobile bottom contacting gears. WGSFD defined fishing intensity as the area swept per unit area, i.e. the area of the seabed in contact with the fishing gear in relation to a surface area of the grid cell.

For this VMS and fisheries logbook data from the Northeast Atlantic and the Baltic Sea were collected from 20092015 following a data call from 15th January 2016. In its raw format, VMS data are geographically distinct points, so-called “pings”, providing information about the vessel, its position, instantaneous speed and heading. VMS transmits at regular intervals of approximately 2 hours, but with higher polling rates for some countries. VMS data points can be linked to logbook data in order to get additional information about the ship, the applied gear and eventually also the catch. Following some analytical steps to identify e.g. misreported pings, the vessel state (steaming, fishing or floating) has to be identified using the actual speed information. Only data, which were assumed to represent fishing activity, were then assigned to a 0.05 x 0.05 degree grid, about 15 km^2 at 60^{o}N, using the approach of C-square reference (Rees 2003). Finally, national data were reported in a gridded and anonymized form summing the number of pings within each grid cell based on the time interval between successive pings, and including information about vessel flag country, gear code (equivalent to DCF level 4), fishing activity category (DCF level 6), average fishing speed, fishing hour, average vessel length, average kW, total landings weight and total value of all species caught. Therefore, estimates on total fishing time within each grid cell and métier are available for the years 20092015.

In order to calculate swept-area values certain assumptions about the spread of the gear, the extent of bottom contact and the fishing speed of the vessel needed to be made and thus a number of working steps were necessary (Figure 2.1, for further details, see ICES WGSFD Report (ICES 2015)). First a full quality assessment of all submitted data were performed (Step 1). Submitted VMS datasets usually contained information on the gear based on standard DCF métiers (from EU logbooks, usually at the resolution of métier level 6) and the gear-specific fishing speed, but not on gear size and geometry. Therefore, vessel size-gear size relationships developed by the EU FP7 project BENTHIS project (Eigaard *et al.*, 2016) or by the Joint Nature Conservation Committee (JNCC) were used to approximate the bottom contact (e.g. gear width). To do this, it was necessary to aggregate métier level 6 to lower and more meaningful gear groups, for which assumptions regarding the extend of bottom contact were robust (Step 2). If possible the so-called "Benthis métiers" were used; otherwise the more general bottom contacting gear groups from JNCC were assigned. Following this, fishing effort (hours) was calculated and aggregated per c-square for each métier and year (Step 3). Fishing speeds were based on average speed values for each métier and grid cell submitted as part of the data call, or, where missing, a generalized estimate of speed was derived (Step 4). Similarly, vessel length or power were submitted through the data call, but where missing average vessel length/power values were assumed from the BENTHIS survey (Eigaard *et al.*, 2016) or were derived based on a review done by JNCC (Step 5). Parameters necessary to fulfil steps 2, 4, and 5 are listed in table 2.1 for Benthis métiers and table 2.2 for corresponding JNCC gear groups. The resulting bottom contact values (m) were finally used to calculate swept-areas (SA) per gear group, grid cell and year (Step 6).

For towed gears (otter trawls, beam trawls, dredges): $\boldsymbol{SA} = \sum \boldsymbol{evw}$,
For Danish seines (SDN_DMF): $\boldsymbol{SA} = \sum(\boldsymbol{pi} * (\boldsymbol{w}/\boldsymbol{2pi})\hat{}\boldsymbol{2} * (\boldsymbol{e}/\boldsymbol{2.591234}))$,
For Scottish seines (SSC_DMF): $\boldsymbol{SA} = \sum(\boldsymbol{pi} * (\boldsymbol{w}/\boldsymbol{2pi})\hat{}\boldsymbol{2} * (\boldsymbol{e}/\boldsymbol{1.9125}) * \boldsymbol{1.5})$,

where *SA* is the swept-area, *e* is the time fished (h), *w* is the total width (m) of the fishing gear (gear group) causing abrasion, and *v* is the average vessel speed (m/h).

The swept-area information was additionally aggregated across métiers for each gear class (otter trawl, beam trawl, dredge, demersal seine) with two layers, one for surface abrasion and one for subsurface abrasion (as proportion of the total area swept, see table 2.1 and 2.2). To account for varying cell sizes of the GCS WGS84 grid, swept-area values were additionally divided by the grid cell area:

$\boldsymbol{SAR} = \boldsymbol{SA}/\boldsymbol{CA}$,

where *SAR* is the swept-area ratio (number of times the cell was theoretically swept), *SA* is the swept-area, and *CA* is the cell area.

Finally effort and swept-area maps were generated at appropriate scales (Step 7 and 8).

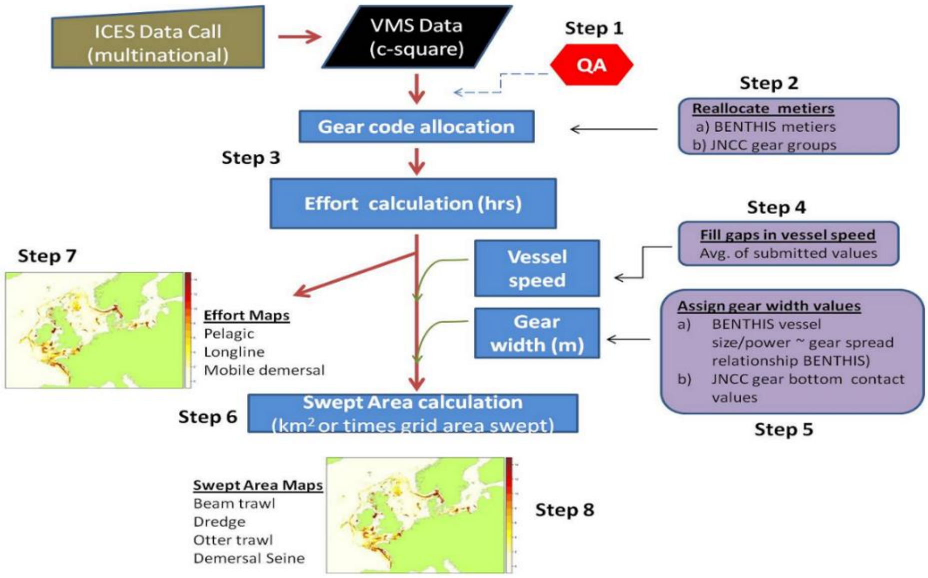

Figure 2.1. Workflow for production of fishing effort and swept-area maps from aggregated VMS data (0.05° x 0.05° C-square resolution) (from ICES 2015).

Table 2.1. Parameter estimates of the relationship between vessel size (as length (m) or power (kW)) and gear width, the average width of fishing gear causing abrasion (surface and subsurface), the corresponding proportion of subsurface abrasion, and the average fishing speed for each BENTHIS Métier (derived from Eigaard *et al*. (2016) and ICES (2015)).

Gear class	BENTHIS métier	Model	Average gear width (m)	Subsurface proportion (%)	Fishing speed (knots)
Otter trawl	OT_CRU	5.1039*(kW0.4690)	79.1	32.1	2,5
	OT_DMF	9.6054*(kW0.4337)	134.8	7.8	3,1
	OT_MIX	10.6608*(kW0.2921)	61.4	14.7	2.8
	OT_MIX_CRU	37.5272*(kW0.1490)	99.2	29.2	3,0
	OT_MIX_DMF_BEN	3.2141*LOA+77.9812	156.3	8.6	2.9
	OT_MIX_DMF_PEL	6.6371*(LOA0.7706)	76.2	22	3.4
	OT_MIX_CRU_DMF	3.9273*LOA+35.8254	114.0	22.9	2.6
	OT_SPF	0.9652*LOA+68.3890	101.6	2.8	2.9
Beam trawl	TBB_CRU	1.4812*(kW0.4578)	17.2	52.2	3
	TBB_DMF	0.6601*(kW0.5078)	19.9	100	5.2
	TBB_MOL	0.9530*(LOA0.7094)	4.9	100	2.4
Dredge	DRB_MOL	0.3142*(LOA1.2454)	17.0	100	2.5
Demersal seines	SDN_DMF	1948.8347*(kW0.2363)	6537	0	NA
	SSC_DMF	4461.2700*(LOA0.1176)	6454	5	NA

Table 2.2. Estimates of fishing gear width causing abrasion (surface and subsurface) and the corresponding proportion of subsurface abrasion for each JNCC gear group (from ICES 2014, section 5.4.2)

JNCC gear group	Gear width	Subsurface proportion (%)	Fishing speed (knots)
Beam Trawl	18	100	4.5
Nephrops Trawl	60	3.33	3
Otter Trawl	60	5	3
Otter Trawl (Twin)	100	5	3
Otter Trawl (Other)	60	3.33	3
Boat Dredge	12	100	4
Pair Trawl and Seine	250	0.8	3

2.3 Results and key features

2.3.1 Surface and subsurface swept-area ratio

In the following swept-area ratios (SAR) were calculated as grid cell averages of the seven annual estimates from 20092015. SARs are shown as surface and subsurface abrasion of the four main bottom-contacting gear groups (beam trawlers, dredges, otter board trawlers, demersal seines, Figure 2.22.5) as well as of the sum of all gear group SARs (Figure 2.6). Highest beam trawling efforts are found in the North Sea, first in coastal areas mainly representing the shrimp fishery and in more offshore areas, mainly representing the flatfish fishery on sole and plaice. Due to the different groundgear, the latter exerts a higher subsurface abrasion compared to the shrimp fishery. Dredging (e.g. on scallops) is supposed to have the highest subsurface impact of all bottom-contacting gears. Thus surface and subsurface SARs are identical and concentrate in the English Channel as well as in some areas of the Irish Sea. Otter trawling is widespread within European Seas and often concentrates along the shelf breaks, but can be also found throughout the North and Baltic Sea. Demersal seines are less frequently used, which results in a more patchy effort distribution. However, due to the large area covered by the seine ropes the surface abrasion estimates can get very high (maximum SAR = 64.5).

Generally, spatial patterns of SAR are very similar from year to year, and variation is highest in less frequently trawled areas (Figure 2.7).

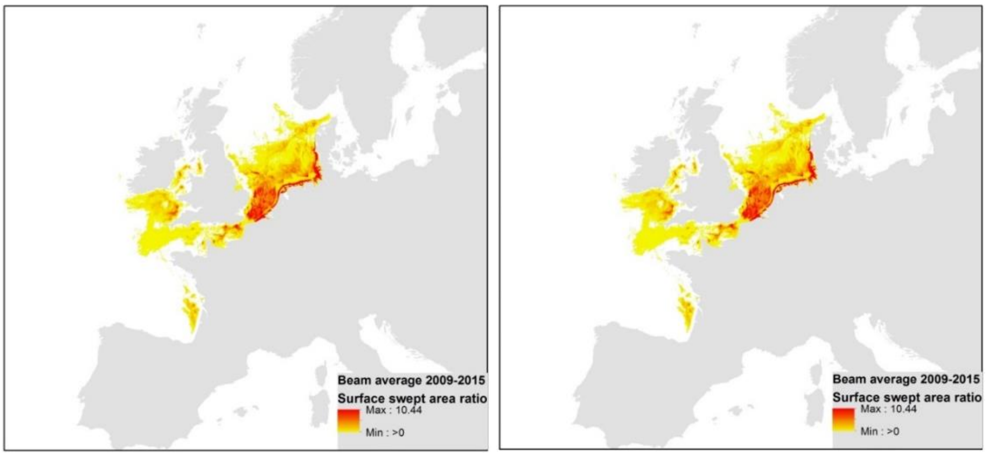

Figure 2.2. Average swept-area ratio of beam trawlers separated into surface (left) and subsurface (right, note wrong text legend: should be subsurface) abrasion.

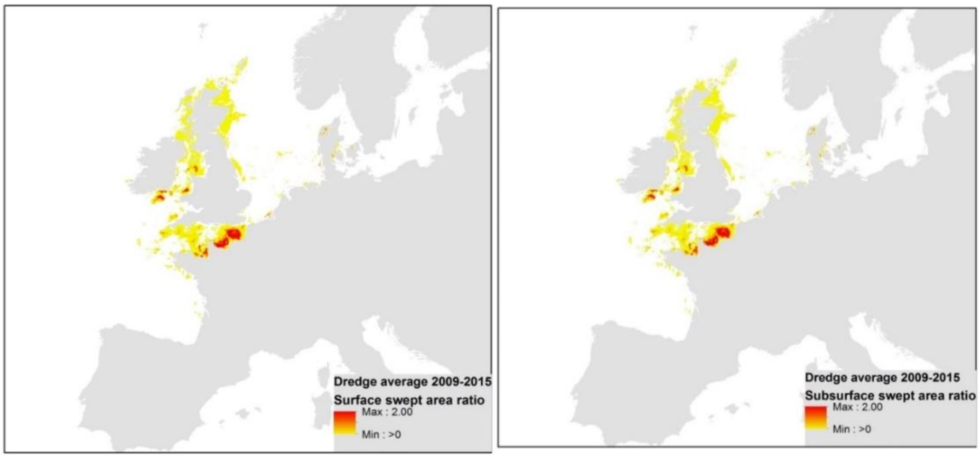

Figure 2.3. Average swept-area ratio of dredges. Surface (left) and subsurface (right) abrasion are identical.

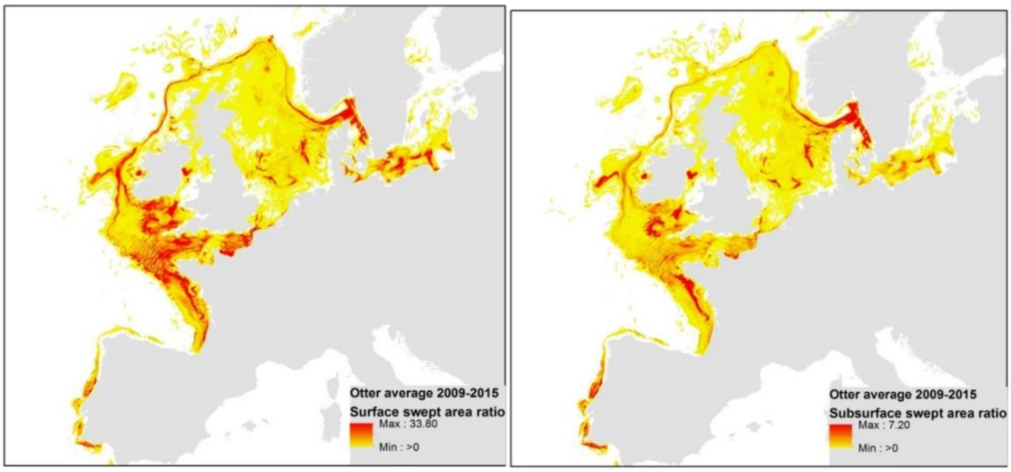

Figure 2.4. Average swept-area ratio of otter board trawlers separated into surface (left) and subsurface (right) abrasion.

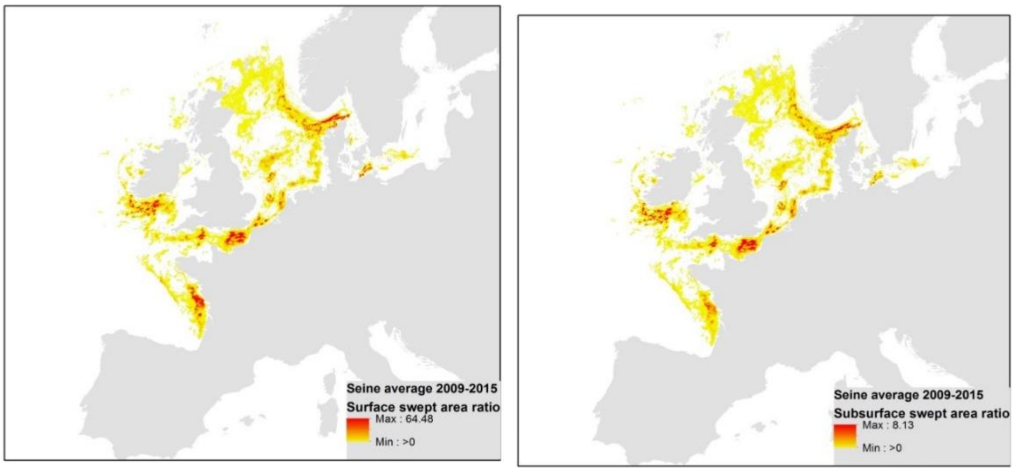

Figure 2.5. Average swept-area ratio of demersal seiners (including Danish and Scottish seines) separated into surface (left) and subsurface (right) abrasion.

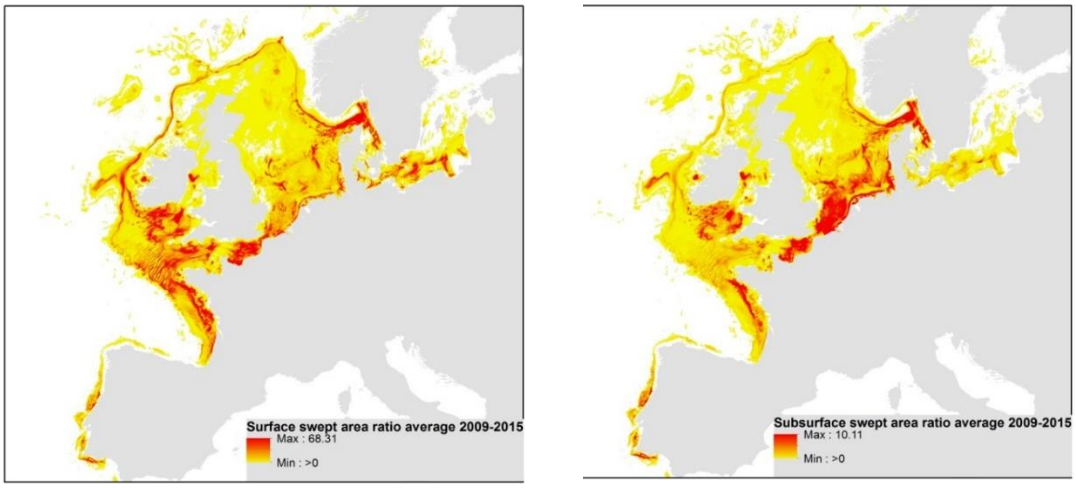

Figure 2.6. Average swept-area ratio of all bottom contacting gears separated into surface (left) and subsurface (right) abrasion.

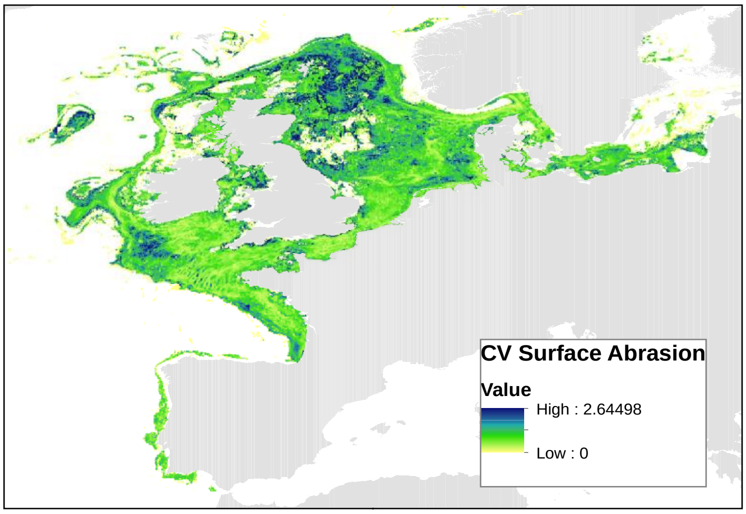

Figure 2.7. Variability of swept-area ratio estimates (surface SAR) within grid cells expressed as coefficient of variation over the seven investigated years (2009-2015).

2.3.2 Distribution of fishing pressure and habitats within C-squares

Fisheries is highly clustered in space and even within the above described 0.05x0.05 C-square resolution a lot of variability can be found. Generally, c-square estimates resulting from a large number of VMS observations will have a high precision, whereas grid cells experiencing low fishing intensity will have a low precision. Further, due to the clustering of VMS points, i.e. the repeated trawling of the same or similar tracks, an SAR estimate of 1 does not mean that 100% of the cell is impacted by the fishing gears. We can rather observe areas that are repeatedly trawled, whereas others are not impacted at all. To illustrate this, we used an example from the North Sea, where the spatial distribution of VMS pings from the Danish fleet is shown in relation to the respective SAR grid cell estimates (Figure 2.8).

Similarly to fishing, benthic habitats can vary on small-spatial scales. Because the resolution of fisheries data are on the 0.05x0.05 C-square grid, habitats, and by this sensitivities were assigned accordingly. As an approximation we used the habitat/sensitivity found at the midpoint of each grid cell. However, as shown in Figure 2.9 this represents not necessarily the prevailing habitat of the grid cell.

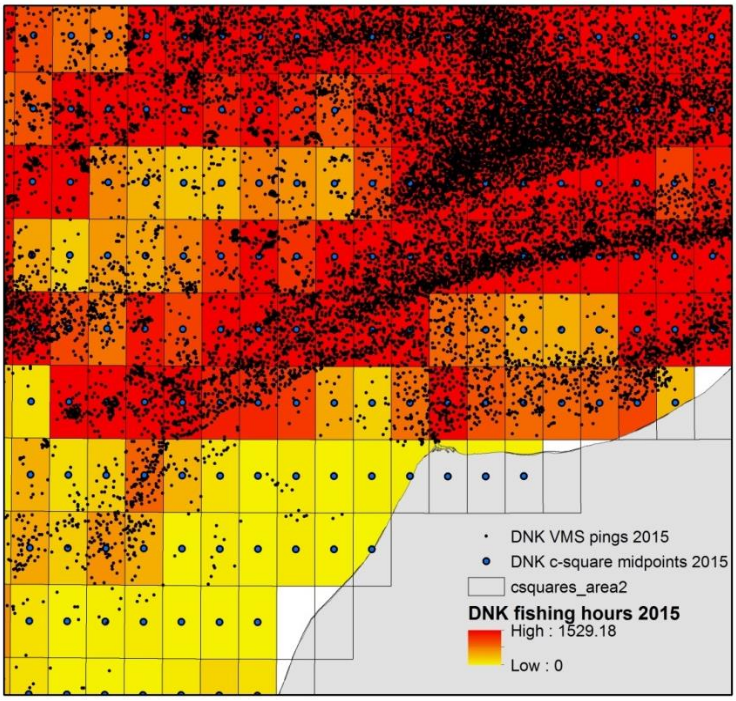

Figure 2.8. Spatial distribution of VMS pings from the Danish fleet recorded in a small area at the Danish North Sea coast in 2015. Pings are shown in relation to the respective swept-area ratio grid cell estimates (0.05°x0.05°) Blue dots represent c-square midpoints.

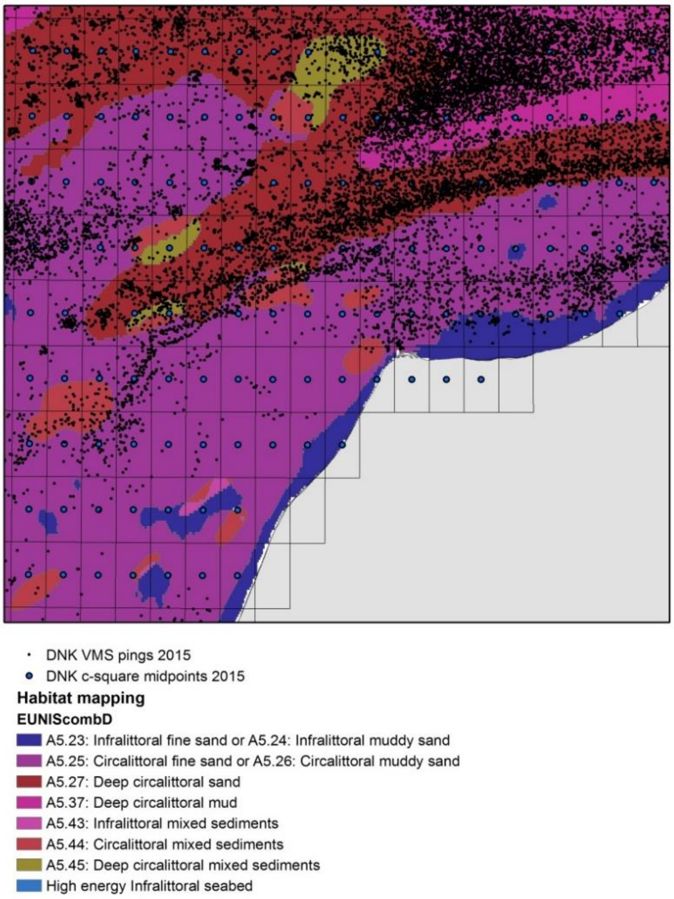

Figure 2.9. Spatial distribution of VMS pings from the Danish fleet recorded in a small area at the Danish North Sea coast in 2015. Pings are shown in relation to the underlying habitat (EUNIS level 3) and the c-square borderlines (0.05°x0.05°). Blue dots represent c-square midpoints.

2.3.3 Caveats and Uncertainties

Vessel monitoring systems are primarily intended for compliance and monitoring purposes and the data collected were not specifically designed to enable effort mapping. As such, there remain some data quality issues and caveats. These have been identified by WGSFD (ICES 2016) and the most important aspects are shortly listed below:

- Although standard routines (using R for statistical computing and the related VMS-tools package (Hintzen *et al.*, 2012)) have been defined, aggregation methods and the identification of fishing activity from VMS data may still vary between countries.
- In Logbooks, vessels are only obliged to allocate landings for any 24hr period to a single ICES rectangle, irrespective of the number of rectangles in which they may have been active over the period.
- The outputs can only reflect the data submitted and data from some countries were still missing (Spain, Iceland, Greenland, Faroe Islands, Russia) or some parameters, e.g. fishing speeds were not fully submitted. Looking at the quality control summaries of WGSFD (ICES 2016) the outputs appear to be consistent over time, but fishing pressure in certain areas (e.g. along the Spanish coast) is certainly underestimated.
- Up to 2011 only vessels larger than 15 meters were obliged to have VMS on board. In 2012 the legislation changed, and data from vessels larger than 12 meters became available. However, due to differences between countries how vessel length categories were reported, it was not always possible to partition this segment and therefore make the data directly comparable before and after 2013. This is likely to be relevant when examining trends in effort for inshore areas.
- Similarly, in nearshore areas and for some countries substantial fleets of smaller vessels not equipped with VMS exist (< 15 m prior to 2012, < 12 m thereafter). For these, only logbook data are available, which is at the spatial resolution of ICES rectangles and is consequently not considered here.
- For calculating fishing intensities, as well as surface and subsurface abrasion, fishing hours, gear widths and fishing speeds are used as input. Where possible, gear widths are an estimate based on BENTHIS project relationships between gear widths and vessel lengths or engine power (Eigaard *et al.*, 2016). Information on vessel lengths and engine power is available as an average per grid cell; if missing, very broad assumptions on average vessel sizes and engine power had to be made in order to estimate gear widths. Corresponding fishing speeds were mostly available and, where missing, were replaced by average fishing speeds on the same or similar gears.
- Gear coding in logbooks is not typically suited for quantitative estimations of seabed pressure, i.e. the exact gear type (width/spread and weight) is unknown. The calculation of swept-areas and the corresponding surface and subsurface abrasion can therefore only be an approximation of the actual values.
- The group partly encountered the problem of misreported gear groups: E.g. Scallop dredging in some countries seems to be reported as HMD, but should be coded as DRB (DRB_MOL). Locally this would cause differences in abrasion. For the UK fishery the values were changed accordingly. Further Otter twin trawling is often reported as OTB (and not OTT).

- Penetration depth of gear components was categorized to surface (<2cm) and subsurface (>2cm) impact and was taken as equal across all sediment types, although the actual depth of the subsurface impact will certainly differ. Proportions of groundgear surface and subsurface impact proportions were subjectively assigned by expert knowledge and according to (Eigaard *et al.*, 2016) should be treated with caution.
- Member countries usually deliver data anonymised in the spatial resolution of 0.05°x0.05° cells (c-squares). In the central North Sea this corresponds approximately to a grid cell size of 18km². However, fishing activities are usually highly clustered and trawling tracks are repeatedly fished over a longer time period. This means, that fishing is not homogeneously or randomly distributed within grid cells and can vary considerably not only over time but over relatively small spatial scales. Swept-area ratios, although being meaningful in a regional approach, can be misleading when investigating smaller spatial scales.
- Information from other anthropogenic activities causing physical damage is so far not included.

3 Sensitivity of benthic habitats

3.1 Introduction

It was proposed by WKFBI attendees that the method for interpretation of pressure maps of fishing intensity for an assessment of the state of seabed habitats should identify both the exposure of benthic habitats to bottom fishing pressures, and the sensitivity of these habitats to fishing pressures in order to understand which habitats are likely to be further impacted. Sensitivity encompasses a measure of the effect of a pressure (sometimes referred to as disturbance, perturbations or stress), on a receptor. The degree of effect of an impact will depend on the resistance (tolerance) (and conversely, the intolerance) of the receptor and the ability of the receptor to recover (resilience). It can simply be defined as "a measure of tolerance (or intolerance) to changes in environmental conditions" (Tillin and Tyler-Walters, 2010).

Assessing the sensitivity of habitats for WKFBI was split into two areas based on the ICES Working Groups: 1) the sensitivity of shelf subtidal marine habitats, collated by BEWG and, 2) the sensitivity of deep-sea marine habitats, collated by WGDEC. Both groups looked at different methods for determining sensitivities and applied a common one to illustrate the WKFBI process.

3.2 Sensitivity assessment methods

In order to complete sensitivity assessments, a review of existing sensitivity assessments and methods for marine habitats was completed. Some existing methods for sensitivity assessments are qualitative (i.e. categorical information) and others try a more quantitative approach. The following sensitivity products were reviewed during the WKFBI process:

Methods which are using categorical classification system for sensitivity:

- **Project MB0102** - "Development of a Sensitivity Matrix" - this work was commissioned in the UK by the Department for Environment, Food and Rural Affairs (Defra) to support the Marine Conservation Zone (MCZ) selection process under the Marine and Coastal Access Act 2009. The project developed a sensitivity and pressures matrix for species and habitats in UK waters covering EUNIS Level 3 broad-scale habitats, OSPAR threatened and/or declining habitats and species and UK Biodiversity Action Plan habitats and species. The sensitivity scores were based on combined scores of resistance (tolerance)[1] and resilience (recoverability)[2] to a variety of marine pressures measured against pressure benchmarks (Tillin *et al.,* 2010). For the moment, it is a complete matrix and provides the greatest coverage of habitat classes, accompanied with confidence assessments. A disadvantage is the fact that the magnitude of the pressures are not taken into account, both on spatial and temporal scales and that the benchmark level of the pressure is quite general. This approach and the accompanied matrix formed the basis for other initiatives that aimed to make improvements to the matrix.

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[1] Resistance characteristics indicate whether a receptor can absorb disturbance or stress without changing character.

[2] Resilience is the ability of a system to recover from disturbance or stress.

- **Marine Evidence based Sensitivity Assessments (MarESA) –** Sensitivity assessments for a large proportion of UK Level 5 biotopes are currently being updated through a project called MarESA. These assessments follow the same method used for MB0102, but with an improved confidence assessment method (Marlin, 2015).
- **Features Activity Sensitivity Tool (FeAST)** - A similar product to MB0102 was developed for Scottish habitats and species as part of the Scottish Marine Protected Area project. The tool, FeAST, uses the MB0102 method to assess sensitivity of Scottish Nature Conservation MPA habitats and species with additional evidence to MB0102 applied for Scotland's seas (Scottish Government, 2013).
- **French benthic habitat sensitivity project**. The French Natural History Museum, at the request of the French Ministry of Environment, has set up a project to assess the sensitivity of French benthic habitats to anthropogenic pressures, drawing on expertise from the wider scientific community. This project's objective is to produce standardized sensitivity assessments at a national level and to be consistent (insofar as possible) with other equivalent European methodologies, in order to support risk/vulnerability assessments at a national and international scale (under the HD, MSFD, OSPAR, etc.). The methodological framework for assessing benthic habitat sensitivity and the assessment results of French Mediterranean habitats' sensitivity to physical pressures are available online (INPN, 2016). The webpage will be updated as the project progresses (with Mediterranean habitats' sensitivity to other pressures, Atlantic-English Channel-North Sea habitats' sensitivity, mobile species' sensitivity, etc.).
- **BH3 approach (OSPAR) (see also Chapter 6):** BH3 (physical damage of predominant and special habitats) is an indicator being developed as part of the commonly agreed set of biodiversity indicators for monitoring and assessment of the OSPAR area. The work utilizes the MB0102, MarESA and ecogroups based on characterizing species to categorically score sensitivity assessments at biotope (Eunis level 5), species and broadscale EUNIS Level 3 levels to increase the resolution of the sensitivity data available. Thus, BH3 aims to analyse large sea areas based on the best available knowledge of species and /or habitats, based on real data and expert judgment. In this way, it takes into account biogeographic variation and environmental factors of local populations and their role in the benthic assemblage. For the moment, this approach is in development for the North Sea area and is not yet applicable/operational in all regions. Any gaps on the habitat classification or no sensitivity data are left blank.

Methods that are using a quantitative approach

- **BENTHIS (see also Chapter 7):** BENTHIS was set up to provide the science base to assess the impact of current fishing practices and proposed two approaches, one based on biological trait longevity and one on population dynamics (benthic biomass). These indicators were used in the project to determine the potential sensitivity of benthic taxa to trawling. These methods strive to a gear-dependent impact assessment, which is in the long term useful for scenario testing and comparison of recovery times in different areas. The status/impact link is not yet quantified and the approaches are not yet fully validated.

- **BalticBOOST (see also Chapter 8):** This is a project under HELCOM to define a sensitivity system for the Baltic Sea. They will use the BENTHIS sensitivity approach and may further refine it in relation to local natural conditions.
- **Kostylev/Desroy approach (**Kostylev V.E., Hannah, C.G. (2007))**:** This method takes into account physical disturbance and food availability as structuring factors for benthic communities (Kube *et al.*, 1996). Kostylev and Hannah's (2007) model is a conceptual model, relating species' life history traits to environmental properties. The model is based on two axes of selected environmental forces: 1- The "Disturbance" (Dist) axis reflects the magnitude of change (destruction) of habitats (i.e. the stability through time of habitats), due to the single natural processes influencing the seabed and which are responsible for the selection of life-history traits; 2- The "Scope for Growth" (SfG) axis takes into account environmental stresses inducing a physiological cost to organisms and limiting their growth and reproduction potential. This axis estimates the remaining energy available for growth and reproduction of a species (the energy spent on adapting itself to the environment being already taken into account). The process-driven sensitivity (PDS) can be seen as a risk map that combines the two previous axes. This quantitative approach is useful, but data driven and therefore not directly applicable for the moment.

Within the WKFBI work, the following approach was used to illustrate how sensitivity assessments could be undertaken for broad scale habitats to support sensitivity and impact mapping processes.

3.3 WKFBI approach: MB0102/MarESA

In order to enable sensitivities to be mapped on a large geographical scale, the quickest method is using a categorical scale, like the MB0102 and MarESA methods, to assign sensitivities to the habitats. In this way, consistency of resulting sensitivity scores between WGs (e.g. BEWG and WGDEC) for shelf subtidal and deep-sea habitats was also achieved. The full method is detailed on the MarLIN webpages (http://www.marlin.ac.uk/species/sensitivity_rationale), but a summary of the following steps are shown below (NB the term feature equates to a habitat or species):

1) Define the key elements of the feature (in terms of life history, and ecology of the key and characterizing species);
2) Assess the feature's resistance (tolerance) and resilience (recovery) to a defined intensity of pressure (the benchmark);
3) Combine resistance and resilience to derive an overall sensitivity score, scored on a scale of Not Sensitive to High (see table 3.1);
4) Assess the confidence in the sensitivity assessments;
5) Document the evidence used; and
6) Undertake quality assurance and peer review.

Table 3.1. The combination of resistance and resilience scores to categorize sensitivity.

Overall Sensitivity		Resistance			
		None	Low	Medium	High
Resilience	Very Low	High	High	Medium	Low
	Low	High	High	Medium	Low
	Medium	Medium	Medium	Medium	Low
	High	Medium	Low	Low	Not sensitive

Two main points for consideration, were:

- The sensitivity scoring in the MB0102/MarESA approach takes a medium pressure level into account (see table 3.2), and therefore does not directly relate to the annual trawling intensity classification used in the pressure maps (Chapter 2): <0.1 y^{-1}: Very low; 0.10.5 y^{-1}: Low; 0.5 - 1 y^{-1}: Medium; 15 y^{-1}: High ; >5 y^{-1}: Very high.
- The sensitivity of the habitats was scored (applying the expert judgment knowledge) based on the current status of those habitats given the resistance (tolerance) and resilience (recoverability) of a subset of benthic species that are typical for the habitat.

The BEWG applied this method to score the shelf sea area and WGDEC for the deep-sea area. The process followed for each group is briefly explained below.

Table 3.2. Extraction from the pressure table and the benchmarking from MB0102 report (Tillin *et al.*, 2010)

Pressure	Definition and examples associated activities	Pressure benchmark for assessment			Justification
		Low-medium	medium	Medium-high	
Structural abrasion/ penetration on: Structural damage to seabed >25mm	The pressure refers to structural damage to features e.g. deep disturbance of sediment, upheavel and piling of boulders		Structural damage to seabed > 25mm		The assessment should consider the direct impact arising from the pressure on the feature
Shallow abrasion/penetration: damage to seabed surface and penetration <25mm	The assessment considers penetration and disturbance of the sediment to 25mm or scoring on rocks		Damage to seabed surface and penetration < 25 mm		The assessment should consider the direct impact arising from the pressure on the feature
Surface abrasion:damage to seabed surface features	Impacts confined to the surface e.g. damage to epifauna/flora on sediment and rock		Damage to seabed surface features		The assessment should consider the direct impact arising from the pressure on the feature

3.4 Mapping shelf sea habitat sensitivities

This request for advice was sent to BEWG in November 2015. Therefore, most of the discussions on methodologies and scoring of benthic sensitivities were conducted intersessionally. A sub-group of 6 BEWG members discussed and quickly reviewed a range of methodologies for scoring the sensitivity of shelf subtidal marine habitats to fishing pressure (see above). The group chose to use the UK MB0102 matrix and to revise it where necessary to make it applicable for all regions. BEWG conducted the work across the three selected areas, namely, the Northeast Atlantic, The Baltic and The Mediterranean.

Prior to mapping the sensitivity, the list of habitats and broad distribution of habitat types was provided from the European Marine Observatory Data Network (EMODNET). The list of available seabed habitat types was mapped at EUNIS level 3 and 4. However, for the sensitivity scoring, the selection of habitats was assessed at EUNIS Level 3 (biological zone + substratum).

3.5 Mapping deep-sea habitat sensitivities

For the deep-sea region (>200m), habitat maps were mainly available at EUNIS Levels 2 and 3 due to limited data availability for the region. During discussion at WGDEC 2016, it was agreed that undertaking sensitivity assessments at EUNIS Level 3 (biological zone + substratum) was not considered viable because of the lack of biological community information. Instead, it was agreed to categorize sensitivities at Level 4 and to aggregate these back to Level 3 for the sensitivity mapping.

However, the deep-sea section of the EUNIS classification is also limited in detail on biological communities, although it is currently being updated (Doug Evans, *pers. comms.*). As such, instead of reviewing sensitivities of EUNIS habitats, the more up-to-date UK deep-sea classification system (Parry *et al.,* 2015) was used. This classifies deep-sea habitats for the Arctic and Atlantic bio-geographic regions into broad communities at Level 4 and biological assemblages at Level 5 (see Table 3.3). The French benthic habitat classification was also reviewed and it was considered that all Mediterranean deep-sea broad communities were included in the UK classification at Level 4, with the exception of deep oyster beds and debris, so these would be included in the sensitivity assessments undertaken using the UK classification.

Table 3.3. Division of Level 3: Atlantic upper bathyal rock and other hard substrata into Level 4: Broad community and Level 5: Biological assemblage

Level 3: Substratum	Level 4: Broad Community	Level 5: Biological assemblage
Atlantic upper bathyal rock and other hard substrata	Barnacle dominated community on Atlantic upper bathyal rock and other hard substrata	Bathylasma hirsutum assemblage on Atlantic upper bathyal rock and other hard substrata
	Brachiopod dominated community on Atlantic upper bathyal rock and other hard substrata	Dallina septigera and Macandrevia cranium assemblage on Atlantic upper bathyal rock and other hard substrata
	Deep sponge aggregation on Atlantic upper bathyal rock and other hard substrata	Reteporella and Axinellid sponges on Atlantic upper bathyal rock and other hard substrata
		Lobose sponge and stylasterid assemblage on Atlantic upper bathyal rock and other hard substrata
	Mixed cold water coral community on Atlantic upper bathyal rock and other hard substrata	Discrete Lophelia pertusa colonies on Atlantic upper bathyal rock and other hard substrata
	Sparse encrusting community on Atlantic upper bathyal rock and other hard substrata	Psolus squamatus, Anomiidae, serpulid polychaetes and Munida on Atlantic upper bathyal rock and other hard substrata
		Psolus squamatus and encrusting sponge assemblage on Atlantic upper bathyal rock and other hard substrata

3.6 Sensitivity assessment methods

3.6.1 Shelf seas

Once the list of shelf sea habitats was compiled, all habitats were summarised in an excel format. The list of habitats was than coupled with the MB0102 habitat-sensitivity scoring table (Tillin et al., 2010; Marlin, 2015). The available information in MB0102 was reviewed across all habitats in 4 sensitivity classes (NE = 0, L = 1, M = 2, H = 3) and was mostly applied or slightly adapted for the three selected regions (Atlantic, Baltic and Mediterranean)(De Falco et al., 2010; Vacchi et al., 2016). Sensitivity of the shelf sea habitats was scored for three pressure levels: surface, shallow subsurface (0-2.5cm) and deep subsurface (>2.5cm) in order to be able to relate the sensitivities to the depth-specific fishing pressure data. At the 30th May -1st June WKFBI meeting, the choice was made that the main discrimination should be between surface and subsurface, as the sensitivity is mostly equal between shallow subsurface and deep subsurface.

The BEWG conducted an extra comparison to the MB0102 habitat classification as is illustrated below. This is important as it considers the discrimination of the different habitat types along a depth gradient. This approach follows the same principle as MB0102 (e.g. "higher sensitivity towards the deeper habitats of the same sediment composition"), but also takes account of the pressure benchmarks adopted in the MB0102 work. The scores of MB0102 were considered valid by the involved experts from the BEWG. The sensitivity scoring is mainly based on the general impact-response principles of the type of fauna living in a certain habitat type (cf MAFCONS [Robinson et al., 2003]; benthis traits work [Benthis 2014b]; Piet et al., 2000; Collie et al., 2000; Tillin et al., 2006). For example, if the trait type 'deep dwelling species' is an important group within a habitat, than the sensitivity score is high for deep penetration. For surface abrasion is mainly looked to the component of species living on the surface and/or forming 2D structures on the surface (cf sea pens, tube builders, Anemones). Nevertheless, the sensitivity scoring was for all shelf sea habitats mainly based on expert judgment and therefore the confidence of the scoring was defined as low. The following specific aspects were considered by the BEWG whilst reviewing/scoring the shelf habitats.

- The same benthic habitats in shallow areas are likely to be less sensitive to bottom disturbance than deeper areas, due both to natural hydrodynamics, but especially the history of bottom-contact gear disturbance. Currently, there is an issue in the mapping procedure, a discrimination between infralittoral (<20m) and circalittoral (>20m) and deep sea (>200m; beyond the shelf). In relation to the species composition of benthos in the same sediment type along the gradient, there is a shift around the 50m depth contour in the North Sea. Therefore, it may be worthwhile making a discrimination at this depth contour during mapping of these habitats and then, per sediment type, those depth-related subtidal habitats could be scored where we consider a gradient in their rate of sensitivity (resistance and resilience), with a higher sensitivity towards the deeper habitats of the same sediment composition (for Atlantic area):
    - Infralittoral (<20m): habitats most adapted to bottom fishing conditions and changing hydrodynamics
    - Circalittoral (20-50m): habitats subjected to high bottom fishing, adapted, but recovery (surface fauna) slower

    - Deep Circalittoral (50-200m): higher sensitivity, more diverse benthic species composition, with clear signs of disturbance and longer footprint of effects on the visible in fauna and sediment (lower recovery).
    - Deep sea (>200m): highest sensitivity
- Coarse sediment was considered to be a broad category, and in the habitat list provided, there was no distinction between coarse sand, gravels and cobbles. For scoring benthic fauna and their sensitivity this aspect is important and could be a relevant discrimination to consider.
- Two habitat type groups are not relevant for this exercise.
    - Intertidal habitats, inland marine waters (cf Waddensea, Fjords) were not taken into account, because the data of the small fisheries (<12m) is not taken into account in the pressure map analyses.
    - Rocky substrata are expected not to be subjected to bottom-trawl fishery and therefore not exposed (NE). At the end of the WKFBI meeting, it was advised to reconsider this aspect for further exercises, because this information should come out by combining the sensitivity layers with the fishery pressures maps and these habitats would be sensitive to fishing pressure.

3.6.2 Deep seas

When identifying the resistance and resilience scores of Level 4 deep-sea habitats, it was apparent that knowledge for the deep-sea is very limited. One of the main areas of work in deep-sea sensitivities has been on defining and mapping the distribution of Vulnerable Marine Ecosystems (VMEs). These are habitats in the deep-sea, such as deep-sea sponge aggregations and coral reefs that are considered particularly vulnerable to pressures (as defined by criteria in (FAO, 2009). VMEs tend to have more evidence to support sensitivity assessments (e.g. (Fossa *et al.*, 2002; Hall-Spencer *et al.*, 2002)) and, due to their known sensitivities to pressures such as abrasion from fishing, are likely to be scored as 'high' sensitivity. However, the limited knowledge of impacts to broad-scale deep-sea habitats such as deep-sea mud, which often still contain fragile species, e.g. sea-pens and soft corals (de Moura Neve *et al.*, 2014), means that these should not necessarily be considered as less sensitive than VMEs.

Additionally, there is a lack of knowledge of the location of all VMEs within the deep sea. Some regions have better mapped data than others, for example the Mareano project has mapped and approximated the percentage coverage of VMEs in Norwegian offshore waters (Dr Lene Buhl-Mortensen, *pers comms*) (see table 3.4). However, for most regions, this is not possible and without being able to identify the areas within deep-sea broadscale habitats that contain VMEs, it was not considered suitable by WGDEC to assign deep-sea habitats as anything other than 'highly' sensitive. In particular there is likelihood that deep-sea communities would have slower recovery rates compared to communities in shelf, coastal or subtidal regions (Kerry Howell, *pers comms*) due to the less naturally dynamic environmental conditions.

Table 3.4. Percentage of VMEs in Norwegian offshore waters compared to the total offshore area, mapped by the Mareano project.

Habitat type	% of tot area
Soft bottom sponge aggregations (Ostur)	16.1
Hard bottom sponge aggregation (Sponge garden)	5.3
Hardbottom coral garden	0.15
Soft bottom coral garden	0.8
Umbellula	1.8
Seapen & burrowing megafauna	1.2
Cold water sponge aggregations (Hexactinellida)	2.9
Lophelia reefs	<0.01
All	28.3

Conversely, there is a large proportion of the deep-sea below depths of approx. 1600 m that has never been fished and never will be fished because it does not contain commercially valuable species (Francis Neat, *pers. comms.*) and as such it should also be questioned if there is any reason to assign sensitivity to these habitats for fishing pressures as they will not be exposed, and therefore vulnerable, to bottom fishing.

On further discussion at WGDEC, it was agreed that with limited evidence, all deep-sea habitats should be assigned as 'high' sensitivity for the habitat mapping work of WKFBI. It should however be noted that 'high' sensitivity in the deep-sea may not equate to 'high' sensitivity in the shelf areas, due to the level of confidence in the evidence used to make these decisions. A highly sensitive habitat on the shelf may have more evidence for that score than the deep-sea.

3.7 Quality assurance

On completion of the three matrices of sensitivity for shelf sea habitats, these were circulated to independent reviewers per region to QA the overall scoring developed by the BEWG subgroups. There were some instances where the scoring adopted was deemed to be uncertain, therefore, the precautionary approach was applied where the current knowledge was not fully justified or where there were gaps in knowledge. The BEWG decided to concentrate the scoring system of shelf seas habitats in the areas where the representatives of the group were able to respond to this request, mainly based on existing knowledge or ongoing research from other initiatives. The resulting sensitivity to shelf habitats undertaken by the BEWG was then provided to the Marine Habitat Mapping Working Group to map the spatial representation.

The deep-sea sensitivity assessments did not get QA'ed as the 'high' scoring was an agreed precautionary approach used by the WGDEC group as no additional information was therefore available to review and QA.

3.8 Caveats and Uncertainties

BEWG and WGDEC adopted the MB0102 sensitivity methodology to ensure the integration of shelf and deep-sea habitat scores. However there are benefits and limitations with this method.

- The MB0102 work takes into account existing physical habitat information relevant to benthic community types and also differentiates between sub-surface and surface abrasion sensitivities.

- This method does not take into account the type of gear used during fishing practices acting upon different habitat types. The consideration of the fishing method, as well as the footprint of the effect resulting from the fishing method adopted, is important when scoring sensitivity and it represents a type of benchmark in the context of assessing a medium-level pressure (this could be not once, and also not permanently upon a habitat type). In a community, there are species that are already impacted by one pass of a bottom gear, whereas others can cope with more disturbance (although this species-specific information is seldom known). Therefore, we have generalized it in relation to resistance and resilience of the main benthic characteristics of those habitats, which is also the principle adopted as part of the MB0102 approach. For some species (e.g. sea pens, sponges) this sensitivity is clearly applied, and if these species were present in certain habitat type, the sensitivity will be likely to be higher.
- The adopted sensitivity approach for this exercise was directly divided into shallow subsurface abrasion and deep penetration, which has not taken the different types of gear (métiers, scales) or levels of footprint across habitat types into account. Ideally, a future suggestion for this work will be to collect all the sensitivity (resistance and resilience) information of the individual species within the broad range of habitats. That is the advantage of using for example certain traits within a habitat to determine the sensitivity (see the BENTHIS approach, described in Chapter 7 of this report). Dedicated traits based approaches can help to capture indicative species' attributes, helping to overcome wider and arbitrary classifications, as has been shown under the MB0102 work.
- The sensitivity of the habitats was scored (applying the expert judgment knowledge) based on the current status of those habitats. However, this means that for some habitats their sensitivity to date could be scored much lower than they might have been previously. The level of scoring can be affected by changes over time resulting from intensive human activities (mainly fisheries). There is therefore a consideration to bear in mind while scoring sensitivities as these habitats have been subjected to human activities and have therefore been altered in some way. Therefore, the sensitivity score applied will only be a snapshot of the conditions of those habitats at the time of scoring. Otherwise, the sensitivity scoring is considered to be fictive, based on pristine benthic habitats, under ideal benthic species composition. Undisturbed benthic habitats should normally be characterized by benthic species living on the surface (3D structures), infauna and deeper living fauna; as the hydrodynamic conditions permits.
- There is a lack of evidence of the distribution of VMEs in the deep sea and lack of understanding of resistance and, particularly, resilience of broad-scale deep sea habitats. As such, this limited the assessment for the deep-sea resulting in a broad-brush approach used for the whole mapped area.
- There were questions during the WKFBI workshop as to whether mapping the deep sea as 'high' sensitivity was appropriate as it is likely to greatly overestimate the amount of highly sensitive habitat in the region. An alternative approach would be to map these areas as 'not assessed' to make it clear that until further evidence becomes available, impact maps based on sensitivity of deep-sea habitats would be inaccurate and would be over-representative of the knowledge base available for these habitats.

3.9 Sensitivity maps

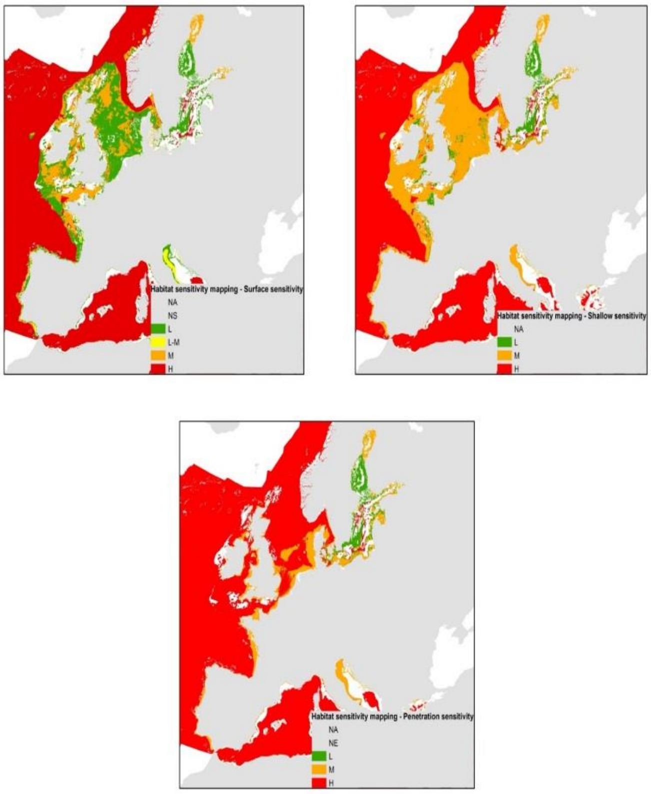


Figure 3.1. Sensitivity maps for surface (left), shallow subsurface (middle) and deep subsurface abrasion (right).

The sensitivity maps are shown in Figure 3.1. A large area is red, due to the precautionary approach applied to classify the deep habitats as highly sensitive.

The habitat sensitivity of the surface layer is generally lower than the shallow and deep subsurface layers. The deep (penetration) subsurface layer is classified as having a high sensitivity to trawling due to the fact that a lot of the benthic fauna living deeper in the sediment are currently thought to be more sensitive (e.g. *Arctica islandica*, tube building polychaetes) than the surface fauna (e.g. brittlestars), even in shallow areas. In this sense, the BEWG members had a slightly different view than what was available in the MB0102 matrix. Therefore, these habitats have been scored a higher sensitivity for deep penetration than for surface and subsurface abrasion.

3.10 Recommendations regarding sensitivity assessments in relation to impact assessments

- The sensitivity scoring methodology used for this work by WGDEC and BEWG was based on data from UK waters and the North Sea only. Whether this is applicable to other marine areas needs to be further evaluated.
- To ensure consistency in future scoring of sensitivity, it is necessary to formalize this process. This may include criteria for assessing ecologically-relevant elements (e.g. community composition and biodiversity, abundance of highly production and/or sensitive/vulnerable species, discreete trait groups) and observable measures for sensitivity.

- The two sensitivity components must be evaluated separately. Measures of resistance and resilience could be considered for individual species as well as for communities/habitats.
- At present the sensitivity is scored based on single pressures. Future evaluations should aim to include multi-pressure and cumulative pressure scoring
- Such sensitivity scoring for individual species or habitats related to single or multiple pressures in the form of a response curve could be related to fishing yield to motivate spatial management.
- The categorical approach based on expert judgments of differences in resistance and resilience tends to overestimate species/habitat sensitivity but could be valuable in data-poor areas. In data-rich areas or for well-known species sensitivity measure should be evaluated on a continuous scale to allow detailed differentiation of the sensitivity scores.
- Sensitivity scoring in intensively trawled areas could be biased by inclusion of the resilience component as recovery is never possible, and resistance is the deciding component of the sensitivity score.

4 Habitat

4.1 Representing habitats (pressure receptors) within the assessment area

The spatial extent of the assessment area is extensive and covers large sea areas. The analysis therefore required habitat coverage over a similar spatial extent. Although many habitat mapping studies are conducted throughout Europe, none would have the required coverage to fulfil the objectives of the request. Efforts to model the broad-scale distribution of coarse benthic habitat classes were therefore the only potential source of information. It was apparent that only 'seabed habitats' component of the Marine Observation and Data Network (EMODnet) was the only source of information available that met the specification of the analysis. The analysis undertaken here used the most up-to-date habitat map available for the assessment area. In fact, the EMODnet seabed habitat maps are perhaps the only source of information with the required extent. Other products are available for large sea areas, but they lack both the necessary coverage and do not match the thematic level used to report habitat sensitivity. There are some caveats associated with the EMODnet maps that limit their value within this analysis – these include:

- The EMODnet interim maps were not provided with confidence layers (these will however be present in the final version of the maps). A dummy confidence layer was used in this analysis - all maps were assumed to have a low confidence. Providing this allowed investigators to address the potential design of an overall confidence assessment.
- Deep-water habitats were classified into biological zones only (i.e. broad bathymetric bands). A shortage of acoustic datasets and ground-truthing limits our ability to produce accurate maps for deep-water habitats.
- Habitats have typically been reported at EUNIS levels 3 and 4 although habitat classifications are available at lower levels. However it was not possible to use this information as the sensitivity scores were provided for EUNIS levels 3 and 4 only.

The habitat maps produced by the EMODnet project are currently being reprocessed. As such, only 2016 interim maps were available for five regional areas (Norway, North and Celtic Seas, Atlantic area, Baltic and Eastern Mediterranean). Representation of the Western Mediterranean Sea relied on a 2012 map as the interim map is still under production. The interim maps were kindly provided by the Joint Nature Conservation Committee in the UK (partners within the seabed habitats component of the EMODNET project). The 2012 map for the Western Mediterranean was downloaded from the EMODnet data portal[3].

All six maps were imported into ESRI ArcMap (v 10.3). The following processing steps were applied to generate a unified map for the entire assessment area. The processing followed:

1) The North and Celtic Seas polygons were cut (ESRI 'Erase' datatool) using the outline of the Atlantic, Baltic and Norwegian habitat shapefiles. This step reduces the creation of 'slither' polygons when maps are merged.
2) The Western Mediterranean polygons were cut using the Eastern Mediterranean and Atlantic polygons to erase overlap.

[3] http://www.emodnet-seabedhabitats.eu/default.aspx?page=1974

3) The main attribute field titles were aligned within each map. Furthermore, all habitat class attribution was standardized. This process removed formatting, labelling and spelling inconsistencies from each of the six maps that would otherwise split classes artificially.

4) All six maps were combined into one map using the ESRI 'Merge' datatool.

5) The resulting map was then simplified using the ESRI 'Dissolve' datatool to remove internal boundaries within polygons of the same habitat class.

6) The ESRI 'Remove multipart' datatool was then used to merge small gaps into large polygons. The size threshold used for the selection of gaps prevented the selection of the smallest possible habitat patch predicted by the modelling approach used by EMODnet, i.e. the threshold was smaller than the grid size used for the predictive model. This process removed extraneous gaps and small, erroneous polygons from the merge.

The sensitivity matrices were then applied to the merged map. To complete this process, the following steps were followed:

1) The sensitivity matrices (Atlantic, Baltic and Mediterranean) were combined into one table and aligned with each habitat class. For each sensitivity label (i.e. NA = not assessed, L = low, M = medium and H = high), additional fields were included for the confidence association with the score and a numerical code to also represent the sensitivity (NA = 0, L = 1, M = 2, H = 3) - numerical codes are often easier for geospatial processing.

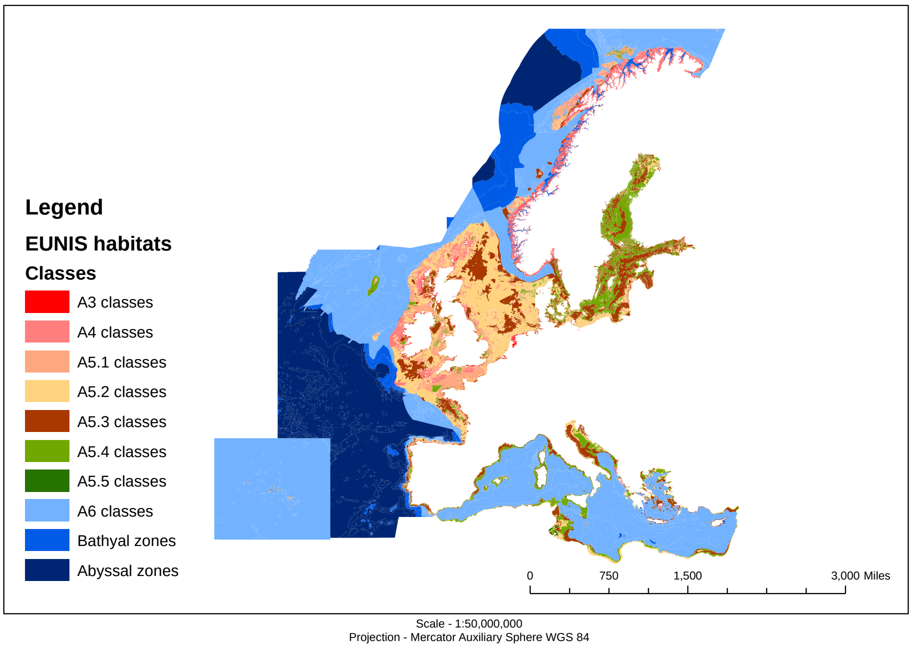


Figure 4.1. Existing and Interim EMODnet EUNIS habitat maps merged

The merged coverage contained 4 EUNIS level 2 habitats, 17 level 3 habitats , 26 level 4 habitats, 3 level 5 habitats and 14 deep-water habitats only classified into biological depth zones only (Figure 4.1). The most extensive habitats were A6.5 (deep-sea mud), M.AtAl (lower abyssal seabed) and Mediterranean communities of bathyal mud A6.51. By contrast, the least extensive habitats were A4 (circalittoral rock), Mediterranean seagrass beds (e.g. A5.531) and A3.6 (Baltic sheltered infralittoral rock. Merging of the files from each of the biogeographic zones resulted in some striking discrepancies between adjoining habitats. For example, the discrepancy between the NE North Sea and the SE Norwegian habitats is due to the latter being attributed with a substratum type and the former classifying the area using just biological depth zones. Equally, the discrepancy between the SW edge of the Atlantic area and the Azores is also the product of differing levels of classification (i.e. a substratum type has been allocated to Azorean seabed).

All deep-water habitats are shown to have a high sensitivity to all forms of pressure considered. Shelf habitats have been attributed with a range of sensitivities from low to high. The majority of the shelf habitats in the North and Celtic Seas are considered to have a moderate sensitivity to the physical pressures generated by bottom-contacting fishing activity.

5 Pilot impact assessment

5.1 Method to assess fisheries impact in the WKFBI approach

To estimate the impact of fisheries on benthic communities and habitats, WKFBI used the annual swept-area ratios (SAR) at the surface and subsurface layer (Chapter 2) as well as habitat sensitivity scores (Chapter 3 and 4). Since WKFBI used a categorical classification system for sensitivity, the information about fishing pressure had to be converted into categories (Table 5.1). Interval boundaries are arbitrarily chosen but based on the range and frequency of SAR values within grid cells of the investigated area. However, other classifications may be also possible and potentially lead to different results.

Table 5.1. Classification of fishing pressure into five different pressure classes from very low to very high defined by intervals of swept-area ratio (SAR)

Fishing pressure	SAR interval
1: Very low	[0.05; 0.1] *
2: Low	[0.1; 0.5]
3: Medium	[0.5; 1.0]
4: High	[1.0; 5.0]
5: Very high	>5

*** The first interval does not include values smaller than 0.05 SAR because this has a high risk of including grid cells where vessel activity has been misclassified as fishing.**

Because fishing pressure values are available on a 0.05°x0.05° c-square grid, a spatial overlay has been performed assigning the habitat and by this the sensitivity metrics found at the midpoint of each grid cell to the respective fishing pressure category (Figure 5.1). In order to create the impact map, impact scores had to be assigned to each possible pressure-sensitivity combination. Four sensitivity categories were distinguished in relation to surface abrasion (Figures 5.2), whereas the sensitivity to shallow abrasion and to penetration had only three categories (Figure 5.3), both resulting in six impact classes ranging from very low to high.

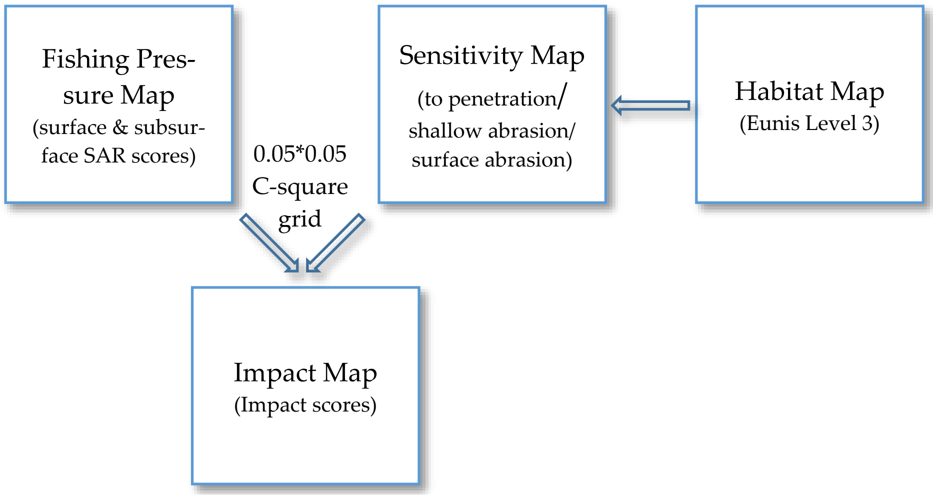


Figure 5.1. Conceptual diagram describing how categorical impact scores were estimated from the overlay between habitat and the respective sensitivity maps and the fishing pressure maps (expressed as surface or subsurface SAR).

Table 5.2. Impact matrix relating five fishing pressure levels to four sensitivity levels (surface abrasion). Adapted from MBI0101, see also sensitivity scoring (Annex 4).

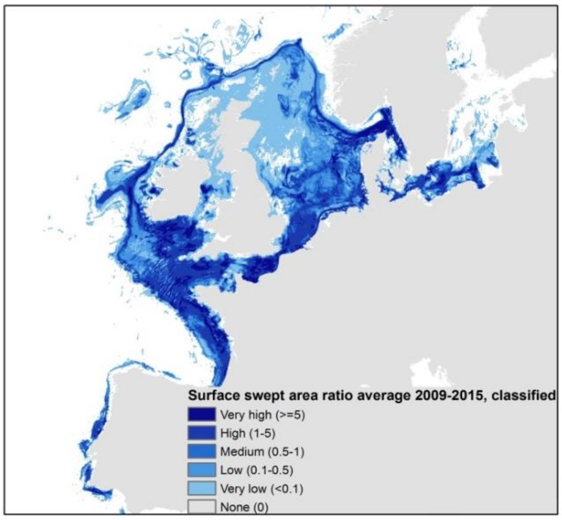
	Sensitivity level to surface abrasion			
Pressure level	L	L–M	M	H
None	None	None	None	None
Very low	Very low	Very low	Low	Low-Medium
Low	Very low	Low	Low-Medium	Medium
Medium	Very low	Low-Medium	Medium	Medium-High
High	Very low	Medium	Medium-High	High
Very high	Low	Medium-High	High	High

Table 5.3. Impact matrix relating five fishing pressure levels to three sensitivity levels (valid for shallow abrasion and penetration). Adapted from MBI0101, see also sensitivity scoring (Annex 4).

	Sensitivity level to shallow abrasion and penetration		
Pressure level	L	M	H
None	None	None	None
Very low	Very low	Low	Low-Medium
Low	Very low	Low-Medium	Medium
Medium	Very low	Medium	Medium-High
High	Very low	Medium-High	High
Very high	Low	High	High

5.2 Results of the WKFBI approach to assess fisheries impact:

SARs averaged over 7 years and summing up all relevant bottom contacting gears range from approximately 0-68 for surface and 0-10 for subsurface layers. Using five different SAR categories instead of the continuously scaled SAR values reduced the amount of information. However, the main spatial patterns with high surface SARs in nearshore areas and along the shelf breaks still persist (compare Figure 2.6 with 5.2). Similarly for subsurface layers high pressure levels were found in those areas where beam trawling and dredging was of particular importance.



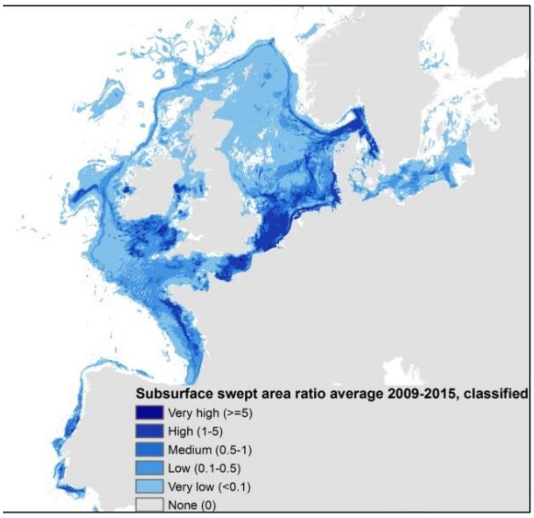


Figure 5.2. Surface (left) and subsurface (right) abrasion from bottom-contacting fishing gears classified into five categories (from very low to very high) based on swept-area ratio estimates between 2009-2015 based on Figure 2.6.

In order to illustrate the spatial and temporal variability of fishing pressure scores, grid cells above a certain SAR threshold (corresponding to the SAR categories in table 5.1) were mapped including the information in how many of the seven years these thresholds were reached (Figure 5.3 and 5.4). Most areas, for which SAR values were available, experience at least a low fishing pressure (Figure 5.5, upper left). Very low SAR values below 0.1 were mainly found in the northwestern North Sea. Only few areas experience very high fishing pressures (>5), but these can be found along all European coasts (Figure 5.3, lower right). The spatial distribution of fishing effort does not vary much between years (see also Figure 2.7) and for most grid cells the same pressure scores are found in all seven years. Highest variability is found at the outer boundaries, which may not only represent the real interannual variability, but can be partly caused by an incomplete data source (e.g. no VMS data from Spain, Iceletc.).

Subsurface abrasion is only a proportion of the total SAR. Thus, the number of grid cells above a certain threshold is generally smaller but spatial patterns are similar to surface SARs (Figure 5.4). Subsurface SAR values above 5 were only found in very few areas, e.g. along the West Frisian Islands (Figure 5.4, lower right).

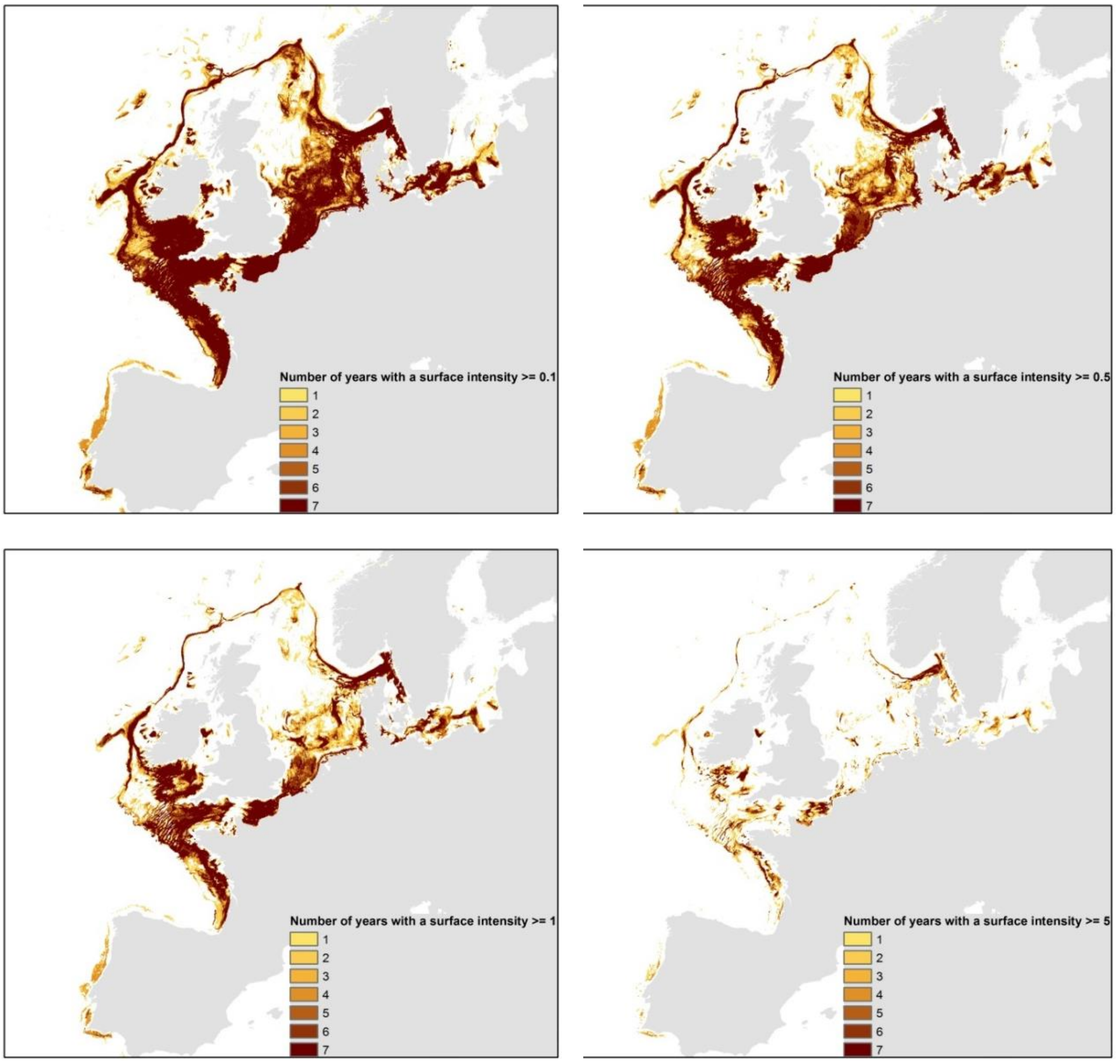


Figure 5.3. Number of years with a surface swept-area ratio of >=0.1 (upper left), >=0.5 (upper right), >=1 (lower left), and >=5 (lower right)

Figure 5.4. Number of years with a subsurface swept-area ratio of >=0.1 (upper left), >=0.5 (upper right), >=1 (lower left), and >=5 (lower right)

Maps of the scores describing the potential impact due to surface abrasion, shallow abrasion and penetration show very distinct patterns (Figure 5.5 – panels on the left). Surface impact scores are mainly driven by the underlying habitat sensitivity scores. Although surface abrasion can be very high, the habitat sensitivity to this pressure is locally low, e.g. in the Wadden Sea, resulting in low to very low impact scores. In contrast to this, deep-water habitats are usually highly sensitive resulting in high impact scores, even when the corresponding fishing pressure was comparatively low. Sensitivity scores in relation to shallow abrasion and penetration are usually higher and thus only few areas show a low impact score. Here the impact scores are mainly driven by pressure, i.e. the subsurface abrasion caused by fishing gears. Consequently, highest impacts were estimated in areas where beam trawling and dredging is taking place, but the main areas for otter trawling, e.g. along the shelf breaks, experience high impact scores as well.

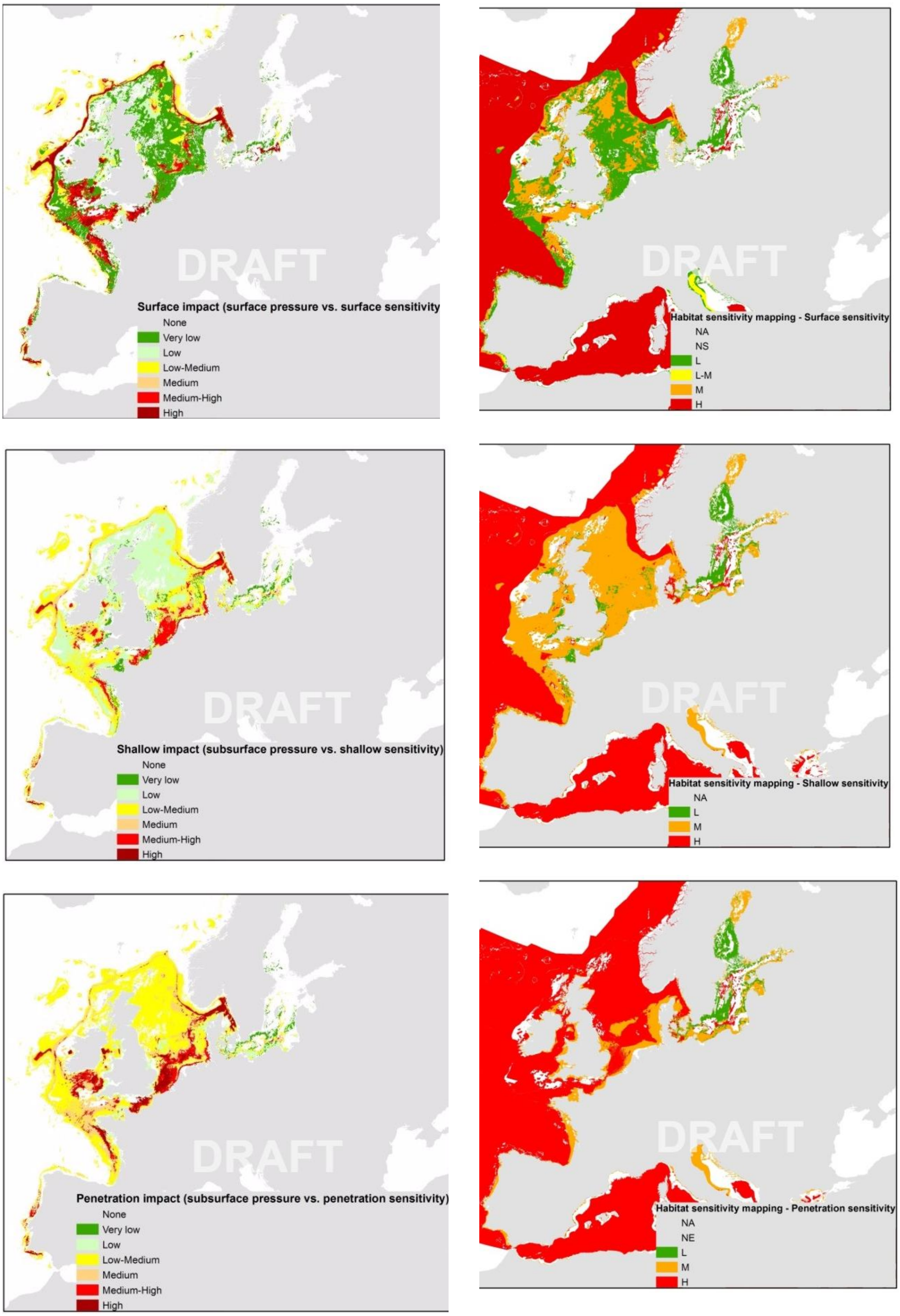


Figure 5.5. Fishing impact scores (left panels) resulting from the combination of swept-area ratio categories (Figure 5.2) and the habitat sensitivity (right panels, the same as in Figure 3.1) to surface abrasion (upper panels), shallow abrasion (central panels) and penetration (lower panels). Note: these are draft images.

The variability of impact scores over the seven years (Figure 5.6) was low for most areas but locally high variability was encountered, resulting from variations in fishing effort between years. Surface impact classes hardly changed from one year to the other. For subsurface abrasion highest variability was found in the southeastern North Sea, mainly driven by changes in beam trawling activities. Before 2012 vessels with a length of 12-15m were not obliged to have VMS on board. Following this legislation change we therefore investigated the variability of impact scores in the three most recent years (20132015, Figure 5.7). The areas with a high variability of impact scores were still detectable, and, according to Figure 5.7 often showed a slightly decreasing trend in impact. However, because only three years are considered, this only provides a rough indication that the situation might have recently improved.

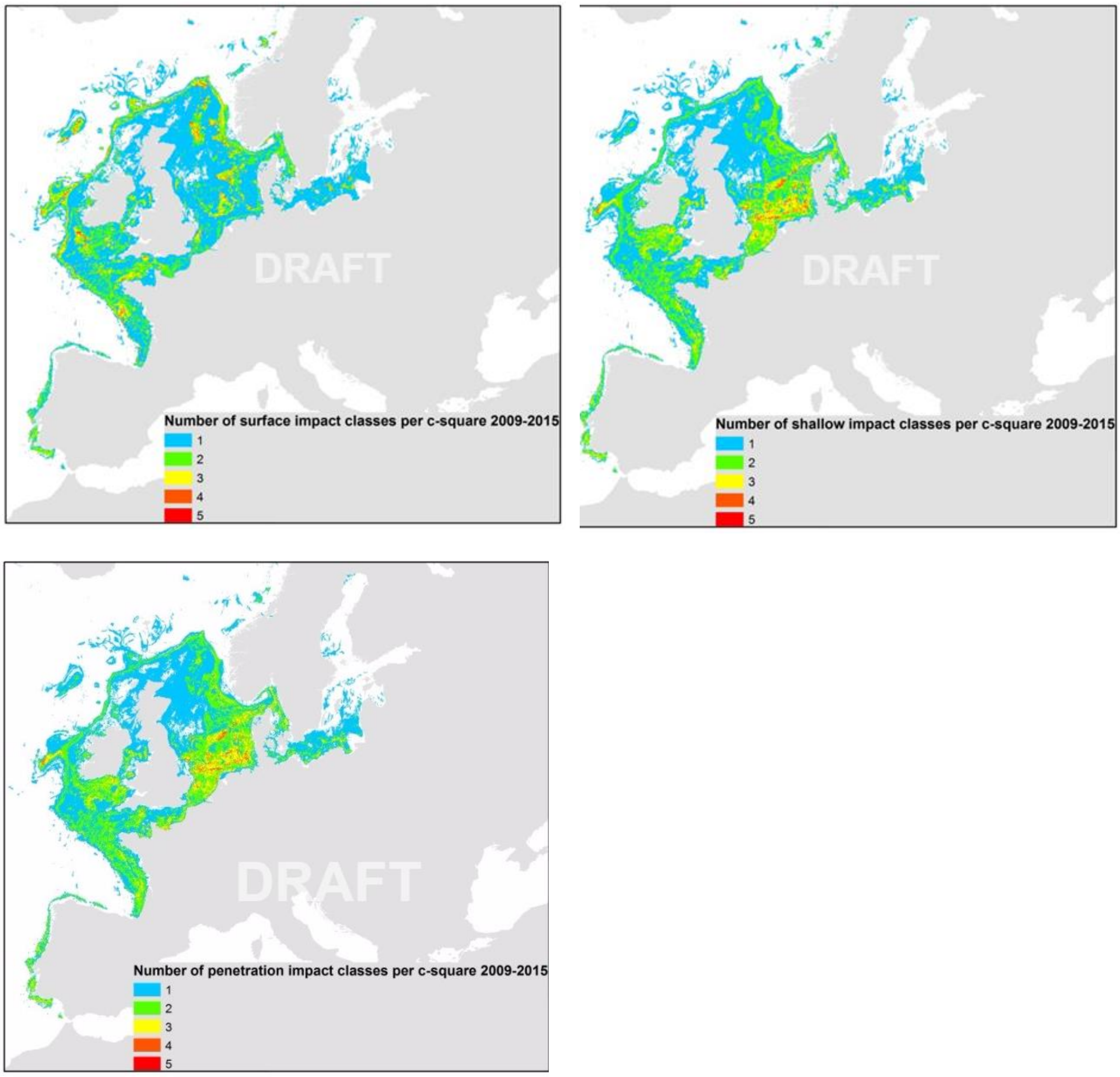


Figure 5.6. Temporal variability of fishing impact scores caused by surface abrasion (upper left), shallow abrasion (upper right) and penetration (lower left) over the seven year time period (2009-2015). Variability is expressed as the number of different impact classes found within each grid cell. Because habitat is not assumed to change, variability is caused only by variations in fishing pressure. Note: these are draft images.

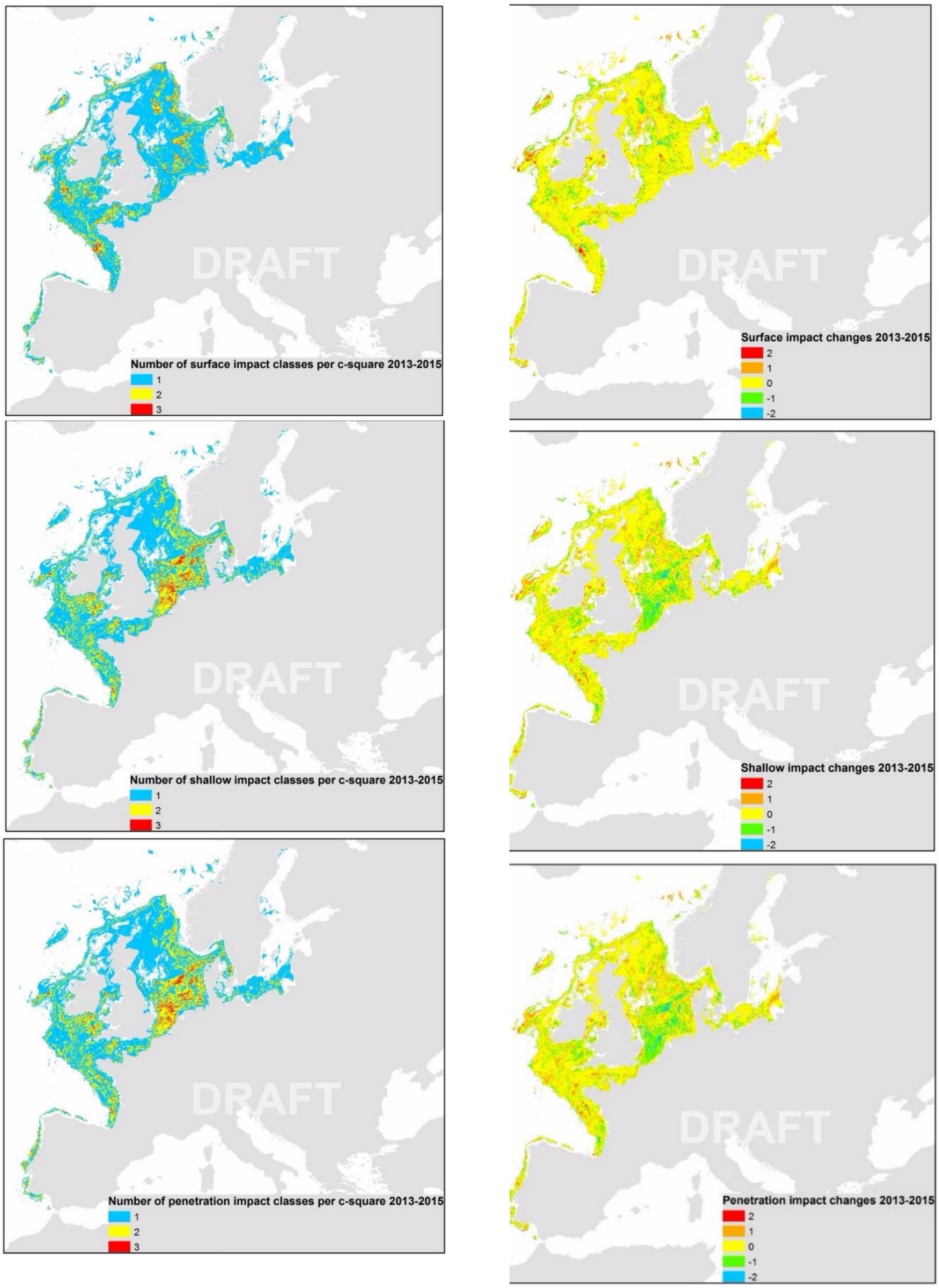


Figure 5.7. Temporal variability of fishing impact scores caused by surface abrasion (upper panels), shallow abrasion (central panels) and penetration (lower panels) from 20132015. Variability is expressed as the number of different impact classes found within each grid cell (left panels), as well as the indication of the trend in impact scores, i.e. if it is increasing or decreasing from 20132015. Note: these are draft images.

The economic importance of the areas (grid cells) was investigated across impact scores for both the catch (in 10^3t) and value of the catch (in Mill. €) (Figure 5.8). Most grid cells show a very low to low impact due to surface abrasion and consequently a very high amount of the total catch and value is made within these cells. However, although fewer grid cells experience a medium-high to high impact the catch and especially the value of the catch from these areas reach similar values. For most of the grid cells, impact scores due to shallow abrasion and penetration were low to low-medium or low-medium to medium, respectively. Highest catches and revenues were made in the few areas experiencing a medium-high impact score in relation to shallow abrasion. Similarly the majority of the catches were made in areas with low-medium to high impact due to penetration. However, the value of the catch from highly impacted areas is very high.

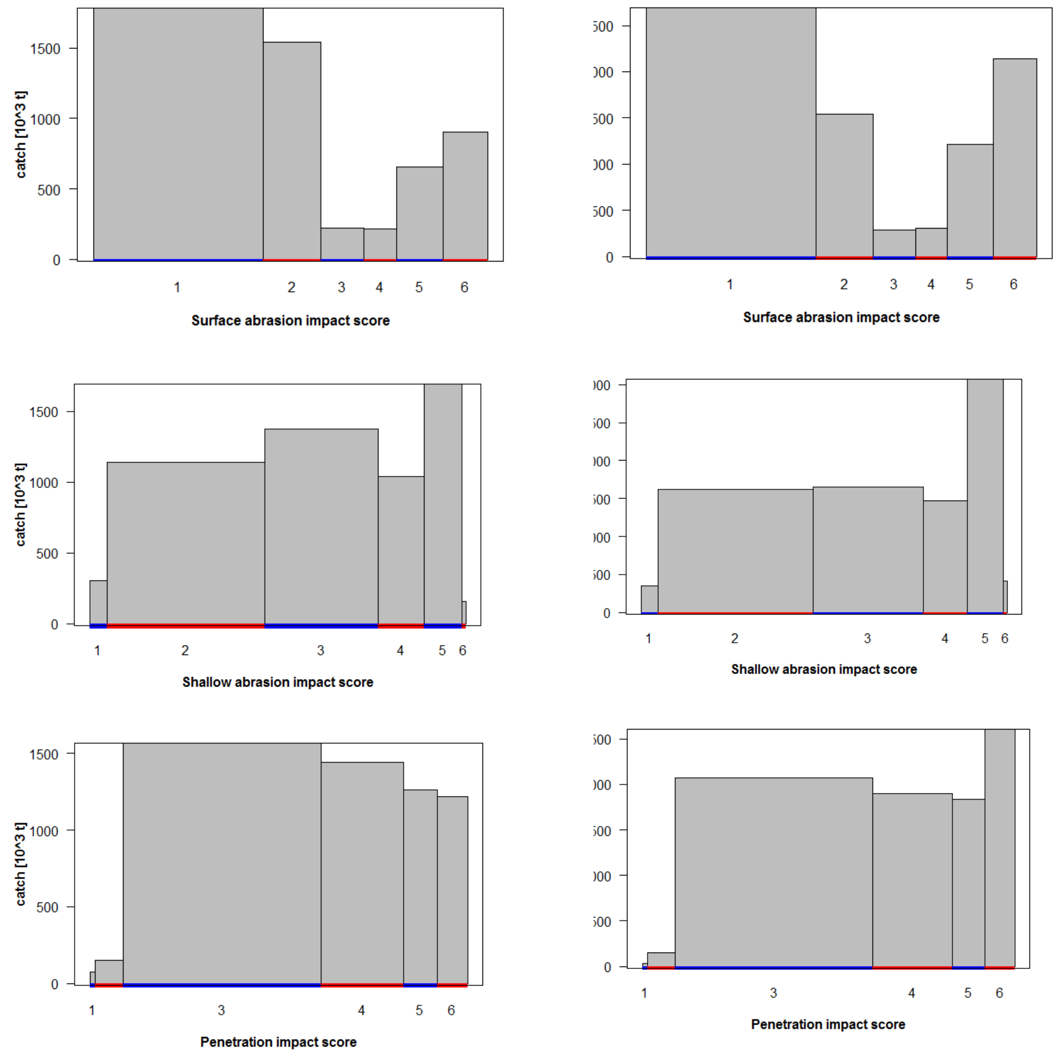


Figure 5.8. Fisheries catch (in 1000t, left panels) and value (in Mill. €, right panels) from grid cells with the same impact score. Bar width corresponds to the number of grid cells with the respective impact score. Impact Scores correspond to 1very low, 2low, 3low-medium, 4 medium, 5medium-high, 6high. Top: Impact scores due to surface abrasion; Centre: Impact scores due to shallow abrasion; Bottom: Impact Scores due to penetration.

5.3 Knowledge gaps, caveats and uncertainties

Estimating fisheries impact on benthic habitats involves a number of assumptions. These are partly related to the underlying data of fishing pressure (Chapter 2) and habitat sensitivity (Chapter 3) but also depend on the methods used to combine this information. The current approach represents a regional assessment, meaning that fine-scale features cannot be resolved.

When using impact scores, categories for habitat sensitivity as well as for fishing pressure are needed. This means that a continuously scaled variable like SAR is converted into an ordinal scale. The underlying uncertainties caused by interval definitions still need to be explored. Further, the definition of the matrix (Tables 5.2 and 5.3, see also Annex 4) describing the impact scores needs to be assessed by using experimental and field studies in order to improve evidence on the pressure-impact-response relationships.

In the current approach we investigated fisheries impact over the last seven years. However, bottom trawling has been an ongoing activity for more than 100 years (Fock *et al*. 2014) and consequently persistent effects on benthic communities need to be expected. This means that sensitive species could have been replaced by opportunistic and less sensitive species over time.

6 BH3 OSPAR

This indicator is being developed under the OSPAR ICGCOBAM benthic expert group and has being adopted as common indicator for the North Sea, Celtic Sea and Bay of Biscay/Iberian Peninsula. The work started in 2013 and has gone under several round of testing, consultation and reviews. The first round of assessments will be produced in August 2016.

The aim of this indicator is to evaluate to what extent the seabed and its associated ecology, species and habitats, are being damaged by human activities, exerting physical pressures such as those caused by some parts of the fishing gears. It is being designed to assess all habitat types and is regarded as particularly useful to analyse larger sea areas with relatively low additional sampling effort.

The indicator is built upon two types of underlying information, i) the distribution and sensitivity of habitats and their components and ii) the distribution and intensity of human activities and pressures that cause physical damage, such as mobile bottom gear fisheries, sediment extraction and offshore constructions. These sources of information are combined using a modelling approach to calculate an index value on the current damage to a given seabed habitat.

Two temporal scales are used:

1. Annually to calculate the distribution of disturbance and PDIs within a year and,
2. Within an MSFD cycle (6 years) to calculate the total aggregated values for a whole cycle.

The indicator method is based on a series of analytical steps to combine the distribution and intensity of physical damage pressures with the distribution and range of habitat and their specific sensitivities using a spatial analysis model. Figure 6.1 shows an overview of the concept, and illustrate each of the steps of the analysis is described in more detail in the following steps

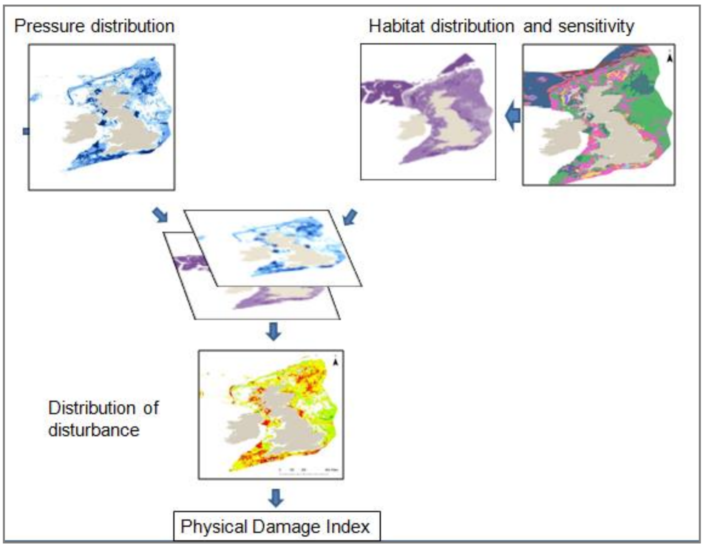


Figure 6.1. Overview of the concept, and illustration of each of the steps in the analysis to combine the distribution and intensity of physical damage pressures with the distribution and range of habitat and their specific sensitivities

6.1 Parameters and metrics

The final parameter/metric of this indicator is the index of physical damage for a given habitat across a region. The metrics and components of the analysis are:

<u>1-Extent and distribution of habitats:</u> Combined habitat maps showing the extent and distribution of habitats (based on observational and modelled data), including the mapped extent of any relevant features (e.g. records and distribution of particular species and biotopes like EUNIS Level 5, 6 habitats or other biological characteristics), all grouped within the relevant EUNIS[4] level 3 (level 2 in the new classification).

The level 3 models have been supplied by EMODnet seabed project. Additional survey data has been collected through data calls.

The specification for a habitat map for the assessment of BH3 included the following conditions:

1. To contain biotope data or smaller units of EUNIS classification (e.g. Eunis level 6)
2. To refer data on biotopes to Level 3 of the EUNIS habitat classification system;
3. To use modelled Eunis level 3 when high resolution data are not available
4. To use the best available evidence;
5. To cover the greatest possible area of the OSPAR Northeast Atlantic region;
6. To contain no overlaps.

Mapping rules were established in order to objectively decide which of the overlapping datasets would be the sole occupant the overlapping area. Where a EUNIS habitat map from survey overlapped with a broad-scale predictive map a threshold MESH confidence score of 58 % was used as a simple rule for deciding whether or not to favour the habitat map from survey. Within the MESH scoring system, for any map to have a score greater than 58 %, the survey techniques must have used a combination of remote sensing and ground-truthing to derive the habitat types. Therefore, 58 % was deemed to be the lower threshold at which an overlapping survey map “wins” against a broad-scale map.

Preprocessing conditions and rules for the combining of data are available on the technical specifications of BH3. A draft version of the combined maps is showing in Figure 6.2.

[4] EUNIS = European nature information system

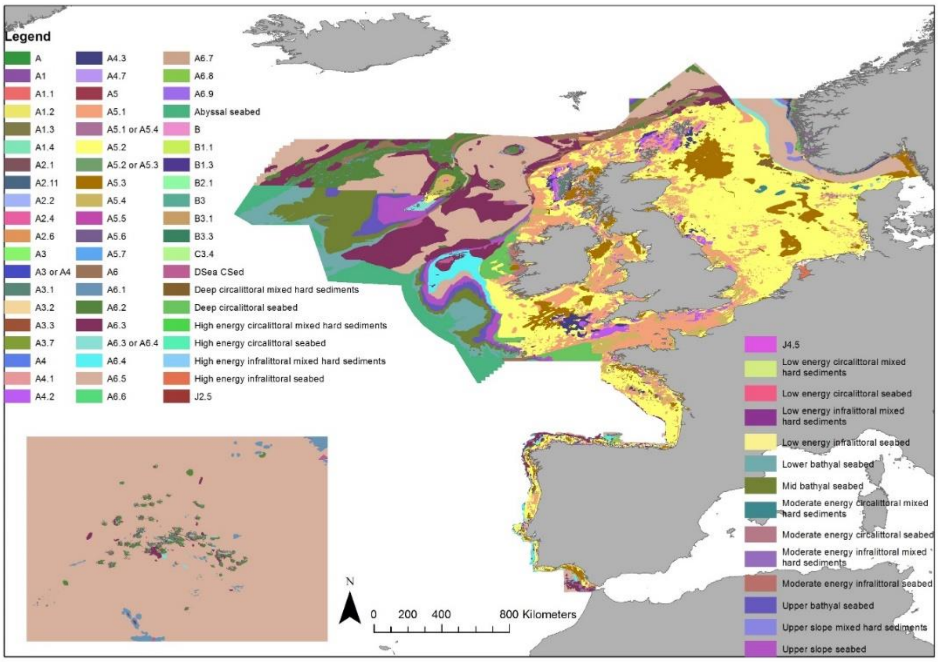


Figure 6.2. Draft EUNIS Level 3 Combined Habitat Map for OSPAR Regions. Please note high resolution data are not being displayed.

2-Sensitivity distribution: Combined resistance (tolerance to impacts) and resilience (recoverability) of habitats based on observational and modelled data at species, biotope/Eunis level 5 (or higher) and Eunis Level 3.

Sensitivity of ecosystem components are determined by two aspects: the ability to withstand disturbance or stress (resistance or tolerance) and the ability and time needed to recover from a perturbation and return to the previous state (resilience or recoverability). A species or habitats with a high sensitivity is therefore one that has both low a low resistance and resilience whereas a species with a low sensitivity is one with a high resistance and resilience.

The sensitivity of an ecosystem can be assessed in a number of different ways. More traditional methods have assessed the sensitivity of a broad scale habitat (e.g. Tillin & Tyler Walters (2010); the UK sensitivity assessment carried out for MPA designation). More recent methods however, analyse the functional groups within the habitat to assign sensitivities to characterizing species within these functional groups based on physical traits (e.g. Tillin *et al*. 2015). Characteristic species should be those that significantly influence the ecology of habitat. They could be species which provide a distinct habitat that supports an associated community, or one that is important for community functioning through interactions with other species, or species which are used for the definition of a habitat. The loss or degradation of one of these species would severely affect the viability, structure and function of the habitat and may result in the loss of the habitat or a changed classification. Ecological groups should not be species-specific, but rather consist of groups of ecologically similar species, e.g. fragile erect epifauna on cobbles and boulders.

In order to undertake the most reliable sensitivity assessments of habitats, the best available evidence should be used where available. We are therefore proposing to take a layered approach when creating sensitivity maps. This allows for the resistance and resilience species, biotopes points to be plotted within a 0.05 grids when point and survey data are available, and extrapolated to a wider polygon following the set of spatial rules. This is summarized in Figure 6.3 below:

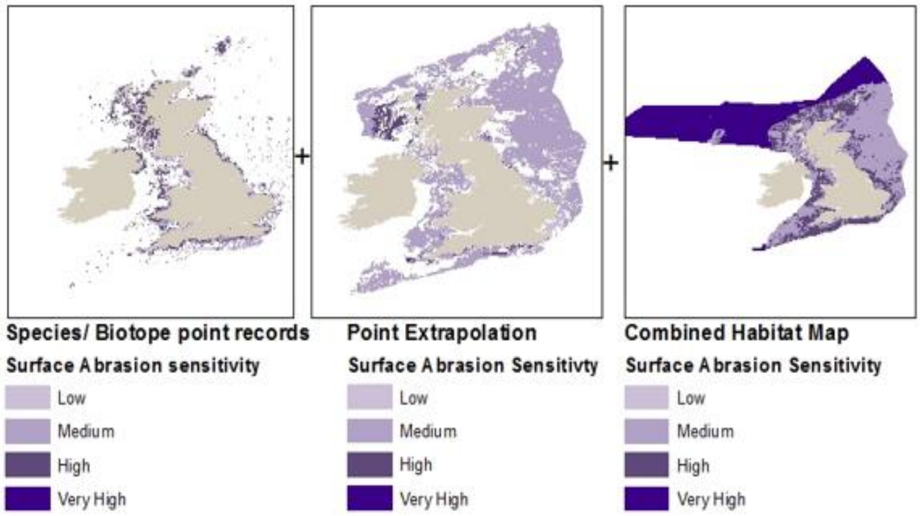


Figure 6.3 Illustration of the proposed layered approach when creating sensitivity maps in BH3.

The sensitivity layers are calculated on the resistance and resilience for the two main pressures categories of surface and subsurface abrasion. Figure 6.4 shows an example for combined sensitivity for surface abrasion

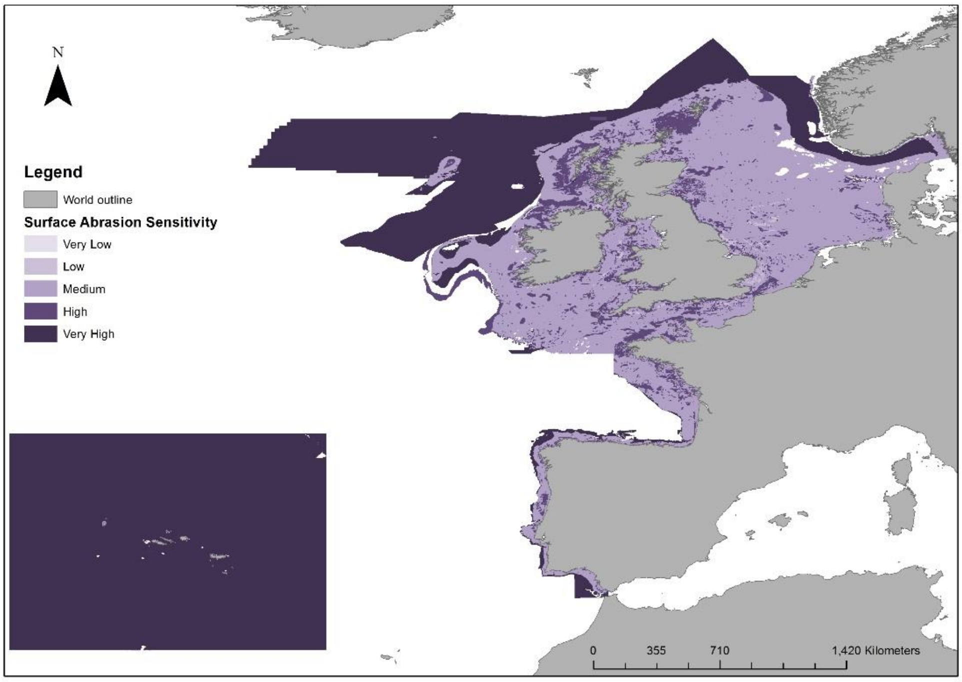


Figure 6.4. Draft Extent and distribution of sensitivity categories to surface abrasion per habitat polygon across OSPAR regions calculated within 0.05 grids

3 -Distribution and intensity of physical damage pressures: Based on swept-area ratio of surface and subsurface abrasion (for fishing >12m vessels only) within 0.05o grids (c-squares).

The method for the calculation of swept-areas ratios per grid cells has been modified following the ICES advice to OSPAR. A brief explanation can be found in the Advice 2015, for which the WGSFD 2015 contributed towards.

The SAR has been classified following several discussions with experts and using some initial results from multimetric indicators (Figure 6.5).

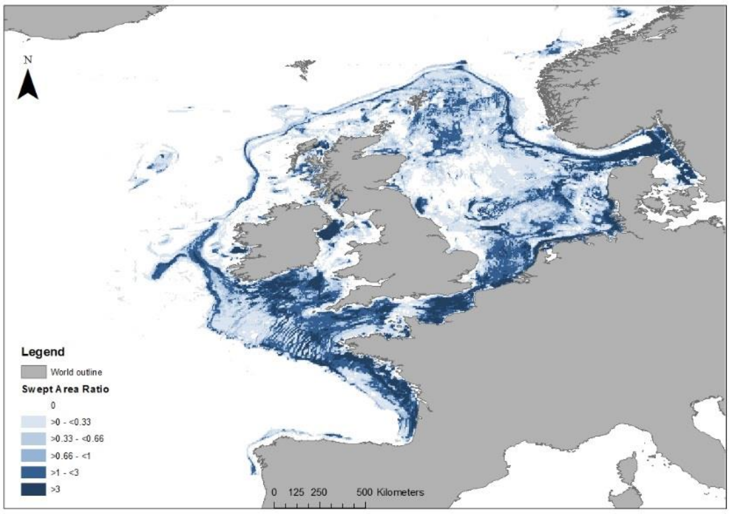


Figure 6.5. Draft classified Surface abrasion pressure for 2013 from VMS data showing swept-area ratio (SAR) for each 0.05x0.05 grid cell.

4 - Distribution of disturbance categories per habitat type: Calculation of nine levels of disturbance based on exposure matrices combining pressure intensity and habitat sensitivity per pressure type (Table 6.1).

Table 6.1. Weighted disturbance values of sensitivity categories over a temporal scale based on SARs within a year. The values are applied per habitat type with each c-square.

Disturbance		Habitat Sensitivity				
		1	2	3	4	5
Temporal extent of pressure	1	1	2	3	4	6
	2	1	2	4	6	7
	3	1	3	5	7	9
	4	1	4	6	8	9
	5	2	4	7	9	9

The levels of disturbance are analysed to calculate the total area of disturbance across the region per habitat type (Figure 6.6), and the Physical Damage Index for surface (PDIsur) and subsurface (PDIsub) abrasion. These PDIs are then combined into one index to calculate total disturbance per year, and aggregated across the cycle to calculate total disturbance and trends across several years.

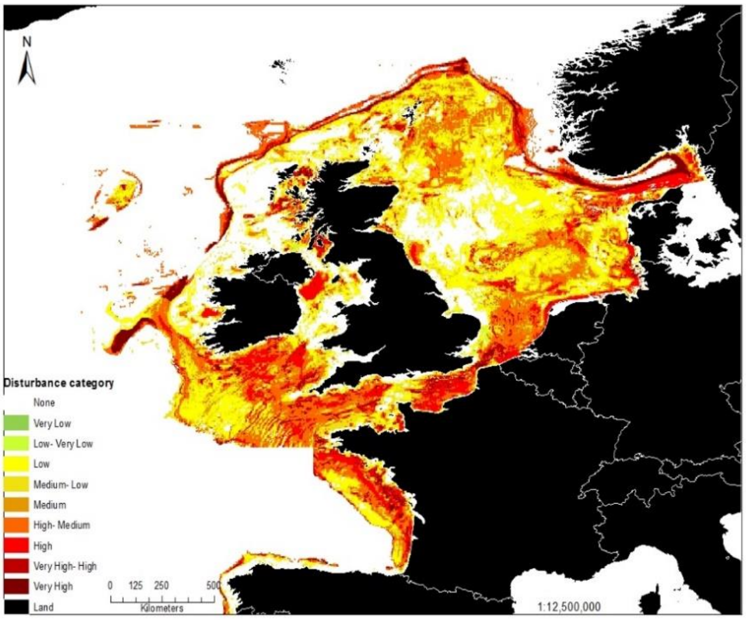


Figure 6.5. Draft distribution of categories of disturbance caused by Surface Abrasion across OSPAR regions based on 2013 VMS fishing data per habitat polygon within 0.05 grids

5- Calculation of the PDI: The final output is the calculation of the Physical Damage Index:

$$PDI = 1 - \left(\frac{\sum_{i=1}^{10} d_i a_i}{100 \times A}\right)$$

where *d* is the degree of disturbance, *A* is the habitat area, and *i, 1-10* represents the disturbance categories derived from the disturbance matrix. High PDI values indicate either pressures with considerable temporal and spatial extent or habitats with high sensitivity towards the occurring pressures. The index provides the combined disturbance results habitat type per year and trends across cycle. It ranges between 0 to 1, where 1 is habitat is not disturbed across its range, and 0 is the full extent of habitat is disturbed.

6 – Confidence calculations: To calculate the degree and distribution of confidence a scoring approach has been developed to combine the amount of data available and the confidence associated with the resilience and resistance scores (Figure 6.7).

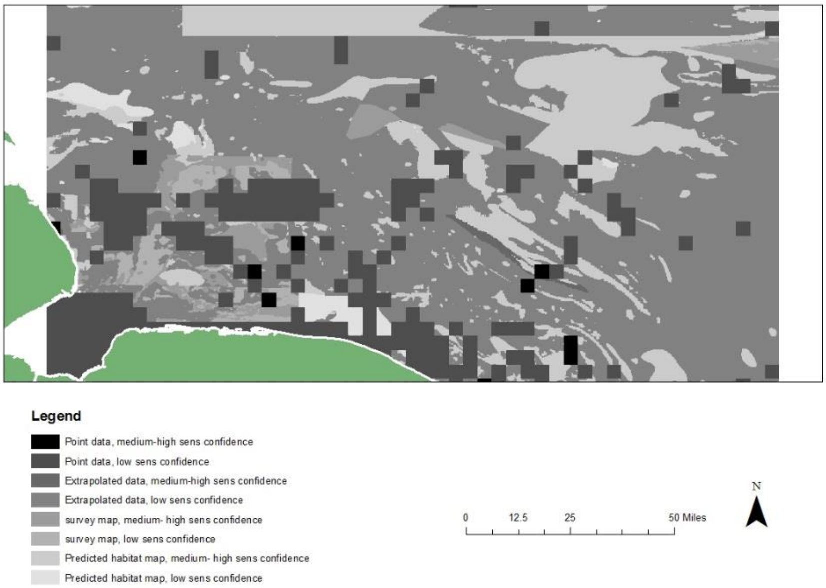


Figure 6.7. Example of Confidence calculation based on data availability and confidence sensitivity scores

Detailed technical information on the methodological steps and data requirements are available on the technical specifications.

6.2 Validation and calibration of BH3 using multimeric and other condition indicators.

The indicator provides a modelled output of disturbance values and quantitative values of PDIs per habitat type. However, more data and information is required, in particular, the scale for the fishing pressure and the matrix underpinning the disturbance values need to be evaluated using experimental and field studies in order to improve our understanding on the pressure-impact-response relationships. In order to address the limitations on the evidence underpinning the sensitivities information and the disturbance values, it is considered necessary to validate or ground-truth the results using quantitative condition indicators. The OSPAR EcApRHA project *(Applying an ecosystem approach to (sub) regional habitat assessments*) is looking at approaches to combine metric across benthic indicators which can help not only to validate the spatial distribution of disturbance values but also to refine and/or improve the threshold values use to categorize the data, in particular reference values. Two condition indicators are being considered for this exercise: Multimetric indices based on WFD tools (BH2) and Typical species indicator (BH1).

Areas under consideration where more evidence is needed to improve the BH3 results:

- Improve our knowledge and better definition on the thresholds for the resilience and resistance values;
- Better data on state-pressure-impact relationship to improve the disturbance matrix;
- Revision of the temporal scale of pressures to quantify a decrease on habitat or community sensitivity
- Quantification of variation of SARs across years.

6.3 Limitations of BH3 concept and results.

The indicator is still under development as other physical damage pressures have not been included. Areas for further development are:

- Availability of survey biotope data and the extent and distribution of some modelled habitats, in particular deep habitats in region IV,
- Small fishing vessels do not operate VMS, therefore creating a gap on the distribution and intensity of abrasion pressures caused by bottom gears
- At present, it is not possible to use the indicator to evaluate historical and chronic damage, as habitats under ongoing fishing pressures tend to be modified and many of the sensitive features have been replaced by opportunistic and less sensitive species.
- An accurate method for combining the cumulative effects of different pressures has yet to be developed for this indicator.

7 BENTHIS EU FP7-project

The FP7-project BENTHIS developed two quantitative methods to determine the state of the seabed depending on trawling pressure and habitat sensitivity: (i) population dynamic approach (Piet *et al*., in prep); (ii) longevity approach (Rijnsdorp *et al*., 2016). The methods are fully quantitative and based on empirical information on the effect of bottom trawls on the biomass and composition of the benthic community and avoid the qualitative scaling of habitat sensitivity. Both methods build on the annual swept-area ratios taking account of the dimensions and rigging of the different bottom trawls following Eigaard *et al* (2016). BENTHIS used grid cell size of 1 minute x 1 minute grid cells as compared to the 0.05 x 0.05 degree C-squares (3 minute x 3 minute) used by ICES. The methods differ in the way they estimated the sensitivity of the benthic community to the trawling pressure.

7.1 Population dynamic approach

The state of the seabed is here assumed to be represented by the benthic community biomass relative to that in an undisturbed situation (B/K). This benthic community biomass can be calculated by solving the logistic population growth model

Eq. 1 $dB/dt = rB(1-B/K) - dFB$

for the equilibrium state (i.e. dB/dt=0), in which case Eq. 1 has the solution (Pitcher *et al.,* in prep):

Eq. 2 $B/K=1-Fd/r$ (or where $F > r/d$, $B/K=0$)

Since the benthic community is composed of a variety of taxa which differ in their population growth rates, and therefore the effect of trawling is also different for each species, the community biomass is calculated as the sum of the individual species. Here we assume that there are no species interactions and that the r and K values have an exponential distribution. Values of K and r were randomly chosen from the exponential distribution for 1000 species with rate of decline and mean = 1. K and r were then rescaled so that the sum of K within the community was summing to 1, and the mean of r being equal to the r in Table 7.1., and the effect of fishing on the biomass of each species was calculated. The community biomass was then calculated as the sum of the biomass of all individual species (Figure 7.1). This community biomass can be used as a proxy for the state of the seabed (Seabed Integrity SI).

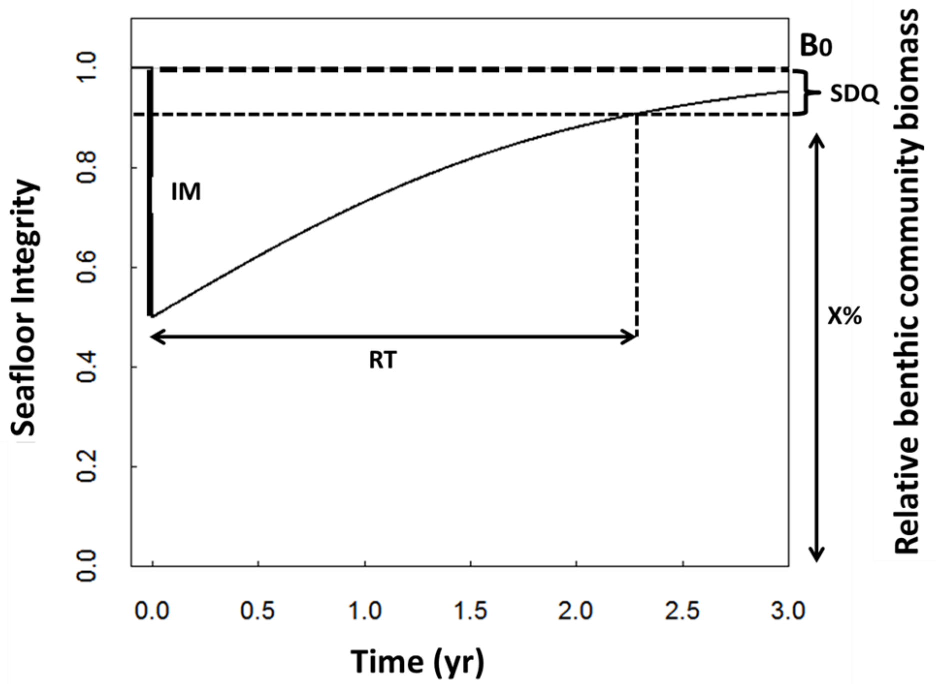


Figure 7.1. Decrease in benthic biomass following the mortality imposed by a trawling event and the subsequent recovery to the carrying capacity B0. The relative biomass can be used as an indicator of the Seabed Integrity. IM denotes the proportion at which the biomass is reduced by a trawling event. RT denotes the recovery time back to above a "significant deterioration of quality" (SDQ) at 90% of the carrying capacity B0 (unimpacted biomass).

Using the mean parameter estimates of d and r from Pitcher *et al* (in prep.), based on data of Collie *et al*. (2000) (Table 7.1), in the approach described above the state of the seabed was calculated based on the composed benthic community consisting of a variety of taxa (Figure 7.2). The analysis shows the higher sensitivity of biogenic and gravel habitat. In gravel and biogenic habitats, benthic biomass is already reduced to 90% at relatively low trawling intensities of 0.1 to 0.2 y^{-1}. For mud habitats, the trawling intensities which result in a reduction in biomass to 90% is between 0.3 - 0.6 y^{-1}. For sand, the trawling intensity is between 0.6 and 0.9 y^{-1}. The results also show the consequences of the higher depletion rate of dredge and beam trawling.

Defining GES as a community biomass of 80%, 90% or 95% of its carrying capacity, our quantitative model gives the corresponding trawling frequency thresholds above which GES is maintained (Table 7.1). In the most common habitat in the North sea, i.e. Sublittoral sand covering almost 60% of the area, a 90% threshold would allow a patch to be fished with a beam trawl less than once every year (Sustainable trawling frequency < 0.87 y^{-1}). In contrast, in case of the application of an otter trawl (OT) in a gravel habitat, this same 90% deterioration in quality threshold would determine any fishing intensity <0.14 yr^{-1} compatible with GES.

When this method is applied to average trawling frequencies in the Greater North Sea over the years 20092015, the following map was obtained. The map shows the equilibrium biomass given the average annual bottom-trawling intensity by all European fishing nations at a scale of 0.05 degrees longitude and latitude. Although that different gears can be active within the same area, all bottom fisheries were classified as otter trawling. Habitat characteristics were obtained from a shapefile compiled within the BENTHIS project that provided a EUNIS habitat for each grid cell used in the calculation. These EUNIS habitats were thereafter converted to categories: gravel, sand, mud and biogenic to link with the parameters in Table 7.1. A lookup table, representing equilibrium community biomass at different fishing intensities, was used to show final SIs on a geographical map.

Table 7.1. Mortality (d) and Recovery rate (r) values for the different gear habitat combinations and corresponding trawling frequencies that result is four levels of "significant deterioration of quality" (DQ) (Piet *et al*., in prep).

HABITAT	GEAR	D	R (Y-1)	TRAWLING FREQUENCY AT WHICH THE BENTHIC BIOMASS IS REDUCED TO A SPECIFIC LEVEL RELATIVE TO THE CARRYING CAPACITY			
				80%	90%	95%	99%
Biogenic	OT	0.39	3.03	0.44	0.17	0.06	0.01
Gravel	OT	0.48	3.03	0.36	0.14	0.05	<0.01
Sand	OT	0.37	15.59	2.28	0.93	0.39	0.06
Mud	OT	0.27	6.39	1.59	0.64	0.26	0.03
Biogenic	BT	0.45	3.03	0.46	0.19	0.09	0.01
Gravel	BT	0.53	3.03	0.36	0.14	0.06	0.01
Sand	BT	0.43	15.59	2.17	0.87	0.40	0.06
Mud	BT	0.33	6.39	1.18	0.43	0.17	0.02
Biogenic	TD	0.67	3.03	0.28	0.11	0.04	<0.01
Gravel	TD	0.72	3.03	0.24	0.09	0.04	<0.01
Sand	TD	0.66	15.59	1.55	0.60	0.25	0.04
Mud	TD	0.61	6.39	0.62	0.25	0.10	0.02

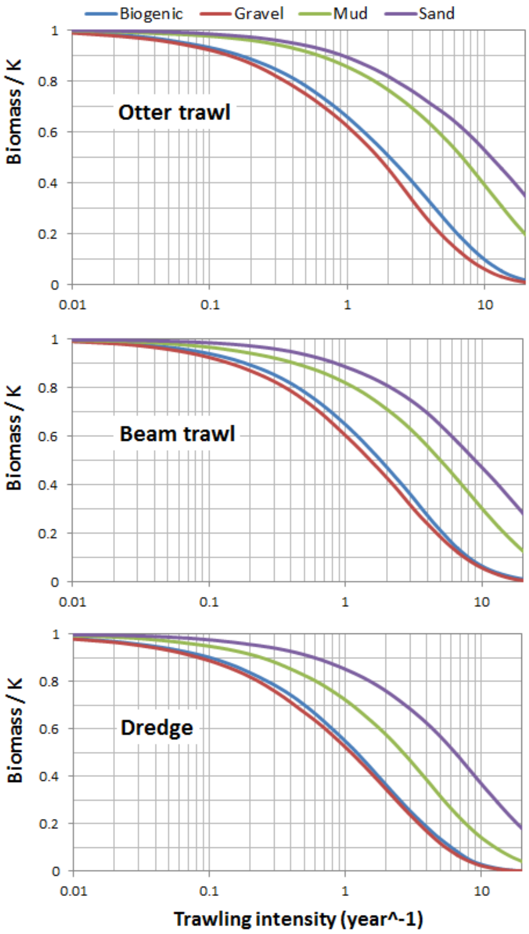


Figure 7.2. State of the seabed, i.e. Seabed Integrity (Biomass / K), at different trawling intensities for three trawling gears (Otter trawl, Beam trawl and Dredge).

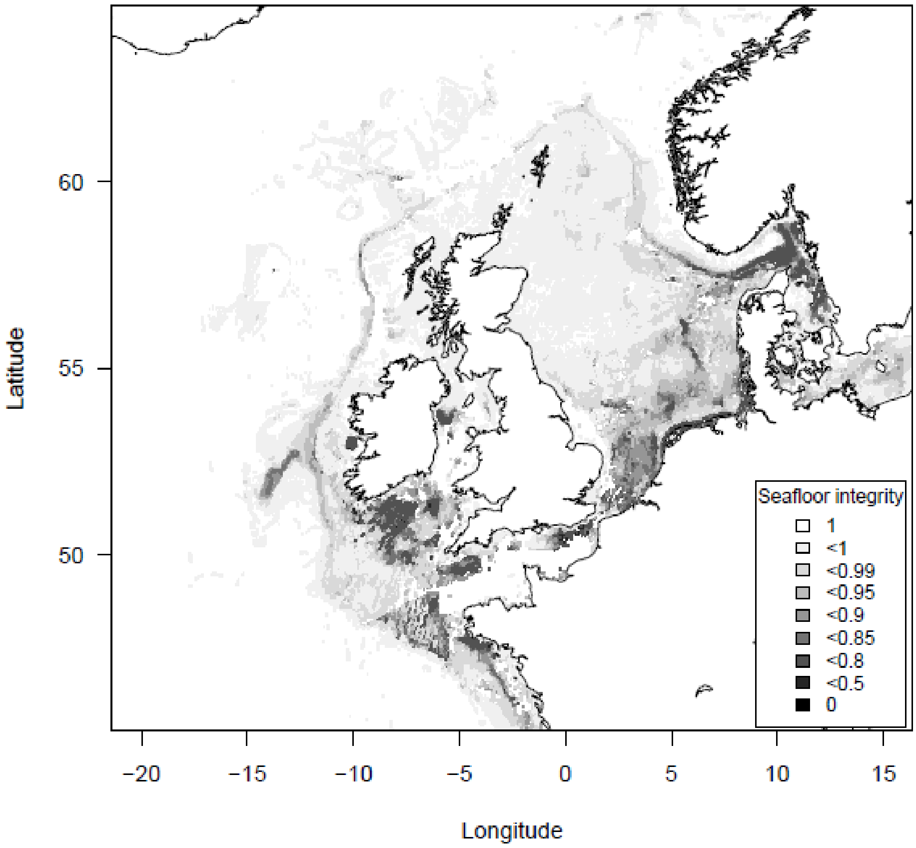


Figure 7.3. Equilibrium biomass (B/K) remaining in the Greater North Sea given the mean annual subsurface bottom-trawling intensities observed between 20092015.

7.2 Approach based on longevity

In this approach, the sensitivity of the seabed is estimated from the longevity distribution of the benthic community that is typical for a seabed habitat (Rijnsdorp *et al.*, 2016). The impact of bottom trawling on seabed was estimated by combining trawling intensity with the longevity distribution of the benthic community. If the reciprocal of the trawling intensity, which reflects the average time interval between two successive trawling events, is less than the lifespan of an organism, the integrity of the seabed habitat to allow the species to complete its full life cycle will be compromised (Thrush *et al.*, 2005). Because the longevity equals the reciprocal of the trawling intensity, seabed integrity can be estimated as the cumulative biomass proportion of the benthic community where the reciprocal of the trawling intensity is larger than the longevity of the taxa:

Eq(2) $SI = \exp[a+b*\log_e(i/t)/(1+\exp(a+b*\log_e(i/t))]$

α and β are the coefficients of the logistic regression of the cumulative biomass against the $\log_e$ of the lifespan of the taxa.

The seabed integrity of a habitat or management area can be obtained by adding up the seabed integrity indices over the grid cells and dividing by the surface area of the habitat or management area.

7.3 Longevity distribution of benthos in untrawled habitats

Differences in the longevity composition of the benthic community across seabed habitats were estimated using benthic samples collected in the North Sea and Channel. One dataset comprise of infaunal samples taken at 304 stations in the waters of England (Bolam *et al.,* 2014). The second dataset comprise of infaunal samples taken annually on about 100 stations on the Dutch continental shelf (van Denderen *et al*., 2015, van Denderen *et al*., 2014). For each sampling station, the EUNIS-3 habitat was determined based on the depth and sediment characteristics. The trawling intensity for each station was estimated by the swept-area ratio of the corresponding 1x1 minute grid cell of four bottom-trawl métiers (dredge, otter trawl, seine, beam trawl) in the period 20102012 (Eigaard et al., submitted). We assumed that the trawling gradient observed in this period reflected the differences in trawling intensity of the stations sampled in other years. The longevity composition was estimated by assigning the longevity (<1, 2-3, 5-10, >10 years) by taxon as compiled by Bolam *et al* (2014).

To estimate the biomass in relation to longevity a logistic regression was fitted through the cumulative biomass (B) in relation to $\log_e$ transformed longevity (L) and taking account of the EUNIS_3 habitat (H) and the $\log_e$ trawling intensity (F) using the following random mixed effect model:

Eq(3) $$B \sim a + b_1 L + H + b_2 L{*}H + b_3 F + b_4 F{*}H + e_1 + \text{random(station intercept and slope)} + e_2$$

We used a mixed effect model to take account on the dependence of the cumulative biomass estimates for each station. The e_1 represents a binomial error. e2 represents the normally distributed error of the random effect on the intercept and slope by station. For stations with zero trawling, a trawling intensity of 10^{-3} was assumed, corresponding to the lowest observed trawling intensity. The random mixed effect model was estimated using library lme4 in R version 3.02.

The analysis showed a significant difference across habitats in both the intercept and slope of the cumulative biomass in relation to the longevity of the taxa (Table 7.2). The benthos community of the coarse sediment habitat A5.1 showed a larger proportion of long-lived species. A5.3 showed the smallest proportion of long-lived species. Habitats A5.2 and A5.4 were intermediate (Figure 7.4). Trawling intensity showed a significant negative effect on the proportion of long-lived species as illustrated with the dashed relationships.

Table 7.2. Parameter estimates of the effect of EUNIS_3 habitat and $\log_e$ trawling intensity on the logistic relationship between the cumulative biomass of the infauna community and the $\log_e$ transformed longevity of the contributing taxa. Parameters were estimated using a mixed effect model with sampling stations and the slope of the relationship as random effects.

	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	-4.43714	0.36551	-12.140	< 2e-16 ***
loge longevity (ll)	2.81834	0.21608	13.043	< 2e-16 ***
as.factor(Eunis_3)A5.2	-1.37804	0.45147	-3.052	0.002270 **
as.factor(Eunis_3)A5.3	-0.99355	0.61474	-1.616	0.106046
as.factor(Eunis_3)A5.4	0.48277	1.01179	0.477	0.633260
lfreq	0.10936	0.03719	2.941	0.003273 **
ll:as.factor(Eunis_3)A5.2	0.99395	0.26780	3.712	0.000206 ***
ll:as.factor(Eunis_3)A5.3	1.10568	0.42025	2.631	0.008514 **
ll:as.factor(Eunis_3)A5.4	0.04438	0.61888	0.072	0.942827

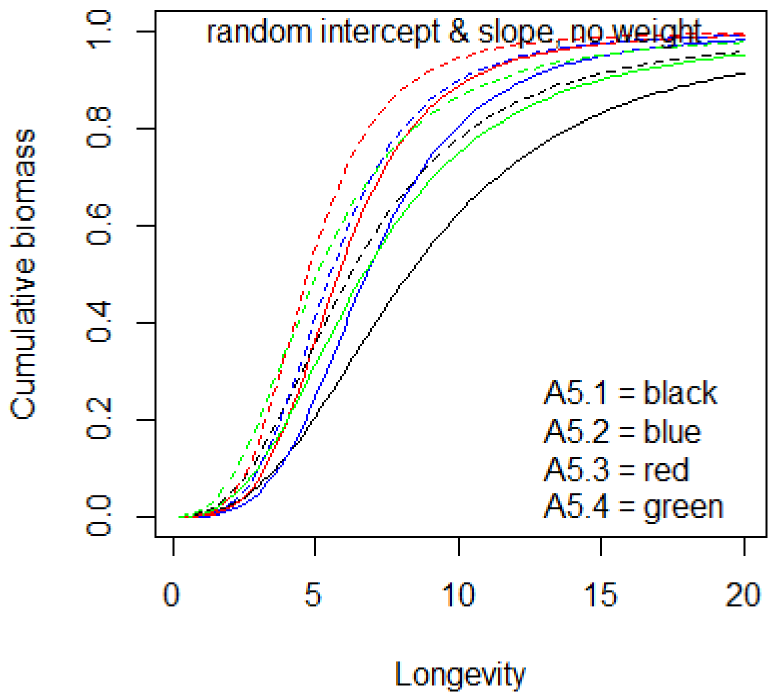


Figure 7.4. Cumulative biomass in relation to the longevity of the taxa for four EUNIS-3 habitats: sublittoral coarse sediment (A5.1); sublittoral sand (A5.2); sublittoral mud (A5.3); sublittoral mixed sediments (A5.4) for two levels of trawling pressure (full line - unfished, dashed line - trawled 1x per year). Data: Bolam *et al* 2014; van Denderen *et al.* 2015. Preliminary result from the BENTHIS project.

With the parameter estimates of the longevity distributions given in Table 7.2, the seabed integrity of each grid cell in the North Sea was estimated given the observed annual trawling frequency and its habitat classification over the past 7 years provided that all nations adjacent to the North Sea provided information on swept-area by gear (Figure 7.5). Habitat characteristics were obtained from a shapefile compiled within the BENTHIS project that provided a EUNIS habitat for each grid cell used in the calculation. These EUNIS habitats were thereafter converted to categories: EUNIS A5.1, 5.2, 5.3 and 5.4. All EUNIS habitats lower than 5.1 were classified as 5.1 and all EUNIS habitats higher than 5.4 were classified as 5.3.

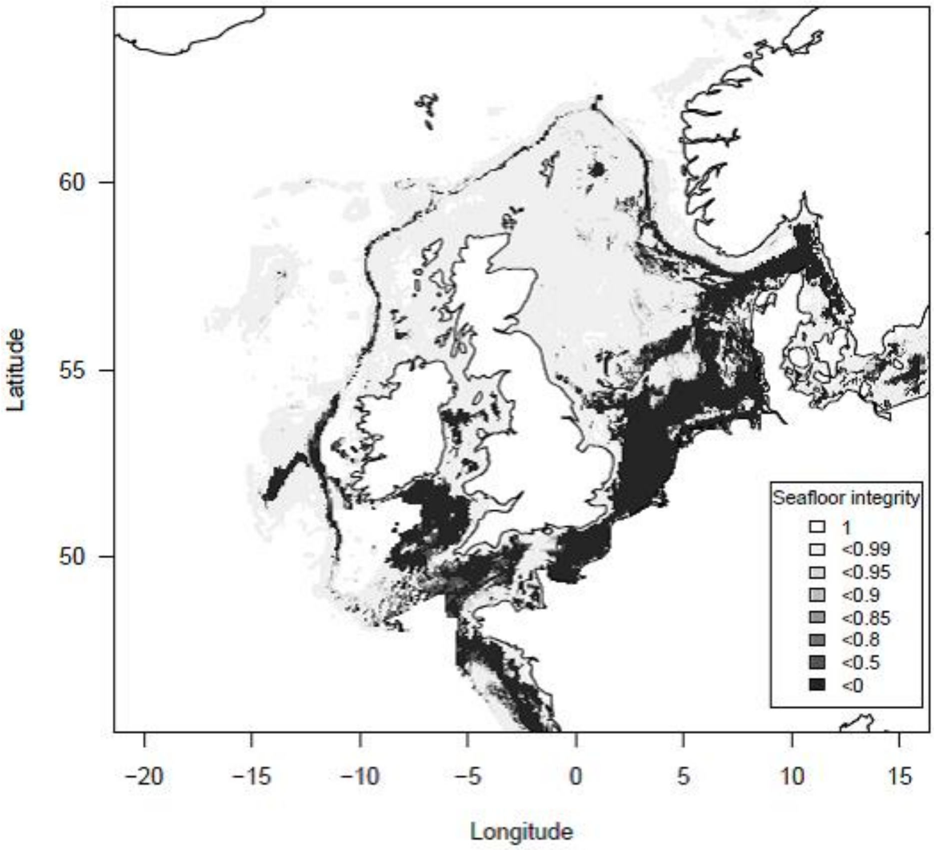


Figure 7.5. Seabed integrity in the Greater North Sea estimated using the longevity distribution by habitat and the mean annual subsurface bottom-trawling intensities observed between 20092015.

7.4 Application in GES context

Seabed integrity and footprint of bottom trawling estimated at 1x1° grid cells were aggregated by management area to compare the impact of bottom trawling across management areas (Eigaard *et al.*, submitted).

Trawling intensity profiles were estimated by plotting the minimum trawling intensity in relation to the cumulative surface area (Figure 7.6). This plot directly shows the surface area trawled above a certain trawling intensity threshold. Once a trawling intensity threshold defining GES is set, the surface area of the seabed that is in GES can be read.

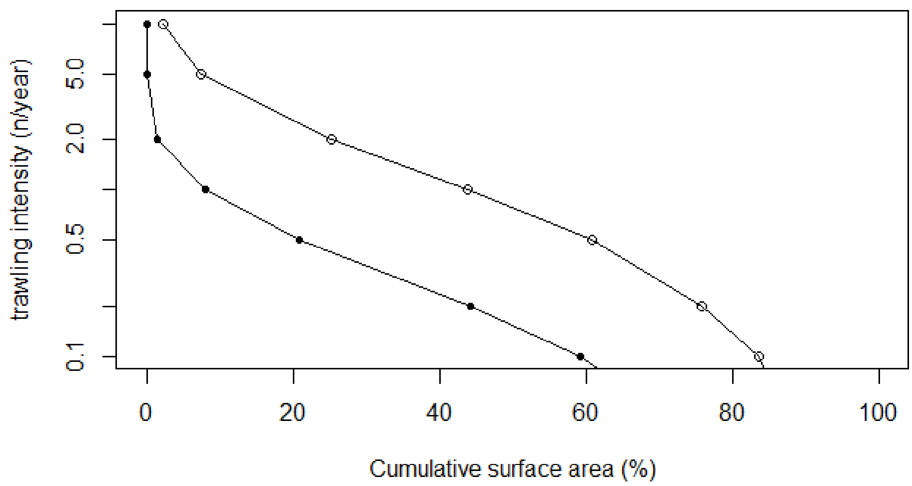


Figure 7.6. Mean annual trawling intensity profiles at the surface (open dots) and subsurface layer (closed dots) estimated for the North Sea for 20102012. The sum of the surface area of the untrawled grid cells is 7% (Eigaard *et al* (submitted).

Due to the aggregated nature of bottom trawling, the surface area of the seabed where 90% of the trawling occurs, or where 90% of the landings or catch value are taken, is less than the total trawling footprint. In the North Sea example, derived from Figure 7.6 the surface area where 90% of the effort occurs is only 45% of the seabed (not shown, but derived from Figure 7.6). Hence 90% of the fishing effort takes place in around 50% of the area trawled.

Comparison of the footprint of bottom trawling with the landings showed clear differences across management areas (Figure 7.7). Footprint per unit of landings was higher in the Mediterranean Sea as compared to the Atlantic management areas. In the Atlantic, footprint per unit of landings was relatively high in the Skagerrak and the western Baltic, as well as in some of the western management areas. It should be noted that the comparison is somewhat biased because of the differences in data coverage across the management areas.

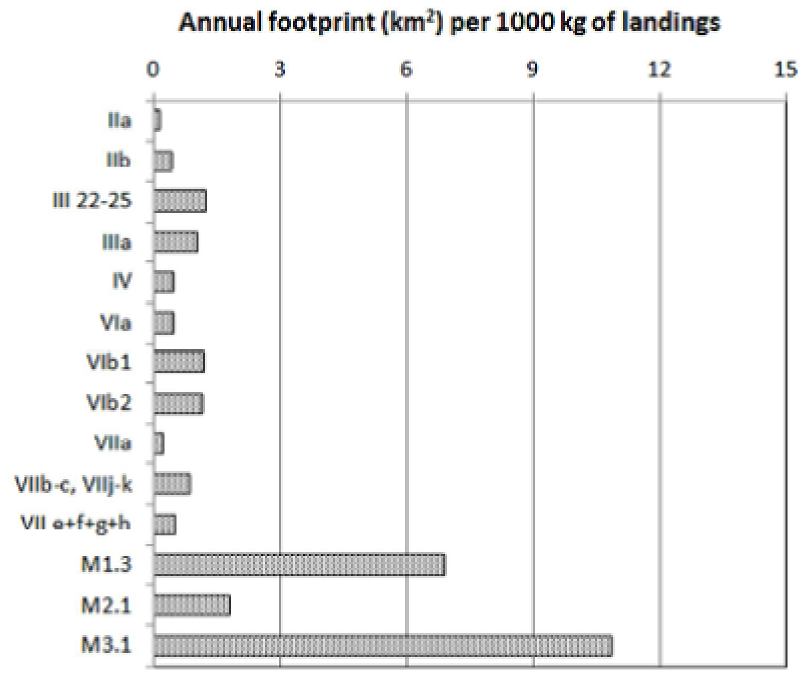


Figure 7.7. Annual trawling footprint per 1000 kg of landings in period 2010-2012. The footprint was estimated as the sum of the surface area of the trawled parts of all grid cells by management area. Eigaard *et al* (submitted).

7.5 Discussion

The two approaches developed in BENTHIS allow us to estimate Seabed Integrity on a continuous scale without the need to classify fishing pressure and habitat sensitivity.

The longevity approach is a rather simple quantitative approach which necessarily makes a number of rather strong assumptions. The key assumption is that the sensitivity of the benthic community can be estimated from its longevity distribution. It is well established that bottom trawling reduce species composition of the community towards short-lived species. Indeed, the analysis of the grab and boxcore samples collected in the North Sea and Channel, showed a significant effect of trawling intensity on the longevity distribution of the community. A second assumption is that the cumulative longevity distribution can be modelled as a log-linear logistic relationship. We are unaware of an established theoretical model of the longevity distribution of communities. Although the choice for a log-linear logistic relationship is an arbitrary choice, the fitted relationship showed a good fit to the data and is considered a useful step to convert the factorial longevity classes into a continuous scale. We are aware of the fact that the longevity of individual taxa is rather poorly known. Nevertheless, because of the wide variation in longevity, the uncertainty in the longevity estimation on the level of the taxa will not affect the estimated longevity distribution of the community.

The method applied here is a first attempt that can be refined. If sufficient data are available on the benthic community, the longevity distribution could be estimated for only those taxa that come into contact with the fishing gear. The longevity distribution of the habitats was estimated based on grab and boxcore samples representing the infaunal community. Whether this also represents the longevity distribution of the epibenthos remains to be studied. Further investigations of the differences in the longevity distribution between the epifaunal and infaunal communities of various seabed habitats will allow a more refined estimate of the seabed integrity which can be coupled to surface and subsurface trawling intensities.

The seabed integrity estimate based on the longevity distribution of the untrawled habitat assumes that the taxa with a longevity exceeding the interval between two trawling events will already be impacted by bottom trawling. Because taxa with a longevity of 10 years or more comprise around 10% of the benthic biomass, a trawling intensity of >0.1 will already reduce the seabed integrity to values below 0.9.

A seabed integrity estimated with the longevity approach does not imply that habitats with a low seabed value of less than 0.9, however, will be devoid of long lived taxa. Only if the trawling interval between two trawling events will approach the time required till the first reproduction, taxa may no longer be able to survive. With trawling intensities that corresponds to a trawling interval between the age at maturation and the maximum lifespan, we may expect taxa to survive although at a reduced population size. The longevity based seabed integrity thus can be considered to be a worst case indicator. An alternative indicator of seabed integrity can be estimated using the same rationale but replacing the longevity distribution of the community by the distribution of the age at first reproduction (age at maturation). BENTHIS currently explores further improvements of this methodology.

The seabed integrity estimated using the population dynamic approach quantitatively takes account of the mortality induced by trawling and the recovery during the time interval between two successive trawling events. It can be considered to be a more realistic representation of how bottom trawling affect the benthic community. The sensitivity of the habitat is a result of the available empirical data on the mortality induced by bottom trawling and the recovery rate of the taxa. An update on the meta-analysis of Collie *et al* (2000) and Kaiser *et al* (2006) is currently being conducted which is expected to provide improved estimates of these parameters.

The results presented here are an illustration of the potential application of the population dynamic approach to provide a quantitative and generic underpinning of the seabed integrity. Further research is required to study the sensitivity of the results for the various assumptions made. Nevertheless, the potential of the method is illustrated by the estimated trawling intensities which will reduce the biomass to a certain threshold level. These results already provide a quantitative basis for the thresholds of fishing pressure and benthos sensitivity as required in the sensitivity matrix approach.

Results of the quantitative estimates of the footprint and seabed integrity can be readily applied in the MSFD context once reference values for GES has been set. Since the analysis allow the comparison of the footprint or trawling impact with the contribution of the seabed to the landings or value of the fishery, the assessment framework provide a scientific basis for making trade-offs between conservation and exploitation.

8 BalticBOOST

8.1 Background

The HELCOM-coordinated BalticBOOST project is co-financed by the EU and is running from September 2015 to December 2016. The HELCOM BalticBOOST project is structured around five Themes and sees the participation of 10 partners from the HELCOM countries and ICES. The project implementation is guided by HELCOM groups, as well as HELCOM workshops carried out as part of the project.

The aim of Theme 3 is to analyse physical loss and impact to the seabed and explore ways to determine how much disturbance from different activities specific seabed habitats can tolerate while remaining in Good Environmental Status (GES).

Theme 3 partners are the Finnish Environment Institute (SYKE), the Technical University of Denmark (DTU Aqua), the Swedish University of Agricultural Sciences (SLU Aqua), the Thünen Institute, the Leibniz Institute for Baltic Sea Research Warnemünde (IOW) and ICES.

To meet the aim the BalticBOOST Theme 3, work has been subdivided into the following Work Packages:

- WP 3.1 With the aim to continue the development of environmental targets in HELCOM by developing common guidelines for setting environmental targets related to pressures on seabed habitats. This work will include consideration on who to integrate impacts from multiple pressures acting on the seabed.
- WP 3.2 With the goal to continue the BALTFIMPA project by producing a quantitative estimation of fishing gear impacts on seabed habitats, with test-case examples.
- WP 3.3 Aiming to define information needs and relevant datasets on pressures and activities that affect the seabed habitats

The HELCOM BALTFIMPA project, completed in 2013, created a preliminary version of a "Generic Tool" addressing fishing gears and their interactions with habitats and species. The BalticBOOST WP 3.2 "Generic support tool for fisheries management" will deliver a quantitative inventory of fishing gears and their interactions with the seabed habitats, based on ongoing research projects and literature involving also Baltic Sea case studies. This inventory is also called a "tool" and will contain detailed spatial information on fishing activities and associated pressures (fishing coverage and intensity by gear types) as well as spatial explicit interactions between fisheries and habitats and species in representative test cases, with a particular focus towards seabed integrity.

WP 3.2 will be harmonized with BalticBOOST WP 3.1, "Development of joint principles to define environmental targets for pressures affecting the seabed habitats", so as to give meaningful parameters on which to develop principles for environmental targets. The outputs of BalticBOOST Theme 3 will also be harmonized with other processes like the Holistic Assessment of the Baltic Sea (HOLAS II) possibly by utilizing the Baltic Sea Impact Index (BSII) being developed under HELCOM-coordinated and EU co-financed TAPAS project. The BSII evaluates pressures from all relevant human activities on the Baltic Sea ecosystem components, including benthic species and habitats. The ongoing work in OSPAR and ICES will also be considered in this process and inspirations or good practices will be drawn from it. The main goal of the tool developed under BalticBOOST WP 3.2 is to provide management-relevant information on the intensity and spatial distribution of fishing pressure on the seabed and possible effects of fishing as a pressure on the seabed.

8.2 Overview of the BalticBOOST approach under development

8.2.1 WP 3.2 fisheries-related pressures:

BalticBOOST plans to develop a Baltic-wide quantitative fishing pressure identification and evaluation tool based on the results of the ongoing EU-FP7-BENTHIS project and on ICES advice to HELCOM. This quantitative based tool could consist of the following (Table 8.1):

The approach is to deliver a tool capable of making fisheries impact evaluation that is mainly quantitatively based.

Table 8.1. Overview of BENTHIS approach.

FOOTPRINT BY GEAR		EFFORT BY GEAR		ABRASION SEABED / SELECTIVE EXTRACTION POPULATIONS	ANALYSIS / MODELLING
Gear Specific Footprint (surface, subsurface)	X	**Fishing Effort**	→	**Fishing Intensity (Abrasion)**	**Static or Dynamic**
Gear Specific Selectivity	X	**Fishing Effort**	→	**Catch by Species /&Size (Selective Extraction)**	**Static or Dynamic**

PRESSURE (ABRASION)		SENSITIVITY RESISTANCE/RESILIENCE		IMPACT & DESCRIPTOR	ANALYSIS / MODELLING
Cumulative Fishing Intensity (surface, subsurface) by gear and habitat	X	**Longevity (sensitivity)**	→	**MSFD Seafloor Integrity Index** BENTHIS SBI (Seafloor Benthic Index)	**Static or Dynamic**
Cumulative Fishing Intensity (surface, subsurface) by gear and habitat	X	**Catch by species**	→	**MSFD Selective Extraction of Species** Fishing mortality indicators (impacts on populations and fisheries)	**Static or Dynamic**

Pressure maps and fishing intensity: First of all fishing pressure maps of fishing effort by bottom impacting fishing gears (vessel based VMS data scaled up to métier) is coupled with gear specific footprint data by vessel (surface, subsurface) to estimate Fishing Intensity (SAR=Swept-area Ratio = proportion of a grid cell fished divided by total grid cell area) on a fine resolution grid 0,05*0,05 degrees (c-square resolution). The fishing intensity maps are then coupled with habitat maps (EUNIS level 3 habitat maps), at the same resolution as the fisheries data, where each grid cell is allocated to a certain EUNIS level 3 habitat (use of existing data for this applied to the fine resolution grid and with an identifier of main habitat by grid cell). Different assessment areas (habitat, management area, other) can accordingly be selected to calculate cumulative fishing intensity. It should be noted that the intensity will not be evenly or randomly distributed in the c-squares.

These abrasion estimates according to métier are then multiplied with sensitivity parameters obtained from literature to obtain fishing impact in form of a Seabed Integrity Index (SBI=Seabed Benthic Index).

The estimation of sensitivity parameters and the impact assessment estimation is fully following the EU FP7 BENTHIS Project approach described in general in Chapter 7 of the present report. A challenge here is to define the critical level of fishery (threshold levels) a benthic community can sustain.

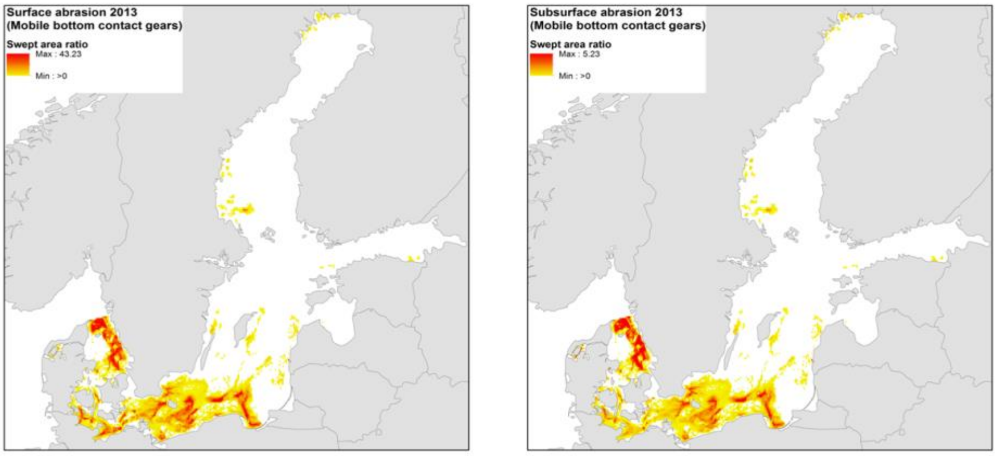


Figure 8.1 Example of Baltic Fishing Intensity for Surface and Subsurface abrasion. Intensity of Fishing Pressure: Swept-area. All mobile bottom contact gears 2013; All Countries Swept-area ratio: SAR = Swept-area in Cell / Area of the Cell. (0.05x0.05 degree grid cells ~ 3nm). www.ICES.dk**; ICES WGSFD; HELCOM_mapping_fishing_intensity_and_effort_data_outputs_2015.**

8.2.2 WP 3.1 other pressures:

The WP 3.1 of the HELCOM BalticBOOST project has the objective to analyse, on the case study basis, how benthic ecosystems will be affected under various human activities and consequent pressures, and how this is reflected in environmental status classifications. This very basic question will provide the basis for setting environmental targets i.e. the reduction in pressure that is required to achieve GES. The ultimate aim of the HELCOM BalticBOOST WP 3.1 is to propose a stepwise guidance for HELCOM Contracting Parties to develop environmental targets for human activities and pressures affecting the benthic habitats and that can also be used for EU Member States under the MSFD article 10.

The WP 3.1 uses literature information to make a semi-quantitative assessment of non-fishery pressures, including an estimate of the extent of impacts. These so called weight scores reflect the impact of specific pressures on species ecosystem components and are also used in the Baltic Sea Impact Index (BSII see BSEP 125, HOLAS I).

The quantitative impact assessments under WP3.2 will potentially be categorized to feed into the WP3.1 semi-quantitative impact assessments and to the development of the BSII. This may be done by providing classes (intervals) of fishing impacts, which cover and are adapted to comparable/similar (weighing) scores of different levels of impacts as used in the BSII.

8.3 Baltic test cases

A set of Baltic test cases will explore these general concepts and use real data on limited scale to explore intensities and impacts.

Within test cases, actual abundance and distribution data of benthic communities, available on finer geographical scales, will be analysed in relation to the extent of fishing pressure. Ideally the data sampled in different parts of the case areas contain different intensities of fishing pressure. Such intensity gradients will then be compared with occurrences of species sampled over a span of time which will illustrate the effects of varying fishing intensities on their distributions and abundances.

This analysis could produce locally detailed maps of fishing pressures and the potential ecosystem response to those pressures. Ideally this will give information on assemblage structures at different pressure levels and information on what these pressure levels could look like in other areas. For example, on a case specific basis, the quantitative tool used at the Baltic scale can be applied, with the addition of an integrated analysis of fishing pressure data and benthic invertebrate data in order to evaluate influence of fishing pressure on benthic invertebrate biodiversity/abundance for different types of EUNIS Level 3 habitats.

For WP 3.2 a set of test cases has been selected in the Fehmarn Belt and Hanö Bay areas, based on the availability of data. Collecting data from additional areas as test cases has proven to be challenging but the project might still consider some cases in the eastern side of the West Baltic, should the data become available at a later stage.

For WP 3.1 both local case studies and sub-basin level case studies will be used. The sub-basin approach will be carried out in 2-3 case study areas: Mecklenburg Bight, Hanö Bight and Gulf of Finland. The number and location of case study areas is still to be decided.

In the local approach, more detailed and spatially restricted case studies of human activities and benthic monitoring will be investigated. By using local examples, the impacts can more easily be linked to the activities. As most of the human impacts dealt with here (dredging, disposal, construction) take place in coastal areas, the impacts on benthic habitats will be assessed using the WFD indicators (macrobenthic indices and macrophytes). The local approach will be carried out in 4-5 case study areas in the northern Baltic Sea. The number and location of case study areas depends on availability of sufficient data and are still to be decided.

9 DISCUSSION

9.1 Evaluate and synthesize findings (TOR a–c) aimed at tangible use of indicators of the state of the seabed in relation to fishing pressure

9.1.1 Spatial resolution.

Our analysis has shown that there may still be substantial variation in trawling intensity and habitat type at the level of the grid cell (0.05°x0.05° C-square). The size of the grid cells is based on the current spatial resolution of fishing pressure data and a finer resolution may be possible in the future. The influence of grid cell size to the assessment needs to be further investigated. However, for many areas the current resolution seems to be sufficient, and an analysis of the frequency of grid cells with multiple habitats, and of the habitat association of the métiers, can already be informative.

9.1.2 Sensitivity of the benthic community

Sensitivity scoring was harmonized across habitats and expressed on a three or five point scale. Sensitivity was scored based on scientific literature and expert judgement. Separate sensitivities were estimated for surface abrasion (epibenthos living on the surface) and shallow subsurface abrasion (epibenthos living on the surface and benthos living in the shallow subsurface (0-2.5cm) layer) and deep subsurface abrasion (epifauna and infauna). It was concluded that it was not recommended to distinguish between shallow and deep subsurface abrasion sensitivity.

Considering the need to assess impacts of trawling on seabed habitats, there is need to consider whether to use the resilience and resistance aspects of the sensitivity scores separately for the purposes of MSFD assessments.

9.1.3 Trawling impact

The results show that large parts of the European shelf is trawled by mobile bottom contacting gear. Trawling generally shows a patchy distribution with some parts of the seabed being trawled very frequently (>5 times per year), whereas other parts of the seabed are trawled only rarely (<0.1 year^{-1}). The trawling intensities, arbitrarily classified into five classes of very low (<0.1), low (0.10.5), medium (0.5-1), high (15) and very high (>5), were coupled to the habitat sensitivity scores to estimate the trawling impact on the surface, shallow subsurface and deeper subsurface benthos. High surface impact was observed in a narrow zone at the edge of the continental shelf and in substantial areas in the Celtic Sea, Bay of Biscay and the Skagerrak-Kattegat. High subsurface impact was observed in the southern North Sea, Celtic Sea, Bay of Biscay and along the continental shelf. The overall trawling impact can be estimated to be reflected by the highest of the surface or subsurface impact for each grid cell.

Because the sensitivity scores were based on a selection of benthic species that were considered typical for the habitat, the medium and high impact scores can be interpreted to indicate where the seabed has been significantly impacted for these typical taxa. The harmonized sensitivity matrices allowed a consistent assessment of the relative impact of bottom trawling on the seabed. The sensitivity matrix approach, however, does not allow a quantitative assessment of the trawling impact. In other words it is difficult to assess how the different impact scores are quantitatively related. For a quantitative assessment of the trawling impact alternative approaches have been suggested. These will be discussed in the next section.

9.2 Discussion of WKFBI results in the context of other methodologies + operational indicator to measure progress towards GES

Table 9.1 evaluates four impact assessment methods, namely WKFBI ICES, BH3 OSPAR, Benthis 1 (longevity-based) and Benthis 2 (based on a population dynamic model). The methodologies are evaluated on the basis of 1) the methodology estimating sensitivity, 2) the pressure variable characteristics (abrasion by bottom trawling), 3) the resolution of impact values, 4) their potential value for management and 5) whether they are operational (for management evaluations) at the moment. Additional information is provided after table 9.1.

Note that the methods are solely evaluated on how the methods are currently employed. Furthermore, note that the WKFBI ICES method and the BH3 OSPAR method are similar in the below evaluation. They are both included since the WKFBI ICES method is not fully overlapping with the method used in BH3 OSPAR (see for more detail Chapter 3 and 6 of the present report). There are considerable differences in the approaches in particular as BH3 includes high resolution data to calculate sensitivities e.g. EUNIS level 5 or 6. Another difference is the way categories for the classification of sensitivity and the split between categories are done.

Table 9.1. Evaluation of different methods to assess benthic impact from bottom trawling (x = yes, (x) = to some extent)

	WKFBI ICES	BH3 OSPAR	Benthis 1 (Longevity)	Benthis 2 (Pop. dynamics)
Sensitivity				
Does the approach accounts for differences in direct mortality between species (groups)?	x	x		x
Does the approach accounts for differences in recovery rates between species (groups)?	x	x	x	x
Does the sensitivity score include other benthic parameters, structural and functional (e.g. species richness, abundance, diversity)?	(x)	(x)	(x)	
Is the score based on the full benthic community (instead of a subset of typical/dominant species)?		(x)	x	(x)
Can the approach be used in data-poor situations?	x	x	(x)	(x)
Is the sensitivity score on a quantitative scale and is it mechaniztically based?			x	x
Is the sensitivity score métier-independent?	x	x	x	
Are surface and subsurface communities assessed separately?	x	x	(x)	(X)
Pressure				
Is the pressure based on a continuous scale?	x	x	x	x
Is the pressure layer estimated at a finer spatial scale than 0.05 x 0.05?			x	x

Impact				
Can the spatial resolution in the pressure layer be passed on to the impact layer?	x	x	x	x
Can the temporal resolution in the pressure layer (between years) be passed on to the impact layer?			(x)	x
Management use				
Does the method lead to impact maps per habitat type?	x	x	x	x
Does the method lead to an estimation of the time it takes for a community to recover from trawling?			x	x
Is the impact score on a quantitative scale and is it mechaniztically based?			x	x
Is an overall index available which can be used to measure progress in time?		(x)	x	x
Does the method include a confidence assessment?		x		
Operationality				
Is the approach already operational?		x		
Can the approach be used at the regional scale?	x	x	x	x
Have stakeholders (e.g. fishing industry) been consulted in developing the approach?		(x)	(x)	(x)

1) Pressure

All pressure layers are derived in a similar way from VMS and logbook data (see Chapter 2). Both Benthis approaches are using a pressure layer estimated on a finer spatial resolution than 0.05° x 0.05°.

2) Sensitivity

Both the WKFBI and BH3 scoring method are categorical and based on expert judgement and define sensitivities of habitats based on the resilience and recovery to trawling of abundant species that are typical for the area. The BH3 method also includes aspects of communities' structure and function in its sensitivity score and uses information on the biotope and/or eco-group. Both Benthis methods derive a score on a quantitative scale and this score is mechaniztically based (essentially showing the reduction in biomass of the benthic community given the observed fishing pressure). Benthis 1 derives this score on the basis of communities' longevity composition, where communities' recovery is directly inferred from this longevity composition. Benthis 2 estimates sensitivity on the basis of a species-specific direct mortality rate and a recovery rate, which are combined using a modelling approach (logistic population growth model). The Benthis 2 parameters are derived from a global meta-analysis of shelf-sea benthic communities resulting in four fairly coarse habitat categories (i.e. Sand, Mud, Gravel and Biogenic). These categories are linked to the more detailed lower level OSPAR habitat categories occurring in the habitat on which sensitivity are evaluated.

All approaches can be used in areas with limited sampling, but sensitivity analyses are needed to evaluate the reliability of the outcome. WKFBI and BH3 assess surface and subsurface sensitivity. Both Benthis approaches are capable of assessing this if sampling data are included for both surface and subsurface layers.

Benthis 1 may assess biodiversity and/or community function (see for community function preliminary results in Rijnsdorp *et al.* 2016)

3) Impact

Habitats are assessed not on a regular grid but in spatial polygons. Thus, the spatial resolution in the pressure layer is in all methods passed on to the impact layer and results in impact maps per habitat type. However, due to uncertainties in the spatial extension of habitats, the resolution of grid cells may be to coarse in some areas. Generally, all approaches use average annual intensities to assess impact.

Both Benthis approaches can use interannual variation in trawling pressure as both can explicitly consider the state of the seabed (affected by historic fishing activities prior to the assessment year) when calculating impact. This is possible because the recovery component is explicitly parameterized in Benthis 1 and Benthis 2 method while the other methods calculate the seabed integrity without a consideration of the past exploitation. Notably for habitats with slow recovery rates (> 1 year) and high historic impacts, the WKFBI and BH3 methods will therefore systematically overestimate impact. BH3 has been developing methods to deal with this by making their impact score dependent on trawling pressure over multiple years.

None of the approaches include overall habitat fragmentation / meta-population concept (recovery time depends on the amount of undisturbed communities in neighbouring areas), but it is agreed that this could be valuable to include if information becomes available.

4) Management use

All approaches lead to maps that show impact of bottom trawls on the basis of sensitivity scores and fishing pressures. These maps may be used to determine which areas are most vulnerable to bottom fishing but, except for BH3, all methods are at this stage too immature to do this.

Since both Benthis approaches include the time aspect, they can also be used to predict the time it takes a community to recover to an undisturbed state (based on the available reference condition; pristine state is unknown). This means that the approaches can be used directly to measure progress in time (e.g. in relation to progress towards the reference state). This is a little harder for WKFBI and BH3 as they need to deal with the temporal aspect. Still, WKFBI and BH3 can compare sequential periods of time and test whether the fraction of a habitat classified as 'impacted to a limited extend' will gradually increase (simultaneously resulting in a decline in the fraction of the habitat that is classified as 'highly impacted').

5) Operationality

Only the BH3 method is operational within OSPAR. All methods can be used to derive impact scores at regional scales. Stakeholder involvement for BH3 is pending via public consultation. Stakeholders are involved in Benthis and will evaluate the methods.

9.3 Seabed integrity and Good Environmental Status

The EU needs scientific advice on how to assess the impact of bottom trawling taking account of the differences in sensitivity of seabed habitats and differences in benthic impacts of different métiers. In order to be of practical use in the context of the MSFD, the assessment methodology should allow for the estimation of metrics of seabed integrity as well as reference levels at which the seabed is considered in GES.

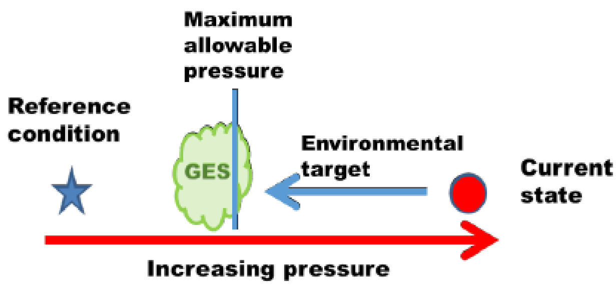


Figure 9.1. Schematic figure (from HELCOM BalticBOOST) of the relations of GES (green area), maximum allowable pressure which is at GES (vertical line) and the environmental target (blue arrow of reduced pressure) on the horizontal pressure gradient (red arrow).

In this report different methods to derive such a metric have been explored. The results of the analyses should be considered preliminary. The purpose of the exercise is to go through all stages of the process to detect potential problems and evaluate and compare the strength and weaknesses of the various approaches. One inherent challenge with the expert judgement approach considered is that the direction of change has unequivocal interpretation, but it is difficult to interpret the differences in trawling impact in quantitative terms as both sensitivity and trawling intensity are categorical. Methods such as developed in BENTHIS provide a quantitative estimate of the impact on a continuous scale in terms of the proportion of the biomass that can close its life cycle without being disturbed by trawling (longevity approach) or in terms of the equilibrium biomass relative to the untrawled biomass. These methods, however, are still under development and the uncertainty of the impact estimates have not been determined nor has the sensitivity of the methods been investigated. The quantitative methods do provide a promising approach to derive the scientific basis to assess the impact of trawling on the state of the seabed. The first results presented in this report are already useful to relate the class-boundaries used in the categorical method with the estimated impact based on the longevity and the population dynamic approach.

All methods explored in this report provide estimates of the trawling impact on the benthic community at the level of the grid cell. In addition to pressure indicators such as the trawling footprint (surface area or proportion of a management unit or habitat) trawled, or the indicator for the degree of aggregation (such as the proportion of the footprint where 90% of the total fishing effort occurs), the estimates of trawling impact can be aggregated to a metric that reflects the trawling impact or seabed integrity at the level of the habitat or management area.

A methodology that develops matrices of habitat sensitivity in relation to trawling pressures (as described in this report) has the potential to provide a consistent assessment of the relative impact of bottom trawling across different habitats. It can consider trawling intensities affecting the surface or the subsurface layers of the seabed. However, in order to make this approach operational, the impact on benthic communities (as the relationship between pressure and sensitivity) still needs to be clearly identified.

An inherent challenge is that, in time, if an area is trawled its subsequent sensitivity will change, i.e. if a previously disturbed site is trawled again it may be impacted less (vulnerable species/habitats have not yet recovered) and can therefore be viewed as more resilient to additional trawling disturbance. In the management context, should fishing activity thus be concentrated on already disturbed areas or should fishing activity be limited in these areas, allowing time for the disturbed area to recover (but resulting in fishery effort displacement to other areas)?

The answer to this question will largely depend on the management context in which fishing impact is assessed. If the goal is to select and protect habitats that are highly sensitive to bottom-trawl fisheries, application of sensitivity scores that include both resistance and resilience in a combined score may be most suitable. Such sensitivity scores reflect (to a certain extent) the conservation value of the habitat and may be linked to impact scores to examine the potential loss. However, for MSFD purposes the needs differ: first an assessment of whether there is impact (from the pressure) is needed (Article 8 assessment; resilience aspect is relevant). Only later, following a decision to reduce that impact, is there a need to consider possible management options such as intensity of trawling, productivity of the area and habitat recovery times. For such a purpose there is a need to decouple the sensitivity score in such a way that it may separately assess impact (based on its current state) and recoverability (by comparing it with its reference state). The advantage of the BENTHIS approaches for assessment purposes is that these methods can at this stage directly be used over time to assess changes in trawling impact and recoverability separately.

An inherent challenge is to interpret the implications of the heterogeneity in trawling and its effect on habitat fragmentation on the recovery, which will depend on the amount of undisturbed communities in neighbouring areas acting as sources of new recruitment to disturbed areas (considered in the context of meta-population/community ecology).

Lastly, there is a need to consider other pressures than those exerted by fishing activity (e.g. gravel extraction, eutrophication, etc.). Steps toward this are currently being made in the Baltic Sea context where fishing activity is relatively less of an issue in the northern parts that have more eutrophication. HELCOM, in the context of BalticBOOST, will address these in their planned work in 2016.

10 Recommendations/Advice

10.1 Principles of good practice

10.1.1 Pressures

- Pressure maps of fishing activity should be estimated by bottom impacting fishing gears (métiers) from high resolution (VMS) data and logbook data distinguishing between surface and deep subsurface abrasion (>2 cm) at the c-square resolution.
- It is recommended not to further refine the subsurface layer into a shallow and deep layer because differences in penetration depth in relation to sediment characteristic are neglected and the sensitivity of the habitat to shallow and deep penetration are considered to be quite similar.
- Higher polling frequencies would improve the derivation of the pressure layer which is needed to assess impacts with greater resolution needed where there is a high heterogeneity of habitats (bathymetry or sediment types).
- A higher spatial resolution (and thus higher VMS polling rates) would be especially useful if smaller vessels (<12m) will be included and certain associated métiers will be analysed.
- The method for linking the habitats to the c-square needs to be refined. The four possible methods are: 1) reporting the habitat under the midpoint of the c-square (used in this analysis), 2) using the habitat with the greatest spatial majority within the c-square (most representative approach), 3) selection of the most sensitive habitat within the c-square (precautionary approach) and 4) report all habitats in square weighted by proportional presence (time consuming and complex but providing the most detailed output). Other possible approached may stem from using reconstructed fisheries tracks or raw ‘pings’ rather than c-square approaches.

10.1.2 Habitats

- Habitat maps should be used at the highest spatial and thematic resolution possible. Assessment conclusions should aggregate to the required thematic level after the analysis, e.g. the reporting at level 2 EUNIS classes.
- Actual observations of habitat distribution should substitute modelled coverage where possible, i.e. BH3 method.
- Maps should include confidence, e.g. BH3 method (climate change terminology maybe helpful).
- The same classification scheme should be used by all and be the most up-to-date version. If this is EUNIS, the new version be used.

10.1.3 Sensitivity

- Sensitivity scores should be created within a standardized and widely-adopted workflow, based on separate assessments of the habitat's resistance and resilience to the pressure (in this case physical disturbance from bottom trawling).
- Criteria should support the objective setting of sensitivity scores (qualitative or quantitative values or descriptions that define the levels), i.e. BH3 method.
- Sensitivity scoring of the benthic community should distinguish between the sensitivity for surface and subsurface abrasion only.
- Sensitivities should be determined for the abiotic or biotic characteristic of the habitat. If other characteristics are used, they must be locally relevant and be particularly reflective of sensitivity relevant (for fishing impacts).
- Where possible, expert judgement of sensitivity should be compared to sensitivity estimates based on mechaniztic understanding of the impact of fishing on the benthic community in order to determine the relevant class boundaries for both fishing pressure and habitat sensitivity.
- Where possible, a continuous scale is preferable, but the application of 5 classes by BH3 was considered informative.
- An absence of information should not get classified as high - rules for reporting no information should be developed.
- The whole evidence base should be made available to all stakeholders.

10.1.4 Impacts

- Impact terminology should be defined clearly, i.e. a distinction should be made between immediate ecological impact and impact incorporating an element of recovery should be made.
- It is important to keep in mind that from a management perspective areas with the highest impact may not be the areas requiring management of conservation priority.
- A quantitative scale should be used to calculate impact. Habitat-specific thresholds for impact/un-impacted can be subsequently applied to classify into impacted and un-impacted classes (e.g. for regional reporting). If an impact threshold is not known, it is important to stress that impact bands are subjective and arbitrary.
- Interpreting the impact of fishing requires other activities to be considered. There is a need to ascertain the status and impacts generated from different human activities to understand seabed integrity. The understanding of seabed integrity will depend on the combination of physical, biological and chemical interactions.
- Maps (habitat, sensitivity, pressure level, impact) should be accompanied by maps showing the corresponding confidence/ uncertainties in the assessment.

10.1.5 Management application

- To set a threshold for the quality of the seabed, based on structural and functional attributes, the relationship by habitat between trawling pressure and quality of the habitat needs to be derived that can be applied to the level of the grid cell and aggregated by assessment area. A plot showing the trawling impact against the cumulative surface area of the assessment area provides information on the proportion in the assessment area (habitat, management area, etc.) that has been impacted and to what degree.
- Trade-off trawling impact and landings / value. It is recommended that graphical information that illustrate the landings (value) of the fisheries and the impact of their activities on the seabed for the total fleet, as well as by métiers separately. One could think of a plot of the cumulative landings and marginal trawling impact against the surface area of the area assessed with grid cells order from low to high. It is recognized that these plots gives a static representation and does not take account of possible changes in the core fishing grounds. Results need to be discussed with stakeholders.
- Assessing fishing impact in an MPA context may be most useful with a combined sensitivity score that includes both resistance and resilience. For MSFD purposes the needs differ: first an assessment of whether there is impact (from the pressure) is needed (Art 8 assessment; resilience aspect is relevant). Only later, following a decision to reduce that impact, is there a need to consider possible management options such as intensity of trawling, productivity of the area and habitat recovery times.

10.2 Recommendations for further work

10.2.1 Habitats

- In the absence of maps with lower levels of classification, efforts should be made to generate additional spatial discrimination, e.g. depth zones within broad-scale habitats.
- An investigation of the consequences of substituting modelled maps with actual maps should be confirmed.
- Updates to the EUNIS classification scheme must be prompt and rapidly circulated to users.
- Deep-sea mapping/modelling is urgently required.
- There are some significant join issues between separate EMODnet maps, e.g. NE North Sea and SW Norwegian waters. These are mostly generated through the inclusion of substratum information in some deep-water habitats. The EMODnet seabed habitats project should try to eliminate these discrepancies.

10.2.2 Sensitivity

- Attempts should be made to quantitatively set thresholds between levels – this must be supported by pressure-state relationships – ideally this will be defined empirically but mechaniztic approaches will also contribute to this understanding. This is particularly important for resistance.
- Sensitivity scores should be validated through direct observation.

- Current approaches should be reviewed to consider applying the resistance aspect of sensitivity separately, leading to an 'impact assessment' and using the resilience aspect as a second step, together with trawling intensity and productivity of the fishery/area.
- Uncertainty for resistance and resilience is reported separately.
- The BH3 approach is considered to be useful for providing a consistent assessment between countries.

10.2.3 Impacts

- Predicted impacts should be validated using empirical studies.
- Metrics for Seabed Integrity need to be developed that can be used in an impact assessment. The metrics should allow the monitoring of the changes in the impact of trawling over time as well as in space.
- An additional stage of interpretation will be required for the prioritization of habitats by relative value (whether by conservation value, contribution to ecosystem service contribution).

10.2.4 Whole process

- Sensitivity assessment of the entire approach and all components. This process supports both weighting, aggregation and QA.
- An informative and transparent method for calculating uncertainty must be developed. The uncertainty assessment would need to draw in uncertainty information from the habitat maps, sensitivity scores and VMS-derived information. This information must then be weighted and aggregated in a meaningful manner before being displayed in manner that allows users to assess whether the analysis outputs are fit for their purposes.
- BH3 provides a good framework for collaboration between member states and ensuring consistency of outputs.

11 Conclusions

- Substantial progress has been made in the assessment of trawling impact on the seabed using information on the fishing pressure and occurrence and sensitivity of seabed habitats.
- Standardized methods for the analysis of VMS data to estimate surface and the subsurface trawling intensities by métiers at a high resolution have been developed and are now applied by ICES to analyse the VMS data made available by a large number of countries.
- Pressure maps show regional differences in the coverage, which is due to lack of data of some countries and missing information from vessels smaller than 12 m overall length.
- It is known that trawling is not homogeneously or randomly distributed within grid cells at the 0.05°x0.05° c-square level. This means that parts of the grid cell experience a higher pressure, whereas other areas maybe devoid of trawling activities. This heterogeneity needs to be considered to improve the pressure maps and evaluate benthos impact appropriately.
- Habitat maps have been standardized over large areas (EUNIS level 3). Improvements are needed in the Arctic, Mediterranean and Deep Sea.
- Estimates of trawling impact were made based on three different methods: categorical sensitivity scoring (expert judgement); mechaniztic approach (continuous scale) based on longevity or population dynamics. Preliminary impact maps show a general agreement of the heavily impacted areas but differ in the estimated degree to which the habitats were impacted. No reference levels for the impact of trawling have been established.
- In the comparison of methods to score the sensitivity of habitats (expert judgement or mechaniztic approach) it was noted that the preliminary results largely show a similar impact, all methods still need to be improved for management purposes, the different approaches can inform each other, and it was concluded that one cannot favour one over the other.
- It was noted that if an open, scientifically informed, iterative and well-documented expert analysis approach to scoring sensitivity is used it may also serve as a good way to involve stakeholders.
- Reference levels for the impact of trawling at regional levels can be based on the state of the seabed habitat in untrawled areas. There is insufficient information available on the pristine state to set the reference level.
- Approaches to provide a scientific basis for the setting of reference levels for trawling impact, and the trade-off between ladings (or value) and trawling impact are suggested

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Annex 1: List of participants

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Annex 2: Agenda

Tuesday 31 May	
9.00–10.30	Welcome + practicalities ICES worked example Sensitivity + Pressure = Impact Regional – caveats, recommendations, advice
10.30–11.00	Coffee
11.00–13.00	So what? Regional guidance for MSFD purposes? Criteria? Other approaches (10min each): a) BENTHIS, b) BH3 OSPAR, c) BalticBOOST 3.2 HELCOM
13.00–14.00	Lunch
14.00–16.00	Subgroup work – revision of table on approaches vs. criteria evaluations + draft report sections (as appropriate)
16.00–17.30	Reporting from subgroups and plenary discussions
18.30	Dinner/Drinks (at own expense)
Wednesday 1 June	
9.00–9.30	Plenary
9.30–11.00	Subgroup work + drafting of: How to evaluation impact maps? Tangible use of indicators of the state of the seabed in relation to fishing pressure? How to regionally operationalize indicators? What are the “principles and good practices”?
11.00–11.30	Coffee + Plenary
11.30–13.00	Subgroup work on: So what? Regional guidance for MSFD purposes? caveats, recommendations, advice?
13.00–14.00	Lunch
14.30–15.00	Plenary
15.00–16.30	Drafting of consensus subgroup work by theme
16.30–17.00	Plenary reporting
17.00–18.00	Finalization / Drafting
18.00	End

Annex 3: Terms of Reference

WKFBI–Workshop on guidance on how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats

2015/2/ACOM48 The **Workshop on guidance on how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats** (WKFBI), chaired by Adriaan Rijnsdorp, The Netherlands, will meet in Copenhagen, Denmark, 31 May – 1 June 2016 to:

a) Evaluate a scoring processes for sensitivity of habitats, which should also include rules on:

   i) How to scale-up sensitivity to a c-square resolution of 0.05° x 0.05°

   ii) How to treat variation in habitat type when evaluating sensitivity within c-square resolution of 0.05 x 0.05

   iii) How to interpolate and/or extrapolate information on sensitivity when habitat data are missing

b) Evaluate information on sensitivity of the benthic community of the various seabed habitats, that ensures habitat maps for sensitivity can be produced for at least one demonstration area of NW European waters (MSFD region/subregion).

c) Evaluate impact maps that combine the benthic information on sensitivity and fishing pressure maps (fishing abrasion, weight and value of landed catch), taking into account differences in benthic impact of the various fishing gears / métiers.

d) Using the workshop, evaluate and synthesis findings (TOR a-c) aimed at tangible use of indicators of the state of the seabed in relation to fishing pressure.

e) Prepare a guidance document on how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats. This should include "principles and good practices" that can be used when regionally operationalizing indicators to assess the impact of fishing to the seabed.

In preparation for the workshop, the Chair Adriaan Rijnsdorp (The Netherlands), together with five ACOM approved invited attendees (tbc) will facilitate coordination and consolidation of work on TOR a-b from respective working groups (BEWG, WGMHM, WGDEC, WGSFD). This group will also help ensure the workshop's objectives TOR d-e are met and that the workshop report is finalized.

WKFBI will report by 9 June 2016 for the attention of the ACOM Committee.

Supporting information

Priority	High, in response to a special request from DGENV on the Common Implementation (CIS) of the MSFD. The advice will feed into ongoing efforts to provide guidance on the operational implementation of the MSFD.
Scientific justification	Member countries and Regional Sea Conventions (RSCs) are developing indicators of impacts on benthic habitats from anthropogenic activities, particularly bottom trawling, for MSFD purposes (D1 biodiversity and D6 seabed integrity). EU projects are also developing approaches across European seas (including the Mediterranean and Black Sea). As part of this process, ICES has provided bottom fishing pressure maps using VMS and logbook data to OSPAR and HELCOM. The next challenge for the process of developing indicators is to interpret what these fishing pressure maps mean in terms of impact on benthic habitats and their utility in management. General guidelines will be required that includes, for example, rules on how to scale-up to a c-square resolution of 0.05^o x 0.05^o when evaluating sensitivity, how to treat variation in habitat type within c-square resolution of 0.05^o x 0.05^o, and how to interpolate and/or extrapolate information on sensitivity when habitat data are missing. Similarly, fishing pressure maps will need to take into account differences in benthic impact of the various fishing gears / métiers. This information will ultimately need to be balanced with the weight and value of landed catch. Early progress on this has been made by European-funded projects and RSCs. ICES is asked to provide guidance in the interpretation of these pressure maps in relation to impacts on benthic habitats and the related indicators. Central to this would be to identify both the environmental benefits and trade-offs for fisheries.
Resource requirements	ICES secretariat and advice process.
Participants	Workshop with researchers and RSCs investigators If requests to attend exceed the meeting space available ICES reserves the right to refuse participants. Choices will be based on the experts' relevant qualifications for the Workshop. Participants join the workshop at national expense.
Secretariat facilities	Data Centre, Secretariat support and meeting room
Financial	Covered by DGENV special request.
Linkages to advisory committees	Direct link to ACOM.
Linkages to other committees or groups	Links to CSGMSFD and SCICOM.
Linkages to other organizations	Links to RSCs and EC.

Annex 4: Habitats Sensitivity Summary table

Atlantic

Pressure theme			
Pressure Broadscale Habitats	Penetration and/or disturbance of the substratum below the surface of the seabed	Shallow abrasion/penetration: damage to seabed surface and penetration	Surface abrasion: damage to seabed surface features
Pressure Benchmarks	Structural damage to seabed >25mm	Damage to seabed surface and penetration ≤25mm	Damage to seabed surface features
Infralittoral and circalittoral gravel beds	L (L)	M (L)	H (L)
A5.13: Infralittoral coarse sediment	M (L)	L (L)	NS (L)
A5.14: Circalittoral coarse sediment	M (L)	L (L)	NS (L)
A5.15: Deep circalittoral coarse sediment	H (L)	M (L)	M (L)
A5.23: Infralittoral fine sand	M (L)	M (L)	L (L)
A5.23: Infralittoral fine sand or A5.24: Infralittoral muddy sand	M (L)	M (L)	L (L)
A5.23: Infralittoral fine sands+B23	M (L)	M (L)	L (L)
A5.25: Circalittoral fine sand	M (L)	M (L)	L (L)

Pressure theme			
Pressure Broadscale Habitats	Penetration and/or disturbance of the substratum below the surface of the seabed	Shallow abrasion/penetration: damage to seabed surface and penetration	Surface abrasion: damage to seabed surface features
Pressure Benchmarks	Structural damage to seabed >25mm	Damage to seabed surface and penetration ≤25mm	Damage to seabed surface features
A5.25: Circalittoral fine sand or A5.26: Circalittoral muddy sand	M (L)	M (L)	L (L)
A5.26: Circalittoral muddy sand	M (L)	M (L)	L (L)
A5.27: Deep circalittoral sand	H (L)	M (L)	L (L)
A5.33: Infralittoral sandy mud	M (L)	M (L)	L-M (L)
A5.34: Infralittoral fine mud	M (L)	M (L)	L-M (L)
A5.34: Infralittoral fine mud or A5.33: Infralittoral sandy mud	M (L)	M (L)	L-M (L)
A5.35: Circalittoral sandy mud	M (L)	M (L)	L-M (L)
A5.36: Circalittoral fine mud	M (L)	M (L)	L-M (L)
A5.36: Circalittoral fine mud or A5.35: Circalittoral sandy mud	M (L)	M (L)	L-M (L)
A5.37: Deep circalittoral mud	H (L)	M (L)	M (L)
A5.43: Infralittoral mixed sediments	M (L)	M (L)	L

Pressure theme			
Pressure Broadscale Habitats	Penetration and/or disturbance of the substratum below the surface of the seabed	Shallow abrasion/penetration: damage to seabed surface and penetration	Surface abrasion: damage to seabed surface features
Pressure Benchmarks	Structural damage to seabed >25mm	Damage to seabed surface and penetration ≤25mm	Damage to seabed surface features
A5.44: Circalittoral mixed sediments	M (L)	M (L)	L
A5.45: Deep circalittoral mixed sediments	M (L)	M (L)	M (L)
A5.531: Cymodocea beds	H (L)	H (L)	H (L)
A5.535: Posidonia beds	H (L)	H (L)	H (L)
Infralittoral Seabed	NA	NA	NA
Circalittoral Seabed	NA	NA	NA
High energy Circalittoral Seabed	M (L)	L (L)	NS
High energy Infralittoral Seabed	M (L)	L (L)	NS
Moderate energy Circalittoral Seabed	M (L)	M (L)	L (L)
Moderate energy Infralittoral Seabed	M (L)	M (L)	L (L)

Mediterranean

Pressure Broadscale Habitats	Penetration and/or disturbance of the substratum below the surface of the seabed	Shallow abrasion/penetration: damage to seabed surface and penetration	Surface abrasion: damage to seabed surface features
PRESSURE BENCHMARKS	STRUCTURAL DAMAGE TO SEABED >25MM	DAMAGE TO SEABED SURFACE AND PENETRATION ≤25MM	DAMAGE TO SEABED SURFACE FEATURES
III.3 Coarse sand and muddy sand	M (L)	L (L)	NS (L)
III. 5 Posidonia oceanica seagrass meadow	H (L)	H (L)	M (L)
III.6.1 Algal dominated Infralittoral rock	NE (L)	NE (L)	L (L)
IV.3.1 Coralligenous Assemblages	NE (L)	NE (L)	H (L)

Baltic

		Sensitivity		
Pressure -> Broadscale Habitats		Penetration and/or disturbance of the substratum below the surface of the seabed	Shallow abrasion/penetration: damage to seabed surface and penetration	Surface abrasion: damage to seabed surface features
Pressure Benchmarks ->	SalinityCl	Structural damage to seabed >25mm	Damage to seabed surface and penetration ≤25mm	Damage to seabed surface features
A3.4: Baltic exposed Infralittoral rocks		NA	NA	NA
A3.5: Baltic moderately exposed Infralittoral rocks	Marine	NA	NA	NA
A3.6: Baltic sheltered infralittoral rocks	Oligohaline	NA	NA	NA
	Mesohaline	NA	NA	NA
A4.4: Baltic exposed circalittoral rocks		NA	NA	NA
A4.5: Baltic moderately exposed circalittoral rocks	Marine	NA	NA	NA
A4.6: Baltic sheltered circalittoral rocks	Oligohaline	NA	NA	NA
	Mesohaline	NA	NA	NA
Subtidal gravel beds		L (L)	M (L)	M (L)
A5.13: Infralittoral coarse sediment	Mesohaline	L (L)	L (L)	L (L)
	Polyhaline	L (L)	H (L)	M (L)
A5.14: Circalittoral coarse sediment	Mesohaline	L (L)	L (L)	L (L)
	Polyhaline	L (L)	H (L)	M (L)
A5.15: Deep Circalittoral coarse sediment	Polyhaline	NA	NA	NA
	Marine	NA	NA	NA
A5.23: Infralittoral fine sand or A5.24: Infralittoral muddy sand	Mesohaline	M (L)	M (L)	L (L)

		Sensitivity		
Pressure -> Broadscale Habitats		Penetration and/or disturbance of the substratum below the surface of the seabed	Shallow abrasion/penetration: damage to seabed surface and penetration	Surface abrasion: damage to seabed surface features
Pressure Benchmarks ->	SalinityCl	Structural damage to seabed >25mm	Damage to seabed surface and penetration ≤25mm	Damage to seabed surface features
	Polyhaline	M (L)	H (L)	L (L)
A5.25: Circalittoral fine sand or A5.26: Circalittoral muddy sand	Mesohaline	M (L)	M (L)	L (L)
	Polyhaline	M (L)	H (L)	L (L)
A5.27: Deep circalittoral sand	Marine	NA	NA	NA
A5.33: Infralittoral sandy mud	Mesohaline	M (L)	M (L)	L (L)
	Polyhaline	H (L)	H (L)	L (L)
A5.34: Infralittoral fine mud	Mesohaline	M (L)	M (L)	L (L)
	Polyhaline	H (L)	H (L)	L (L)
A5.35: Circalittoral sandy mud	Mesohaline	M (L)	M (L)	L (L)
	Polyhaline	H (L)	H (L)	L (L)
A5.36: Circalittoral fine mud	Mesohaline	M (L)	M (L)	L (L)
	Polyhaline	H (L)	H (L)	L (L)
A5.37: Deep circalittoral mud	Mesohaline	NA	NA	NA
	Polyhaline	NA	NA	NA
A5.43: Infralittoral mixed sediments	Mesohaline	L (L)	L (L)	L (L)
	Polyhaline	L (L)	H (L)	M (L)
A5.44: Circalittoral mixed sediments	Mesohaline	L (L)	L (L)	L (L)
	Polyhaline	L (L)	H (L)	M (L)

		Sensitivity		
Pressure -> Broadscale Habitats		Penetration and/or disturbance of the substratum below the surface of the seabed	Shallow abrasion/penetration: damage to seabed surface and penetration	Surface abrasion: damage to seabed surface features
Pressure Benchmarks ->	SalinityCl	Structural damage to seabed >25mm	Damage to seabed surface and penetration ≤25mm	Damage to seabed surface features
A5.45: Deep Circalittoral mixed sediments	Mesohaline	NA	NA	NA
Circalittoral seabed	Oligohaline	NA	NA	NA
	Mesohaline	NA	NA	NA
Deep circalittoral rock	Mesohaline	NA	NA	NA
	Marine	NA	NA	NA
Infralittoral seabed	Oligohaline	NA	NA	NA
	Mesohaline	NA	NA	NA
	Polyhaline	NA	NA	NA
Subtidal macrophyte-dominated sediment		L (L)	M (L)	H (L)
Subtidal biogenic reefs		NE	NE	H (L)

Deep Sea

Pressure theme			
Pressure	Penetration and/or disturbance of the substrate below the surface of the seabed	Shallow abrasion/penetration: damage to seabed surface and penetration	Surface abrasion: damage to seabed surface features
Broadscale Habitats Pressure Benchmarks	Structural damage to seabed >25mm	Damage to seabed surface and penetration ≤25mm	Damage to seabed surface features
A6.1: Deep-sea rock and artificial hard substrata	H (L)	H (L)	H (L)
A6.11: Deep-sea bedrock	H (L)	H (L)	H (L)
A6.2: Deep-sea mixed substrata	H (L)	H (L)	H (L)
A6.3: Deep-sea sand	H (L)	H (L)	H (L)
A6.3: Deep-sea sand or A6.4: Deep-sea muddy sand	H (L)	H (L)	H (L)
A6.4: Deep-sea muddy sand	H (L)	H (L)	H (L)
A6.5: Deep-sea mud	H (M)	H (M)	NS-H (M-H)

A6.52: Communities of abyssal muds	H (M)	H (M)	NS-H (M-H)
Deep Circalittoral rocks	NA	NA	NA
Deep Circalittoral Seabed	H (L)	H (L)	H (L)
Deep sea coarse sediment	H (L)	H (L)	H (L)
Deep-sea coarse sediment	H (L)	H (L)	H (L)
Deep-sea Seabed	H (L)	H (L)	H (L)
Low energy Circalittoral Seabed	M (L)	M (L)	L-M (L)
Low energy Infralittoral Seabed	M (L)	M (L)	L-M (L)
Lower Abyssal Seabed	H (L)	H (L)	H (L)
Lower Bathyal Seabed	H (L)	H (L)	H (L)
Mid Abyssal Seabed	H (L)	H (L)	H (L)
Mid Bathyal Seabed	H (L)	H (L)	H (L)
Upper Abyssal Seabed	H (L)	H (L)	H (L)
Upper Bathyal Seabed	H (L)	H (L)	H (L)

Annex 5: Review ICES WKFBI REPORT 2016

Review group:

- Jan Geert Hiddink, UK (chair)
- Jake Rice, Canada
- Drew Lohrer, New Zealand
- Andrew Kenny, UK

June 2016

The review group was tasked to review the ICES WKFBI report.

The WKFBI was asked to:

a) Evaluate a scoring processes for sensitivity of habitats, which should also include rules on:

  i) How to scale-up sensitivity to a c-square resolution of 0.05o x 0.05o

  ii) How to treat variation in habitat type when evaluating sensitivity within c-square resolution of 0.05 x 0.05

  iii) How to interpolate and/or extrapolate information on sensitivity when habitat data are missing

b) Evaluate information on sensitivity of the benthic community of the various seabed habitats that ensures habitat maps for sensitivity can be produced for at least one demonstration area of NW European waters (MSFD region/subregion).

c) Evaluate impact maps that combine the benthic information on sensitivity and fishing pressure maps (fishing abrasion, weight and value of landed catch), taking into account differences in benthic impact of the various fishing gears / métiers.

d) Using the workshop, evaluate and synthesis findings (TOR a–c) aimed at tangible use of indicators of the state of the seabed in relation to fishing pressure.

e) Prepare a guidance document on how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats. This should include “principles and good practices” that can be used when regionally operationalizing indicators to assess the impact of fishing to the seabed.

The review group was asked to identify any errors in the proposed guidelines based on methods/analysis and correct them. The review group evaluated the response to the advice request from WKFBI. Our review focuses on whether we think the conclusions are robust and whether the working group missed important points relevant to the request.

Preamble

The review panel commend the WKFBI for tackling an important and complex question and producing an impressive collation of approaches that each produced trawling impacts maps for the NW European shelf seas. The report provides a critique of the currently developed approaches for assessing fishing benthic impacts with detailed and objective accounts of their strengths and weaknesses (‘caveats and uncertainties).

The report assigns the approaches into one of two categories, namely; i. expert driven categorical approaches, and ii. quantitative/continuous mechanistic approaches. The review panel recognized the challenges presented by the necessity to provide assessments of trawling impacts over large spatial scales, and that the extrapolation of the current understanding of trawling impacts is required to achieve this. WKFBI did an important job in bringing together and evaluation several distinct approaches and completing an evaluation of impacts of trawling on benthic ecosystems. Below we comment on the WKFBI report, providing a consensus response from the panel and identifying key strengths and weaknesses.

Unfortunately we only had a few days between receiving the draft report and this review being due, and as a result, some of this review does not synthesize the comments of the different reviewers as well as we would have liked. The tone of the review may also seems a bit 'abrupt' at times because of limited time for editing, apologies for this.

Review

The report would benefit from an introduction where the concepts of resistance and resilience are cleared linked to the mechanisms through which bottom trawling affects benthic organisms. Figure 7.1 does this, but does not mention resistance and resilience. Benthic trawling changes the benthic ecosystem by killing a fraction of organisms each time a trawl passes over the seabed, this fraction is captured by the 'resistance' or IM in Figure 7.1 or d in equation 1 and 2 in section 7. Past and ongoing work have shown that this fraction tends to lie between 5 and 40% depending on the fishing gear used (Kaiser *et al.*, 2006). Resilience is a measure of how fast organisms recover after a trawl pass, and measured as the number of years to recover from for example 50 to 90% of untrawled biomass, or characterized by the logistic recovery rate *r*, or RT in Figure 7.1. Equation 2 in section 7 shows that the sensitivity of the community can be characterized by the ratio of the (1-resistance)/resilience, or d/r.

This discussion makes it clear that Resistance and Resilience in Table 3.1 can be expressed in units (Resistance = 1–d in %, Resilience = recovery time from x% depletion in years). We think that the expert judgment of sensitivity have been unnecessarily subjective because no units were used, and recommend that future exercises score resistance and resilience separately on a quantitative scale. Experts may not be comfortable with this, and this is exactly why this is necessary as it makes them think a lot harder about the assignment to particular categories. As an example, there is a category Resistance = None. To our knowledge there are no papers that show 100% mortality caused by a trawl pass (just as the catchability of a trawl for the target species is always well below 100% and more in the range of 25% or so).

We agree with the conclusion that resistance and resilience scores need to be reported separately rather than only the sensitivity scores. It would also be important to include a justification for the scores in the table in Appendix 4.

We are confused by the assignment of subsurface and surface sensitivity, and we are getting the feeling that the BEWG may have been mixing two different concepts. The BEWG felt that the sensitivity of deep living fauna are higher than for epifauna but does not explain whether this is because of a lower resistance or lower resilience. A gear that penetrates the sediment more deeply is likely to kill a larger fraction of the organisms than a gear that skims the surface, and this is true for both the organisms that live at the surface and the ones that live more deeply. In my mind, it also means that the resistance of epifauna to trawls is likely to be smaller than for infauna (if resistance is defined as the 1-% killed by a trawl pass). A higher sensitivity of subsurface organisms to the same gear can therefore not be due to a lower resistance and has to be due to a lower resilience. In our opinion, the evidence of such a pattern of lower resilience for infauna than for epifauna are absent, but has a large effect on the impact maps. As a result Figures 5.5 and 5.8 do not make intuitive sense to at least two members of the RG. This is obviously an area that needs attention in future work.

It is not possible to statistically combine ordinal scores, and this is exactly what the categorization approaches are working towards. In our opinion there exist serious problems in the categorization approaches with the violation of basic statistical practices. There are problems with arbitrary boundaries of the classes of impacts. In addition to this sometimes categories are defined by the average conditions rather than boundaries and this is bad practice. The developers may consider categorization unavoidable but the lack of an even ordinal scale needs to be taken into account when scores are used. Analyses assuming normal – or even continuous or uniform distributions will be invalid. A problem with categorization is that we need to know the degree of discontinuity of the habitat classifications and how constant the gradients are across types of habitats forming ecotones. Otherwise the boundaries may not represent comparable amounts of change in ecosystem condition. The bias due to combinations of categories and artificiality of category boundaries could be having strong influence on results from this approach. For example, in Table 6.1, a score of 6 from a three and a three and a score of 6 from a 1 and a 5 may be completely different ecologically while being the same on the computation because of the categorical issues. The interpretation of subsequent differences among scores as if the individual scores had been on an interval scale (as for example done when calculating the PDI) is unlikely to represent the ecological impact of trawling. The PDI should therefore not be used.

We do not agree with the way the Precautionary Approach was applied for assigning all deep-sea habitats as high sensitivity, and are glad to see the WG agreed with this. It is important that such inappropriate application of the Precautionary Approach are avoided in the future, as the approach just makes the term "high" meaningless. Every advocacy group will seize on this scoring and associated maps as science saying all the deep-sea should be fully protected, and policy-makers and managers won't know what it means or to do when they see an area called "high".

In the discussion of the categorical approaches there are several mentions of sensitivity of the habitat depending on the trawling history, and therefore suggesting that "sensitivity" is not an absolute property of a locations or habitat, but only relative to the 2009 benchmark. The occurrence of highly sensitive or biogenic or long-lived species is unlikely in some areas that have been repeatedly and intensively fished for a century. Therefore, using modern day organism distributions as a means of evaluating 'seabed integrity' effectively lowers the standard and makes it harder to detect impacts. It is saying that "sensitivity" is about likelihood of *further* degradation from the point when a study started, and not a property of the habitat type itself. Does that mean the MSFD accepts 2009 as a GES for all Europe? This also relates to the first point made in this review, about more clearly defining how sensitivity relates to the mechanics of the effects of trawling. We feel that the sensitivity scoring should capturing the features of the place being assessed that is independent of the history of use. A good impact assessment methodology will then be able to use the trawling history to assess the impact based on the sensitivity of the place.

It is suggested that the categorical sensitivity assessment should assess the sensitivity of characteristic species. They could be species which provide a distinct habitat that supports an associated community, or one that is important for community functioning through interactions with other species, or species which are used for the definition of a habitat, but importantly, they will need explicit selection criteria and independent evidence-based assessments if the decision is made to go down this pathway. It is also suggested that a single species may have a different sensitivity in different habitat types. In our opinion there may be minor differences between habitats, but they are unlikely to be large enough to be of concern, especially relative to other sources of error in the approach.

The Benthis longevity approach implicitly assumes that a trawl pass kills 100% of adult organisms, and therefore gives a worst-case assessment of the state of the seabed. Because of this, it is important that the acknowledgement that this is very much a worst-case assessment is not lost when communicating this. It should not be difficult to adapt the approach to take account of the instant mortality caused by a trawl being <100%, by evaluation where the (inverse of the trawling frequency * fraction instant mortality) > longevity. Moreover, if instant trawl mortality is <100%, there will likely be a faster rate of recovery, as not all individuals will be forced to 'reset' back to year 0 again. Meta-community dynamics (which are acknowledged as being potentially important on page 69) also have the potential to affect recovery rates. That is, if there is high variability of fishing pressure in adjacent grid cells, the lesser disturbed areas may contribute larval propagules to the more disturbed areas. This increases complexity into the modelling, but some simple ways of incorporating this concept could be trialled.

Although Benthis longevity approach may be a worst-case assessment, the Benthis population dynamics approach may be overly optimistic. The colour scales on the GIS maps (even for quantitative analyses, e.g. Figures 7.3, 7.5) can make a very big difference to the appearance of the maps, especially considering that the colour interval classes are not uniform in size. The Benthis population dynamics approach does not differentiate among the various species in the community; it suggests that "community biomass can be used as a proxy for the state of the seabed (Seabed Integrity SI)". In reality, however, biomass (similar to total abundance and richness) likely reaches pre-disturbance levels well before true recovery occurs. High seabed integrity is dependent upon having mixtures of young and adult organisms and at least a few large, long-lived, functionally important species; this would take longer than simple biomass recovery, and so using biomass recover as the proxy would not protect many of the most functionally important species. Biomass is probably a good proxy for the functioning of the ecosystem, but not necessarily for the size or longevity distribution of biodiversity. When using this approach to assess SI it therefore has to be highlighted that it works as an indicators for particular aspects of integrity but not others.

The Benthis 1 approach needs a justification for choosing the 80 and 90% of benthic biomass as target or at least the management benchmark. Alternatively, it could perhaps calibrate relative to biomass of fish when all fish stocks are being exploited at just below F_{MSY} relative to virgin biomass?

ToR ai–iii are not covered that well in the report, but we feel that those issues have relatively minor effects on the impact assessment relative to other uncertainties. In particular, the uncertainty in the habitat maps is less important than uncertainty in sensitivity of those habitats. Most of the habitats have similar sensitivities, so uncertainty about the precise habitat type has little effect on the final impact assessment. Efforts should therefore focus on getting more robust sensitivity estimates rather than on refining habitat maps. The Benthis 2 collapses habitat information into 4 classes: biogenic, gravel, sand, mud, this makes very large assumptions about the similarities of grid cell communities that happen to have similar sediment types, and some further refinement of the habitats used there may be useful.

We generally agree with the recommendations and conclusions, but it is not always clear how these conclusions were arrived at, so a justification for each of the conclusions would be useful. The report appears to go out of its way to sit on the fence in terms of concluding which approach is preferable, it sets out the pros and cons of each and concludes that no one approach is better than the other in terms of meeting the assessment and policy objectives. We have the feeling that too much confidence is placed in the approaches that are based on expert opinion relative to quantitative approaches. For example, it is written that the quantitative 'methods are still under development and the uncertainty of the impact estimates have not been determined nor has the sensitivity of the methods been investigated'. In our opinion this is just as valid for the categorical approaches. However, if one considers (which the report does not) that the assessment needs as defined by the policy objectives under the MSFD are to ensure GES while sustaining the provision of marine ecosystem good and services, then methods which can determine limits for sustainable development have greater utility to those which simply take a precautionary approach. Categorical (expert driven) approaches may become redundant as quantitative approaches will out-perform them in terms of reflecting reality and the work done under BENTHIS reflects the development of science in this direction and we see this only growing in application for management which points to the greater utility and application of these methods. We would consider it better science-based assessment practice to use BENTHIS -type methods in coarsely defined habitat groupings, and extrapolate – with strong user warnings – to not-yet-studied habitat types, than use categorization methods that can be applied at much finer levels of habitat type disaggregation, but where the results are statistically incorrect in both the details and fundamentals. The conclusions are missing commentary on the analytical inappropriateness of treating ordinal categories as if they were continuous. This really needs to be stressed, as ICES is about providing science advice, rather than advice on popular practices.

Recommendations

The review group unanimously preferred the quantitative approaches over the categorical approaches. We have identified several major problems in the categorical approaches that cannot easily be solved. We would therefore like to recommend that ICES puts more emphasis on proceeding impact assessments using quantitative, mechanistic approaches rather than on the use of categorization exercises.

Editorial comments. Where numbers are given, they refer to page and line numbers in the draft version of the report, because of the compressed time-scale for this review, the RG chair did unfortunately not have time to cross-refer these to the final report. These are the most pertinent comments, some further comments were given by Jake Rice and these can be made available if required.

There are a number of instances where the BH3 approach has inappropriately been highlighted, e.g. under section "10.2 Recommendations for further work" "10.2.2 Sensitivity" the last bullet point starting BH3 – "The BH3 approach is considered to be useful for providing a consistent assessment between countries" – this is not a recommendation for further work. Also under 10.2.4 "BH3 provides a good framework for collaboration between member states and ensuring consistency of outputs." This also is not a recommendation for further work. In both cases I suggest these bullet statements be deleted.

- Page 11 – third column. The level of precision presented here is not appropriate.
- Page 34- line 25. The figures 4.4 to 3.5 – the figures give a fine general impression but one can't really see much of the detail of the intermediate categories. If there are 10 categories, they need to be displayed so they can be differentiated better. If alternatively the authors are trying to make a categorical analyses look like a gradient, then those looking at the figures may misinterpret the maps, because of the problems with combining ordinal categories to get the final scores, because there might not be a true continuum from 1 to 10, but conditions that produce the intermediate scores may not be an ecological continuum at all.
- 43:18 and beyond, too much jargon to reach much of a potentially interested readership
- 44:26 This 58% communicates an amazing precision in the results. Not 56 or 60, but 58%. It underscores a concern with some the report – that it places a blanket of artificially sophisticated looking analytical playing with some very conceptually simple and arbitrary subjective creation of categories out of continua. It ends up camouflaging a mix of "expert judgement" and outright preconceptions in proportions that are variable but always unknown (at least to the reader), as if some very complex and highly accurate and precise science was behind the results.
- 46:11. These figures look like the extrapolation is massive, and no guidance given for what the extrapolation is based on.
- 47:13. There is inadequate explanation of origins of either the data in the figure or how the data were used to create the figures.
- Benthis 2: 57:21 This equation needs fuller explanation for non-experts.
- 60 Figure 4. This is a very informative figure but took some time to assimilate, the explanation may be insufficient for the policy and management community as it is not a type of graph they are used to seeing.
- 61:17. This is an important question and I think that there is literature the authors should get into.
- 61: 23. This rationale can be made stronger, and with use of a log-linear model it gives scope for constant ratio of uncertainty as long as bias does not change markedly on a log scale.
- 28: 8 The text is a misuse of the precautionary PRINCIPLE rather than precautionary approach, and it is the PA not the PP that should be applied in these types of analyses.

References

Kaiser, M.J., Clarke, K.R., Hinz, H., Austen, M.C.V., Somerfield, P.J. & Karakassis, I. (2006) Global analysis and prediction of the response of benthic biota to fishing. *Marine Ecology Progress Series*, **311**, 1–14.