WORKING GROUP ON FISHERIES BENTHIC IMPACT AND TRADE-OFFS (WGFBIT; outputs from 2021 meeting)

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Contents

i Executive summary

The Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT) develops methods and performs assessments to evaluate benthic impact from fisheries at regional scale, while considering fisheries and seabed impact trade-offs.

In this report, new fishery benthic impact assessments are carried out for several sub-regions in the Mediterranean (Greek waters, South Adriatic Sea, Sicily waters). For other regions, updates of the whole assessment or specific steps only were presented. A standard advice sheet for the regional benthic assessments, intended as input to the next generation of the ICES Ecosystem and Fisheries Overviews, was finalised and compiled for some regions as example (Greek waters, Baltic Sea). A validation of the longevity relationships using new data was executed for the Kattegat area and the Southern North Sea. In relation to the methodology, some recommendations were formulated concerning the update on depletion rates, the use of epifauna- or infauna-based data, guidance on which set of epibenthic species to include and the time scale for setting the average swept-area-ratio (SAR) used in model fitting and assessment. A benchmarking process comparing available benthic impact assessment approaches for MSFD descriptor 6 "Seafloor integrity" is needed, as the WGFBIT approach (relative benthic state) is not the only way to assess benthic impacts from physical disturbances. A start was made to explore how to incorporate more explicitly ecosystem functioning in to the WGFBIT seafloor assessment methodology. An improved understanding of the relationships between total community biomass and ecosystem functioning may assist in setting acceptable thresholds for ecosystem impacts from trawling. Furthermore, an improved understanding of the link between species functional effect traits and proxies and processes for specific ecosystem functions could help increase our ability to predict the impact of fishing disturbance on benthic ecosystem functioning more accurately. The ecosystem function we focus on is the biogeochemical cycling of organic matter. Two approaches were discussed (i) Biological traits approach focusing on the linkage between biological traits and ecosystem functions and (ii) biogeochemical modelling approach using the established the OMEXDIA model.

ii Expert group information

Expert group name	Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT)
Expert group cycle	Multiannual
Year cycle started	2021
Reporting year in cycle	1/3
Chairs	Gert Van Hoey, Belgium
	Marija Sciberras, UK
	Jan Geert Hiddink, UK
Meeting venue and dates	22–26 November 2021, Palermo, Italy (hybrid meeting); 46 participants

1 Highlights from WGFBIT 2021

Highlights from WGFBIT 2021 meeting are summarized below:

- Major progress was made in fishery benthic impact assessments for the Mediterranean and the Biscay/Iberia regions. Complete or preliminary assessments are now available for about half of the EU seas. Some progress was made in almost all regions, and paths towards full assessments are becoming clear for almost all regions, but with notable gaps for Portugal, Croatia and the Black Sea.
- Validation of the longevity relationships using new data was executed for the Kattegat area and the Southern North Sea (Dutch coast and Brown bank area).
    - For the Kattegat, we concluded that using the Baltic Sea longevity prediction is more reliable than the North Sea predication.
    - At the Brown bank area, the observed median longevity in a heavily fished area was very close to the predicted one without fishing. It is opposite to what is expected, so further examination of this relationship is required.
    - The analyses along the Dutch coast indicates that the available predicted longevity estimates are not yet applicable in very shallow, dynamic areas (< 20m depth).
- Recommendations were formulated for several methodological issues:
    - Depletion rates are now specified for 10 metièrs.
    - A fishery benthic impact assessment based on epifauna or infauna based are likely to differ, so any differences need to be further explored and actions taken.
    - Guidelines are formulated on which set of epibenthic species caught by trawl (e.g. *Cephalopoda*, *Gobiidae*, commercial species, …) to exclude or not. At least, the choices made in the assessment need to be documented.
    - An average SAR over a 3-to-6-year period is defined as time scale to use in fitting the statistical models and final assessments.
- Discussions at the meeting identified potential synergies between the FBIT and NAFO WG ESA work. The wealth of data in the NAFO area could allow estimating the recovery rate parameter r, if the depletion d and the SAR can be estimated for the fishery. This, in combination with species distribution models, may allow the estimating of impacts on VMEs in the NE Atlantic. This will be explored at next year's meeting.
- The WGFBIT seafloor assessment framework is not the only way to assess benthic impacts from physical disturbance. Therefore, comparison with other methods (alternative assessment methods) need to be explored. Therefore, a set-up for such comparison (benchmark process) was discussed and is likely to be further developed in dedicated ICES workshops.
- The main discussions on ToR D (ecosystem functioning) resulted in a consensus to carry out:
    - (a) multivariate analysis to link biological traits to biogeochemical proxies and processes,
    - (b) methodological development of a biological model using trait-specific depletion (d) and recovery (r) values to examine effect of trawling on biogeochemical cycling, and
    - (c) parametrization of the biogeochemical OMEXDIA model to examine the biogeochemical vulnerability to trawling around Europe. To this effect a number

of datasets where both fauna and biogeochemical data exist for the same sampling stations were identified for the North Sea, Celtic Sea, Baltic Sea and the Mediterranean Sea.

- WGFBIT had a very successful hybrid meeting, with 46 participants representing all regions.

2 Introduction

The objectives of the Fisheries Benthic Impact and Trade-offs Working Group (WGFBIT) 2021 meeting were to continue the benthic impact assessment for as many (sub-) regions as possible, to execute validation analyses, to discuss methodological issues and to explore the implementation of ecosystem functioning aspects into the assessments. This is organised into four ToRs:

- ToR A: Regional assessments: Apply and improve the MSFD D6/D1 assessment framework developed by WGFBIT (2018–2020) to produce (sub-)regional assessments for the North, Celtic, Baltic, Arctic (Icelandic, Norwegian Barents sea), Mediterranean Seas and the Bay of Biscay and the Iberian Coast
- ToR B: Updates for assessment framework: Explore and potentially implement options to improve the parameterisation of framework components, in shallow waters and deep-sea areas.
- ToR C: FBIT and the wider world: Alignment of the FBIT framework with other assessment methods for benthic habitats under relevant EU directives.
- ToR D: ecosystem functioning: Explore if ecosystem functioning can be incorporated more explicitly into the assessment methodology.

The specific aims and deliverable for 2021 FBIT meeting were formulated as follows:

1. Physical (+hybrid) meeting with lots of time for informal chats and catch up to strengthen link within the group and progress towards WGFBIT aims (ToR A, B, C, D)
2. Progress integration into WGFBIT framework state of the art methods to quantify ecosystem goods and services using traits and ecosystem function (ToR D)
3. Present and discuss recent update of progress (pressure, impact, trade-offs) and next coming 3 years for WGFBIT (ToR A, B, C)
4. Online tutorial and an update of 2017 technical guidelines for running WGFBIT assessment framework, with regional specific calibration (data sources, traits, etc.) (ToR A, B, C, D)
5. Strengthen framework for deep-sea trawling impacts assessment by identifying opportunities and agreeing timeline in collaboration with NAFO's WG-ESA group (ToR A, B, C, D)
6. Improving the methods (ToR B): 1) standardisation (grab, core, trawl) between sampling methods for WGFBIT purposes 2) resolution of gear-specific depletion rates, 3) traits, biotic indices and ecosystem function, 4) update of 2017 technical guidelines for running seafloor assessment
7. Progress regional specific calibration, ground truthing, and assessment sheets (ToR A)
8. Regional seafloor assessments and WGFBIT (ToR C): Denmark example, ICES overviews, OSPAR QSR, HELCOM HOLAS, Mediterranean, Black Sea, Arctic, and beyond (NAFO, Barents Sea, Iceland)

The WGFBIT meeting was in the format of a hybrid version, where half of the people were present in Palermo, whereas the other half participated remotely via online platform (entire period or for certain agenda points). The agenda was structured around a seminar session (a theme related to the ToRs) in early afternoon and sub-group work in the morning and late afternoon.

3 Regional assessments (ToR A)

The aim of ToR A is to produce (sub-) regional fishery benthic impact assessments for the North, Celtic, Baltic, Arctic (Icelandic, Norwegian, Barents sea), Mediterranean Seas and Bay of Biscay and the Iberian Coast.

Table 1 provides an overview for how far the FBIT framework is implemented in each region and on which information the assessment is based. For each region, we have executed the FBIT framework to a certain level, which proves the applicability of it. Of course, the assessments are preliminary and many steps need further developmental work, as indicated in the regional specific reports.

Table 1. Overview of the progress in the implementation of the FBIT framework in each region.

	(sub)-REGION	**Arctic Region**	**Arctic Region**	**Arctic Region**	**Baltic**	**Greathern North Sea Region**	**Celtic, Bay of Biscay and Iberian Coast**	**Celtic, Bay of Biscay and Iberian Coast**	**Celtic, Bay of Biscay and Iberian Coast**	**Mediterranean**	**Mediterranean**	**Mediterranean**	**Mediterranean**	**Mediterranean**	**Mediterranean**	**Black Sea**
		Barents Sea	Norwegian Sea	Iceland	All	All	Celtic Sea	Bay of Biscay	Iberian Coast	Spain	France	Southern Adriatic	Italy + international waters	Central and Ionian Seas	Aegean-Levantine Seas	
	Contacts	Julian Burgos	Julian Burgos	Julian Burgos	Josefine Egekvist	Daniel van Denderen	Jose Gonzalez Irusta and Pascal Lafargue	Jose Gonzalez Irusta and Pascal Lafargue	Jose Gonzalez Irusta and Pascal Lafargue	No progress for now	Sandrine Vaz	Andrea Pierucci, Walter Zupa	Sasa Raicevich	Gabriele di Bona, Cristina Mangano, ISPRA	Chris Smith, Nadia Papadopoulou, Irini Tskikopoulou, Irida Maina, Sofia Reizopoulou, Stefanos Kavadas	
STEP 1	**Pressure layer information**	ICES data 2018 (Otter trawls only)	ICES data	ICES data	ICES data 2009–2018	ICES data 2009–2018	At the moment OSPAR 2021 data, but will switch to the ICES VMS data later	At the moment OSPAR 2021 data, but will switch to the ICES VMS data later	At the moment OSPAR 2021 data, but will switch to the ICES VMS data later		VMS from 2012 to 2020, full international split by gear types. Includes incertainty.	AIS data	SAR from ISPRA dataset (VMS +AIS), Italy only	SAR derived ISPRA VMS dataset 2007–2019. Not complete?	Complete 2015 to 2018. Missing non-Greek fleet (although primary fleet is Greek)	Effort map exist for Bulgaria and Romania

STEP 2	**Habitat information**	MSFD Broad habitat types	MSFD Broad habitat types	MSFD Broad habitat types	MSFD Broad habitat types, udated with latest EU SEAMAP.	MSFD Broad habitat types	MSFD Broad habitat types	MSFD Broad habitat types	MSFD Broad habitat types	MSFD Broad habitat types	MSFD Broad habitat types	MSFD Broad habitat types	MSFD Broad habitat types	MSFD Broad habitat types	MSFD Broad habitat types
	Longevity curves based on:														
STEP 3	**Biological traits**	Benthic data updated, more longevity classes. Compiling all available data	Benthic data updated, more longevity classes. Compiling all available data	Benthic data updated, more longevity classes. Compiling all available data	Benthis/ Tornroos & Bonsdorff 2012	Benthis	Benthis plus some extra from a Spansh database when missing	Benthis plus some extra from a Spansh database when missing	Benthis plus some extra from a Spansh database when missing	None	Not compiled, but Crete traits database >50% of biomass does not have longevity data. Med group will collate all trait data in a common database	Same list as for Sicilia	Biological traits for SOLEMON and GAP2 ADRIATIC SEA. Med group will collate all trait data in a common database	ISPRA Med megaepifauna + Bolam 2014	Complete, 888 macroinfaunal species. Full BENTHIS 11 traits.

Benthic samples	Norwegian-Russian Ecosystem Survey (only data from 2011 and 2015)	MAREANO project beam trawl data (2006–2017)	Icelandic Autumm Trawl Survey (4 years), but only for stations at depths >400m.	Only from low fishery, high oxygen data	Incl. fishery gradient data, but missing the deepest and most coastal parts and being updated with these areas	Irish IBTS, and beam trawl data. Also some grab samples there, also Irish waters. UK mostly grab data.	Data from IBTS	Data from IBTS	MEDITS exists but no access at the moment	MEDITS, and beam trawl available but very coastal where the VMS coverage is poor	MEDITS epifauna	SOLEMON Trawl survey (rapido). OTB and rapido trawl discard data from observers on fishery dependent data (GAP2);	MEDITS OTB survey. Aiming to convert abundance to biomass for some hauls.	Macrofaunal surveys and experiments. EU projects, PhDs, WFD and MSFD. 204 stations, 1364 samples
Modelling basis (environmental variables)	Depth, temperature, sediment composition	Depth, temperature, sediment composition	Depth, temperature. Other variables are being explored.	Salinity, depth, wave exposure at the seabed (low oxygen areas omitted) van Denderen *et al*. 2020	Percentage mud and gravel, bottom-shear stress (fishing effect is fitted using subsurface abrasion)	Working on this stage. EMODNET: Energy, depth, substrate type, SBT, surface chla	Working on this stage. EMODNET: Energy, depth, substrate type, SBT, surface chla	Working on this stage. EMODNET: Energy, depth, substrate type, SBT, surface chla		No models fitted yet. Planning to use grain size, sea bed stress, food availability at the seabed. Probably will need to include SAR	Depth only, EUSeamap habitats	No model fitted yet. Planning to use EU-Seamap, depth, productivity, grain size distribution.	EU-Seamap habitats and depth. Depth only selected as explanatory variable.	Station habitat data from sampling, depth, sediment fractions.

STEP 4	**Impact assessment**	2018, preliminary	2018, preliminary	2021, preliminary	2009–2018	2009–2018	Not yet	Not yet	Not yet		Not yet	2021	Not yet, possible early assessment by 2021	Run it the meeting n 2021	2015 to 2018	
					Exclude hypoxic areas											Exclude hypoxic areas.
STEP 5	**Validation (alternative assessment availability)**	To do	To do	To do	Kattegat validation compare between the North Sea and Baltic assessment	Kattegat validation compare between the North Sea and Baltic assessment	Plan is to use earlier years for fitting, use 2020 for validation	Plan is to use earlier years for fitting, use 2020 for validation	Plan is to use earlier years for fitting, use 2020 for validation		To do		To do	Solomon project Eliza Puzzo	Will investigate	
STEP 6	**Confidence / uncertainty**	To do	To do	To do	To do	Preliminary	To do	To do	To do	To do	To do	To do	To do	To do	To do	
STEP 7	**Trade-off**	To do	To do	To do	ICES, 2021	ICES, 2021	To do	To do	To do	To do	To do	To do	To do	To do	Tried in TRADE3	

Note: This document is not actual ICES advice developed in response to a request from a client, but rather a demonstration of the type of advice ICES could provide if requested.

3.1 Regional advice sheet documents

An assessment sheet template for use in communicating the results of WGFBIT seafloor assessments was finalized. We aim to use this template to produce a concise summary of the region-specific advice which WGFBIT provides. A template ensures that advice is consistently formulated across regions and years. The filled in templates will also form the basis of the update of WGFBIT output into the ICES Ecosystem Overviews. An annotated version of the advice sheet template is added to this report as Annex 4.

For Baltic Sea, Greek Sea area and Southern Adriatic Sea and advice sheet document is compiled.

3.1.1 Greek Sea area

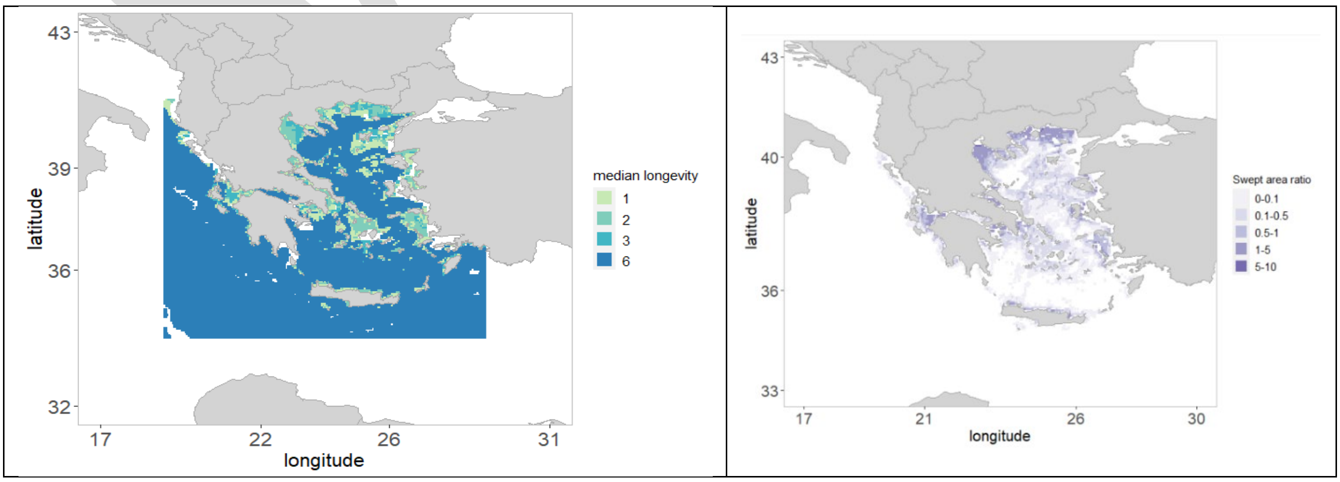
ICES seafloor assessment of mobile bottom fishing: Eastern Mediterranean (Eastern Ionian, Aegean and Cretan Seas) ecoregion

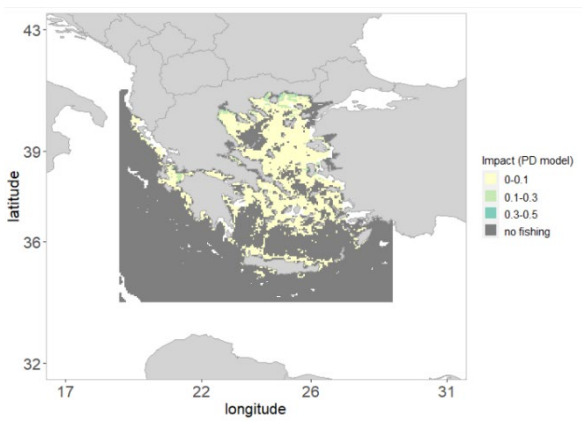
Assessment summary

This is a seafloor assessment of the Greek sea areas in the Eastern Mediterranean (Eastern Ionian, Aegean and Cretan Seas). It is based on estimates of sensitivity of benthic macroinfauna, otter trawl swept area ratios and habitat maps and follows the WGFBIT methodology. The bottom fishery (OT) is the single most important activity impacting the seafloor of this area. Other impacts from restructuring of seabed morphology by dredging and depositing of materials, coastal defences or shipping and tourism/leisure related seabed interactions occur, but are of much less importance (ICES WKBEDPRES1, 2018). This is the first preliminary assessment for Greek sea areas, indicating low levels of impact over wide areas with a few notable hotspots in northern coastal waters and in the coastal Ionian. References to the full assessment and advice documentation can be found below under ‘Format of the assessment’.

Assessment results

Status in year [2015–2018]





n/a

Figure 1. Greek sea areas maps of i) predicted median longevity (top left); ii) swept area ratio (average of year 2015–2018) based on VMS data for demersal otter trawls (top right); iii) relative benthic impact (bottom left). The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2021). n/a = not analysed.

Table 2. Assessment estimates per MSFD broad habitat type in the Greek sea areas. The columns show extent of the habitat, swept area, average fishing intensity (I-1), proportion of area in fished grid cells (I-2), proportion of area fished per year (I-3), the smallest proportion of area with the 90% of fishing effort (I-4) and relative benthic state

Habitat type (Eunis lvl X)	Extent of habitat (1000 km^2)	Swept area 1000 km^2	Average fishing intensity (I-1)	Prop. of area in fished grid cells (I-2)	Prop. of area fished per year (I-3)	Smallest prop. of area with 90% of fishing effort (I-4)	Relative benthic state
Upper bathyal sediment or Lower bathyal sediment	369.1	10.64	0.03	0.17	0.03	0.08	0.996
Circalittoral mud	20.7	9.91	0.48	0.54	0.33	0.32	0.967
Offshore circalittoral mud	14.9	5.55	0.37	0.84	0.3	0.43	0.962
Circalittoral sand	11.4	7.16	0.63	0.57	0.37	0.33	0.952
Infralittoral mud	7.3	0.1	0.01	0.02	0.01	0.01	0.978
Infralittoral sand	5.9	0.26	0.04	0.07	0.03	0.03	0.927
Circalittoral mixed sediment	0.6	0.16	0.26	0.46	0.18	0.23	0.924
Infralittoral mixed sediment	0.2	0	0	0	0		

Table 3. Summary of the pressure and impact indicators in the Greek sea areas. The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2021).

Habitat type (Eunis lvl X)	Area 1000 km2 (fraction of total)	Fraction untrawled (+-CI)	Mean SAR (+-CI)	Fraction SAR>[5] (+-CI)	Mean Impact (+-CI)	Fraction with impact below [0.3] (+-CI)
Upper bathyal sediment or Lower bathyal sediment	369.1 (0.86)	0.83	0.03	0.0000	0.004	1
Circalittoral mud	20.7 (0.05)	0.46	0.48	0.0023	0.033	1
Offshore circalittoral mud	14.9 (0.03)	0.16	0.37	0.0000	0.038	1
Circalittoral sand	11.4 (0.03)	0.43	0.63	0.0063	0.048	0.98
Infralittoral mud	7.3 (0.02)	0.98	0.01	0.0000	0.022	1
Infralittoral sand	5.9 (0.01)	0.93	0.04	0.0000	0.073	1

Circalittoral mixed sediment	0.6 (0.00)	0.54	0.26	0.0000	0.076	1
Infralittoral mixed sediment	0.2 (0.00)	1.00	0.00	0.0000	0.002	1

Time trends

Not yet available

Interpretation of results

In this subregion, the relative benthic state is high for every habitat type, indicating high recovery values of the benthic biomass – particularly in the circalittoral mud and sand habitats with the highest swept area ratios. The highest fishing intensity is mainly concentrated in the northern part of Greece and coastal large area gulfs. The main explanation variable for mapped longevity distribution (sensitivity) was benthic habitat type. Overall low median longevity characterizes the shallow waters of the area, whilst the muddy sediments, deeper and more coarse sediments are characterized by higher values of median longevity. The most extensive habitat, upper/lower bathyal sediment is indicative of the characteristic deep waters of the area with an overall low proportion of area fished

Validity and limitations

For the current Greek sea area assessment, issues concerning the selection of unimpacted benthic stations for longevity modelling were resolved by setting a selection threshold for SAR for stations of unknown status. Different thresholds were trialed with SAR<0.1 selected as the most precautionary (the lower threshold will limit the number of stations available for assessment). The EUSeaMap habitat database needs to be improved as it is largely modelled in the Greek sea area with inconsistencies with ground truthing. Further work is needed to improve Mediterranean habitat specific gear depletion rates particularly in deeper waters, as available rates are based on shallower waters that may not be so sensitive to impacts. Although the Greek fleet is the primary fleet in the Greek sea area, there are vessels from other national fleets fishing in some of the assessment area with no data on those vessels in the current assessment. In undertaking a Mediterranean regional assessment, it will be important have standard methodologies and data selection, in particular to use a common cell size, temporal resolution and to define a common approach for incorporating the gear width in SAR estimations, taking into account local fleet specifications. A unified database is needed for longevity in Mediterranean waters and standards for gear and fauna selection for longevity modelling.

Format of the assessment

This seafloor assessment of the Greek sea area in the Mediterranean region consists of this assessment text, consisting of a series of maps and description. As a first preliminary assessment caution should be used in its use.

Sources and references

ICES. 2018. Workshop on scoping for benthic pressure layers D6C2 - from methods to operational data product (WKBEDPRES1), 24–26 October 2018, ICES HQ, Copenhagen, Denmark. ICES CM 2018/ACOM:59. 62 pp.

ICES. 2019. EU request to advise on a seafloor assessment process for physical loss (D6C1, D6C4) and physical disturbance (D6C2) on benthic habitats. In Report of the ICES Advisory Committee, 2019. ICES Advice 2019, sr.2019.25, https://doi.org/10.17895/ices.advice.5742.

3.1.2 Southern Adriatic Sea

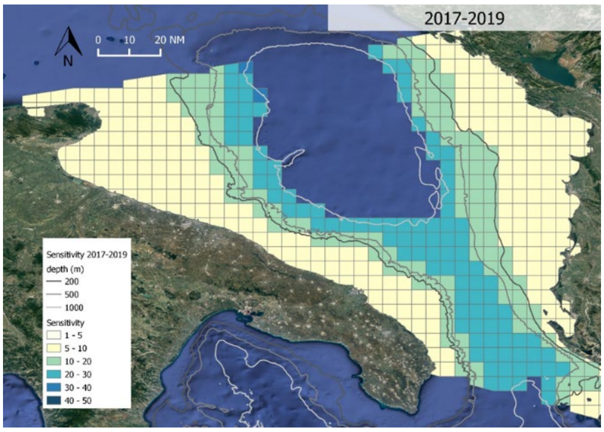
ICES seafloor assessment of mobile bottom fishing: Southern Adriatic Sea

Assessment summary

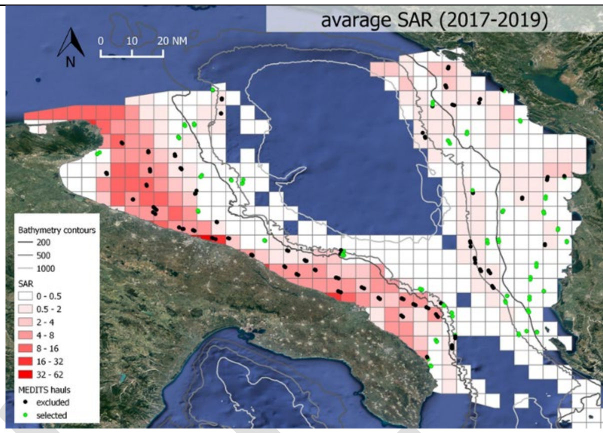
This is one of two assessments of WGFBIT for Southern Adriatic Sea (GSA 18) based on MEDITS Survey data. The method is described in section 2.4. Bottom fishery (OT) is one of the most important fishing activities impacting the seafloor of this area. Preliminary results show a higher fishing pressure and its impact around the Gargano promontory and north of Brindisi area (Figure 1 b and c). No defined advices are provided by the WGFBIT team.

Assessment results

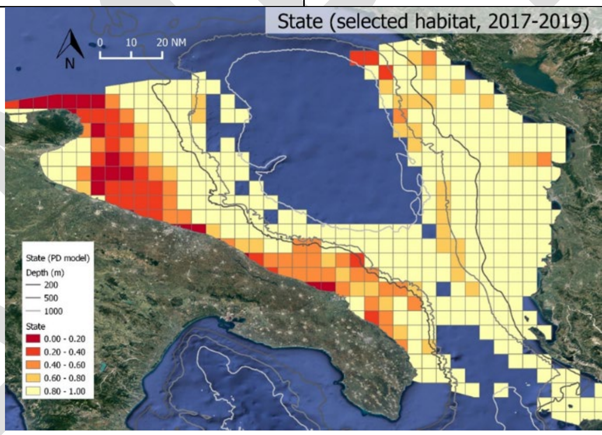
Status in year (2015–2017)



a) Map of sensitivity. The predicted longevity curves by MSFD habitat and maps for median longevity (sensitivity) of the Southern Adriatic Sea (screening samples SAR < 0.5).



b) Map of abrasion. Extent of the average swept area ratio (SAR) in the South Adriatic Sea from 2017–2019 plotted on a 0.1° x 0.1° grid. Green dots represent MEDITS survey selected hauls with SAR < 0.5; black dots show survey removed hauls with SAR >= 0.5.



c) Map of Impact, expressed as 1-Relative Benthic State (RBS) based on PD model of the Southern Adriatic Sea (SAR < 0.5).

Figure 2. Variation across assessment of [UU] for region Southern Adriatic Sea. Sensitivity (a), pressure (b) and impact (c). The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2021).

Table 4. Summary of the pressure and impact indicators by (sub-)region for 0–200 and 200–800 m depths. The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2021).

Habitat type (Eunis lvl X)	Area km2 (fraction of total)	Fraction untrawled	Mean SAR	Fraction SAR	Mean State	Fraction with impact below
Circalittoral mixed sediment	90.33	NA	0.09	NA	0.988	NA
Circalittoral mud	4496.48	NA	4.71	NA	0.561	NA
Circalittoral mud or Offshore circalittoral mud	227.64	NA	3.42	NA	0.659	NA
Circalittoral rock and biogenic reef	486.54	NA	5.73	NA	0.476	NA
Circalittoral sand	2139.22	NA	0.82	NA	0.894	NA
Infralittoral mud	66.12	NA	0.07	NA	0.991	NA
Infralittoral rock and biogenic reef	539.69	NA	3.15	NA	0.664	NA
Infralittoral sand	103.68	NA	0.03	NA	0.995	NA
Na	2161.23	NA	0.12	NA	0.983	NA
Offshore circalittoral mud	10081.28	NA	1.86	NA	0.764	NA
Offshore circalittoral sand	1908.02	NA	0.43	NA	0.939	NA
Upper or lower bathyal sediment	17304.68	NA	0.33	NA	0.914	NA

Interpretation of results

The assessments (assessment I and II section 2.4) clearly show a high fishing pressure in Southern Adriatic Sea. The GLMM tested confirm Depth as the main explained variable. Overall low median longevity characterizes the shallow waters of the area. Higher median longevity is observed over 500 m depth (Figure 1a). Relative Benthic State (RBS) based on PD model of the Southern Adriatic Sea (Figure 1c) is very consistent with SAR (Figure 1b).

Validity and limitations

The main limitation of the assessments presented mainly concerns the need of improvement in a unified grid resolution over all the Mediterranean Sea (AIS and or VMS). Also, the lack of an agreed and unified depletion value by gears with uncertainty, taking in account Mediterranean seabed sediment granulometry, as well as Mediterranean gears characteristics. Finally a longevity unified list of species for all the Mediterranean basin is needed. Finally, a unified sensitivity analysis protocol for detecting issues of model overfitting would improve the robustness of the assessment provided by WGFBIT in the future.

Format of the assessment

This seafloor assessment of WGFBIT for Southern Adriatic Sea it consists of this assessment text and a data product, consisting of a series of interactive maps and regional assessments and the AIS aggregated fishing data (Global Fishing Watch 2021). The seafloor assessment text should be read in conjunction with the maps and can also be informed by the regional assessments. Within the text, references to the interactive maps and regional assessments and their specific “sections” are made. The limitations and caveats described in the Southern Adriatic Sea should be considered before using the data products.

Sources and references

ICES. 2019. EU request to advise on a seafloor assessment process for physical loss (D6C1, D6C4) and physical disturbance (D6C2) on benthic habitats. In Report of the ICES Advisory Committee, 2019. ICES Advice 2019, sr.2019.25, https://doi.org/10.17895/ices.advice.5742.

3.1.3 Baltic Sea

Assessment summary

For the Baltic Sea, no further method development was needed to run the assessment, as this was already completed in the 2018 report (ICES, 2018) and also published in ICES advice answering the EU request on how management scenarios to reduce mobile bottom fishing disturbance on seafloor habitats affect fisheries landing and value (ICES, 2021). The model for the sensitivity layer (median longevity) includes the parameters salinity, depth and shear stress. An update to the MSFD broad habitat map (EUSeamap 2021) has recently become available, as well as recent data on the distribution of the fishing fleet. Below follows a brief summary of the output of the 2018 assessment, in accordance to the advice sheet draft outline. During the WGFBIT 2021 meeting, oxygen conditions in the Baltic Sea where was discussed, and it is recommended to map anoxic areas as a separate habitat and also consider severely hypoxic areas.

Assessment results

Status in year 2018 Baltic Sea.

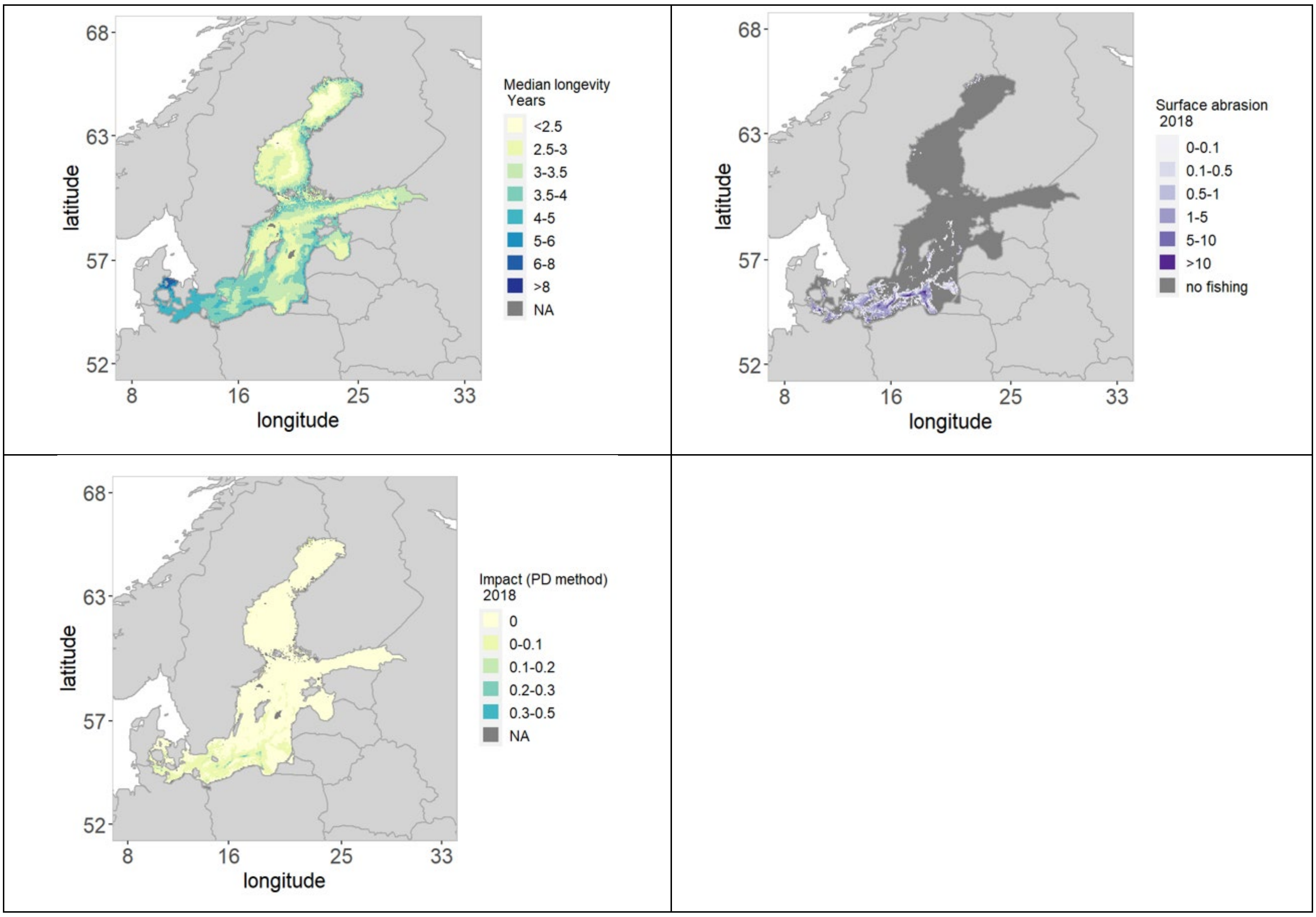


Figure 3. Baltic Sea maps of i) predicted median longevity (top left); ii) surface (0–2cm sediment depth) based on VMS and logbook data for all mobile bottom-contacting gears (top right); iii) relative benthic impact (bottom left)

Table 5. Assessment estimates per MSFD broad habitat type in the Baltic Sea in 2018. The columns show extent of the habitat, swept area, Average fishing intensity (I-1), Proportion of area in fished grid cells (I-2), Proportion of area fished per year (I-3) and indicating the concentration of the fishery the smallest proportion of area with the 90% of fishing effort (I-4)

MSFD broad habitat type	Extent of habitat (1000 km2)	Swept area 1000 km2	Average fishing intensity (I-1)	Prop. Of area in fished grid cells (I-2)	Prop. Of area fished per year (I-3)	Smallest prop. Of area with 90% of fish-ing effort (I-4)
Circalittoral mixed sediment	102.88	4.41	0.04	0.06	0.02	0.02
Circalittoral mud or Circalittoral sand	54.45	1.19	0.02	0.08	0.02	0.03
Offshore circalittoral mud or Offshore circalittoral sand	33.82	0.36	0.01	0.08	0.01	0.05
Circalittoral sand	32.63	12.69	0.39	0.33	0.16	0.06
Circalittoral mud	29.6	8.52	0.29	0.16	0.1	0.03
Infralittoral sand	26.35	8.89	0.34	0.33	0.16	0.06
Offshore circalittoral mud	21.77	15.79	0.73	0.42	0.24	0.12
Infralittoral mixed sediment	21.46	0.66	0.03	0.05	0.02	0.01
Offshore circalittoral mixed sediment	19.09	16.23	0.85	0.35	0.21	0.07
Circalittoral coarse sediment	12.23	0.35	0.03	0.07	0.02	0.02

Infralittoral coarse sediment	8.26	0.36	0.04	0.12	0.03	0.04
Circalittoral rock and biogenic reef	7.63	0.02	0	0.01	0	0
Infralittoral rock and biogenic reef	5.3	0.02	0	0.02	0	0.01
Infralittoral mud or Infralittoral sand	4.6	0.02	0	0.01	0	0.01
Infralittoral mud	3.06	0.15	0.05	0.08	0.03	0.02
Offshore circalittoral sand	2.73	4.09	1.5	0.6	0.41	0.15
Offshore circalittoral coarse sediment	0.73	0.01	0.01	0.1	0.01	0.03
Offshore circalittoral rock and biogenic reef	0.21	0	0	0	0	0
Unknown	0.14	0	0	0	0	NA

Time trends

Time trends (Figure 4) indicate that impact resulting from demersal trawling is on a low and relatively stable level. The proportion of the habitat with impact scores below 0.2 (which we use as an arbitrary threshold for a favourable state here) is also relatively stable.

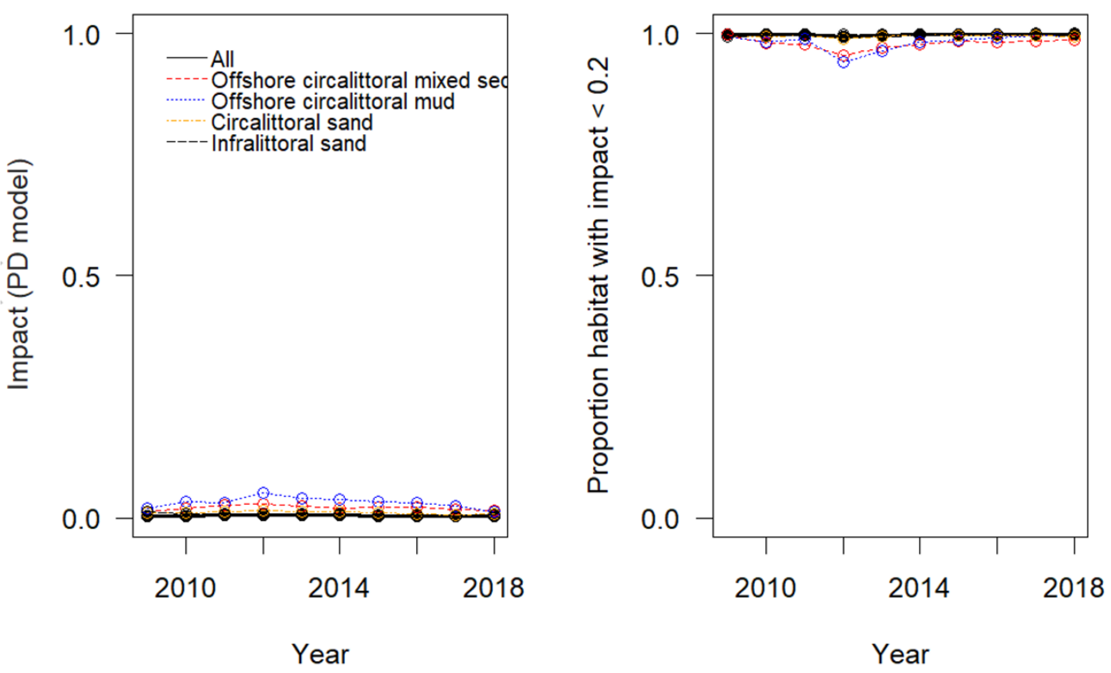


Figure 4. Time trends in impact (Left panel) and state above a hypothetical threshold value of 0.2 (Right panel) overall and in each of the 4 most dominant habitat types in the Baltic Sea ecosystem.

Interpretation of results

The method and associated code established and adopted by WGFBIT in 2018 has proven to be robust to updated input data.

The current abrasion map includes the effects of one main bottom fishing métier, which is otter trawl for demersal fish. Benthic longevity estimates for the Baltic Sea ecoregion were based on macrofauna data from Gogina *et al.* (2016). This dataset has information on macrofauna biomass for 2268 locations. Each location contains one or multiple sampling events, taken in different years or different periods in the year, that are aggregated to a 5 x 5 km cell. At all locations, benthic samples were collected with box-cores or grab-samplers.

Impact, as measured by the PD method, has been relatively stable and low in the Baltic Sea as a whole, and within the main habitat types present.

3.2 Regional assessment updates

3.2.1 Icelandic Waters

Progress towards an assessment in Icelandic Waters

Data sources

Samples in the Icelandic dataset were obtained during the Icelandic Autumn Groundfish Survey (AGS), which is conducted annually by the Marine and Freshwater Research Institute (MFRI). The otter trawl used for sampling is of the Granton type, with mesh size of 135 mm, 80mm and 40 mm on the front section, middle section and cod end respectively. Bentic invertebrates were obtained in 2016, 2017, 2018 and 2020 on board the RV Árni Friðriksson, on 427 sampling stations located on the continental slope. Benthic organisms were identified to the lowest possible taxonomic level, counted and weighted. Biomass estimates were standardized by the swept area of each trawl. A total of 654 taxa were identified. The study area was defined as all c-squares located at a distance of 250 km or less from a sampling location.

Estimation of longevity relationships

The longevity estimates for the Icelandic dataset were derived from the estimates obtained for the Norwegian Sea and Barents Sea, given the known similarities in the benthic fauna among these areas, and the sampling gears used to obtain the data for the assessments The estimates for the Norwegian Sea and Barents Sea included 546 taxa and were based on literature, existing longevity databases (Degen and Faulwetter 2019, the trait list from the BENTHIS project) and on expert judgment (ICES 2020). Because the samples from the Norwegian Sea and Barents seas were obtained with beam trawls and otter trawls, respectively, they tended to capture more long-lived species than other gears like grabs or box cores. Therefore, the longevity estimates were assigned to six classes: <2 years, 2–5 years, 5–10 years, 10–20 years, 20–50 years, and >50 years.

To assign longevities in the Icelandic dataset, taxa were first matched with the Norwegian dataset based on their Aphia ID number. A total of 185 taxa (28.3%), corresponding to 48.7% of the biomass were matched. Longevities for an additional 140 species in the Icelandic dataset (22.4%, 27.9% of the biomass) were estimated by averaging the longevities of the taxa of the same genus found in the Norwegian dataset. An additional 20 taxa (3.2%) were matched at the class, order and family. These represented a small proportion of the total biomass (< 0.98%). A total of 323 taxa in the Iceland dataset, representing 22.4% of the biomass, were not matched with the Norwegian dataset and were removed from this analysis. Some of these may be taxa from the hypebenthos, which were not removed from the Icelandic dataset.

As predictor variables we utilized bottom depth, derived from the General Bathymetric Chart of the Oceans (GEBCO), and bottom temperature derived from data from the NISE (Norwegian Iceland Seas Experiment) project. We also attempted to use broad-scale MSFD habitat as a predictor, but none of the models with this parameter achieved convergence. A total of six models were fitted using all c-squares in the study area. Because the Icelandic VMS data was not available at the time of the analysis, it was not possible to identify which c-squares had no or little fishing effort, nor it was possible to incorporate fishing effort as a predictive variable. Therefore, the results of this analysis should be considered preliminary. The resulting model fits are shown in the below table.

Table 6. Akaike Information Criterion values for the six longevity models tested in the Icelandic Seas area. The terms of the models included different combinations of longevity (ll), temperature (temp) and depth. The c-square was included in the model as a random term. Models 5 and 6 included an interaction term between longevity and the two environmental predictors. Model 5 had the lowest AIC value.

Model	Terms	AIC
1	ll + (1/ID)	26749.99
2	ll + temp + (1/ID)	26742.86
3	ll +'depth + (1/ID)	26749.15
4	ll +temp + depth + (1/ID)	26741.23
5	ll + temp*ll + depth + (1/ID)	26692.12
6	ll + temp + depth*ll + (1/ID)	26737.20

Model 5 was used to predict mean longevity as function of bottom temperature and depth. In the vast majority of c-squares (99%), the predicted median longitude ranged between 6.7 and 8 (Figure 5). This results seem to suggest that there is not a high degree of variability in seabed sensitivity to bottom trawling in the study area. Nevertheless, the study area is comprised of a mosaic of different habitats, including areas with Vulnerable Marine Ecosystems (VMEs), and the map of predicted mean longevity does not reflect this. This may be caused by a) the lack of vessel monitoring system data that did not allowed for the identification of c-squares impacted by fisheries, b) the potential presence of hyperbenthos in the trawl data, and c) the fact that the variables used do not capture the spatial variability in mean longevity. These issues will be addressed in the near future.

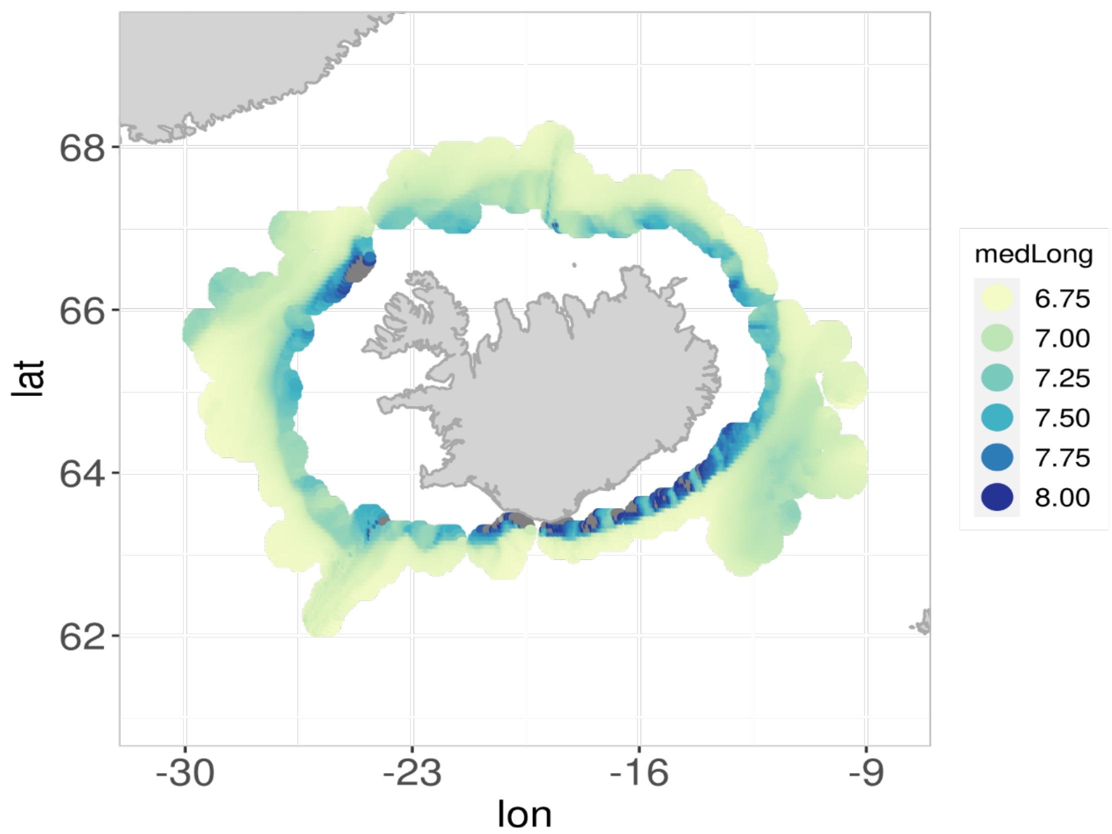


Figure 5. Predicted mean longevity on areas of the Icelandic Seas at a distance of 250 km or less from a sampling location.

3.2.2 Celtic Sea, Bay of Biscay, Iberian Coast

The FBIT workflow was adapted and applied to the western waters region (Celtic Seas, Bay of Biscay, Iberian Coast, Irish Sea). **The results presented are preliminary and should not be considered as a relevant assessment for the area under consideration**. Moreover, analyses were performed for a set of subareas consistent with the available biological datasets.

Fishing pressure layers were available for the whole area (step 1).

In order to harmonize the workflow, and especially concerning the formatting of the biological data, and the longevity traits base, we defined a specific workflow and wrote scripts for preprocessing the biological data, the longevity trait base and the environmental data. We also set up a certain number of standardized "tests" to evaluate the data used, in particular biological data. We will be able to propose a combined analysis of all or part of the data available on the "western waters" area in the near future.

For this interim report, the results are not presented globally for the "western waters" region but for 3 "sub-regions" (Iberian coast, Bay of Biscay and Celtic Sea, Irish Sea, Bristol Channel and Celtic Sea North).

3.2.2.1 Workflow

Environmental variables

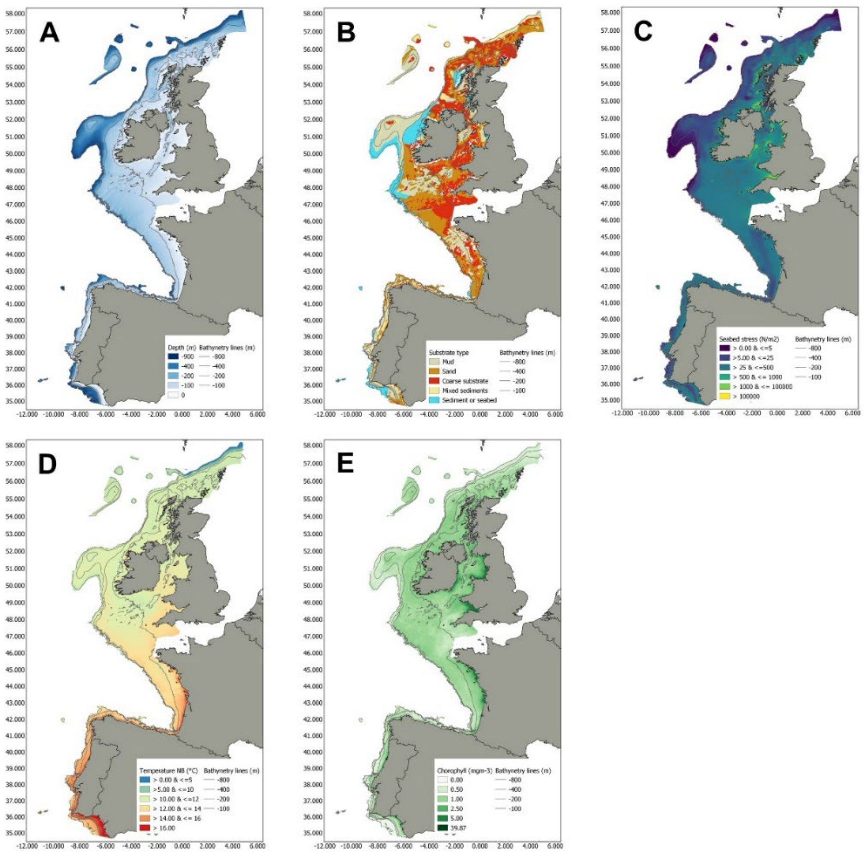


Figure 6. Environmental layers used in the FBIT workflow for the Celtic seas, Bay of Biscay, Iberian coast and Irish sea. A) Bathymetry (m) B) Substrate type C) Seabed stress D) Temperature near bottom (°C) E) Chorophyll (mg m^{-3})

Habitat information (step 2) was based on environmental layers from EMODnet and CMEMS. In total, a set of five environmental variables were generated, including depth, substrate type, seabed stress (the combination of these 3 layers provides the MSFD broad habitats), temperature near bottom (Clare *et al.*, 2020) and primary production (González-Irusta *et al.*, 2018). Although initially the work was focused only on Iberian waters, finally a unique set was generated for the whole Celtic seas, Bay of Biscay, Iberian coast, and Irish sea region (Figure 6).

Depth was downloaded from EMODNET bathymetry (https://www.emodnet-bathymetry.eu/) and resampled to a final resolution of 3 x 3 km using a bilinear interpolation. Substrate type was downloaded from EMODNET seabed habitats (https://emodnet.ec.europa.eu/en/seabed-habitats). The original layer was rasterized to the same final resolution than the depth layer (3 x 3 km) and simplified by merging the original categories into just 5 values; Mud (including fine mud, muddy sand, sandy mud and combinations of these categories), sand, coarse sand, mixed sediment and sediment (including "seabed" category). Rock and all the biogenic reefs were classified as NA values and therefore removed from the analysis since this type of substrate are not well sampled in most of the surveys used in this exercise. Seabed stress was also downloaded from EMODNET seabed habitats, using the different models available for the different areas included in this exercise. This layer is divided in two different datasets, including "kinetic energy at the seabed due to waves" and "kinetic energy at the seabed due to currents" which at the same time are available as different layers for different regions. In total, 6 different layers (3 from waves and 3 from currents) were downloaded covering the whole region, including from North to South; Celtic seas, Bay of Biscay and Iberian region. All the layers for each type of data (waves and currents) were resampled to the final resolution (3 x 3 km) using a bilinear interpolation and then merged (keeping in the overlapping areas the data from northern models) to obtain two final layers covering the whole region, one with kinetic energy at the seabed due to waves and other with the same type of information from currents. The temperature near bottom was downloaded from two different oceanographic models available in https://marine.copernicus.eu/. In the northern part of the study area, we used data from the model "Atlantic- European North West Shelf- Ocean Physics Reanalysis" whereas in the southern part (Iberian region) we used data from the model "Atlantic-Iberian Biscay Irish- Ocean Physics Analysis and Forecast". Both models were resampled to the final resolution using a bilinear interpolation and merged using the function merge from raster package (Hijmans, 2021), keeping data from the northern model in the overlapping areas. Finally, a layer with chlorophyll values (as a proxy to primary production) from satellite observations was extracted from https://marine.copernicus.eu/, specifically from the product: "North Atlantic Chlorophyll Concentration from Satellite observations (daily average) Reprocessed L4 (ESA-CCI)". The mean value for the months of April and May during the period 2016–2020 was computed and resampled to the final resolution using bilinear interpolation.

Longevity modelling

The work focused on the estimation of longevity curves from biological samples from marine surveys in the regions evaluated (step 3). Biological traits were based on the matrix of benthic taxa and longevity traits as constructed within various projects (e.g. BENTHIS) and expert groups. About 1500 taxa covered into the whole data matrix; the trait matrix was completed for some of these taxa using the median longevity values assigned to the same genus or families.

3.2.2.2 Iberian coast

As part of the application of the FBIT tool to Iberian waters, a set of environmental variables was generated, based on the environmental information used to generated MSFD broad habitats complemented with other environmental variables which can affect the mean longevity of benthic organisms

Biological data from the Spanish IBTS (ICES, 2017) were used to model the distribution of benthos longevity in Iberian waters. Two different surveys; DEMERSALES (northern coast of Spain) and ARSA (south-west coast of Spain) were used in the exercise. In both cases, all invertebrates cached during the scientific hauls are classified and weighted, providing biological samples with a good distribution across the studied area (Figure 7). The only exception was the coast of Portugal, which was not covered by the biological samples. Only valid hauls for the period 2013–2020 were retained and records with invalid information or no species name were removed. The species list was taken from Worms.org and catch numbers were standardized by the swept area. Swept area was calculated using the width of the sampling gear, ground speed and haul duration. Benthic taxa were restricted to Arthropoda, Mollusca, Echinodermata, Annelida, Cnidaria, Porifera, Platyhelminthes, Sipuncula, Priapulida, Nemertea, Acanthocephala. AphiaIDs were matched with the longevity traits database which resulted in a loss of ~10% of records without longevity estimates. Finally, the hauls were filtered by selecting only samples located in areas exposed to low values of fishing effort (SAR < 0.5). From the original 1571 hauls available, 296 hauls were located in areas with these levels of effort (Figure 8).

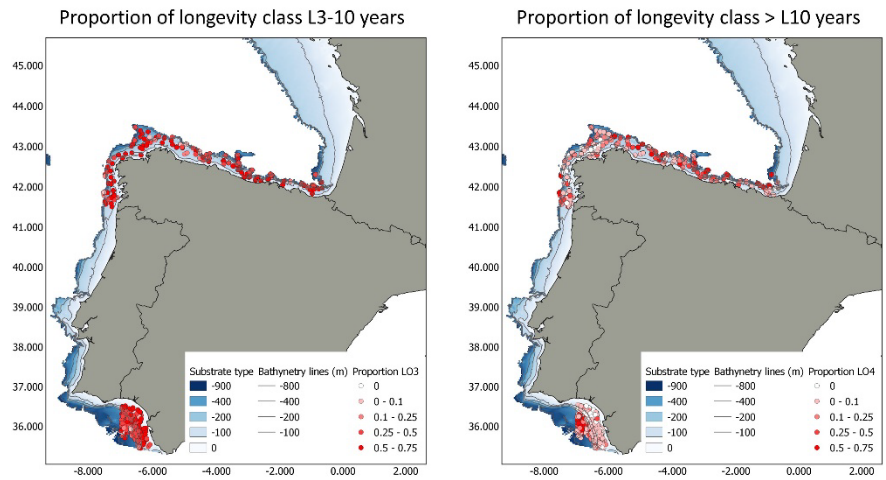


Figure 7. Proportion of longevity classes 3–10 years (left) and >10 years (right) in the benthic samples of the DEMERSALES (northern coast of Spain) and ARSA (south-west coast of Spain) surveys. The proportion of species with longevity lower than 3 years is not shown.

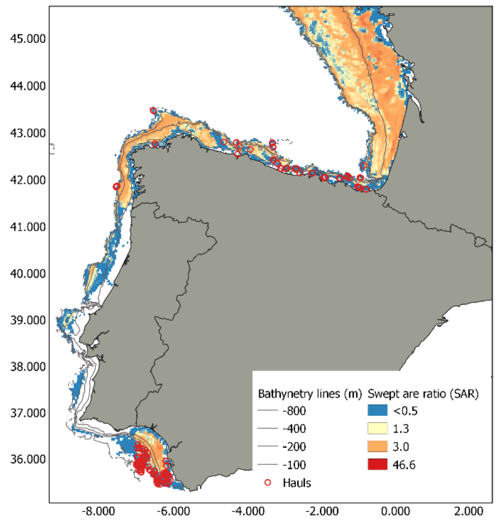


Figure 8. Distribution of fishing effort in the Iberian region and location of hauls carried out in areas with low levels of disturbance (SAR <0.5). * There was not data from Portugal fishing vessels which decreases artificially fishing effort distribution in some areas.

Fifteen linear mixed models with sampling station as random factor and the available explanatory drivers were tested. Their AIC scores were compared, resulting in one selected model, with depth and substrate as explanatory variables (Table 7). The preliminary modelled longevity distribution for the Iberian coast is presented (Figure 9), but caution is needed before interpreting this output as a final product, especially in Portugal waters were no biological data were available. The production of the longevity map is in fact the application of predictive habitats model techniques with the aim of generate a continuous longevity map and therefore the use of ICES standard to this purpose is highly advisable (ICES, 2021). The adaption of the tool to include non-linear responses in the models, the use of evaluation metrics to test its accuracy or a more homogeneous and standard way to select the explanatory variables across regions could help to increase the robustness of the approach in this first but crucial step. Furthermore, a better understanding of the impact of sampling gear (box corers Vs otter trawl) is needed before areas sampled differently can be evaluated under the same frame.

Table 7. Explanatory variables and AICs for the model runs. LL: log+1 of longevity category (1,3 or 10 years) Depth: bathymetry, Chl: mean annual Chlorophyll concentration, Temp: mean annual temperature, Energy: mean annual hydrodynamic energy, Substrate: sediment type

Model number	Model formula	AIC
13	LL + Depth + Subst + D	385.48
14	LL + Depth + D	386.13
7	LL + Depth + Chl + Subst + D	386.45
11	LL + Depth + Chl + D	386.53
10	LL + Depth + Temp + Subst + D	387.16
3	LL + Depth + Chl + Temp + Subst + D	387.2
8	LL + Depth + Chl + Temp + D	387.39
4	LL + Depth + Chl + Energy + Subst + D	388.44
5	LL + Depth + Temp + Energy + Subst + D	389.06
1	LL + Depth + Chl + Temp + Energy + Subst + D	389.18
2	LL + Depth + Chl + Temp + Energy + D	389.31
6	LL + Chl + Temp + Energy + Subst + D	398.77
9	LL + Chl + Temp + Subst + D	399.43
12	LL + Chl + Subst + D	416.28
15	LL + Subst + D	440.26

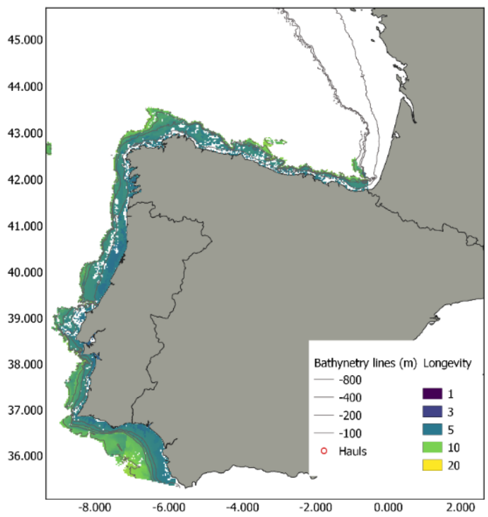


Figure 9. Preliminary results of median longevity distribution in years. It is important to highlight that the values in Portuguese waters were extrapolated using data from Spanish waters.

3.2.2.3 Bay of Biscay and Celtic Sea (ICES Divisions 8ab,7fghj)

The epifauna datasets used to model the longevity distribution are derived from bottom trawl catches made during the IBTS-Q4 EVHOE survey series (https://doi.org/10.18142/8). For the FBIT exercise, we used data from 2012 to 2016 and providing a total of 707 sampled stations (Figure 10). The longevity trait database includes 344 taxa covering close to 90% of the species richness (total of 390 taxa) and 85% or more of the total biomass of the megabenthic epifauna of the Bay of Biscay and Celtic Sea.

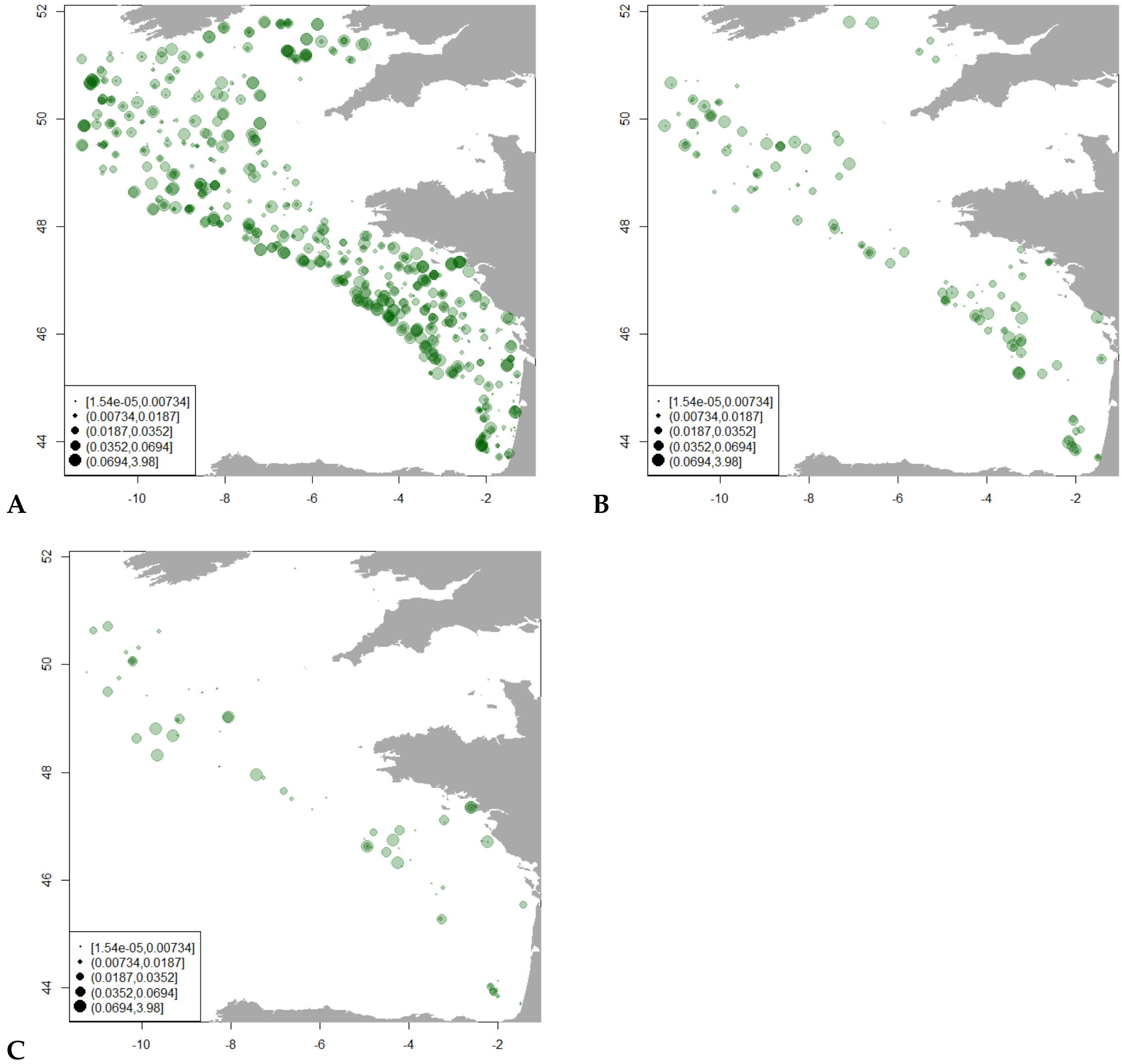


Figure 10. Trawling stations from EVHOE surveys (2012–2016) in the bay of Biscay and the Celtic sea, A. for the whole dataset (707 stations), and for a selection of stations with B. SAR threshold ≤ 1 year^{-1} (165 stations), and C. SAR threshold ≤ 0.5 year^{-1} (83 stations). The values (biomass in kg) indicated refer to the sum of the biomass of epibenthic fauna corresponding to longevity categories of 3–10 and >10 years.

The modelling of the longevity distribution was carried out on the basis of biological data filtered to retain only the stations with low fishing pressure. It is impossible for the analysed region to recover enough data corresponding to stations with zero trawling pressure. We therefore tested 2 filters for the selection of the SAR variable : ≤ 0.5 and ≤ 1 fishing SAR over a 1 year period (Figure 11). Even so, these filters lead to a very limited selection of data (only 165 stations retained with

SAR threshold ≤ 1 year^{-1}, Figure 11) and moreover a biased spatial distribution and benthic habitats coverage that raises questions about the validity of the baseline models of longevity distribution.

Available and utilized fishing pressure layers for this report were only the annual cumulated SAR for all the bottom trawling gears operating in the area of interest without any distinction between the different métiers or gears (Figure 11). To select the biological data corresponding to the minimum fishing pressure (minimum SAR), the cumulative SAR value of the year before sampling was assigned for each epifauna observation station. This choice should be reviewed in a future version in order to select a temporal aggregation that is more relevant to the impact on benthic mega-epifauna and to assess the sensitivity of the results to different temporal aggregations of fishing pressure.

The Glmm models of the distribution of longevity were carried out by testing all the selected combinations of environmental variables. The model selected is the one that has both the lowest AIC and respects the no «singularity» rule (Table 8).

For the final calculation of the relative benthic status (RBS), we used a median depletion parameter of 0.1 corresponding to the main fishing activity in the area. This part will have to be reviewed with fishing data by fishing gear.

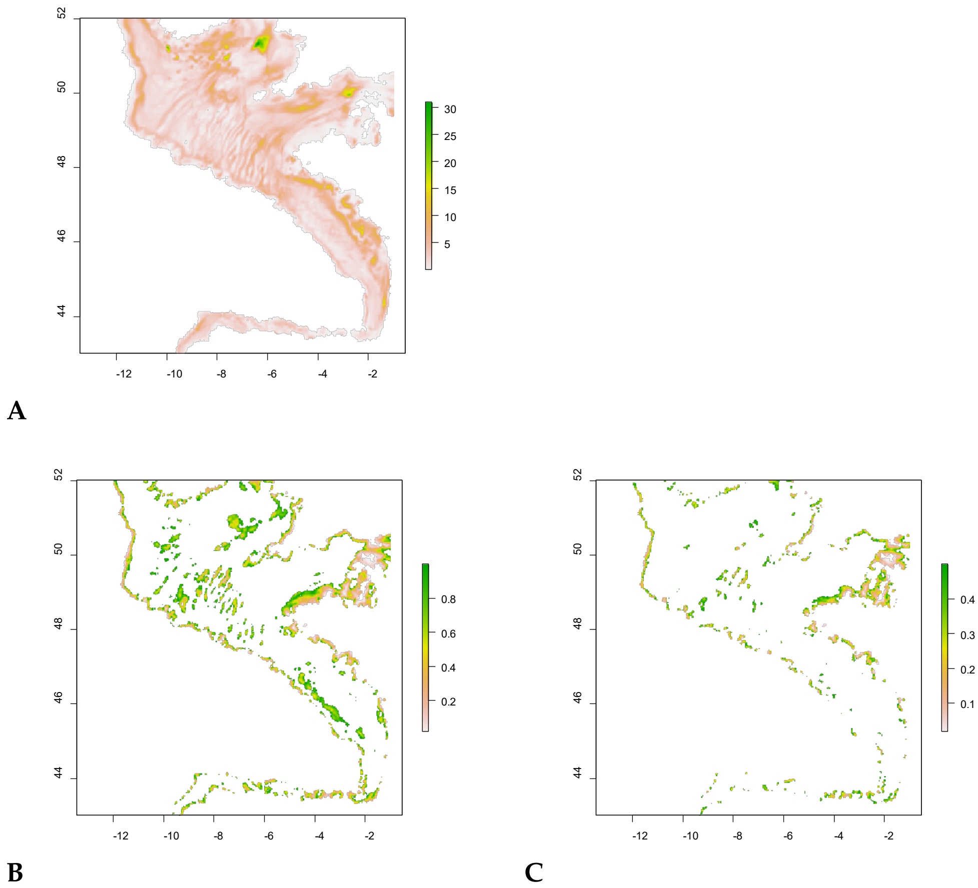


Figure 11. Mean fishing SAR (Surface Area Ratio in year^{-1}) for all trawling gears and the period 2012–2016, A) whole dataset, B) with SAR threshold ≤ 1 year^{-1} and C) with SAR threshold ≤ 0.5 year^{-1}

Longevity models have been computed with the cumulative epifauna biomass («Cumb») as a function of longevity category (« ll », log+1 of longevity 1, 3 or 10 years) and summed with selected environmental variables. It has been performed by testing all possible combination of environmental variables. The best retained model was the one meeting the criterion of no "singularity" (i.e. no variance of one or more linear combinations of effects equal or close to zero) and having the lowest AIC value (8 models out of a total of 31 possible, Table 8).

Table 8. Explanatory variables and AICs for the model runs and "adjustment" results with dataset filtering for fishing SAR threshold ≤ 1 y-1. Only models without "singular results" are displayed.

Model number	Explanatory variables	AICs
24	**Cumb ~ ll + Chl + Energy + Substrate + (1 ǀ Station)**	**35.719**
26	Cumb ~ ll + Depth + Chl + Temp + Energy + (1 ǀ Station)	39.182
9	Cumb ~ ll + Depth + Substrate + (1 ǀ Station)	39.439
31	Cumb ~ ll + Depth + Chl + Temp + Energy + Substrate + (1 ǀ Station)	39.444
21	Cumb ~ ll + Depth + Energy + Substrate + (1 ǀ Station)	41.438
8	Cumb ~ ll + Depth + ALLenergy + (1 ǀ Station)	42.521
29	Cumb ~ ll + Depth + Temp + Energy + Substrate + (1 ǀ Station)	42.617
14	Cumb ~ ll + Temp + Substrate + (1 ǀ Station)	50.044

*** Complete model formula : Cumb ~ ll + Raster_Depth + Raster_Chl + Raster_Temp + Raster_ALLenergy + Raster_Substrate + (1 ǀ Station) with Cumb: cumulative biomass, ll: log+1 of longevity category (1,3 or 10 years) Depth: bathymetry, Chl: mean annual Chlorophyll concentration, Temp: mean annual temperature, Energy: mean annual hydrodynamic energy, Substrate: sediment type, Station: sampling station.**

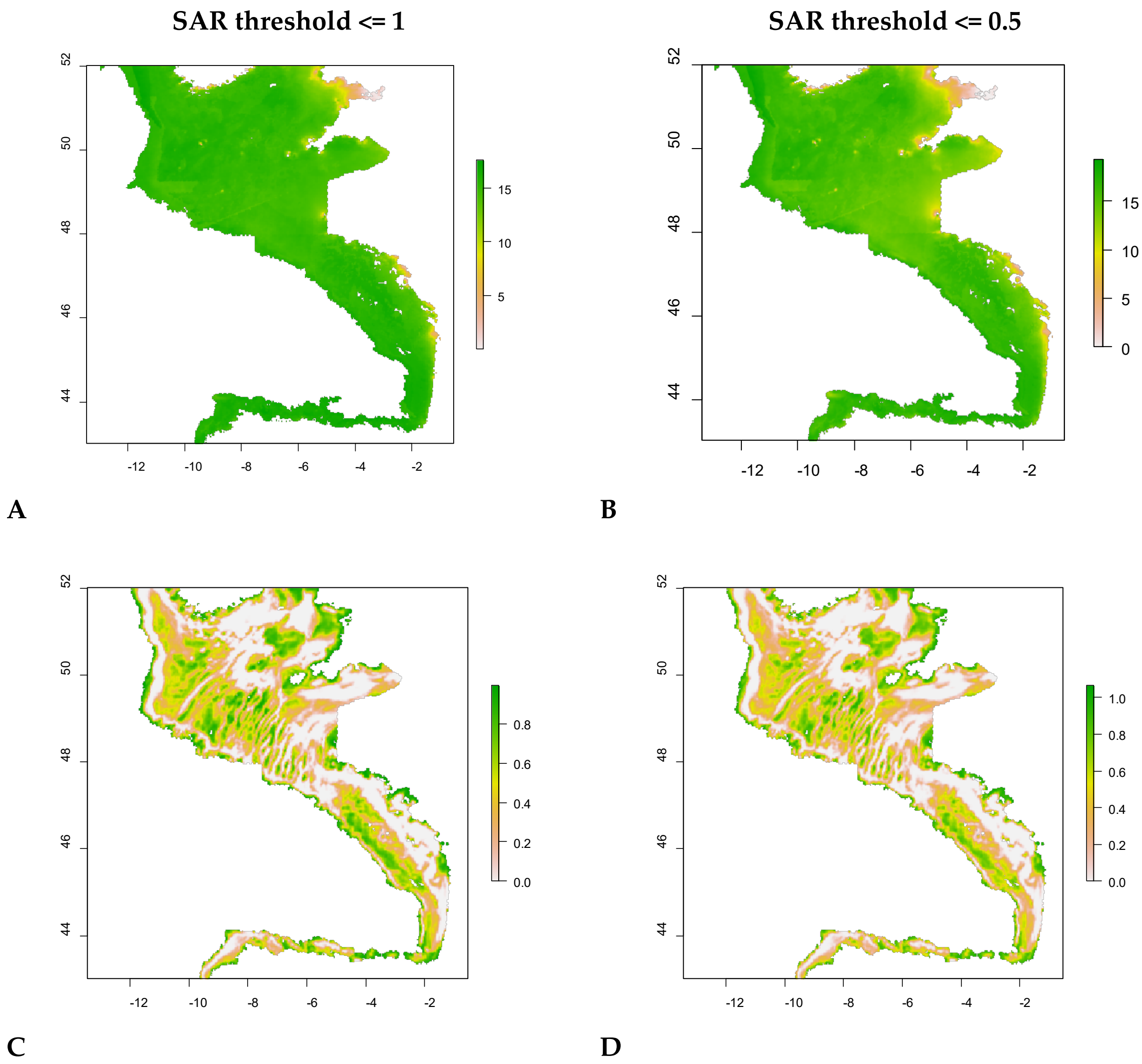


Figure 12. Preliminary results of A and B modelled median longevity distribution in years, C and D Relative Benthic Status (RBS) as computed for 1 y^{-1} et 0.5 y^{-1} SAR threshold. It is important to highlight that the outputs for the northern coast of Spain is an extrapolation based exclusively EVHOE data.

The results presented here (Figure 12) do not constitute a final and relevant assessment of the status of the benthic communities in the studied area. These results are preliminary and should only be understood as a demonstration of the applicability of the FBIT workflow to epifauna data for the Bay of Biscay/Celtic Sea area. Several steps of the workflow need to be amended (including the use of relevant data for each area, e.g. DEMERSALES data in the northern coast of Spain were at the moment the results are an extrapolation based on EVHOE data) and the data adjusted to ensure relevant and meaningful results.

3.2.2.4 Irish Sea, Bristol Channel and Celtic Sea North (ICES Divisions 7afg)

The benthic samples between 1993 and 2019 in the Irish Sea were extracted from the ICES DATRAS database (Figure 13). Only valid hauls during daylight were retained and records with invalid information or no species name were removed. The species list was taken from Worms and catch numbers were standardized by the swept area. Swept area was calculated using the width of the sampling gear, ground speed and haul duration. Benthic taxa were restricted to Arthropoda, Mollusca, Echinodermata, Annelida, Cnidaria, Porifera, Platyhelminthes, Sipuncula, Priapulida, Nemertea, Acanthocephala. AphiaIDs were matched with the longevity traits database which resulted in a loss of ~10% of records without longevity estimates.

Proportion of longevity class L3–10 years Proportion of longevity class > L10 years

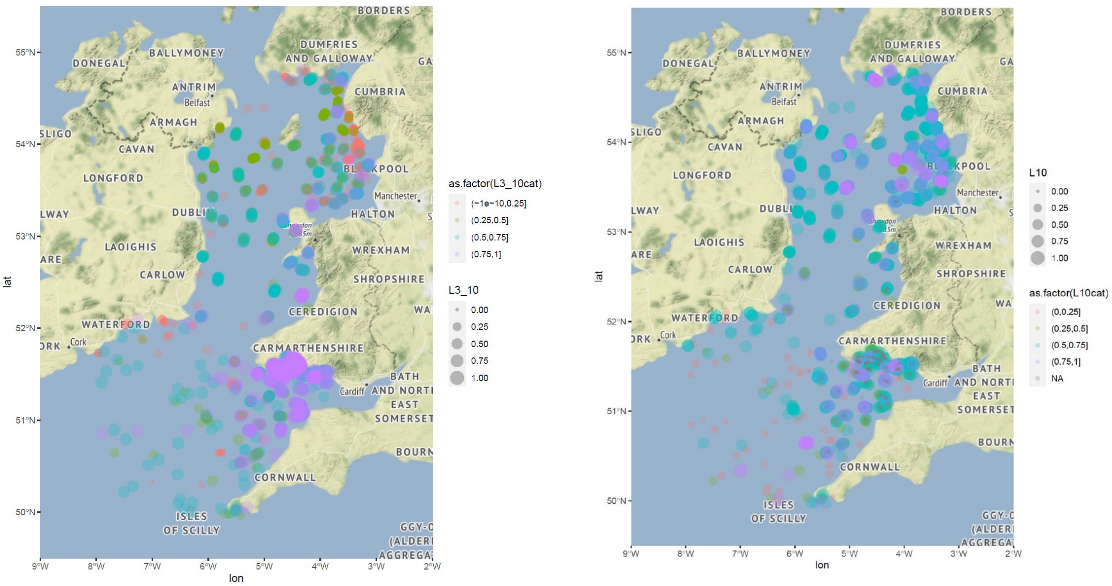


Figure 13. Proportion of longevity classes 3–10 years and >10 years in the benthic samples of the ICES divisions 7afg Longevity classes of L1 and L1–3 years are not shown. The highest proportion of long-lived species occurs in the Northeast of the Irish Sea. The higher proportion of taxa with longevity between 3 and 10 years occurs in the Bristol Channel.

The available explanatory layers to predict the longevity distribution in this region included five environmental variables (depth, Chlorophyll-a as measures of productivity, temperature, wave and current energy and substrate) and depletion (SAR*depletion rate) as measure for fishing intensity. Twelve linear mixed models with sampling station as random factor and the available explanatory drivers were tested. Their AIC scores were compared, resulting in two selected models, all having longevity, depth, temperature and energy as explanatory drivers (Table 9). Model 8 also included Chlorophyll-a while model 11 included SAR. The modelled longevity distribution for the Irish Sea (7a), the Bristol Channel (7f) and the Celtic Sea North (7g) are presented. The longevity distribution of the Bristol Channel and the Celtic Sea North overlap with other DATRAS surveys, such as EVHOE and the monk and megrim survey. Next steps include the assessment of the longevity distribution of the various surveys before moving into the next step.

Table 9. Explanatory variables and AICs for the model runs. LL: log+1 of longevity category (1,3 or 10 years) Depth: bathymetry, Chl: mean annual Chlorophyll concentration, Temp: mean annual temperature, Energy: mean annual hydrodynamic energy, Substrate: sediment type.

Model number	Explanatory variables	AICs
8	LL + Depth + Chl + Temp + Energy	2625.707
11	LL + Depth + Temp + Energy + D	2627.032
12	LL + Chl + Temp + Energy + D	2632.272
1	LL + Depth + Chl + Temp + Energy + Subst + D	2634.418
9	LL + Depth + Chl + Temp + D	2664.960
2	LL + Depth + Chl + Temp + Energy + Subst	2665.183
3	LL + Depth + Chl + Temp + Energy + D	2731.811
10	LL + Depth + Chl + Energy + D	2866.538
5	LL + Depth + Chl + Energy + Subst + D	2891.967
4	LL + Depth + Chl + Temp + Subst + D	2892.202
6	LL + Depth + Temp + Energy + Subst + D	2892.427
7	LL + Chl + Temp + Energy + Subst + D	2914.424

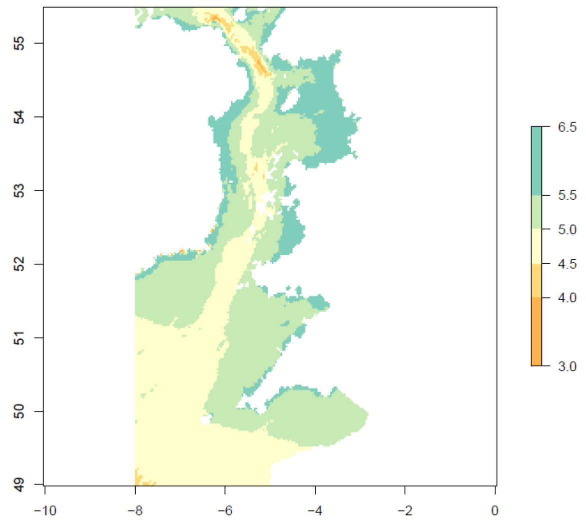


Figure 14. Modelled median longevity distribution in the Irish Sea, Celtic Sea North and the Bristol Channel. Note that the median longevity largely falls with the same range (4.5 to 6 years).

3.2.2.5 Celtic Sea (Irish area); (ICES Divisions 6a, 7, 7b, g,& j)

Sampling data from the Irish Groundfish Survey (IGFS), and Irish Anglerfish and Megrim Survey (IAMS) from 2003–2020 and 2016–2020 respectively, was incorporated into the WGFBIT methodology (Figure 15). The surveys operate under agreed protocols; IGFS operates in daylight hours with 30min hauls, whereas IAMS operates on a 24hr rotation with 60min haul durations. Records with invalid or missing species identification were removed, swept area calculations were completed as in section 3.2.2.4 above. Benthic taxa were extracted and matched to longevity trait data developed at WGFBIT working group meeting held in Palermo Sicily in November 2021.

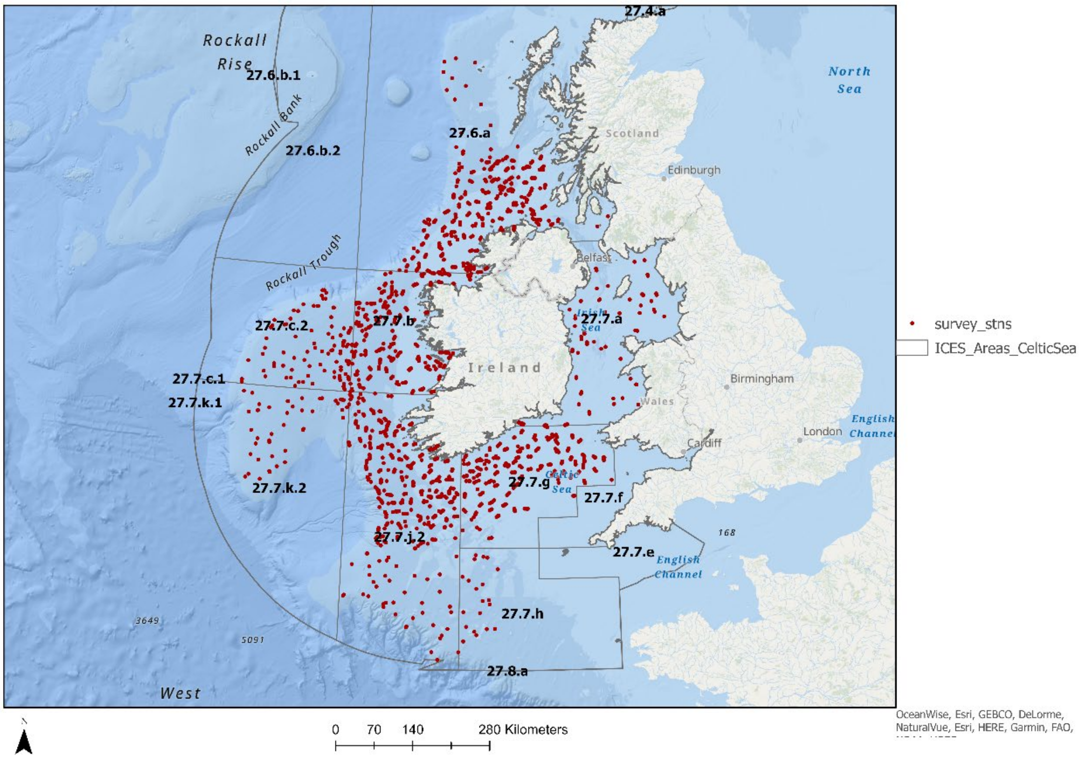


Figure 15. Coverage of the IGFS and IAMS surveys present in ICES divisions 6a, 7, 7b,g&j.

A total of 61 402 benthic observations were extracted from survey data; however, a loss of approximately 70% was observed when merged with longevity trait data. Due to varying time and resource constraints; further analysis into this anomaly could not be conducted in time to be reported in 2021.

Further analysis and modelling of the data based on the environment variables (step 3 WGFBIT workflow) outlined in section 3.2.2.1 would not be appropriate at present. Further investigative analysis of the benthic and longevity trait data will be conducted in the coming year in order to progress the Irish survey data through the WGFBIT workflow steps.

3.2.3 Mediterranean Sea

3.2.3.1 Introduction

For the Mediterranean Sea, the WG has considered a range of case studies (CSs) related to different sub-regions; the applications were based on different data-sets.

In particular, the outcomes of three case studies were presented on: southern Adriatic Sea (GSA 18); Sicilian Continental shelf (GSA 10, 16, 19) and Greek waters (GSA 20, 22 and 23), while the main elements of current pilot implementation for Northern Central Adriatic Sea (GSA 17) were also shared. Case studies' features, details and outcomes are presented in the next paragraph, followed by a comparison of the approaches adopted by different researchers or research groups (Table 19). During the meeting, the main elements that need a common/consistent approach to enhance comparability of the assessment were discussed, identifying a range of elements that will need further consideration in a future application. The focus of the discussion related to spatial resolution of the elaborations, the selection of longevity data and modelling approach with the main emerging issues reported one after another.

The discussion aims to provide a preliminary assessment to test to what extent the WGFBIT framework can be currently applied in the Mediterranean Sea and assess future prospects and needs for achieving a consistent implementation of assessment of trawling impact on benthic habitats.

3.2.3.2 Portfolio of case studies including further elaborations

3.2.3.2.1 Central Mediterranean - Sicily (GSA10, GSA16, GSA19)

Study area: a wide area around Sicily was selected geographically to fully include the continental shelf (up to 200m depth) and its main habitats (Figure 16). This sub-region (xmin= 11.6, ymin=36.4, xmax= 15.6, ymax= 38.4; SR= WGS84) falls within three GFCM Geographical Subareas (GSAs): GSA10 in the northern part, GSA16 in the southern one and GSA19 in the eastern one. The area inside GSA15 was excluded as no VMS fishing data were available.

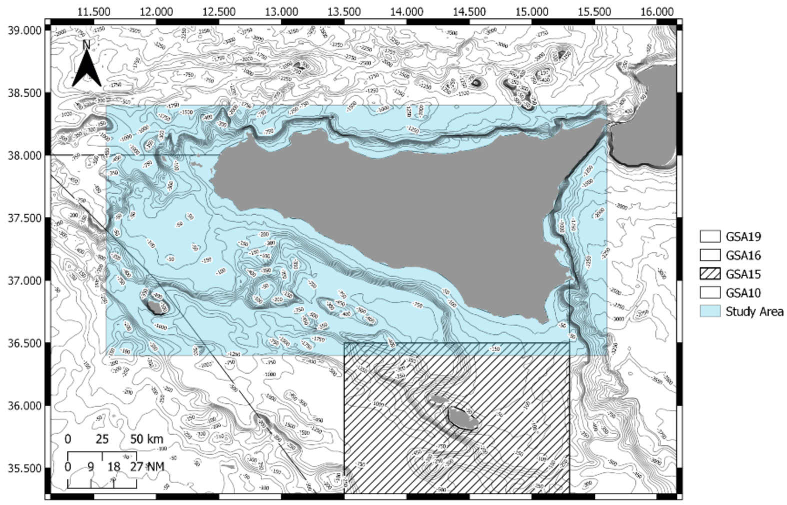


Figure 16. Study area, Sicily island (Southern Italy).

The available data for the area were:

- Otter trawl bottom (OTB) VMS data year 2007–2019 for the study area selected.
- MSFD habitat classification derived from EMODnet EUSeaMap 2019
- Benthic abundance (number of individuals) data derived from the three datasets:
- Fishing trawl surveys from Interreg HARMONY Project year 2019 and 2020, (11 hauls).
- Fishing trawl survey from ISPRA campaign year from 2016 to 2020 derived from Italian National Monitoring Programme (57 hauls).
- Fishing trawl survey from PhD M.C. Mangano (MEDITS protocol) campaign from 2010 to 2013 (85 hauls)

The results presented here have to be considered as a preliminary assessment using the scripts proposed by Van Denderen (https://github.com/ices-eg/FBIT) for running the Population Dynamic (PD) model approach for the Sicilian waters.

Followed steps

Step 1 Assign region of interest

The study area was converted into c-square polygons and for each cell an MSFD habitat was assigned by overlapping with EMODnet EUSeaMap 2019. This process allowed the estimation of the surface occupied by each habitat inside the sub-region (Table 10 – Figure 17).

Table 10. Spatial coverage (km2) and relative proportion of the different MSFD habitat across the study area selected.

Habitat (MSFD classification)	Surface (km^2)	Relative surface
Upper bathyal sediment or Lower bathyal sediment	34756.71133	0.657514604
Circalittoral sand	9513.572716	0.179974248
Offshore circalittoral mud	2564.968828	0.048523131
Offshore circalittoral sand	2322.378959	0.043933906
Infralittoral sand	1382.299902	0.026149838
Infralittoral rock and biogenic reef	824.6591032	0.015600596
Circalittoral mud	778.3085219	0.014723753
Circalittoral mud or Offshore circalittoral mud	446.7133474	0.008450758
Circalittoral coarse sediment	105.9338964	0.002004018
Circalittoral rock and biogenic reef	102.8209292	0.001945128
Infralittoral mud	20.42360728	0.000386366
Infralittoral coarse sediment	20.41128019	0.000386133
Upper bathyal rock and biogenic reef or Lower bathyal rock and biogenic reef	8.856272457	0.00016754
Na	8.808804337	0.000166642
Circalittoral mixed sediment	0.970145078	1.83528E-05
Offshore circalittoral coarse sediment	0.969219523	1.83353E-05
Infralittoral mixed sediment	0.968954811	1.83303E-05
Offshore circalittoral rock and biogenic reef	0.968425034	1.83203E-05

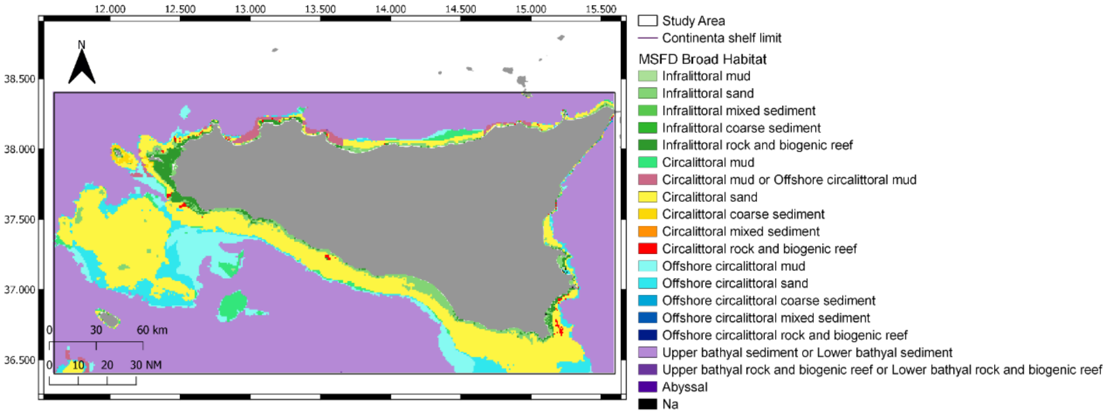


Figure 17. EMODnet Seabed Habitat 2019 Broad Habitat Map for the Sicilian sea study area.

Benthic longevity distribution estimation

All benthic abundance data derived from surveys data set were first standardised by surface swept of each haul (in km2) and represented as n.individuals/km2. For each species a fuzzy coding longevity classification was assigned to the lowest taxonomic level possible, using epifaunal longevity trait data matrix created by Stefan Bolam integrated to the Italian National monitoring programme-MEDITS longevity data list.

After having multiplied abundance with fuzzy coded trait data and summarized it per sample ID to calculate the fraction of longevity classes, the most represented habitat between samples were selected, respectively: Circalittoral mud (8 samples), Circalittoral Mud or Offshore circalittoral mud (33 samples), Circalittoral sand (72 samples), Upper bathyal sediment or Lower bathyal sediment (34 samples).

These data were used to fit a generalised linear mixed model (GLMM) with sampling station as random factor and MSFD habitat and Depth (categorical variable: 0–100m, 100–200m, >200m) as exploratory variable to predict the cumulative abundance-longevity distribution. Due to insufficient number of representative unfished samples, it was preferred also to insert in the model the Swept Area Ratio (SAR) instead of using it as an exclusion criterion on sample selection. Alternative model versions during the stepwise approach were compared using Akaike Information Criteria (AIC); (Table 11). In the end, even if model 5 was considered as the best fitting model, for habitat impact assessment model 1 was used.

Table 11. Sicilian results from fitting linear mixed model to cumulative abundance proportion setting samples as random effect and different fixed effects combination. LL: longevity; MSFD = MSFD broad habitats; SAR: fishery intensity.

Model	Relation	df	AIC
1	Cumb ~ ll + MSFD + SAR + (1 ǀ ID),	7	93.69828
2	Cumb ~ ll + MSFD*ll + SAR +(1 ǀ ID),	10	97.64647
3	Cumb ~ ll + MSFD*ll + Depth + SAR + (1 ǀ ID),	12	96.86973
4	Cumb ~ ll + MSFD + SAR + MSFD:ll + MSFD:SAR + (1 ǀ ID)	13	99.93914
5	Cumb ~ ll + Depth + SAR + (1 ǀ ID)	6	90.58307
6	Cumb ~ ll + Depth*ll + SAR + (1 ǀ ID),	8	93.54480

Sensitivity estimation

The outputs (intercept and coefficients) obtained from the GLMM were used to predict median longevity inside the study area (Figure 18), to exclude the influence of trawling intensity it was set as 0 during longevity prediction. As can be seen, median longevity differs mainly between areas that fall inside or outside continental shelf.

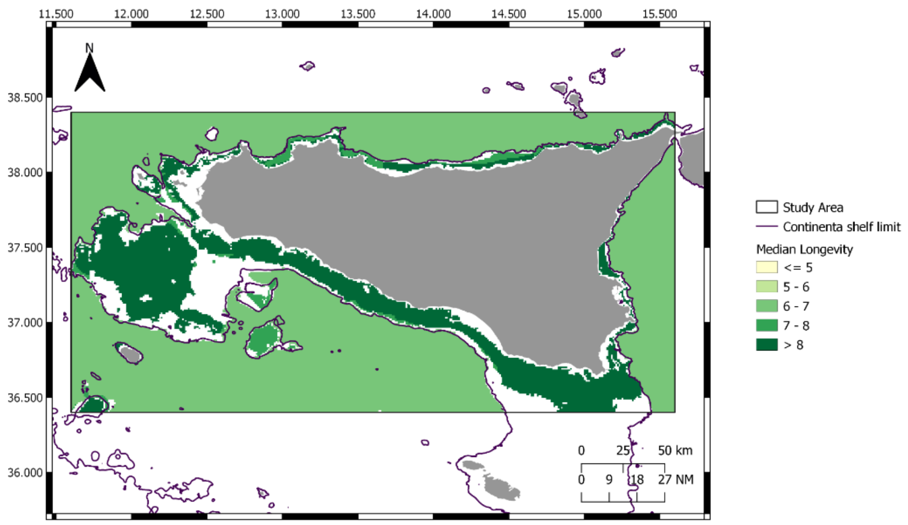


Figure 18. Median longevity estimates obtained from GLMM applied to each selected habitat. The bold black line underlines the limit of the continental shelf.

Impact calculation

Available VMS otter trawl SAR for the five-year period 2015–2019 were used for the impact estimate (Figure 19).

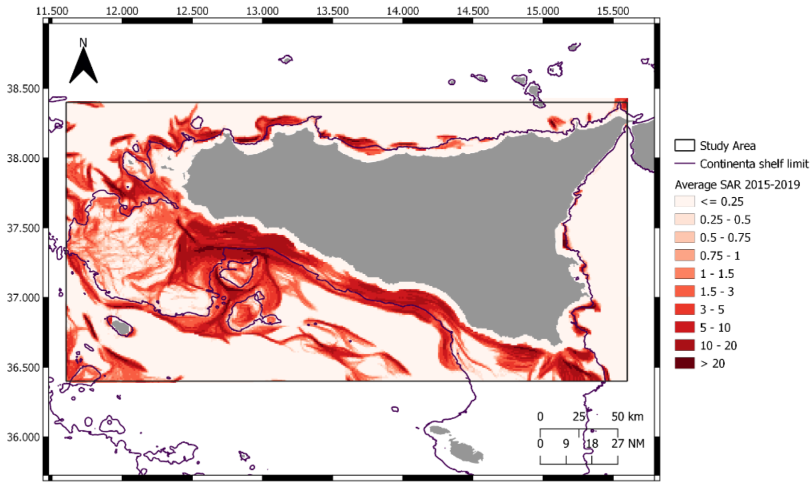


Figure 19. Average otter trawl Swept Area Ratio calculated from VMS data of period 2015–2019 (cell size = 1x1km). Higher values can be identified near Adventure Bank, on the continental slope of the southern part of the GSA19 and in close proximity to main Sicilian ports.

These data, assigned to each cell, were multiplied by OTB depletion rates extracted from the literature (Hiddink *et al.*, 2017) to calculate the depletion caused by this type of fishing gear (d= 0.06). Then the slope and intercept of the binomial model for longevity distribution were used to compute K. Consequently, all the outputs were used to calculate the RBS index. Estimates of the relative benthic status were reported to the full study area (Figure 20) and for each habitat (Table 12), accounting also the area within the continental shelf. The results suggest an overall good status of the benthic community, with values higher outside the continental shelf (it is also true that probably the uncertainty of model outputs increases over 200m of depth due to low representativity of the samples). Hotspots of values near 0 (high impact) are found in areas corresponding to higher values of SAR, especially near the ports of Mazara del Vallo and Portopalo di Capo Passero.

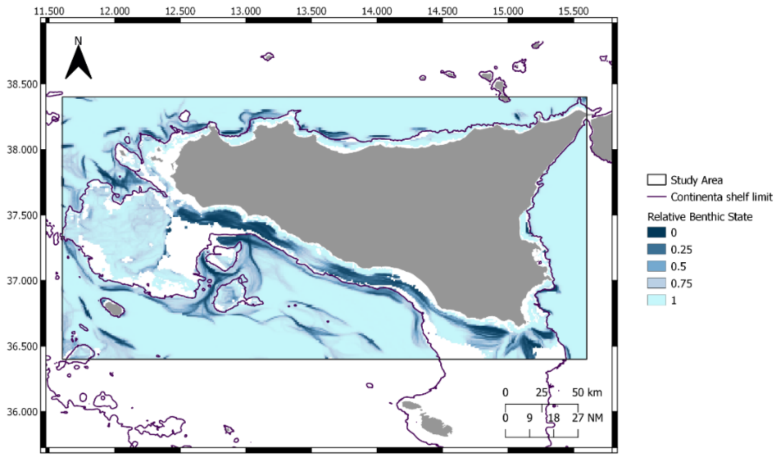


Figure 20. Map of the RBS index calculated for the region of interest. Black bold lines underline the limit of continental shelf.

Table 12. Mean impact (1-RBS) and standard deviation reported for each selected habitat for the whole sub-region and within continental shelf.

Habitat Type (MSFD classification)	Area km² (% of total)	Mean Impact (± St.D)	Mean Impact (± St.D) continental shelf
Circolittoral mud	778.308 (1.47%)	0.231 ±0.235	0.202 ±0.213
Circalittoral mud or Offshore circalittoral mud	446.713 (0.84%)	0.107 ±0.162	0.066 ±0.148
Circalittoral sand	9513.573 (18.00%)	0.241 ±0.299	0.267 ±0.320
Upper bathyal sediment or Lower bathyal sediment	34756.711 (65.75%)	0.108 ±0.213	0.208 ±0.243

Future work

Considering the study as a preliminary approach no uncertainty map could be produced. A following aim is certainly to obtain more data of fishing pressure and benthic data therefore new AIS and VMS data will be requested, as well as MEDITS data, especially for the southern part of Sicily (GSA16 and GSA15). An effort will be made to estimate biomass from number data using hauls with both abundance/biomass measurements as a reference.

3.2.3.2.2 Southern Adriatic Sea (GSA 18)

Two assessments were carried out considering SAR data referred to two periods, 2017–2019 and 2015–2021. Both assessments are presented below.

Assessment 1 (average SAR 2017–2019)

Step 1: Assign region of interest

For the Southern Adriatic Sea case study both the western and eastern parts of the GSA 18 were considered. A reference grid of 0.1° x 0.1° c-squares was used, covering the area in the 15.65°E – 20.02° E range of longitude and in the 39.77° N – 42.47° N range of latitude. MSFD habitat information were derived from the latest version (2021) of the EMODnet EUSeaMap habitat layer (Figure 21). The grid covered the bathymetrical depth range of 0–800m. Depth data were taken from EMODnet DTM (2021).

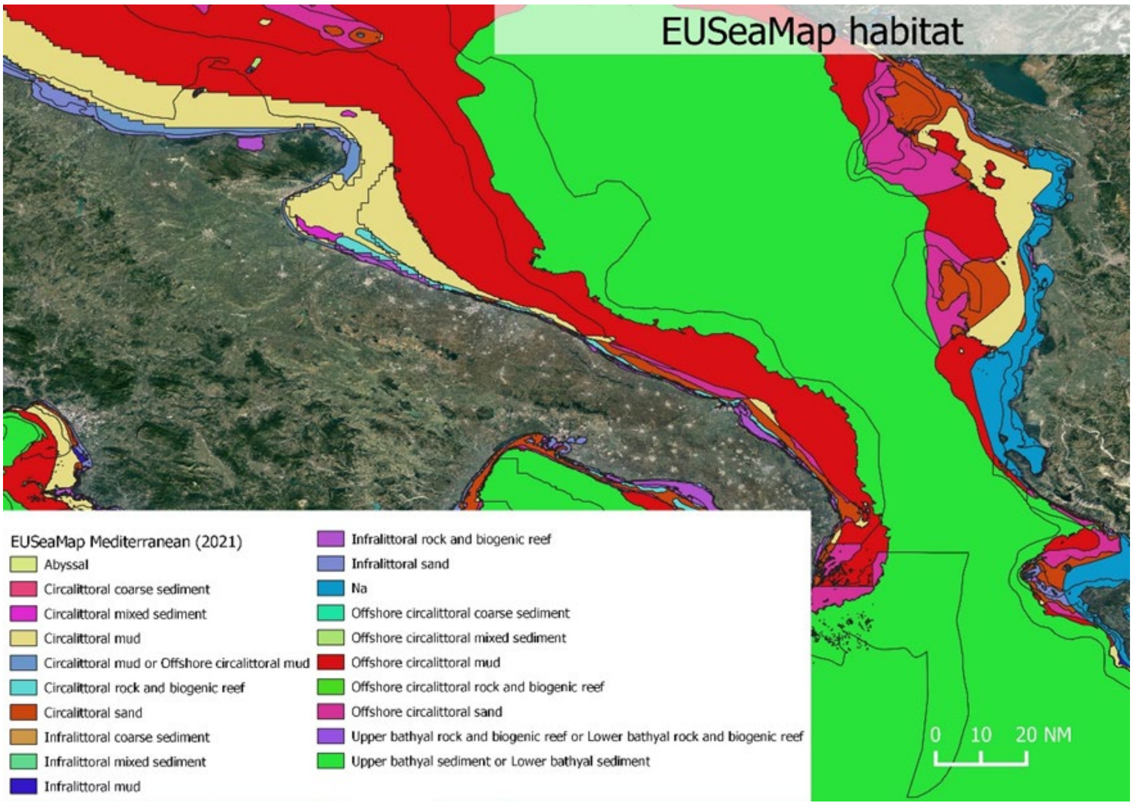


Figure 21. EMODnet EUSeaMap habitats in GSA 18.

Table 13. Spatial coverage (km2), proportion of total seabed area (%) of individual MSFD Broad Scale Habitats in the South Adriatic Sea (GSA 18), delineated from the EUSeaMAP 2021 (version September 2021). Swept area ratio (SAR) represents the distribution of trawling effort (OTB) over each of the habitats. Habitats (*) have been removed from the longevity modelling being not overlapped to the survey selected hauls (green dots in Figure 22).

MSFD habitat	Area (km^2)	Area %	SAR
Circalittoral mixed sediment*	90.326	0.23%	0.094
Circalittoral mud	4496.475	11.35%	4.713
Circalittoral mud or Offshore circalittoral mud*	227.643	0.57%	3.416
Circalittoral rock and biogenic reef	486.541	1.23%	5.734
Circalittoral sand	2139.217	5.40%	0.821
Infralittoral mud*	66.121	0.17%	0.065
Infralittoral rock and biogenic reef*	539.693	1.36%	3.151
Infralittoral sand	103.679	0.26%	0.026
Na	2161.234	5.46%	0.117
Offshore circalittoral mud	10081.281	25.45%	1.855
Offshore circalittoral sand	1908.016	4.82%	0.428
Upper or lower bathyal sediment	17304.679	43.69%	0.327

Step 2: Pressure layer information

Fishing intensity was estimated using the swept area ratio (SAR). The swept area is the cumulative area contacted by a fishing gear within a grid cell over one year. The source of pressure data for GSA 18 is AIS data from Global Fishing Watch. Vessels' fishing activity, reported as fishing hours, were analyzed in a predefined grid (e.g. 0.1° × 0.1°). For the estimation of the SAR the total gear width (door spread) was derived using Eigaard *et al.* (2016) equations. Estimates on total SAR within each grid cell were calculated for demersal otter trawls. In Figure 22, an average of the SAR for the years 2017–2019 is presented and it is related to the trawling frequency of demersal otter trawls.

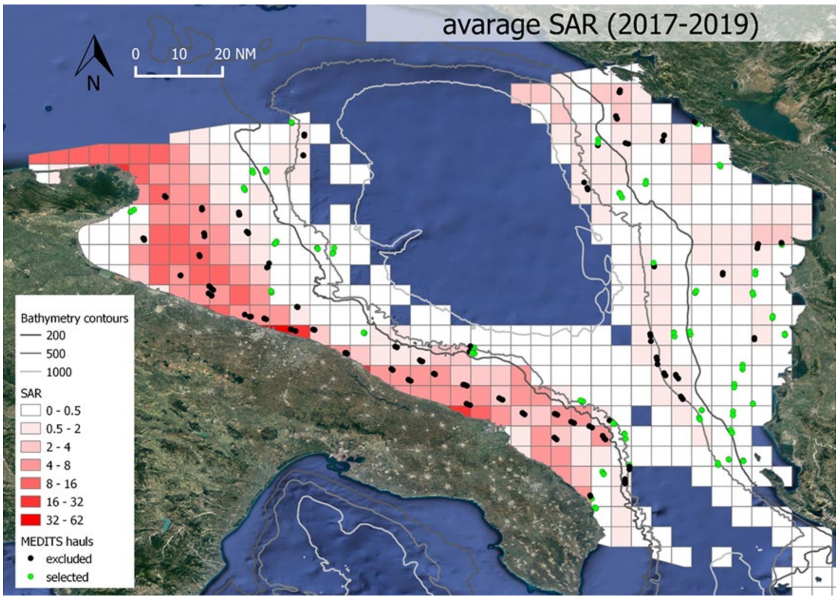


Figure 22. Extent of the average swept area ratio (SAR) in the South Adriatic Sea from 2017–2019 plotted on a 0.1° x 0.1° grid. Green dots represent MEDITS survey selected hauls with SAR < 0.5; black dots show MEDITS survey removed hauls with SAR >= 0.5.

Step 3: Estimate of the longevity relationship

Benthic longevity estimates for the South Adriatic Sea (GSA 18) were based on epifauna data from MEDITS scientific survey (Figure 22). The hauls were carried out in the 10–800m depth range using the standard MEDITS trawl net GOC73 (AAVV, 2017; Spedicato *et al.* 2019). A total of 264 hauls were surveyed from 2017 to 2019. For each location, species were linked to a species-by-trait matrix of longevity based on the information derived by two different trait databases. The first was made by expert judgment of the Italian Society of Marine Biology (SIBM) working group, after improved by COISPA ageing expert team. The second was made by ICES experts. The final database was made of 323 longevity data at the species level.

Sampling locations probably undisturbed by fishing activities (in accordance with actual available AIS data) were selected using SAR < 0.5 in years 2017–2019 in order to estimate benthic longevity. After the removal of the likely disturbed locations, 111 samples were retained.

The cumulative biomass-longevity relationship was estimated based on Generalized Linear Mixed Models (GLMMs) using a stepwise forward selection approach and including MSFD habitat type and Depth as fixed effects and assuming stations as a random effect. Total biomass by longevity class and by station is reported in Figure 23. Alternative model versions were compared using the Akaike Information Criterion (AIC); (Table 14).

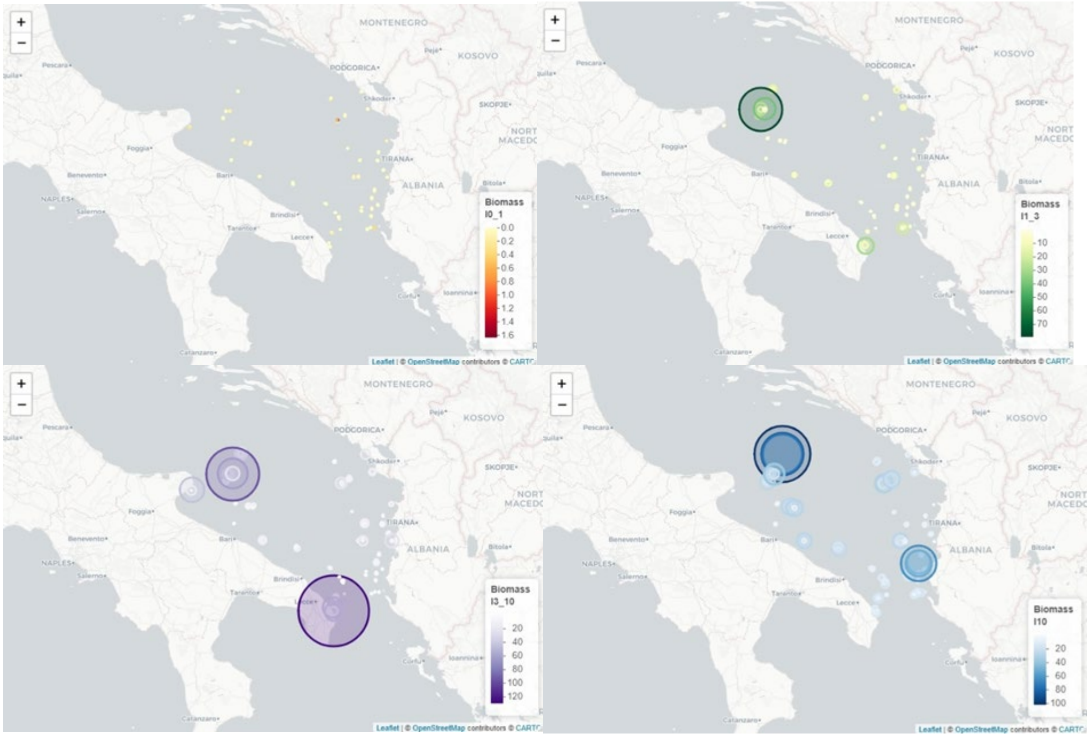


Figure 23. Overview of the biomass for the different longevity classes in the Southern Adriatic Sea.

Table 14. Southern Adriatic Sea results from fitting linear mixed models with the station as random effects variable and MSFD and depth as fixed independent variable to the longevity response variable. The best model selected is highlighted in grey. Cumb: cumulative biomass, ll: log+1 of longevity category (1,3 or 10 years) Depth: bathymetry, MSFD: MSFD broad habitat types.

mod1 <- glmer(Cumb ~ ll + MSFD*ll + Depth + (1 | station), data=fulldat, family=binomial)
mod2 <- glmer(Cumb ~ ll + MSFD + Depth + (1 | station), data=fulldat, family=binomial)
mod3 <- glmer(Cumb ~ ll + (1 | station), data=fulldat, family=binomial)
mod4 <- glmer(Cumb ~ ll + Depth + (1 | station), data=fulldat, family=binomial)
mod5 <- glmer(Cumb ~ ll + Depth*ll + (1 | station), data=fulldat, family=binomial)
mod6 <- glmer(Cumb ~ ll + MSFD + (1 | station), data=fulldat, family=binomial)
mod7 <- glmer(Cumb ~ ll + MSFD*Depth + (1 | station), data=fulldat, family=binomial)

Three different scenarios were tested providing a progressive reduction of low representative habitats (Table 15). Model 4 is the most robust over all the three scenarios tested, in accordance to the AIC values. Scenario C was preferred do to the fact that the habitats with few hauls are not representative.

Table 15. A, B and C represent the three different scenarios tested with a progressive reduction of low representative habitats. AIC and degree of freedom (df) are reported in the tables below.

A

Habitat	Hauls N
Circalittoral mud	14
Circalittoral rock and biogenic reef	1
Circalittoral sand	4
Infralittoral sand	1
Na	11
Offshore circalittoral mud	26
Offshore circalittoral sand	9
Upper or Lower bathyal sediment	45

	df	AIC
mod1	18	203.8
mod2	11	194.9
mod3	3	200.9
mod4	4	189.0
mod5	5	189.9
mod6	10	196.0
mod7	16	198.4

B

Habitat	Hauls N
Circalittoral mud	14
Circalittoral rock and biogenic reef	1
Circalittoral sand	4
Infralittoral sand	1
~~Na~~	~~11~~
Offshore circalittoral mud	26
Offshore circalittoral sand	9
Upper or Lower bathyal sediment	45

	df	AIC
mod1	-	not converged
mod2	9	176.5
mod3	3	183.5
mod4	4	171.3
mod5	5	172.5
mod6	8	176.4
mod7	13	184.0

C

Habitat	Hauls N
Circalittoral mud	14
~~Circalittoral rock and biogenic reef~~	~~1~~
~~Circalittoral sand~~	~~4~~
~~Infralittoral sand~~	~~1~~
~~Na~~	~~11~~
Offshore circalittoral mud	26
Offshore circalittoral sand	9
Upper or Lower bathyal sediment	45

	df	AIC
mod1	10	166.3
mod2	7	163.6
mod3	3	168.8
mod4	4	159.4
mod5	5	160.1
mod6	6	163.6
mod7	10	167.7

The selected model was used to predict the mean longevity as a function of habitat type (Figure 24). The mean longevity is considered a measurement of the seabed sensitivity to bottom trawling.

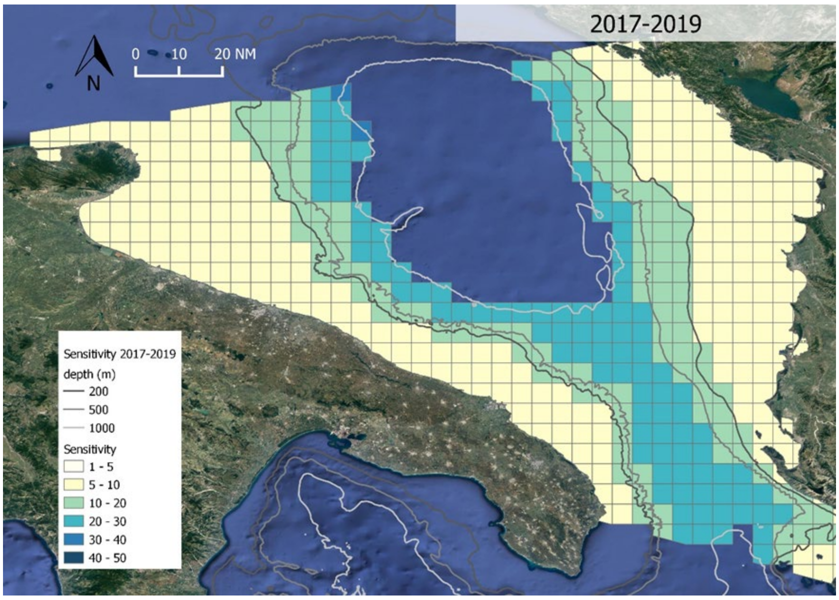


Figure 24. The predicted longevity curves by MSFD habitat and maps for median longevity (sensitivity) of the Southern Adriatic Sea (screening samples SAR < 0.5).

Step 4: Impact assessment

Figure 25 shows the distribution of the Relative Benthic State (RBS) indicator across the Southern Adriatic Sea estimated using the 0.06 depletion value reported in Hiddink *et al.* (2017). Relative benthic state value ranges between 0 and 1, it is equivalent to the biomass over carrying capacity (B/K) indicating the state of the biomass over the habitat carrying capacity. The RBS value is high for every habitat type indicating high recovery values of the benthic. An ad hoc analysis of the fleet activities in the eastern side of the study area could likely improves the next WGFBIT assessment due to the possible underreported AIS data of the fleet in the eastern side.

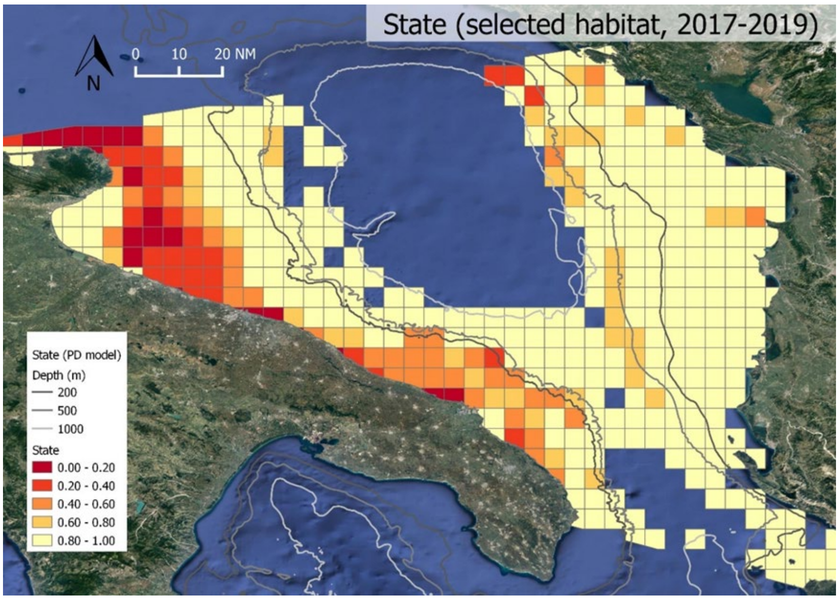


Figure 25. Impact as 1-Relative Benthic State (RBS) based on PD model of the Southern Adriatic Sea (SAR < 0.5).

Assessment 2 (average SAR 2015–2019)

Step 1: Assign region of interest

In accordance with assessment 1, a reference grid of 0.1° x 0.1° c-squares was used, covering the area in the 15.65°E – 20.02° E range of longitude and in the 39.77° N – 42.47° N range of latitude. MSFD habitat information was derived from the latest version (2021) of the EMODnet EU-SeaMap habitat layer (Figure 21). The grid covered the bathymetrical depth range of 0–800m. Depth data were taken from EMODnet DTM (2021).

Step 2: Pressure layer information

Fishing intensity was estimated using the swept area ratio (SAR). The swept area is the cumulative area contacted by a fishing gear within a grid cell over one year. The source of pressure data for GSA 18 is AIS data from Global Fishing Watch. Vessels' fishing activity, reported as fishing hours, were analyzed in a predefined grid (e.g. 0.1° × 0.1°). For the estimation of the SAR the total gear width (door spread) was derived using Eigaard *et al.* (2016) equations. Estimates on total SAR within each grid cell were calculated for demersal otter trawls. In Figure 26, an average of the SAR for the years 2015–2019 is presented and it is related to the trawling frequency of demersal otter trawls.

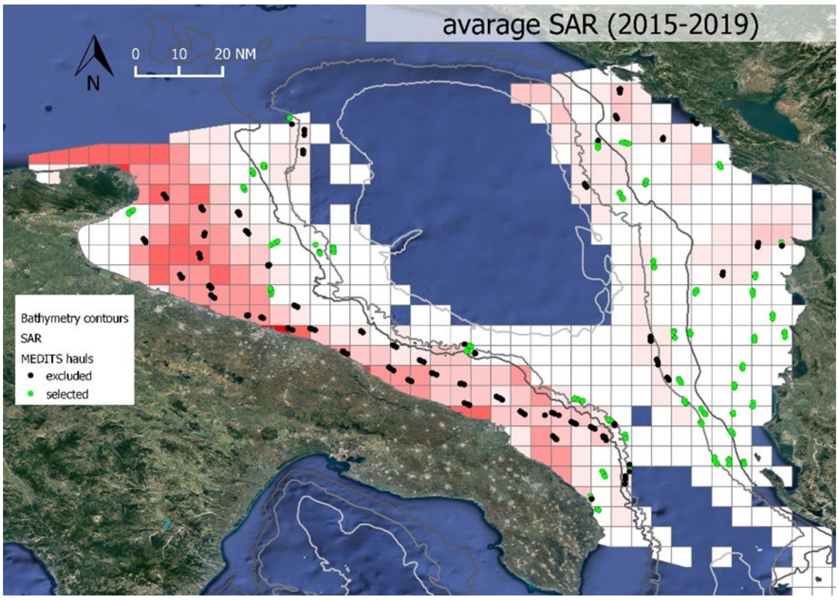


Figure 26. Extent of the average swept area ratio (SAR) in the South Adriatic Sea from 2015–2019 plotted on a 0.1° x 0.1° grid. Green dots represent MEDITS survey selected hauls with SAR < 0.5; black dots show MEDITS survey removed hauls with SAR >= 0.5.

Step 3: Estimate of the longevity relationship

Benthic longevity estimates for the South Adriatic Sea (GSA 18) were based on epifauna data from MEDITS scientific survey (Figure 26). The hauls were carried out in the 10–800 m depth range, using the standard MEDITS trawl net GOC73 (AAVV, 2017; Spedicato *et al.* 2019). A total of 444 hauls were surveyed from 2015 to 2019. For each location, species were linked to a species-by-trait matrix of longevity based on the information derived by two different trait databases. The first was made by expert judgment of the Italian benthic experts from the Italian Society of Marine Biology (SIBM) working group, after improved by COISPA ageing expert team. The second was made by ICES experts. The final database was made of 323 longevity data at species level.

Sampling locations probably undisturbed by fishing activities (in accordance with actual available AIS data) were selected using SAR < 0.5 in years 2015–2019 in order to estimate benthic longevity. After the removal of the disturbed locations 202 samples were retained.

The cumulative biomass-longevity relationship was estimated based on Generalized Linear Mixed Models (GLMMs) using a stepwise forward selection approach and including MSFD habitat type and Depth as fixed effects and assuming stations as random effect. Total biomass by longevity class and by station are reported in Figure 27. The models used (mod1-mod7) are the same of the Assessment 1 (Table 14). Akaike Information Criterion (AIC) values are reported in Table 16. Model 4 is confirmed as the most robust, in accordance to the AIC values.

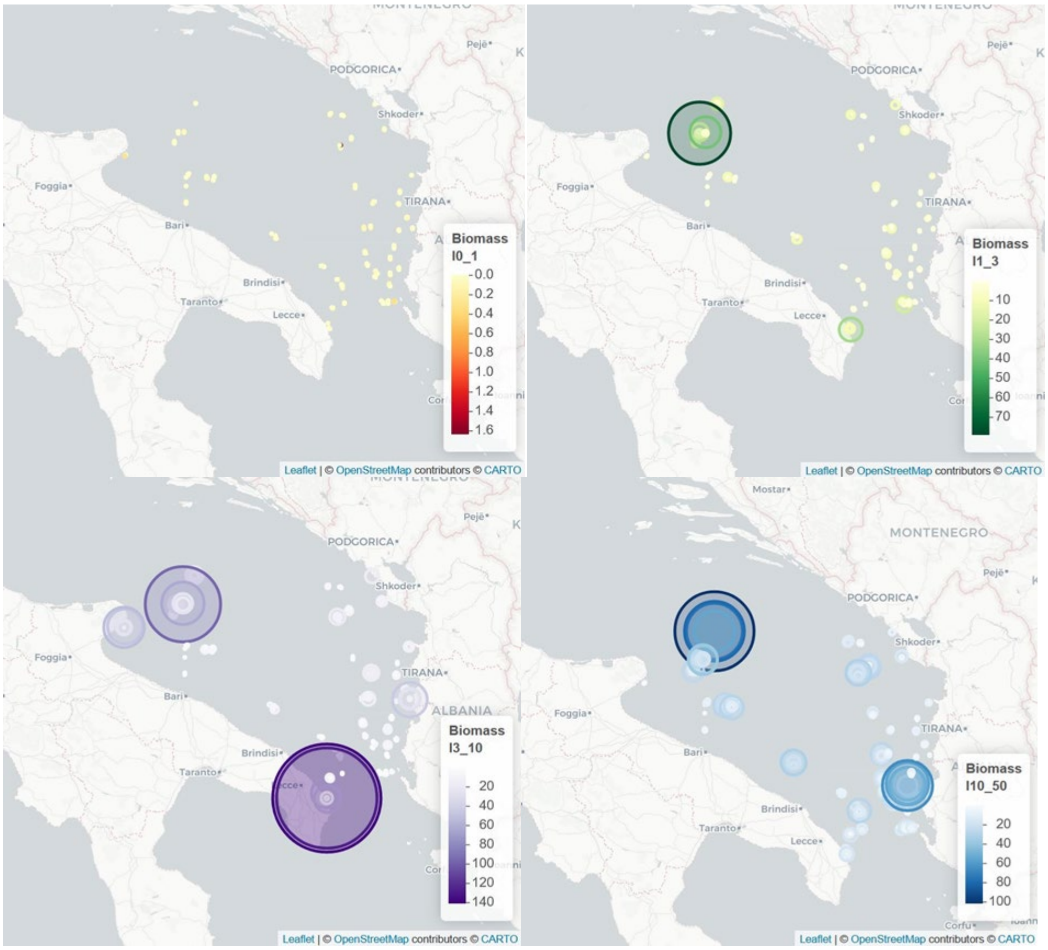


Figure 27. Overview of the biomass for the different longevity classes in the Southern Adriatic Sea.

Table 16. Summary table of the modelling results. AIC and degree of freedom (df) are reported in the tables below.

Habitat	Hauls N
Circalittoral mud	28
~~Circalittoral rock and biogenic reef~~	~~1~~
~~Circalittoral sand~~	~~6~~
~~Infralittoral sand~~	~~1~~
~~Na~~	~~19~~
Offshore circalittoral mud	45
Offshore circalittoral sand	15
Upper or Lower bathyal sediment	86

_	Df	AIC
mod1		Not converge
mod2	7	291.6
mod3	3	307.9
mod4	4	288.1
mod5	5	288.7
mod6	6	295.3
mod7	10	294.6

The selected model was used to predict the mean longevity as a function of habitat type (Figure 28). The mean longevity is considered a measurement of the seabed sensitivity to bottom trawling.

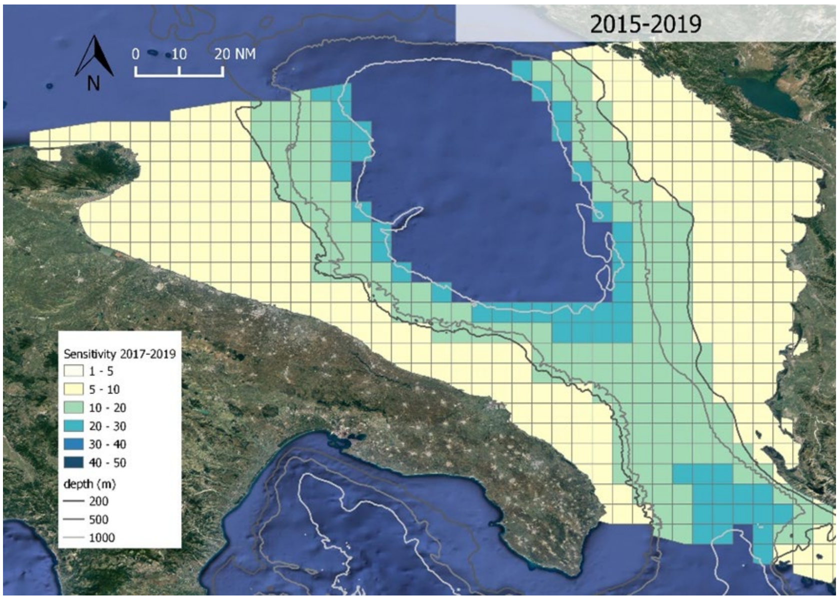


Figure 28. The predicted longevity curves by MSFD habitat and maps for median longevity (sensitivity) of the Southern Adriatic Sea (screening samples SAR < 0.5).

Step 4: Impact assessment

Figure 28.1 shows the distribution of the Relative Benthic State (RBS) indicator across the Southern Adriatic Sea estimated using the 0.06 depletion value reported in Hiddink *et al.* (2017). Relative benthic state value ranges between 0 and 1, it is equivalent to the biomass over carrying capacity (B/K) indicating the state of the biomass over the habitat carrying capacity. The RBS value is high for every habitat type indicating high recovery values of the benthic. An had hoc analysis of the fleet activities in the eastern side of the study area could likely improves the next WGFBIT assessment due to the possible underreported AIS data of the fleet in the eastern side.

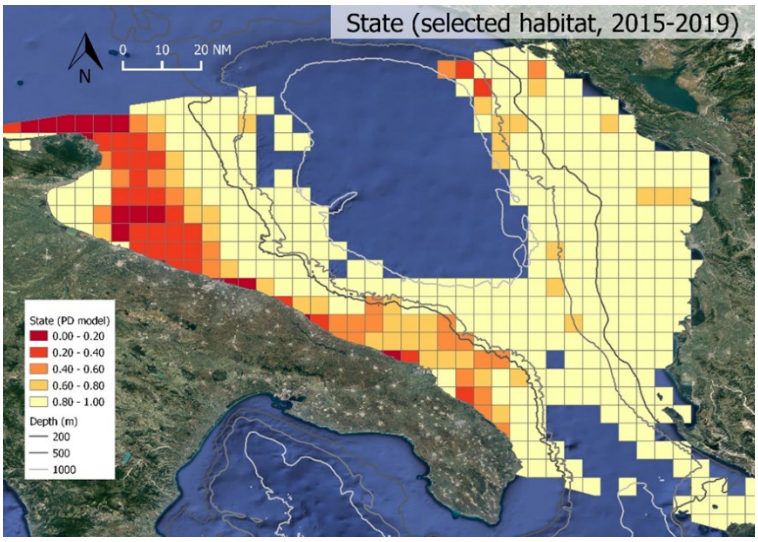


Figure 28.1. Impact as 1-Relative Benthic State (RBS) based on PD model of the Southern Adriatic Sea (SAR < 0.5).

3.2.3.2.3 Greek waters (GSA 20, 22 and 23)

Step 1: Assign region of interest

For the Eastern Mediterranean, the Greek sea areas (Eastern Ionian, Aegean and Cretan Seas) were taken into account for the assessment. An update to the MSFD broad habitat map (EMODnet EUSeamap 2021) has recently become available and used in the assessment (care was taken as it has recently been updated with changes to categorization and the areas of the broad habitats). The region of interest is defined as a polygon with resolution 0.05x0.05° c-squares, latitude range 34–41° north and longitude range 19–29° east. The distribution of habitat types in the region is shown in Figure 29 and Table 17.

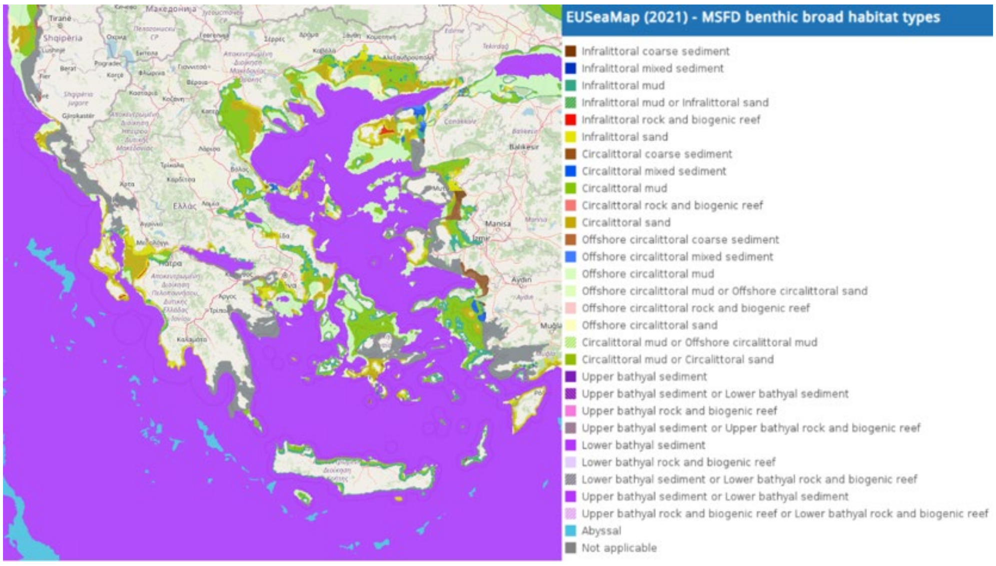


Figure 29. EMODNET EU Sea Map 2021 broad habitat types for the Greek seas region.

Table 17. Spatial coverage (km2), proportion of total seabed area (%) of the individual MSFD Broad Scale Habitats in the Greek region, delineated from the EUSeaMap 2021 (version September 2021). The final column is the Greek fleet Swept Area Ratio (SAR), showing distribution of trawling effort over each of the modelled habitats.

MSFD habitat	Area (km^2)	Area %	SAR
Infralittoral coarse sediment	0.532	0.11%	0.033
Infralittoral mixed sediment	0.216	0.05%	0.000
Infralittoral mud	7.299	1.58%	0.020
Infralittoral rock and biogenic reef	0.431	0.09%	0.000
Infralittoral sand	5.927	1.28%	0.041
Circalittoral coarse sediment	0.753	0.16%	0.027
Circalittoral mixed sediment	0.627	0.14%	0.234
Circalittoral mud	20.660	4.46%	0.545
Circalittoral sand	11.413	2.46%	0.654
Offshore circalittoral coarse sediment	0.293	0.06%	0.065

Offshore circalittoral mixed sediment	0.167	0.04%	0.033
Offshore circalittoral mud	14.877	3.21%	0.381
Offshore circalittoral sand	4.620	1.00%	0.370
Upper or Lower bathyal sediment	369.137	79.66%	0.036
Abyssal	8.142	1.76%	0.000
Na	18.281	3.95%	0.101

Step 2: Pressure layer information

Fishing intensity was estimated using the swept area ratio (SAR). The swept area is the cumulative area contacted by a fishing gear within a grid cell over one year. Vessel speeds representing fishing activity were analyzed in a predefined grid (i.e. 0.05° × 0.05°). The swept area ratio is the swept area divided by the surface area of the grid cell. Estimates on total SAR within each grid cell were calculated by métier. In Figure 30, an average of the SAR for the years 2015–2018 is presented, related to the trawling frequency of demersal otter trawls.

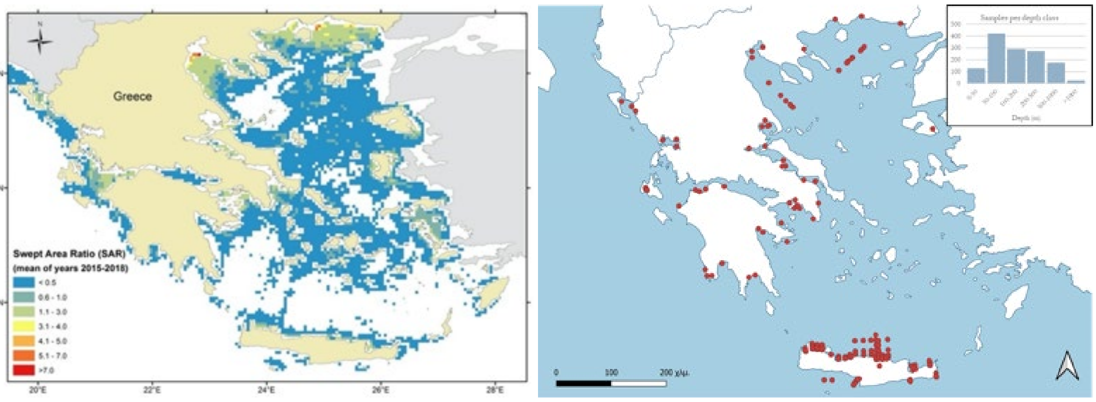


Figure 30. Left figure: Extent of average swept area ratio (SAR) in the Greek Seas from 2015 to 2018, plotted on a 0.05° × 0.05° grid. Right figure: Overview of the benthic sampling locations for the Greek region.

Step 3: Estimate of the longevity relationship

Benthic longevity estimates for the Eastern Mediterranean region were based on macrofauna data from several scientific projects and the Water Framework Directive (WFD) monitoring program. The compilation of these data resulted in a dataset with information on macrofauna for 204 locations and 1364 samples (Figure 30). At all locations, benthic samples were collected with van Veen or Smith McIntyre grab sampler (0.1 m2). Samples were sieved either on a 0.5 mm mesh or on a 1 mm mesh. Preliminary statistical analysis indicated that for this region, sieve size had no statistically significant effect on the distribution of biomass in longevity classes and habitat and no effect on the comparison of biodiversity metrics between different sieve sizes. For each location, species were linked to a species-by-trait matrix of longevity (Greek trait database with 889 taxa).

In order to estimate benthic longevity, sampling locations that are largely undisturbed by fishing were selected in order to derive, as far as possible, an undisturbed reference state. For this reason, three cases were analyzed. For all cases, samples less than 50 m or greater than 1000 m depth were included as being protected from trawling. The first case included locations with average fishing intensities of SAR<1 in years 2015–2018. The second included locations with SAR<0.5, while in the third scenario, locations with SAR<0.1 were included in the analysis. After the removal of the disturbed locations in each case, 973, 895 and 598 samples were retained, respectively.

The cumulative biomass-longevity relationship was estimated for each case based on Generalized Linear Mixed Models (GLMMs) using a stepwise forward selection approach and including MSFD habitat type as fixed effect and assuming stations as random effect. Alternative model versions were compared using the Akaike Information Criterion (AIC) and Model 1 was identi-fied as fitting the data best (Table 18).

Table 18. Greek results from fitting linear mixed effects models with station as random variable and MSFD habitat type as fixed independent variable to the longevity response variable

MODELS		AIC		
		SAR<1	SAR<0.5	SAR<0.1
MODEL 1	glmer(Cumb ~ ll + MSFD + (1 | station)	2203	1959	1223
MODEL 2*	glmer(Cumb ~ ll + ll*MSFD + (1 | station)	2168	-	-
MODEL 3	glmer(Cumb ~ ll + (1 | station)	2218	1971	1233

* *Model 2 could not run without violation*

The selected model was used to predict the mean longevity as a function of habitat type (Figure 31). The mean longevity is considered a measurement of the seabed sensitivity to bottom trawling. Large confidence intervals were indicated for those habitats with a low number of samples. The maps for SAR<0.5 and <0.1 were very similar with small differences that are not seen within the longevity bands. SAR<0.5 may be a more useful cut-off as more samples for longevity are retained with better habitat coverage.

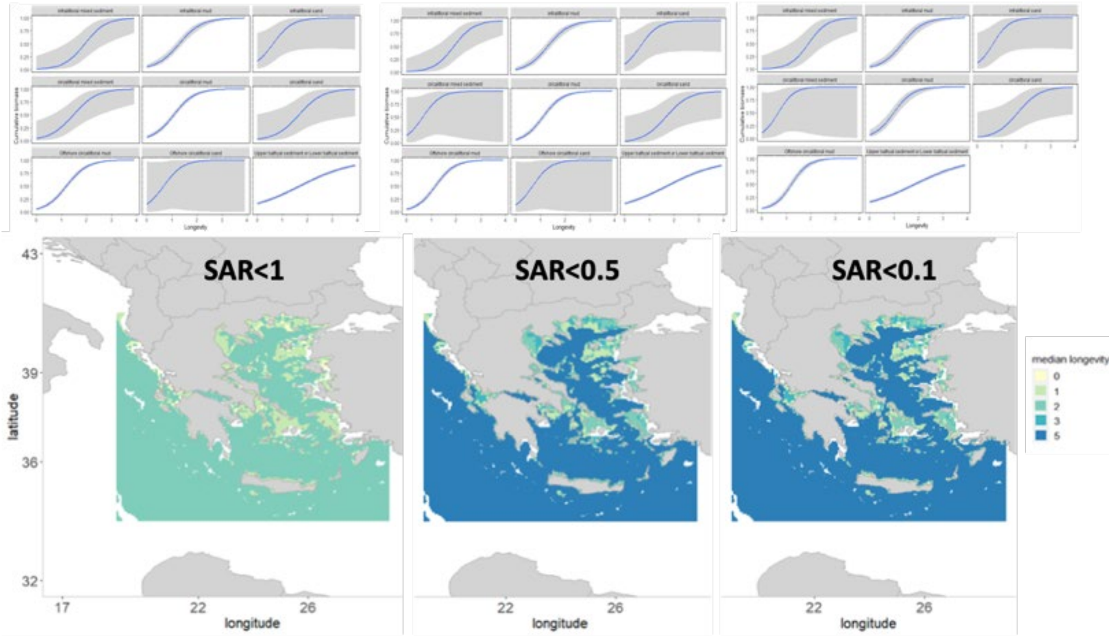


Figure 31. The predicted longevity curves by MSFD habitat and maps for median longevity (sensitivity) of the Greek region for each case analysed (screening samples for SAR<1, SAR<0.5 and SAR<0.1).

Step 4: Impact assessment

Figure 32 shows the distribution of the Relative Benthic State (RBS) indicator across the Greek region. Relative benthic state value ranges between 0 and 1, and it is equivalent to the biomass over carrying capacity (B/K) indicating the state of the biomass over the habitat carrying capacity. The relative benthic status by analysed MSFD habitat type is shown in the Table 19. The RBS value is high for every habitat type indicating high recovery values of the benthic biomass – particularly in the circalittoral mud and sand habitats with the highest SAR.

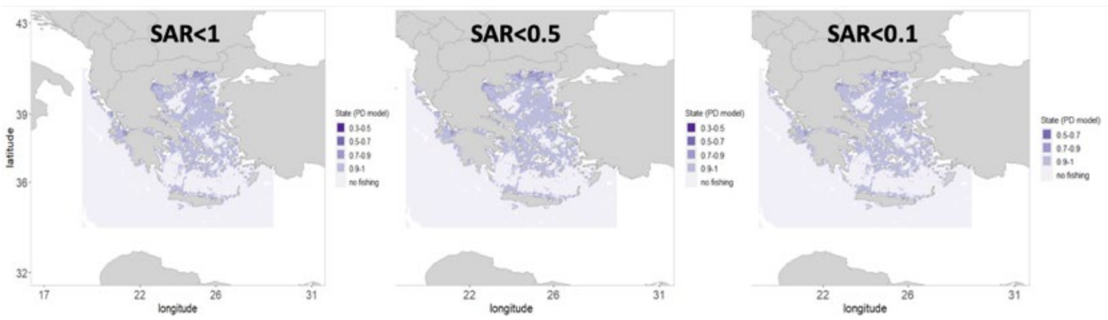


Figure 32. Relative Benthic State (RBS) based on PD model of the Greek region for each case that analysed (SAR<1, SAR<0.5, SAR<0.1).

Table 19. Greek average RBS per MSFD habitat type. The final column shows the SAR for each of the habitats.

MSFD Broad Habitat Type	SAR<1	SAR<0.5	SAR<0.1	Fishing
	State	State	State	SAR
Infralittoral mixed sediment	0.996	0.997	0.998	0.000
Infralittoral mud	0.969	0.975	0.980	0.020
Infralittoral sand	0.898	0.919	0.933	0.041
Circalittoral mixed sediment	0.974	0.916	0.931	0.234
Circalittoral mud	0.937	0.952	0.966	0.545
Circalittoral sand	0.952	0.958	0.951	0.654
Offshore circalittoral mud	0.941	0.953	0.962	0.381
Offshore circalittoral sand	0.890	0.911	-	0.370
Upper or Lower bathyal sediment	0.994	0.995	0.995	0.036

Moving Forward

In the next period work will be done on improving the longevity modelling (environmental parameters), on updating the SAR for more recent years, possibilities for validation work and uncertainty in the assessments. Investigations will be made on working with the MEDITS community to initiate an epifaunal assessment compatible with other regional participants.

3.2.3.2.4 Italian Adriatic Sea (GSA17)

Current implementation of modelling in the GSA 17 (Northern and central Adriatic Sea) are in place based on both fishery dependent and fishery independent data. The area is known to be one of the most exploited sea in the Mediterranean (and possibly the world) given the high intensity of trawling beyond the 3 nM. Pressure data are expressed according to SAR estimated based on the integration of VMS and AIS data on a grid with 1 km*1 km cell resolution extrapolated for both otter-trawlers (OTB) and rapido trawlers (TBB). Yearly estimates assessed under MSFD monitoring are being used (years 2012–2016).

The current assessment is based on the use of longevity data that were based on literature data, expert knowledge gathered in the context of SIBM - ISPRA working group and datasets. Longevity is expressed through fuzzy coding in the 4 longevity classes 0–1y, 1–3 ys, 3–10 ys > 10 ys.

Biological data refers to data collected from:

- OTB and TBB discards, in the framework of the international project GAP2 (northernmost part of the Adriatic Sea; 2013 and 2014);
- SOLEMON trawl survey in ys 2014–2015–2016.

All data are expressed as biomass per square kilometer. These data encompass a relatively low depth ranged, i.e. from 10 to 100 m. The GAP2 project database and SOLEMON benthic epifauna database (the latter, associated to a sampling area of about 36 700 Km2), already showed to be useful to characterize the benthic community and identify main assemblages in the area (Piras *et al.*, 2016; Santelli *et al.*, 2017).

According to Santelli *et al.* (2017) the analysis of epimegazoobenthic assemblages in this area showed the temporal persistency of 4 main groups of species, inhabiting i) the muddy sand sediments of the offshore waters of the northern and central Adriatic Sea (characterized by the presence of *Holothuria (Panningothuria) forskali*, *Amathia semiconvoluta, Parastichopus regalis, Phallusia mammillata and H. tubul*osa), ii) the northernmost part of the basin (characterized by Ocnus planci, *Astropecten irregularis* and *Suberites domuncula*), iii) the western coast of the Adriatic (*Anadara kagoshimensis* and *Anadara transversa* together with *A. irregularis*) and iv) the deepest part (characterised by *Liocarcinus depurator* and, to a lesser extent, *A. irregularis* and *Goneplax rhomboides*).

A first round of modelling is now being developed and results will be shared and discussed at the next WGFBIT meeting.

3.2.3.2.5 French Mediterranean EEZ (Gulf of Lion GSA7 and Corsica GSA8

The biological data available to apply the assessment framework is MEDITS trawled mega-epifauna benthic invertebrate species (expressed in g.km^{-2}, Jadaud and Certain, 1994, Figure 20). A first assessment carried out in 2020 (ICES, 2021) revealed that up to 47% of the biomass was lacking longevity information in the longevity databases available at the time. New and updated longevity data is now available and it is likely that this status will soon vastly improve as a common Mediterranean longevity database may be build. Moreover, decision was taken to remove cephalopods and commercial species from the dataset as they often dominate the total biomass and their distribution is not independent from effort (risk of circularity in the approach). The impact of this approach may be later investigated as a source of uncertainty in the assessment. MEDITS data from 2017 to 2019 will be used to perform the assessment and data from 2021 may be used to validate it.

France has updated SAR data in its Mediterranean EEZ from 2012 to 2020 including all fishery vessels operating in the area (including Spanish and Italian fleets) at a 1’x1’resolution based on VMS data. Benthis gear width models were used but when gear specifications were available in DC-map data (observation at sea of fishery catches), they were used to develop new specific gear models for the local trawling fleets. Uncertainty arising from both the models parameter errors and the use of multiple gear for any given fishing trip was quantified through 3000 bootstrappings (George *et al.*, in prep). Total SAR was computed as the median of the 3000 bootstrap (as data distribution was not normal) and uncertainty was computed as the difference between the first and third quartiles of the distribution of the 3000 simulated values. SAR was also disaggregated by gear (beam trawl, dredge, other trawls) and revealed that almost all impact is caused by other trawls since beam trawl are no longer allowed in the French Mediterranean territorial waters (with few exceptions still persisting in certain localities) and dredges are mostly used by small vessels (<12m) targeting bivalves beds in very coastal areas which are not equipped with VMS, For this reason, total SAR will be considered as being entirely due to other trawling and is likely under-estimated near shore (<6nm to the coast).

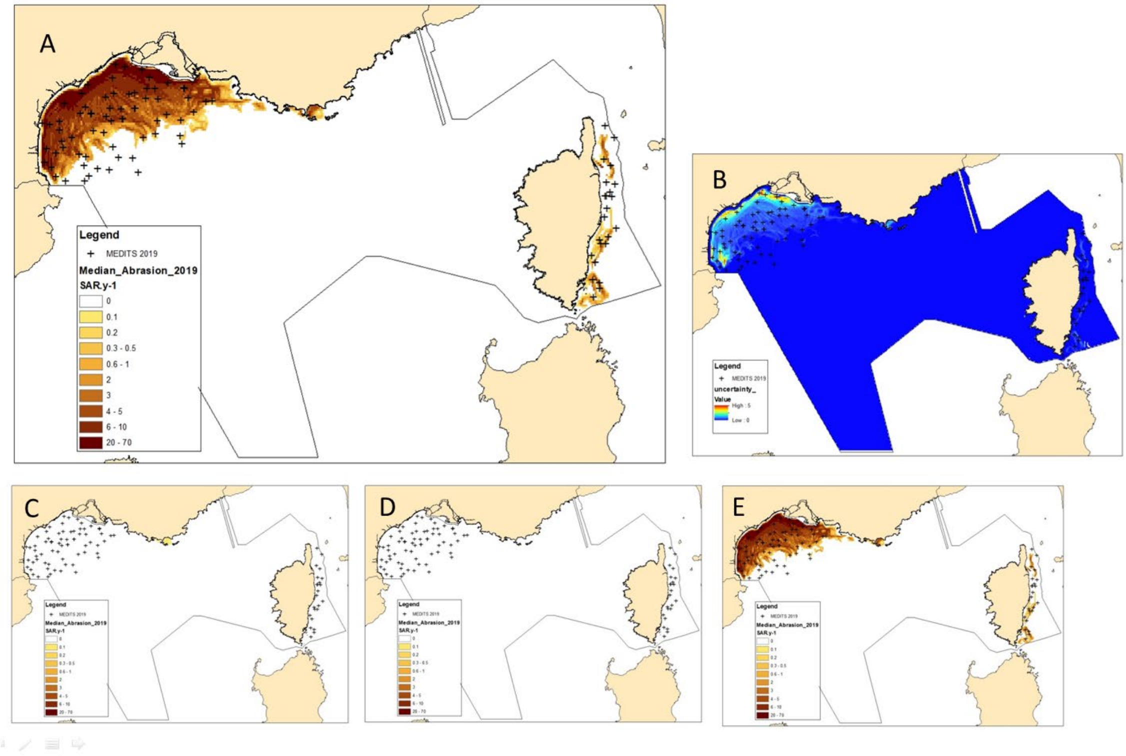


Figure 33. A. MEDITS trawl hauls distribution and SAR data in GSA7 and 8 in 2019 , B. SAR uncertainty in 2019, C. beam trawl SAR in 2019, D. dredge SAR in 2019, E. other trawl SAR in 2019.

MEDITS observations are made each year in May and June and may be related to SAR based on 1) the previous year SAR value, 2) the 5 previous year average SAR value, 3) the 5 previous year maximum (or 90th percentile) value or 4) a weighted average of the 5 previous years, giving decreasing weight to years that are most distant in time. The 5 years period was chosen based on literature reporting that recovery were often observed over such duration following trawling impacts (Hiddink *et al.*, 2017). The approach (4) will be used but other metrics may also be computed to investigate the impact of this choice in later uncertainty studies.

Similarly, depletion rate value may be set to the usual 0.06 value in the following assessment steps. Nevertheless the ground rope used by French Mediterranean trawlers often is a simple heavy chain (resembling tickler chains), contacting and penetrating the seabed over all the gear width. It may therefore be necessary to correct the value in a way similar to Rijnsdorp *et al.* (2020). Again, the effect of different depletion values on the final assessment values will need to be investigated.

A first analysis of the SAR values encountered during the MEDITS survey revealed that only few stations above -200m depth experienced low SAR values. These deeper habitats are located in the aphotic zone and the process shaping their longevity pattern may not be easily extrapolated to other shallower areas which could prove problematic in estimating the longevity relationships. Alternatively, SAR may be used to become a forcing variable of the longevity model but its strong correlation to depth and distance to the coast may also prove problematic (risk of model overfitting).

Other environmental predictors may also be tested in the model to account for habitat variability. These will be depth, sediment average grain size, seabed stress, food availability at bottom, bottom oxygen saturation and bottom temperature.

The full application of the assessment framework will be carried out for the next WGFBIT meeting and special attention will be given to the robustness of the initial framework assumptions (initially developed for North Sea macrofauna) and resulting uncertainty.

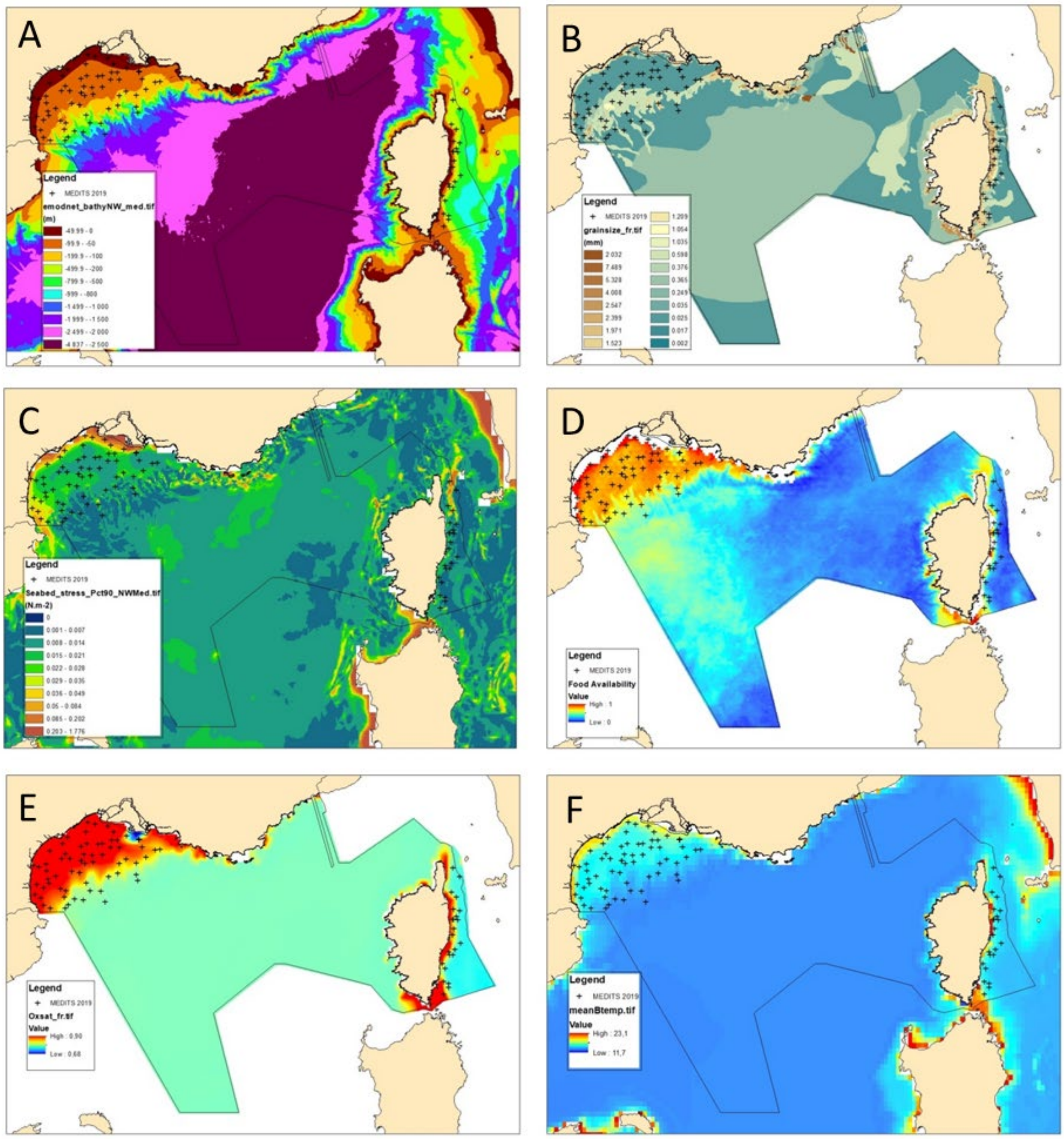


Figure 34. A. Depth (Emodnet bathymetry, 2018), B. Sediment average grain size in French Mediterranean waters (mm, generated from grain size range (mm) per sediment group and % fraction of each main sediment group applying Römkens *et al.* (1997) equation for the estimation of average grain size from sediment typologie and fraction (https://sextant.ifremer.fr/Donnees/Catalogue#/metadata/5b62e0c9–05ab-4b86-bd04–282fec733f87), C. Seabed shear stress (N.m-2) estimated from current and wave hydrodynamic models in the north-west Mediterranean.The 90th percentile was computed over the available period (Rivier, 2010; https://sextant.ifremer.fr/Donnees/Catalogue#/metadata/0364bd13-ed7a-4b33–95d8-b0237035ac7b), D. Food availability at sea bottom (computed as Fa = log(Chl.a/bathymetry) – stratification, centered, standardised and range between 0 and 1. Maximum concentration of surface chlorophyll was obtained from monthly satellite observations from 1998 to 2014 (MyOcean, http://marine.copernicus.eu/, "OCEANCOLOUR_MED_CHL_L4_REP_OBSERVATIONS_009_078"). Stratification was considered as the average absolute difference between surface and 30 (± 5) m depth density over 20 years. Salinity and temperature data used to compute density cover the 1994–2014 period and were from monthly model predictions (MyOcean, http://marine.copernicus.eu/: "MEDSEA_REANA-LYSIS_PHYS_006_004"). High Pressure International Equation of State of Seawater (1980) was used to compute Sea water Density. E. Average bottom disolved oxygen (O mmol.m-3 from1999 to 2014, from monthly model predictions (MyOcean, http://marine.copernicus.eu/: "MEDSEA_REANALY-

SIS_BIO_006_008"); expressed as dissolved rate based on Weiss, 1970 equation). F. Mean sea bottom temperature derived from monthly model predictions 1994–2014 (MyOcean, http://marine.copernicus.eu/: "MEDSEA_REANA-LYSIS_PHYS_006_004).

3.2.3.3 Comparisons of case studies' main approach

Below we report the main features of the CS presented at the meeting, including those where modelling has not been yet carried out and area under development (Table 20).

Table 20. Main features of the Mediterranean case studies presented the WG.

Case study name	Area	Bathymetric range	Grid cell size	Pressure data (basic sources and ys)	Benthic community data (basic features e and ys)	Index and method applied	Objectives at the meeting
Preliminary assessment in Central Mediterranean - Sicily (GSA10,16,19)	Sicilian continental shelf (bbox = 11.6,15.6,36.4, 38.4 WGS84)	0–200m	1km²	ISPRA VMS dataset 2015–2019	-PhD MCM trawl survey year 2011–2012–2013 -Interreg HARMONY Project trawl survey year 2019 and 2020 -ISPRA MEDITS campaign trawl survey year 2016–2017–2018–2019–2020	Abundance (number of individuals) index with SAR included in model for longevity distribution estimation	Present a preliminary assessment for the area and highlight further improvement needed
Preliminary assessment in Southern Adriatic Sea (GSA18)	bbox = 15.65,20.02,39.77,42.47	0–800m	5–6NM	Global Fishing Watch AIS data (2015–2019)	MEDITS surveys (2015–2019)	biomass index (only hauls with SAR < 0.5 were selected)	Present a preliminary assessment for the area and run a sensitivity analysis
France (upcoming assessment)	Gulf of Lion (GSA7) and East Corsica (GSA8)	30–800m	1'x1'	Fr ministry VMS dataset 2012–2020 transformed in SAR with updated and specific gear size models and uncertainty assessment of gear size and metier choice impact on SAR results	MEDITS surveys (2012–2019)	standardised biomass (g/km²), filtering out commercial species, SAR included in longevity model (then set to 0 for estimation)	Prepare necessary data and discuss methodological choice for preliminary assessment (in particular species longevity traits and data and period filters)

Greece (eastern Ionian, Aegean, Crete)	GSA 20, 22, 23	0–1570 m	0.05x0.05 decimal degree (following FBIT N. Europe)	Estimation of SAR based on analysis of VMS data. Years: 2010–2015 completed, 2015–2020 ongoing and will be updated Cell size: 0.05dd (more options could be applied)	Grab sampled macroinfauna from research projects, WFD, MSFD. 1990's-present	Wet weight biomass	Present a preliminary assessment for the area and highlight issues and further improvement needed
Northern Adriatic Sea (GSA17) (Upcoming assessment	Northern Adriatic Sea (GSA17)	10–100 m	1 km2	MSFD ISPRA VMS+AIS dataset 2012–2019	-GAP2 project OTB and TBB discard data (2013–2014); -SOLEMON survey (TBB) macroepifaunal data 2014–2016 (to be extended towards 2020)	Biomass index (Kg/Km2), longevity data expressed with coding, SAR. Model setting under testing	Present current stage, finalize data preparation and discuss alternative options for actual testing of the model

Many differences between the CSs are evident, both in terms of data typology and sources used, and in terms of methodology. These include grid size, pressure data (e.g. in most of the cases only VMS, in other AIS or AIS and VMS integrated). Also, the settings for the longevity model differ, along with the sources of longevity data. These elements are further discussed below with the aim of achieving higher consistency and comparability in the future.

Developing a common ground

The differences in the methods adopted in the CS were discussed during the WFBIT meeting among Mediterranean participants. Below a synthesis of the range of topics discussed is reported with the aim of providing guidance for the setting of future approaches.

1. Grid and cell size

To conduct a consistent regional assessment it is easier to use and apply a common grid size across areas. In the CSs presented at WGFBIT, different cell sizes were used, ranging in size from ICES grid to 1x1' to 1x1 km and 0.5x0.5 km. Cell size definition shall be determined considering different aspects. For instance, large grid size may encompass several BHTs (especially where the bathymetric gradient is higher). In contrast, a small grid size may not be compatible with low frequency vessel positioning data.

Moreover, the methods used for the estimation of SAR are sensitive to the grid cell size. Accordingly, most often grid size selection depends on the availability of datasets for assessing spatial distribution of vessels (e.g. VMS, AIS). The trade-off between grid size, uncertainty in BHT representation and in SAR estimates should be explored to define the appropriate grid size according to data availability. In addition, the optimal grid to be used shall be defined considering different options available, including EEA grid, GFCM grid, ICES grid, national grid and others. Consistency at the Mediterranean Sea scale should be prioritized. For the Italian National Monitoring Programme the EUSeaMap grid system was applied and all the cartography related to the European Reporting will be generated and delivered with this type of grid.

2. SAR and gear width estimates

SAR estimates vary according to cell size (see Amoroso *et al.*, 2018) and might affect the modelling output. In the Mediterranean CSs different data were used to assess SAR, ranging from VMS, AIS and a combination of the two. The consequences in terms of SAR accuracy of using the two data sources are not yet addressed in the Mediterranean Sea; while it is expected that the general pattern would be similar from the two sources of data, local distortions might be present. Different methods were also used to estimate SAR based on these data.

Approaches for incorporating the gear width in SAR estimations in the Mediterranean CSs also differed. The coupling of VMS data with logbook data is currently the method adopted by ICES for describing the spatial dynamics of fishing activities and identifying fishing metier. A similar approach might be applied in the Mediterranean but the quality and availability of logbook data must be addressed. The application of gear width estimates based on relationships between average gear widths and average vessel length or engine power (kW), as stated in Eigaard *et al.* (2016) should be revised taking into account local specificities of fishing vessels and gears.

3. Longevity estimates

Longevity estimates were made on the basis of different reference lists that are described in the Table 21 below. From the preliminary analysis, it emerges that the sources used vary across CSs, ranging from literature data and databases to expert judgement. In some cases, data from outside the Mediterranean Sea were also used.

Table 21. Metadata of the longevity lists used as references in the Mediterranean case studies

Data Source	Assemblage (Epifauna/Infauna)	Reference Area/DB	Bathymetric range (m)	Number of taxa	Taxa resolution	N. of classes estimated for longevity	Methods/Sources used for longevity estimates
Italian National monitoring programme-MEDITS	Epifauna	Italian coasts; MEDITS epifuana species	10–800	323	Species or Genus	3 levels (<1ys; 1–10ys; >10ys)	Expert judgment; SIBM* ISPRA Experts Literature
Solemon Rapido Trawl survey 2014–16 and GAP2 epibentic data	Epifauna	GSA 17 Italian Northern Central Adriatic Sea	10–100	220	Species or Genus	3 levels (<1ys; 1–10ys; >10ys) 4 levels (<5ys; 5–10ys; 10–50 ys ; >50ys Besito index levels) 4 levels (<1ys; 1–3ys; 3–10 ys ;	Expert judgment; SIBM ISPRA Experts Literature

						>10ys RBS model levels)	
Greece	Macrofauna	GSA 20, 22, 23 Greek Waters: Aegean Sea, Cretan Sea, Eastern Ionian	15–1500	889	Genus	5 levels (<1ys; 1–3ys, 3–10ys; 10–50 ys, >50ys) No species in the last class, so effectively **4 levels**	Allocations by fraction fuzzy logic CEFAS database, Other databases Literature Expert Judgement
Greece	Megafauna	GSA 23 Cretan Sea	70–250	164	Genus	4 levels (<1ys; 1–3ys, 3–10ys; >10ys,)	Allocations by fraction fuzzy logic CEFAS database, Other databases Literature Expert Judgement
MEDITS survey 2015–19	Epifauna	GSA 18	10–800	323	Species	4 levels (<1ys; 1–3ys; 3–10 ys ; >10ys RBS model levels)	Expert judgment; SIBM* ISPRA ICES Experts Literature

*Italian Society for Marine Biology

The use of different sources for assigning longevity could potentially introduce a bias in the assessments, i.e. adopting different longevity classes for the same taxon. This could reduce the actual comparability of case studies outcomes in cases of major inconsistencies on many taxa.

Further to this, another issue that needs to be checked and reconciled through consensus is the use of fuzzy logic in the classification. The direct comparison of the longevity classes assigned to species was not carried out at the meeting but common activities in this regard are in progress in order to underline the concordances and discrepancies and develop a common Mediterranean longevity list.

4. Benthic community data (infaunal grab sampling vs. epifaunal net sampling)

There are two current approaches being used in the Mediterranean, based on either grab sampled infauna or trawl sampled epifauna. Whilst the grab sample approach is well developed/standardised following the original FBIT methodology, the availability or accessibility to comprehensive infaunal data sets by the participants in the Mediterranean is difficult, whereas most of the participants have access to trawl survey data, and in particular to their EU Mediterranean Member States MEDITS annual trawl survey, SOLEMON survey or other National Monitoring Programmes. The two different approaches are incompatible for simultaneous use in a common assessment as the communities sampled are different in terms of spatial distribution, size, longevity, sensitivity and accessibility/catchability. Trawl surveys may be less liable to differences between gear/sampler types than macro-infaunal surveys. With grab samples surveys, information is often directly available on habitat type, whereas for trawl surveys this has to be previously known or abstracted from EMODnet Seabed Habitats (www.emodnet-seabedhabitats.eu), or deduced from the species catch composition.

A standardised methodology of the FBIT analysis for a common regional analysis is not fully available already and, further standardisation efforts are required to resolve issues of:

- Taxonomic expertise available;
- Which part of the fauna should be investigated for FBIT analysis;
- Standardized biomass measurements are required. If no biomass measurements are available, a species/average weight database could be set up and used to convert abundance to biomass;
- Common longevity measurements/classes;
- Characterisation of MSFD habitat in the sampling area;
- Finding sufficient representative undisturbed samples (or low disturbed) to create longevity models for the relevant MSFD habitat types.

5. Identification of reference conditions

Both assessments in the South Adriatic case study (GSA 18) report a cumulative biomass-longevity relationship estimation based on probably low impacted MEDITS survey hauls. Hauls sampled in high impacted cells with SAR > 0.5 were removed in the longevity estimation.

The exclusion criteria approach however may be unfeasible in areas subject to high levels of fishing intensity, for example, the Sicily Channel (Central Mediterranean), or may require a very large sampling effort to access more communities in a low impact condition. This perspective, common in the Mediterranean Sea due to its historical background of exploitation, may require the implementation of fishing intensity in the model used to predict cumulative biomass-longevity distribution, even if this approach is more inclined to a biased estimation.

As a rule of thumb, for the Mediterranean Sea, it would be recommended to use the cut-off criteria on hauls sampled in cells with SAR<0.5, as it leaves a robust sample representativity in comparison to the cut-off criteria with SAR<0.1. Nevertheless if sampling exclusion leads to a loss of habitat representativeness or to a drastic reduction in sample size, the second approach would be a valid alternative to assess community response.

6. Model settings

For the Greek case study, the cumulative biomass-longevity relationship was estimated based on Generalized Linear Mixed Models (GLMMs) using a stepwise forward selection approach. Several variables were included as fixed effects and all of them are related to in-situ data measured during the sampling of the benthic community (and not remote sensing or predicted). These variables were:

- habitat type classification according to the MSFD broad habitat scale (from the site data);
- sampling depth;
- grain size in terms of the percentage of silt and clay fraction.

The analysis conducted for the Southern Adriatic Sea and in Sicily used the same method described for the Greek case study except for the variables included in the models:

- habitat type classification according to the MSFD broad habitat scale
- sampling depth

Furthermore in the Sicilian case study, fishing intensity, expressed as SAR, was included in the model as a fixed effect in order to cope with the high presence of data derived from hauls sampled in high impacted cells. Consequently to predict abundance-longevity relationship in absence of impact a SAR value of 0 was set.

Way forward towards a regional assessment

CSs presented at the WG clearly show the emergence of progress towards the assessment of the impact of benthic impacting fishing gears at the Mediterranean Sea level. Indeed, in some areas, new applications were presented (Greece, Southern Adriatic), while in others further refinement of past studies was achieved (Sicily Channel). Finally the ongoing effort in the Western Mediterranean Sea (France, Spain) and in the Northern Adriatic Sea points to the forthcoming availability of new CSs to further test the methodology in the Mediterranean Sea It is envisaged that such progress will allow the development of a common approach suitable for the variable data availability and ecological features of the area.

In order to move towards future consistent assessment, it will be necessary to progress in several aspects of the assessment including:

- reference grid and cell size;
- methods for SAR estimation;
- longevity codification;
- implications of using infauna vs epifaunal data;
- possible use of other habitat types to complement assessment on BHT;
- defying suitable model parameters for assessments of biological effects at depth >200m.

Some of these issues could be discussed in the intersessional period and benefitting from the ongoing efforts carried out by Mediterranean MS in the context of the MSFD, the progresses achieved by TG Seabed in setting a common ground for D6 assessment, the activities carried out in the ABIOMMED project in conjunction with SPA/RAC, the work from Mediterranean scientists within WGFBIT and ICES and GFCM activities, in general.

Coordination among the different players would be needed to prevent duplication and ensure smooth development and knowledge sharing.

In the next WGFBIT 2022 meeting we envisage running "local" models with more consistent settings (common grid/cell size, SAR estimation method and longevity matrix) to allow for comparability of the outcomes and testing the implication of alternative model selection.

3.2.4 North Sea

For the North Sea, no further method development was needed to run the assessment, as this was already completed in the 2018 report (ICES, 2018) and also published in ICES advice answering the EU request on how management scenarios to reduce mobile bottom fishing disturbance on seafloor habitats affect fisheries landing and value (ICES, 2021).

During WGFBIT 2021, new analyses were done to validate and improve the current sensitivity layer and fishing impact predictions. These analyses used data that were not included in the original estimation of longevity (Rijnsdorp *et al.* 2018). The analyses are described in the below sections:

- 3.3.1: validation of longevity prediction in Kattegat area
- 3.3.2: validation of longevity prediction in infralittoral (coastal) area of the Dutch EEZ
- 3.3.3: validation of the longevity composition of the benthic community at the Brown Bank

During WGFBIT 2021, an update to the MSFD broad habitat map (EUSeamap 2021) has been included in the FBIT workflow (Figure 35). The new habitat information will be used in the next impact assessment.

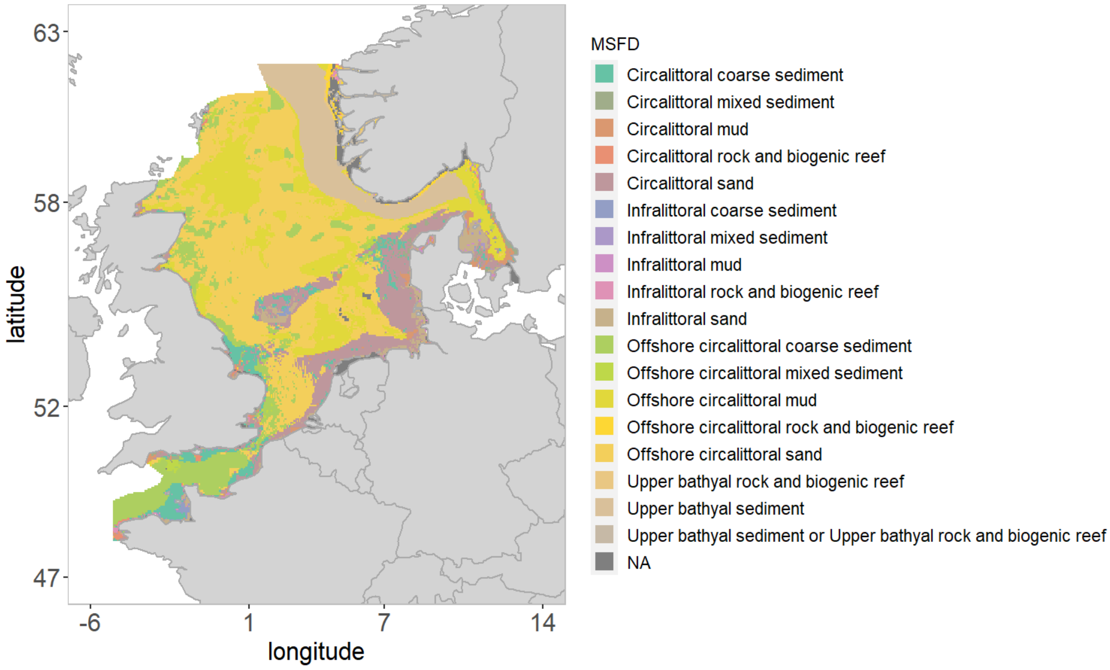


Figure 35. MSFD broad habitat types for the Greater North Sea using the updated data layer (EUSeamap 2021).

3.2.5 Baltic Sea

3.2.5.1 Anoxia/hypoxia in the Baltic Sea

Parts of the Baltic Sea are affected by anoxia or hypoxic events, affecting the possibilities for fishing with demersal trawling. As noted in the 2019 WGFBIT report, the permanently anoxic areas should be identified and treated as a separate habitat and excluded from the fishery impact assessment to the broad scale habitats in the Baltic Sea.

Anoxia is understood as the total lack of oxygen (Lehman *et al.*, 2014), while the thresholds for defining hypoxia can be discussed. Severe hypoxia can be defined as >0–2 mg/l and moderate hypoxia as 2–4 mg/l, respectively, based on fish responses from literature (especially cod, see Chabot and Claireaux, 2008). These are rough estimations because literature on fish (mainly cod) responses to hypoxia are in % of oxygen saturation. This is because the oxygen that is available to metabolism is more biologically relevant than the actual dissolved oxygen concentrations that are reported in hydrography. 2 mg/l ~ 20% saturation at 5 degrees Celsius in marine waters and 4 mg/l ~80% saturation. In the upper range of moderate hypoxia, fish will survive but will have a reduced metabolic scope for feeding, swimming and growth, hence they are physiologically suppressed Bickler and Buck, 2007).

Regarding oxygen available to benthos:

1. The sediment can be anoxic while the water above is less hypoxic, or even normoxic. This is due to the low exchange of pore water and the retention of hydrogen sulphide, which is essentially a chemical oxygen debt.
2. There exists a boundary layer between the seafloor and the water column where there is little mixing and hence, low exchange of dissolved components.

These two things mean that the oxygen conditions on, and especially in, the seafloor will probably be worse than the above water column, where many of the measurements are taken.

Oxygen deficiency impacts on benthos strongly depend on both the severity of oxygen deficiency and its duration. Studies of oxygen deficiency typically suggest that mass mortality occurs with seasonal concentrations around 0.5 ml O_2 l^{-1} (Diaz and Rosenberg, 1995) (note: oxygen concentration conversion between mg/l and ml/l is around 1 mg/l = 0.7 ml/l in the Baltic Sea). Oxygen concentrations above which species do not suffer any mortality are highly species dependent. Concentrations of <1.4 ml O_2 l^{-1} are sometimes defined as hypoxic waters, but sensitive species experience lethal effects from oxygen deficiency at these concentrations (Vaquer-Sunyer and Duarte, 2008). Concentrations above 3.2 ml O2 l^{-1} cause notably less mortality (Vaquer-Sunyer and Duarte, 2008).

Figure 36 shows the seasonal minimum bottom oxygen concentrations in ml O_2 per liter. The Figure 36 highlights that large areas of the seafloor are hypoxic and even anoxic. Table 22 shows the proportion of anoxic and hypoxic waters per MSFD broad habitat type. Especially, offshore circalittoral habitat types have large areas with very low oxygen concentrations.

The group recommends to map areas with seasonal oxygen concentrations <0.5 ml O_2 per liter as a separate habitat, as any concentration below that threshold generates mass mortality in benthos.

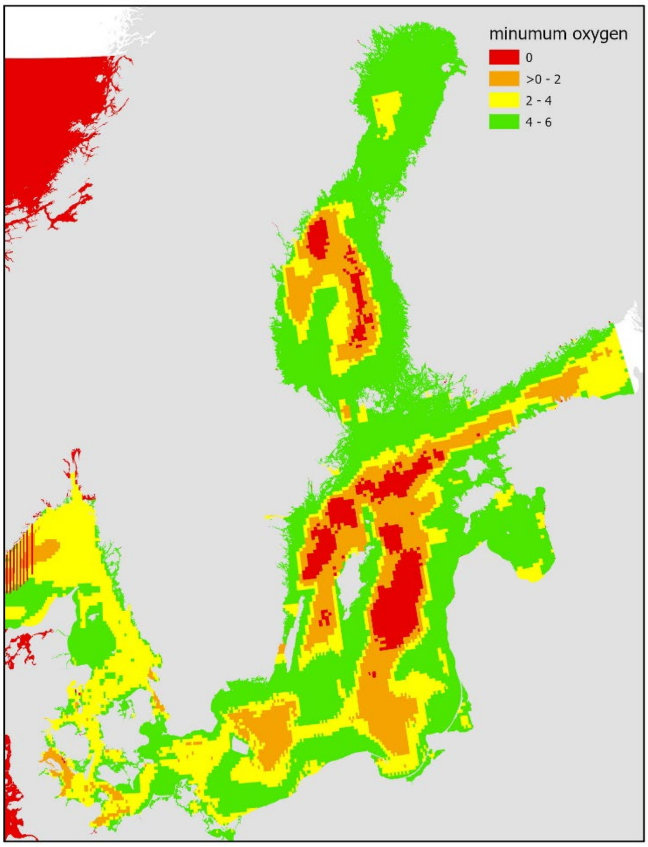


Figure 37. Seasonal minimum bottom oxygen concentrations (in ml/l) from the Baltic Sea environmental layer based on Schernewski *et al.* (2015) – for further information see van Denderen *et al.* (2019).

Table 22. Percentage of area per broad habitat type that is anoxic (0 ml O2/l), or has seasonal minimum bottom oxygen concentrations of 0–2, 2–4 or >4 ml O_2/l following the data in Figure 37.

Broad habitat type	% of area anoxic	% of area 0–2 ml/l	% of area 2–4 ml/l	% of area >4 ml/l	Total area (km^2)
Circalittoral mixed sediment	1.0	11.4	19.9	67.7	100771.3
Circalittoral mud or Circalittoral sand	7.2	22.6	27.3	42.9	51957.0
Offshore circalittoral mud or Offshore circalittoral sand	43.0	48.2	8.6	0.3	33805.6
Circalittoral sand	0.1	3.4	22.8	73.7	31397.9
Circalittoral mud	0.8	13.3	29.4	56.5	28506.3
Infralittoral sand	0.0	1.8	30.6	67.6	22985.4
Offshore circalittoral mud	11.7	57.0	30.1	1.2	21755.3
Offshore circalittoral mixed sediment	21.2	55.1	22.0	1.7	18878.9
Infralittoral mixed sediment	0.1	1.9	13.3	84.7	17939.8
Circalittoral coarse sediment	0.9	4.4	13.4	81.3	11319.0
Infralittoral coarse sediment	0.0	0.6	12.0	87.4	7139.7
Circalittoral rock and biogenic reef	0.9	3.3	9.2	86.6	6996.8
Offshore circalittoral sand	1.0	27.4	69.0	2.7	2710.7
Infralittoral mud	0.1	3.4	43.4	53.1	2094.1
Offshore circalittoral coarse sediment	51.5	26.6	21.0	0.9	719.4
Offshore circalittoral rock and biogenic reef	46.7	30.8	20.2	2.3	204.9

3.3 Validation

3.3.1 Comparison and validation – the case Kattegat

The area Kattegat borders the North Sea and the Baltic Sea and can potentially be included and assessed in each region (Rijnsdorp *et al.* 2018; van Denderen *et al.* 2019). However, the predictions of longevity as a sensitivity layer for the untrawled status of the habitats differs significantly (Figure 38 & Figure 39). The explanation to this discrepancy is that only the model by van Denderen *et al.* (2019) is developed based on benthic samples of communities from the Kattegat. The model also use salinity which is an important predictor in the Baltic and the Kattegat. In summary this means that the Kattegat is considered better predicted and assessed according to van Denderen *et al.* 2019.

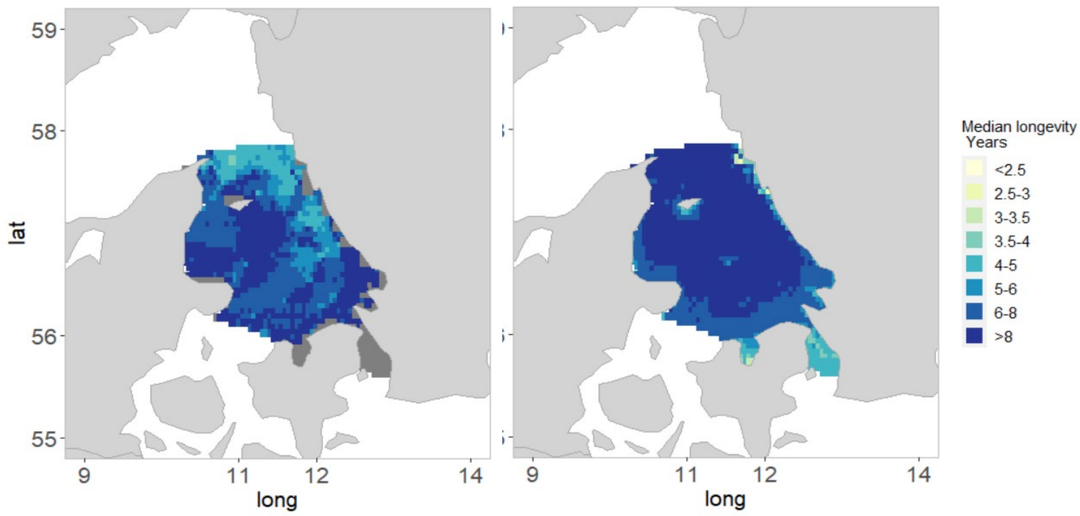


Figure 38. Kattegat. Predictions of longevity in untrawled state according to Rijnsdorp *et al.* 2018 (left) and van Denderen *et al.* 2019 (right).

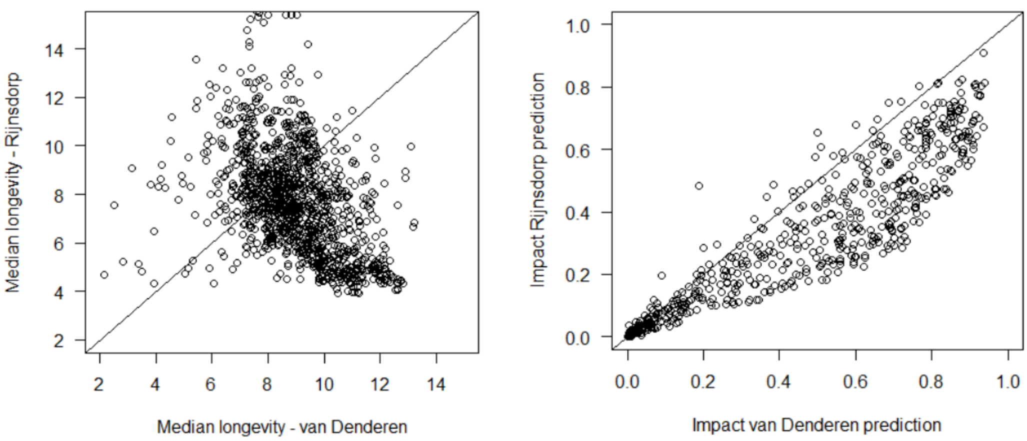


Figure 39. Kattegat. Comparisons between predictions for longevity (left) and trawling impact (right) using the two models.

The models were also validated with boxplots of untrawled predicted biomass per longevity class for c-squares that overlap with the sampling points of an independent benthic data set from 58 sites in the Kattegat (Sköld *et al.* 2018). That dataset includes stations that are fished up to 10 times a year but still has a very high biomass fractions of long-living organisms (Figure 40).

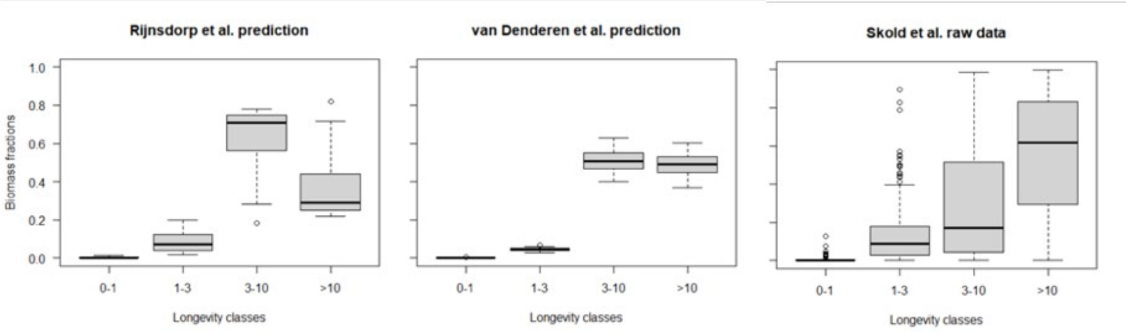


Figure 40. Box- plot of predicted biomass per longevity class for c-squares that overlaps with the sampling sites of an independent benthic data set from Sköld *et al.* (2018).

The predicted impact by bottom trawling in terms of total biomass loss according to the population dynamic model (PD) was compared with actual biomass at sampled sites by Sköld *et al.* (2018) along the gradient in trawling intensity. The Sköld data set indicate no decline along the gradient of trawling intensity and thus did not correlate with predicted impact on biomass (Figure 41).

The high biomass fractions with long-living organisms in the Kattegat is comprised of two species of brittle stars *Amphiura filiformis* and *Amphiura chiajei* which represents about 60% of the total biomass. These dominating brittle stars are long-lived and are tolerant to bottom trawling, rather *A. chiajei* tend to increase with trawling intensity, and both species decreased within an MPA after the establishment in 2009 (Sköld *et al.* 2018).

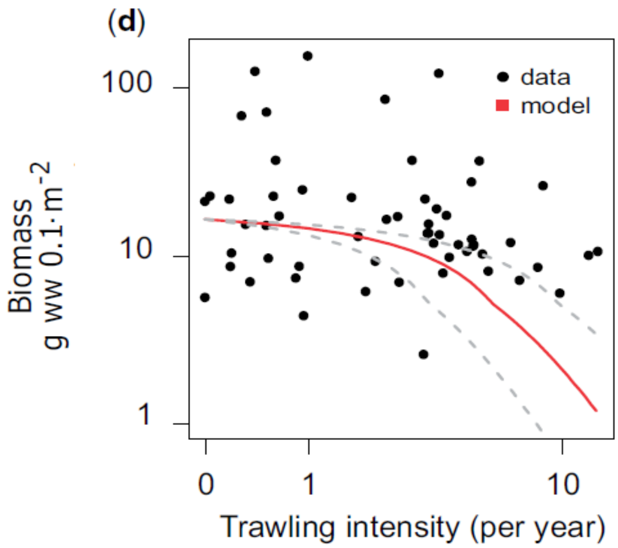


Figure 41. Prediction of trawling impact on biomass by the PD model (red line) and biomass per site along the gradient in trawling intensity in the Sköld *et al.* dataset. Figure taken from van Denderen *et al.* (2019).

3.3.2 Validation of longevity in the coastal zone of the southern North Sea

The statistical model used in the WGFBIT regional assessment of the Greater North Sea is constructed from several datasets of grabs and box-core samples throughout the central and southern North Sea and the English Channel (Rijnsdorp *et al.*, 2018). One of these, the Dutch MWTL monitoring programme, covers the Dutch continental shelf in the North Sea. For the construction of the statistical model, samples within 12 nautical miles from the coast where excluded, as benthic communities from coastal habitats are likely highly influenced by natural disturbance and by coastal fisheries rather than offshore fisheries (van Denderen *et al.*, 2014). Yet, the statistical model is used to predict the sensitivity later in this area. WGFBIT therefore compared the prediction of median longevity by the Rijnsdorp *et al.* (2018) model with that of a statistical model specifically constructed using exclusively the MWTL box-core samples from within the 12 nautical miles zone. The variables included in the coastal zone model were longevity (log-transformed), surface SAR (square root-transformed), gravel (categorized into four categories) and an interaction term between longevity and gravel. A probit-transformation was applied to the response variable so that the values would follow a normal distribution. This allowed for a Linear Mixed Model to be applied rather than a more complex Generalized Linear Mixed Model with assumed binomial distribution, as done by Rijnsdorp *et al.*

The predicted median longevity by Rijnsdorp *et al.* (predominantly 4–6 years) seems to be consistently lower than the median longevity predicted by the coastal zone model (predominantly 6–8 and 10–15 years, Figure 42). Furthermore, the spatial patterns of median longevity differ, with no clear congruence in areas with either low or high predicted median longevity. Although the difference in model input and set-up likely has contributed to these differences, there are potential other reasons. First, the razor clam *Ensis* is an abundant and large bivalve in the coastal zone, and frequently caught in the MWTL macrobenthos survey. Its high longevity (>10 yr) may therefore have led to the relatively high median longevity predictions by the coastal zone model. The Rijnsdorp *et al.* model is based on a much larger dataset, including offshore areas, and the resulting longevity-habitat-trawling relationships from this model therefore did not predict such high longevity in the coastal zone. Second, despite the high longevity of *Ensis,* it is not considered sensitive to trawling. In the Dutch part of the Wadden Sea, density of *Ensis* individuals even increased with increasing fishing pressure (Tulp *et al.*, 2020). An explanation could be that communities and species, such as *Ensis*, occurring in naturally disturbed habitats are already adapted to disturbed conditions (Tulp *et al.*, 2020). There is some empirical evidence that in some cases, natural disturbance induces the same shift in benthic communities as is predicted for bottom trawling (van Denderen *et al.* 2015). Any additional disturbance by bottom trawling would, in that case, not lead to the response (decrease in proportional biomass of long-lived species) which would be expected for communities living in deeper and more undisturbed habitats. A study in the northern part of the Dutch coastal zone even demonstrated that in areas with both high natural disturbance and high trawling frequency, the proportional biomass of long-lived species increased, whereas in areas with low natural disturbance but high trawling frequency, a decrease in the proportional biomass of long-lived species was observed, as one would normally expect (Pérez Rodríguez and van Kooten, 2019). Coastal species living in and adapted to naturally disturbed habitats likely have particular traits that enable them to thrive in disturbed areas, for example the ability of *Ensis* to burrow itself quickly or to jump away, or to colonize new areas quickly after disturbance. For such species, longevity is therefore likely not a good indicator of sensitivity to trawling.

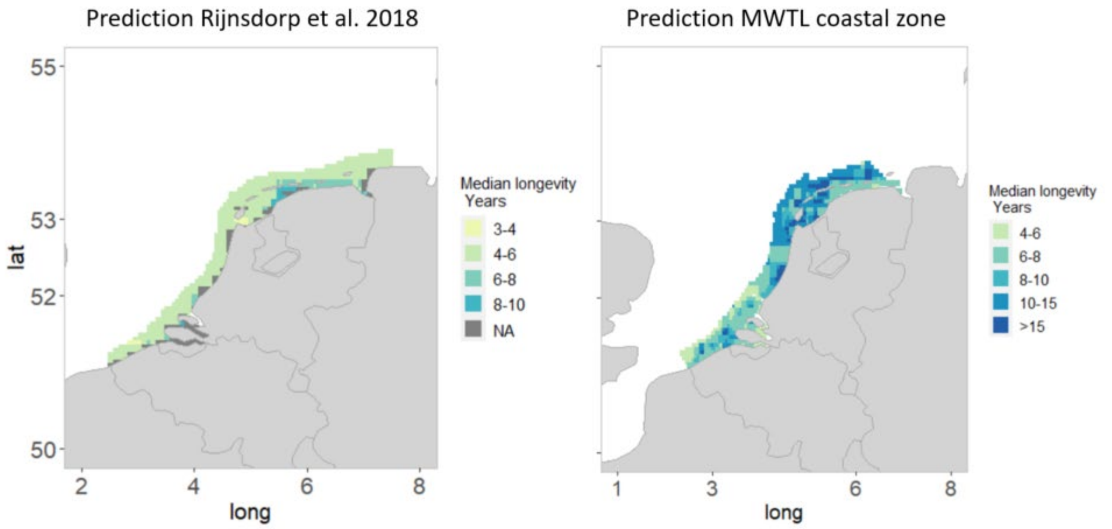


Figure 42. The predicted median longevity by the Rijnsdorp *et al.* (2018) model (left) and the coastal zone model (right).

3.3.3 Validation of the longevity composition of the benthic community at the Brown Bank

The impact assessment model of WGFBIT is partly based on local estimates of the expected community longevity composition (Hiddink *et al.* 2019). For this, longevity compositions have been determined for benthic grab and boxcore stations in the English Channel and the southern and central North Sea, and are subsequently predicted for the entire Greater North Sea based on their relations with some environmental variables (Rijnsdorp *et al.*, 2018). WGFBIT is exploring methods to validate these predicted longevity compositions. As a first step, new datasets are used to perform a direct comparison between observed and predicted longevity compositions. Here, we perform such a comparison using a benthic dataset from the Brown Bank area. This dataset comprises the abundances of benthic macrofauna at 22 stations across the Brown Bank region (Figure 43), collected using a boxcore (Mestdagh *et al.*, 2020).

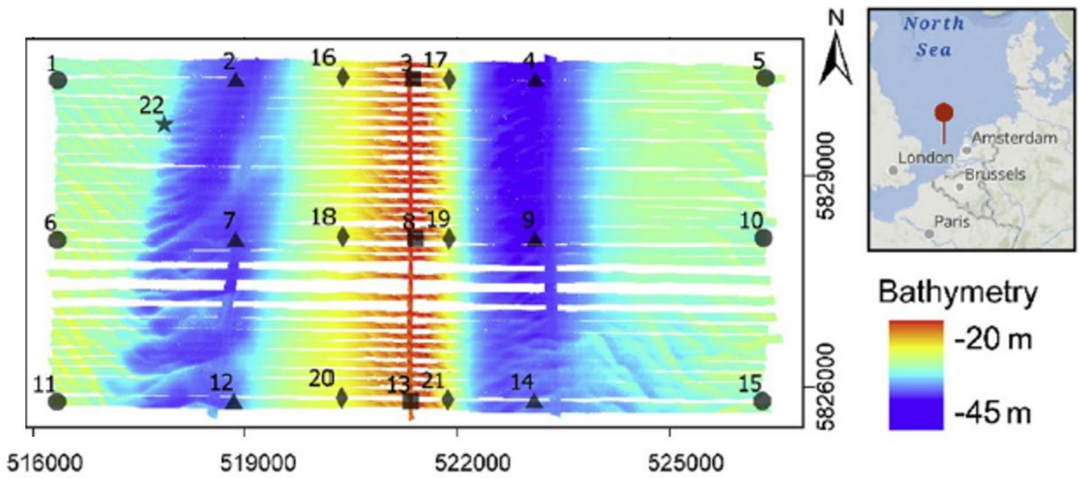


Figure 43. The sampling locations in the Brown Bank dataset and their relation to water depth. Figure adjusted from Mestdagh *et al.* (2020).

Species abundances were converted to biomass, using the genus-specific wet-weight averages as described in Annex 5 of (ICES, 2020). When an observed genus could not be matched, a match was tried at a higher taxonomic level (first order, then class). Abundances of five species were deleted as they could not be converted to a weight. The longevity composition was then determined for each station, by multiplying the biomass with genus-specific longevity estimates (Bolam *et al.*, 2014). The cumulative biomass proportion could then be calculated per station. Next, a generalized linear model (glm) was applied to determine the relation between longevity and cumulative biomass (Figure 44). In (Rijnsdorp *et al.*, 2018), this relation is determined using a Generalized Linear Mixed Model (glmm) that includes longevity and multiple environmental variables as fixed factors and sampling station as a random factor. Our data did not allow for a GLMM, probably because of the possible identification of two groups at a longevity of 1. As we could not identify a logical environmental variable that caused this grouping, we decided to apply a GLM and ignore the differences between stations.

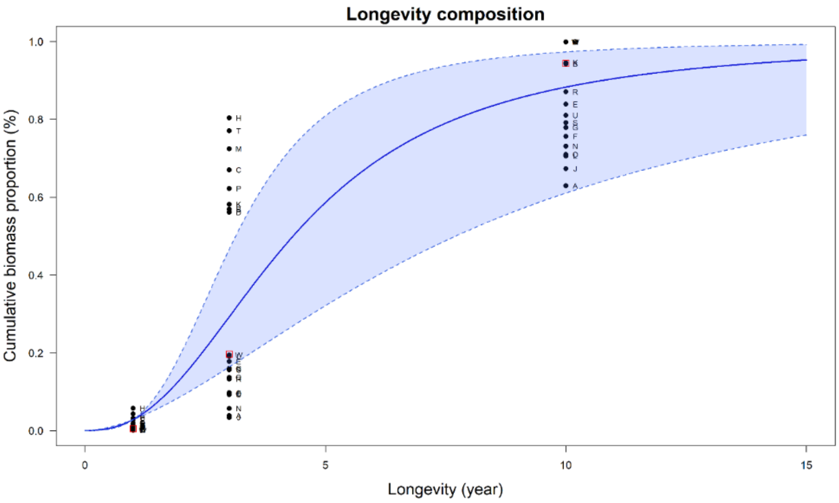


Figure 44. The relation between the cumulative biomassa proportion and longevity for the Brown Bank dataset. Different letters represent different stations. The GLM is shown in blue, including the 95% confidence interval. The red squares show the average of the predicted cumulative biomass proportion at the Brown Bank stations, using the model of Rijnsdorp *et al.* (2018).

The GLM predicts a median longevity of 4.33 for all stations combined, which is rather similar to the predicted median longevity in the currently used model: 4.49. The predicted longevity composition for the stations is also within the range of the observed composition (Figure 44). We therefore can conclude that the predicted longevity closely resembles the longevity composition of the current benthic community.

Rijnsdorp *et al.* take fishing activity into account in their spatial modelling, and the predicted longevity estimates therefore represent unfished conditions (Rijnsdorp *et al.*, 2018). The Brown Bank region, on the other hand, is subjected to high fishing intensities, dominantly from beam trawlers targeting sole (*Solea solea*) (Hintzen *et al.*, 2019; van der Reijden *et al.*, 2018). The close match in longevity estimations is therefore unexpected and may indicate that the predicted longevity estimates do not fully represent unfished conditions.

The analysis also showed that there can be a large local variability of longevity composition, as also observed by (Rijnsdorp *et al.*, 2018). The grouping observed at the Brown Bank can most likely be attributed to the presence of the (biogenic) *Sabellaria* reefs that were found within this area, and that affected the local community composition (Mestdagh *et al.*, 2020; van der Reijden *et al.*, 2019, 2021). However, also the prevailing large- and small-scale morphological structures at the seafloor (sandbanks, sandwaves, megarippels) have been demonstrated to affect the benthic community composition (Damveld *et al.*, 2018; Koop *et al.*, 2019; Mestdagh *et al.*, 2020).

3.3.4 Iberian Coast (opportunistic species response)

The FBIT method assume a decrease of total biomass with fishing effort as part of its theoretical framework. This total biomass decreased is assumed to be more drastic in areas with a higher proportion of long-lived species and less intense in areas dominated by short-lived species, but its correlation with SAR is always negative. However, the analysis of biological samples in the northern Iberian coast show that this is not always the case and positive correlation between trawling disturbance and total biomass have been already described in the area (González-Irusta *et al.*, 2018). Preliminary analysis of this positive correlation shows that species of genus *Munida* (mainly *Munida sarsi* but also *Munida intermedia*) showed a significant and positive correlation with fishing effort across the area, reaching values up to 10t per square km in areas exposed to high levels of trawling (Figure 1). A first analysis of the drivers explaining the distribution of *Munida* spp. in the area using delta GAMs showed that trawling effort have a statistically significant (p-val <0.001) and positive effect on the abundance of *Munida* spp. in the area, especially clear at low levels of trawling (from 0 to 3, Figure 45). These aggregations of *Munida* spp. in area exposed to high levels of trawling seems to be constant across years and seasons (they have been found in summer and fall). Correlation is not causation and therefore is not possible to infer a direct relationship between both variables without further analysis. However, regardless of if there is a direct positive effect of trawling on *Munida* spp. biomass (opportunistic response) or just a coincidence in terms of ecological niche between these species and trawling, together with a tolerant response to the pressure, it seems clear that *Munida* biomass is not responding negatively in this areas to trawling. Because of the high values of *Munida* spp biomass (up to several tons by square kilometre) this also affect to the total community biomass which neither shows a clear negative correlation with trawling (González-Irusta *et al.*, 2018). Similar counter-intuitive effects of trawling on total biomass have been described in other parts of the world and have been recently linked with temperature in the southern North Sea (Clare *et al.*, 2021). Therefore, complementary approaches to the use of total community biomass (or an adaptation of the current method) seems advisable under these or similar circumstances

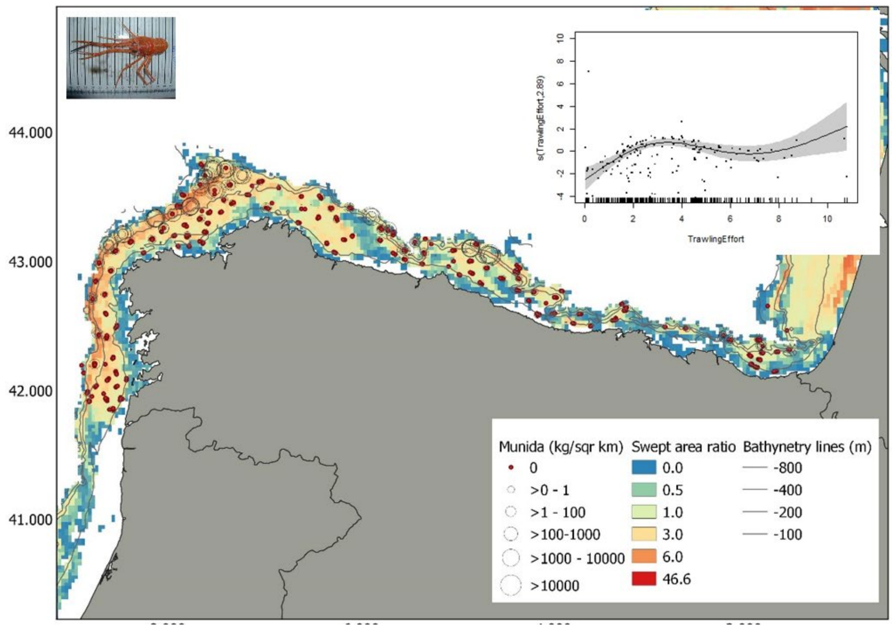


Figure 45. Distribution of swept are ration and *Munida* spp. abundance in the northern coast of Spain and response curve for trawling effort and Munida spp abundance. The curve shows a clear positive effect of trawling on Munida abundance in the first levels of trawling (from 0 to 3) with a less clear trend after these values.

4 Updates of assessment framework (ToR B)

This ToR has the aim to explore and potentially implement options to improve the parameterisation of the WGFBIT seafloor assessment framework components, in shallow waters and deep-sea areas. An essential component of the approach is the depletion rates, which were now available for 10 métiers (Rijnsdorp *et al.*, 2020 and as used in WKTRADE3). Nevertheless, we evaluate the necessity of updating the meta-analyses behind the depletion rates (see section 4.1). Another methodological aspect is the fact that some assessments will be based on epibenthic fauna, whereas other on infauna. Therefore, it need to be investigated if the assessment differs depending on the ecosystem component focused on (section 4.2). Another methodological aspect where recommendations are given is about time scale over which to use SAR for fitting statistical models and executing the assessment (section 4.3). As for some regions, trawl data will be used to reflect the benthic community, recommendations are formulated on which species groups to include/exclude (section 4.4). Finally, both ICES and the Scientific Council of the Northwest Atlantic Fisheries Organization (NAFO) have provided scientific recommendations to managers in support of the protection of vulnerable marine ecosystems (VMEs) from bottom contact fishing gears. Therefore, a joint session was organized as outlined in section 4.5.

4.1 Gear-specific depletion rates (ToR B/D): way forward

The most up to date depletion rate estimates for different métiers is available from Rijnsdorp *et al.* (2020); (Table 23). This updated parameterisation is included in the FBIT script and protocol (see technical guidelines) and used for the assessments in WKTRADE 3 (ICES, 2021).

Table 23. Gear types, target species and depletion rates for the 10 different metier types (Rijnsdorp *et al.* 2020).

Metier	Main gear type	Target species assemblage group	Main target species	Depletion rate
DRB_MOL	Dredge	Molluscs	Scallops	0.200
OT_CRU[1]	Otter trawl	Crustaceans	Nephrops, Pandalus, mixed fish	0.100
OT_DMF	Otter trawl	Demersal fish	Cod or plaice	0.026
OT_MIX[2]	Otter trawl	Mixed fish	Mixed fish	0.074
OT_SPF	Otter trawl	Small pelagic fish	Sprat or sandeel	0.009
SDN_DMF	Danish seine	Demersal fish	Plaice, cod	0.009
SSC_DMF	Flyshooter (seine)	Demersal fish	Cod, haddock, flatfish	0.016
TBB_CRU	Beam trawl	Crustaceans	Brown shrimp	0.060
TBB_DMF	Beam trawl	Demersal fish	Flatfish	0.140
TBB_MOL	Beam trawl	Molluscs	Whelk, snails and scallops	0.060

- [1] including OT_MIX_CRU and OT_MIX_CRU_DMF
- [2] including OT_MIX_DMF_BEN, OT_MIX_DMF_PEL

An extra modification to the depletion rate is to include habitat type, so there are habitat specific depletion rates. This is investigated in the paper of Pitcher *et al.* (2022). Once this paper is published, the outcome can be used and implemented in the FBIT script.

On the longer term, it is necessary to update the meta-analyses behind the depletion rates, as this meta-analyses is based on literature up to 2014 and almost no info for deep water fauna (Sciberras *et al.* 2018). It is advised to include such work in a research project and therefore put this question on the EU research agenda (E.g. through the FARO directors, …).

Two other related discussion points were raised and tackled.

- Can species/functional group specific depletion rates be incorporate into the FBIT approach?
    - It is possible, but very complex, as for example underlying species/functional group distribution maps are needed. Besides, the concern was raised that this high level of detail does not guarantee a considerable improvement in the approach. Nevertheless, a more detailed depletion estimate could be explored in the case for assessments of habitat/species of conservation concern (vulnerable & biogenic/geogenic reef habitats and their species).
- The values used to estimate the depletion rates are mainly based on infauna. Are therefore those values relevant for epifauna (surface living) as well?
    - Actually, it is based on both epifauna and infauna. This can be checked when an update of the meta-analyses will be done, but based on the previous analyses, the values seems to be close to each other for infauna and epifauna (pers. Communication Jan-Geert Hiddink).

4.2 Benthic data samples with different gears: assessment consequences

Problem setting

The modelled sensitivity layer is for the NS and BS based on biomass longevity data, obtained from grab samples. In most other regions, the sensitivity layer will be based on data from trawl samples, possibly combined with grab sample data when available. Trawl data is generally better available because it originates from the national fish trawl surveys, whereas similar surveys for benthos do not exist. However, trawls generally target a different component of the benthic communities, with higher catch rates for the larger epibenthic species. Grabs, on the other hand, dominantly catch the smaller endobenthic species. It can be expected that this causes for differences in the longevity estimates, with the epifauna-dominated trawl samples having a higher longevity than the endobenthos-dominated grab samples. This may also be region dependent. This could result in deviating predictions of the sensitivity layer, which could subsequently result in differences between RBS-estimates.

WGFBIT therefore wants to investigate the exact differences between grab and trawl samples. A first step was taken by creating an inventory of datasets that could be used for such comparisons (Table 23). This list will be used in the coming 2 years to execute some dedicated analyses in certain (sub-) regions. For example, a comparison between trawl and grab data is foreseen for the North Sea area in the coming year, under the EU 'SEAwise' project (a lot of datasets are highlighted in Table 24).

Table 24. Overview of potential datasets for comparing sensitivity predictions from grab and trawl samples.

Dataset	Area	Sampling type	Period	Benthos biomass data?	Other remarks
Beam Trawl Survey (BTS)*	North Sea	Beam trawl	Annual in quarter 3	Yes	Available via DATRAS, large spatial content.
International Bottom Trawl Survey (IBTS)	North Sea	GOV-trawl	Annually in quarters 1 and 3	Unknown	Availability of benthic data probably varies between participating countries. Very large spatial coverage
MAFCONS	Central North Sea	2m beam trawl (Jennings *et al.*, 1999)	2003–2004	Some, but mostly abundances in number	Data not publicly available.
North Sea Benthos Survey 1986	North Sea	Grabs, boxcore	Around 1986	Density in numbers	Data available from EMODnet.
North Sea Benthos Survey 2000	North Sea	Grabs, Boxcore	Around 2000	Density in numbers	Follow-up of the NSBS’86, but data are not presented as 1 dataset. Instead, individual datasets (unsure which ones exactly) can be downloaded from EMODnet.
Dredge data NIOZ	North Sea	Triple D dredge	Unknown	Unknown, but most likely numbers.	Data not publicly available, and unknown what it exactly comprises.
MAREANO programme	Norwegian Sea and Barents Sea	Beam trawl, grabs, RP sledge	2006–2017	Yes	Data available from EMODnet.
MEDITS survey	Mediterranean east	Otter trawl	Annually	Unknown	For Mediterranean east, currently grab is used, data available at HCMR
MEDITS survey	Adriatic Sea (North & South)	Trawl	Annually		Several grab data available for certain areas (need to be further specified/explored)
Trawl survey (IVANHOE)	Celtic Sea	Trawl	Annually	yes	Grab data (CEFAS) for Celtic Sea (ICES, 2020)

* The SEAwise project will focus on producing a longevity-based sensitivity prediction based on benthic biomass observations from the Beam Trawl Survey. This layer can then be compared to the current sensitivity layer for the North Sea, which is based on grab data.

Considerations

In the discussion, some considerations on this kind of analyses were raised, and should be taken into account in the future analyses, so recommendations can be formulated for it.

- Important note: trawl benthos data has increased identification quality over the years.
- How to ensure that the trawling samples are **representing a ‘pristine’ community**?
  - Trawling samples themselves are per definition subjected to trawling, especially when sampling locations of the surveys are fixed over the years. However, the first step would be to match trawling stations to commercial fishing activity (SAR). Chris’ analysis showed that sampling locations with a SAR <0.5 are usually ‘pristine’.

- What taxa to include?
  - Highly mobile, pelagic species should be excluded, but what about commercial species? We suggest to perform the analysis with and without commercial species. On the one hand, they should be included as they are part of the system, but they may on the other hand blur the FBIT analysis, e.g. due to their high biomasses in areas with high fishing pressure, which would provide a reason to exclude them. It is not clear when a species is considered to be highly mobile. Then there are small benthic fish, such as gobies, that could be considered part of the benthic system, especially small burrowing species. It is also unclear how to determine whether a species is territorial enough, or whether it is too mobile. Hence, we advise to exclude all fish, to avoid this discussion. Further recommendations are given in chapter 4.4.
- Catchability of species…
  - It matters whether you are looking at epifauna or all megafauna. What about catching bivalves (that are part of the endobenthos)? This relates to catchability of species and whether that is consistent between habitats. Pascal mentioned that he uses trawl samples to predict benthic communities only within the habitat the sample was obtained. Gert and Chris do not expect that this is really problem, as the modelling includes the relation between community composition and habitats.
- Can we create a **super-benthic-dataset**, were we compile all available benthos data, while correcting for catchability?
  - This probably takes too much work, while the results may not be useable (epifauna will dominate the endobenthos based on biomass). In the deeper parts of the Mediterranean, differences in the boxcore surface size is causing for incompatibility between surveys, because the number of species observed are so different. This will probably be similar for trawls with different trawl durations.

4.3 Time scale over which to use SAR 1) for fitting the statistical models and 2) for the final assessments

The PD model is based on the equilibrium solution of the logistic population growth model, and that means that the outputs assume that the benthic community is in equilibrium with the fishing intensity quantified as the swept-area-ratio. Similarly, when fitting the statistical models, it is likely that the observed state of the benthic community from samples is the result of the amount of fishing in a period several years previous to sampling. The key is to decide how many years of fishing effort data to average over for both applications. It is probable that the most recent years of fishing activity have the largest impact on the current state of the benthos, because recovery from fishing longer ago would reduce the impact of historic fishing. However, the relevant period is likely to depend on the life-span and recovery time of the dominant species in the community. E.g. if only very short-lived species occur, a very short fishing intensity time frame would be more appropriate than when most species are long-lived. In most communities, most biomass in unfished communities seems to be positioned in the 3–10 year longevity class. The time to recovery of 0.95 x K is a function of longevity and the starting B/K as:

Recovery time =(longevity/5.31)*(log((0.95* B/K)/((1-B/K)*(1–0.95)))) (Hiddink *et al.*, 2017)

This means that the recovery time is a function of longevity, and that recovery from 0.5K to 0.95K takes 0.55 x longevity (years). This suggests that averaging the SAR over a period of between 0.5x longevity would seem appropriate. An average SAR over a 3-to-6-year period is therefore considered suitable for both purposes. On the other hand, if the spatial pattern in trawling intensity is stable over time, like it is for many fisheries, the outcome of the assessment would be the same regardless of the time-period chosen.

4.4 What species to include as part of the community when estimating the cumulative biomass ~ longevity relationships?

The FBIT methods are designed to assess the impact on the benthic invertebrate community for each grid cell. The state of the benthos in a grid cell will therefore be appropriately predicted for species that have a low mobility. Benthic samples often contain species that may not be part of the low-mobility of the invertebrate community, like squid or fish. Such species should be excluded from samples before analysis. Low-mobility cephalopods, such as octopus and sepiolids can be included.

Benthic samples also often contain species of relatively large and long-lived benthic invertebrates that may be the target of the commercial fishery, such as large shrimps, *Nephrops norvegicus* and *Pecten maximus*. Although these species are part of the assessed benthic community, the precise targeting of the distribution of these species by commercial fisheries may lead to positive correlations between their biomass and swept-area-ratio that are not representative of the general effect of bottom trawling on benthic fauna. This in turn may cause problems when fitting the cumulative biomass~longevity models, leading to suggestions of positive effects of fishing on the relative biomass of longer-lived biota. These commercial species can however have large effects on some ecosystem processes. For example, the Norway lobster *Nephrops norvegicus*, creates large burrows and moves a lot of sediment and is likely to strongly affect biogeochemical processes. It is therefore likely to be important to take account of the contribution of such commercial species to ecosystem processes.

It is therefore recommended to investigate the effect of including or exclude the target species of the fishery when fitting the statistical relationships. Excluding can be preferable, due to the above described effect, but this need to be investigated, before a final advice is formulated. Therefore, it is recommended that the regional assessments record and justify the exclusion of species from analyses.

4.5 Deep-sea

Deep-sea Trawling Impacts Assessment*: identify the opportunities and agree a timetable for WG-ESA and WGFBIT collaboration*

- general on-going **cooperation between WG-ESA and WGFBIT** (Andy Kenny)
- recent discussion around **applying the WKEUVME methods** to NAFO data (Ellen Kenchington)
- Use of NAFO **VME biomass data bottom trawling impact data** for deep sea seabed fishing disturbance assessments (Andy Kenny, Anna Downie and others)
- The use of **Predictive habitat modelling** in the assessment of **Significant Adverse Impacts** (Daniel van Denderen)

WGFBIT and WGESA met and exchanged information on the different assessment approaches and their underpinnings. Below we report on this exchange.

To assess Significant Adverse Impacts (SAI) by bottom trawling activities in the NAFO Regulatory Area (NRA), NAFO created a gridded layer of fishing effort (km fished/km^2/yr) using VMS data (2010–2019) and a 1km^2 gridded layer of VME biomass data derived from an extensive survey of fishery independent trawls recording VME indicator species biomass. Combining these two data sets has allowed an estimate of bottom trawling impact on deep sea VME to be determined which is similar to the benthos depletion estimates developed by WGFBIT. To determine if an impact is 'significant' a fishing effort impact cut-off value has been derived which corresponds to a level of fishing effort where 95% of the biomass has been impacted (or removed) by trawling. This cut-off value is then applied to the fishing effort layer associated with each of the VME polygons to determine the total area of VME impacted (all areas above the cut-off value) and the total area of VME at risk of impact (all areas below the cut-off value). Following the presentation made by FBIT it is apparent there would be benefit in using the NAFO deep sea VME and SAI data to plug a data gap in the FBIT approach for the assessment of deep sea fishing impacts on VMEs. Furthermore, it would be interesting to understand and possibly apply the FBIT methodology to assess SAI in NAFO, thereby potentially unifying the assessment methods currently being applied to continental shelf and deep sea ecosystems in the North Atlantic. WG-ESA will be meeting between 15 and 24 November 2022 in Halifax, Canada and it is hoped that some members of WG-ESA will be able to join the WGFBIT meeting next year.

Both ICES and the Scientific Council of the Northwest Atlantic Fisheries Organization (NAFO) have provided scientific advice to managers in support of the protection of vulnerable marine ecosystems (VMEs) from bottom contact fishing gears. Each organization has taken a different approach to the provision of this advice, shaped by the data available for analyses. In NAFO, an extensive database of research survey invertebrate bycatch (over 5000 random stratified tows) has enabled a quantitative identification of VMEs based on a combination of high biomass and discreteness identified using kernel density estimation. This approach is unique amongst Regional Fisheries Management Organizations but has been applied in Canada where similar rich datasets exists. Species distribution modelling and in situ camera surveys provided supporting evidence for the location of the VME habitats. In ICES, the workshop WKEUVME which was held in the spring of 2020, developed a data-driven approach to provide management options for the protection of VME in EU waters. Two broad scenarios were provided, each with a set of rules defined for producing the outcomes. The first scenario defined VME closure polygons without any modification by known fishing activity; the second scenario identified areas where the fishing footprint overlapped with Scenario 1 and then used VME biomass/fishing intensity relationships to identify a threshold for areas where effort was low and unlikely to have caused significant adverse impacts to the VMEs-opening those areas above the threshold. Within each scenario two options were provided based on the level of uncertainty associated with VME presence. The data on the VMEs comes from a variety of sampling gears and is held in the ICES VME Database where it has undergone QA/QC evaluations. The ICES VME Index is used to identify the location of the VMEs, and the WKEUVME outlined a series of steps for amalgamating C-squares (the base resolution in the ICES advice) under the management options. During the WGFBIT meeting the ICES WKEUVME steps for Scenario 1 were applied to the NAFO data and the resultant maps compared with the areas closed to protect VME. Some differences were apparent and it was suggested that the NAFO data could be a useful input to a proposed benchmark workshop to establish an ICES procedure for the production of evidence-based advice on the occurrence of VMEs and management options to prevent significant adverse impacts by fishing activities on such ecosystems (WKVMEBench).

WKPHM and WGMHM: Contributions towards ICES VME advice

ICES provides advice to NEAFC and the EU on where VMES are known or likely to occur. To this date, the advice is based on records from the ICES VME database, including bona-fide VME records (e.g. observations from ROVs) and records of possible VME with varying uncertainty (e.g. by-catch of VME indicator taxa). The observations are used to compute a VME index at the c-square resolution.

In the last few years, the ICES community has been discussing the possibility of using predictive habitat models (a.k.a. habitat suitability or species distribution models) to identify areas where the presence of VMEs is likely. In 2021, the ICES Workshop on Predictive Habitat Models (WKPHM) was convened to establish a set of criteria to evaluate existing and new models that could be used for providing advice. A total of 48 evaluation criteria were defined, each one with three levels: "unacceptable", "required", and "desired". The criteria included all aspects of the modelling process, including evaluation of dependent and independent data, the modelling process itself (methods, evaluation of uncertainty, etc.), and model outputs.

The next step was carried out during the 2021 meeting of the Working Group on Marine Habitat Mapping. During this meeting a literature search to identify PHMs of VMEs and VME indicator taxa in the North Atlantic and Mediterranean Sea. The criteria developed in the WKPHM was applied to the 38 identified models. In addition, modifications to the criteria were suggested. A large proportion of models reached the "required" level in most criteria.

Discussions at the meeting identified potential synergies between the FBIT and ESA work. The wealth of data in the NAFO area could allow estimating the recovery rate parameter r, if the depletion d and the SAR can be estimated for the fishery. This, in combination with species distribution models, may allow the estimating of impacts on VMEs in the NE Atlantic. This will be explored at next year's meeting.

5 WGFBIT and the wider world (ToR C)

The WGFBIT seafloor assessment framework (based on assessing the relative benthic state) is not the only way to assess benthic impacts from physical disturbance. Therefore, comparison with other methods (alternative assessment methods) needs to be explored.

What do we consider under alternative assessment methods?

- We consider primarily assessment methods that were used or proposed for assessment of D6 "Seafloor integrity" under the MSFD by countries or regional organisations (the sea conventions, ICES). These methods should aim to assess areal extent of habitat that is impacted or under/above GES (D6C3 criteria).
- Although relevant, assessment methods that evaluate impact on benthos in relation to impact gradients or which are under scientific development, fall outside FBIT's scope for the moment to use them for assessment validation.

At the meeting, we discussed how such comparison should be structured and what the key aspects are. This will also be taken forward in an upcoming EU Request to ICES (Review, evaluation and advice on methods to assess adverse effects on seabed habitats for MSFD purposes). A key aspect in this advice is to set up a common framework to benchmark methods to assess benthic risk (model) and state (data) indicators, with respective threshold values. This should be done based on some cases with appropriate benthic data for this purpose.

This all fits under the umbrella of the MSFD descriptor 6 "Seafloor integrity" assessment, wherefore 5 criteria were defined. Benthic indicators were used to evaluate criteria D6C3 ("Adverse effects of physical disturbance on habitat") and D6C5 ("Condition of habitat) (Figure 46). In the current scientific developments to evaluate those criteria, two type of benthic indicators are developed. One type are the "risk" indicators, which try to estimate the effect of physical disturbance on the benthic habitat community by means of a modelling approach. In other words, they estimate the potential (risk) effect (impact) of a certain physical disturbance level on the benthic community state. Examples of those risk-based indicators is the FBIT approach (relative benthic state), OSPAR BH3 and the HELCOM Cumuli. The other type of indicators are identified as "state" indicators, as they have the purpose to judge on the "real" state of the benthic community, based on benthic variables (diversity, abundances, …) derived from specific derived monitoring data. Examples of those indicators are the WFD benthic indicators (m-AMBI, IQI, BQI, BEQI, …) and the OSPAR indicators BH1 and BH2, among a lot of others.

Therefore, state indicators are assessing the quality, whereas the risk indicators are assessing the risk in reduced quality status. Risk indicators are suited for large scale assessment and more easily extrapolatable than state indicators. Whereas state indicators are a more local assessment based on real monitoring data of the assessment period.

To compare the various indicators, developed for different purposes, it is important to know what is compared. Besides, a methodology need to be developed to standardize this comparison. In the Water Framework Directive, an intercalibration procedure is set-up to test indicators and their thresholds in a statistical way (e.g. benthic indicators Van Hoey *et al.*, 2015). On one side it is based on a correlation analyses, where the different indicators have to show their comparability among a common yardstick. Secondly, the class bias and class differences are evaluated, which has to fall within a certain deviation class. Otherwise, the indicator has to adapt its boundary thresholds, to align the indicator with the other ones.

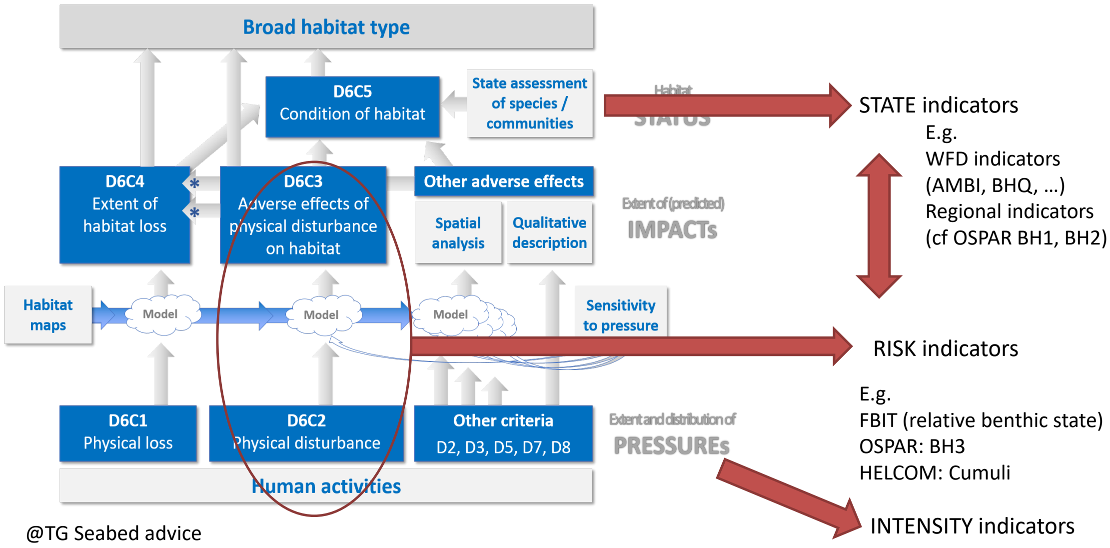


Figure 46. MSFD Descriptor 6 'Seafloor integrity' and the place of state and risk indicators to assess the benthic seafloor ecosystem for criteria D6C3 and D6C5.

Of course, the MSFD has the purpose to avoid such detailed and long-lasting intercalibration process, but certain level of comparison among indicators seems necessary. This can be seen as a kind of benchmarking process of the MSFD indicator methodologies. This process will probably be discussed in a separate ICES workshop, based on the EU request. This can then further be used in WGFBIT to check the comparability of benthic indicators assessing fishery impact. In first instance, it shall be on the level of comparing the risk-based indicators among each other's. At a second level, it can be comparing the outcome of the risk and state indicator(s) for a certain (sub-) area.

6 Ecosystem functioning (ToR D)

The goal of ToR d is to explore if ecosystem functioning can be incorporated more explicitly in to the WGFBIT seafloor assessment methodology. In this report, a start is given to explore the possibilities and necessities to perform this.

Marine sediments harbour significant levels of biodiversity that play a key role in ecosystem functions and services such as biogeochemical cycling, carbon storage and the regulation of climate (Covich *et al.* 2004; Solan *et al.* 2004). Bioturbation and bioirrigation, the faunal behaviour that results in particle displacement and increased exchange of solutes (e.g. O2, CO2, dissolved organic matter, inorganic nutrients) across the sediment-water interface and within the sediment matrix (Kristensen *et al.* 2012; Wrede *et al.* 2018), constitute significant drivers of ecosystem functioning (primary production, benthic-pelagic coupling, biogeochemical cycling) (Lohrer *et al.* 2004; Middleburg 2018).

Ecosystem functioning is defined here, as the movement and transformation of substances within the ecosystem (Boero & Bonsdorff 2007; Hooper *et al.* 2005). This encompasses the movement of carbon in a food web, the incorporation of nutrients into organic matter through primary production, and the degradation of organic matter into inorganic bioavailable forms. All processes and organisms are essential for the functioning of ecosystems, and they are deeply interconnected.

By depleting fauna and changing the species composition, bottom fishing results in alterations in the functional effect traits (bioturbation, bioirrigation) of a community, which in turn may have broad implications for the overall ecosystem performance (Figure 47). The relocation of organic matter and resuspension of sediment due to trawling will also have a direct effect on the biogeochemical cycling, which will in turn potentially influence trait – bgc relationships.

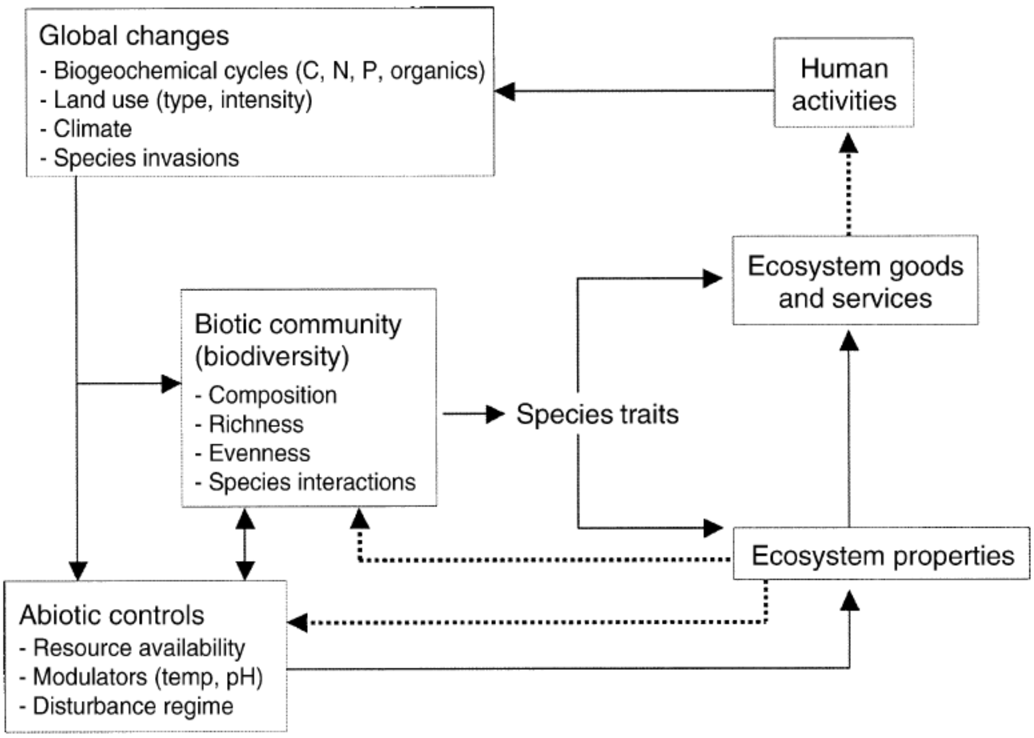


Figure 47. Feedbacks between human activities, global changes, and biotic and abiotic controls on ecosystem properties. Bottom fishing may alter both the biotic community and abiotic conditions (e.g. porosity and pH) that influence process rates and control ecosystem properties. Changes in ecosystem properties can feed back to further alter the biotic community either directly or via further alterations in abiotic controls (dotted lines). Feedbacks from altered goods and services can lead to modification of human activities. This figure is taken from Hooper *et al.* 2005.

The current PD method utilized in the WGFBIT assessment method combines information on total benthic biomass with the relative abundance of different longevity classes to estimate the relative impact of different types of fishing on the seabed. The working assumption of this method is that high community biomass will coincide with communities where the body size distribution, age structure as well as numbers of the benthic fauna are close to natural, and thus a community where its ecosystem functioning is less likely to be impaired by trawling. A caveat of this, however, is that total community biomass does not necessarily reflect changes in species and functional trait composition which play a key role in regulating ecosystem functions.

An improved understanding of the relationships between total community biomass and ecosystem functioning may assist in setting acceptable thresholds for ecosystem impacts from trawling. Furthermore, an improved understanding of the link between species functional effect traits and proxies and processes for specific ecosystem functions could help increase our ability to predict the impact of fishing disturbance on benthic ecosystem functioning more accurately.

In this ToR we set out to explore how ecosystem functioning can be incorporated more explicitly into the WGFBIT assessment methodology. The ecosystem function we focus on is the biogeochemical cycling of organic matter. Two approaches are being explored:

1. Biological traits approach focuses on the linkage of biological traits such as bioturbation, bio-irrigation and filter feeding capacity with ecosystem functions such as carbon mineralization and nutrient cycling. The premise of this approach is that ecosystem functions have well-established relationships with biological communities. While the relationships may be clearly established for individual species in mesocosm experiments (e.g. Braeckman *et al.* 2010; Olsgard *et al.* 2009), it should be examined whether we can reliably relate traits on a community and regional scale to ecosystem functioning (more details in section 6.1).

2. Biogeochemical modelling approach using OMEXDIA model (Soetaert *et al.* 1996). Whilst the biological traits approach focuses more on the effect of trawling on ecosystem functioning through the loss of biota, the biogeochemical modelling approach also considers changes in functioning due to changes in the biogeochemical nature of the sediment due to sediment erosion, mixing or deposition (more details in section 6.2).

6.1 Fauna functional traits and ecosystem functioning

6.1.1 Infauna functional traits and sediment biogeochemistry

Presented by Ulrike Braeckman (guest speaker)

Taxonomic identity, abundance or biomass of species alone have little power in explaining ecosystem processes (e.g. bioturbation, oxygen consumption, denitrification), as these processes are determined by the ecological effect traits of the organisms involved (Covich *et al.* 2004; Hooper *et al.* 2004; Braeckman *et al.* 2014). Functional effect traits comprise all characteristics of organisms which may affect their habitat and thus the functioning of the surrounding ecosystem.

Trait-based indices provide a useful tool for the prediction of biogeochemical cycling where these have been empirically shown to relate to biogeochemical proxies (e.g. aRPD) and processes (e.g. oxygen consumption, denitrification) that support biogeochemical functions. Two such indices are the bioturbation potential of the community, BPc (Solan *et al.* 2004) and the irrigation potential, IPc (Wrede *et al.* 2018). Studies have linked the BPc to biogenic mixing depth, total organic carbon content, chlorophyll concentrations, oxygenation depth, sediment oxygen consumption, ammonium efflux and denitrification (Birchenough *et al.*, 2012; Braeckman *et al.*, 2014; Gogina *et al.*, 2017, 2020; Toussaint *et al.* 2021). IPc has been correlated with bioirrigation rate, nutrient flux across the sediment water interface, and bioirrigation depth (Neumann *et al.* 2021; Toussaint *et al.* 2021; Wrede *et al.* 2018, 2019). It is thus justified to apply these biotransport indices to estimate macrofaunal impact on biogeochemical processes where a correlation has been empirically shown to exist.

These relationships, however, are both region- and sediment type-specific. For example, whereas the BPc was shown to be a good predictor of oxygen and nutrient fluxes at the sediment-water interface in the Belgian and German part of the North Sea (Braeckman *et al.*, 2014; Neumann *et al.* 2021), it was not found to correlate with nutrient fluxes in the German part of the Baltic Sea and in permeable sediments (Braeckman *et al.* 2014; Gogina *et al.* 2018).

A caveat of trait-based indices such as the BPc and IPc is that they are static descriptors, and do not account for changes due to seasonality, life history and species interactions. Nevertheless, indices such as the BPc are useful to understand the role of fauna in mediating bgc and how the BPc-bgc relationships change in space, time and with trawling impact. Empirical testing of these relationships should take into account sediment differences and other environmental variables (e.g. temperature) that influence community composition and dynamics.

6.1.2 Linking infaunal traits, biogeochemistry and bottom trawling

Presented by Clement Garcia

Physical (sediment, porosity), biological (infauna abundance and biomass) and biogeochemical (pigment, carbon, oxygen and nutrients) data collected from 55 stations in the southern part of the Celtic Sea were examined to explore the relationships between functional traits of sediment dwelling invertebrates and seabed biogeochemical processes (Figure 48, Table 25, Table 26). The sites were divided into two (roughly equal) groups; “undisturbed” and “disturbed” according to VMS data. The relationship between traits and biogeochemical metrics was explored using a Co-Inertia Analysis (CoIA), a two-table multivariate method that simultaneously ordinates both sets of variables onto the same reduced space (scaled PCA – biogeochemistry & fuzzyPCA – Hellinger-transformed biomass-weighted trait data).

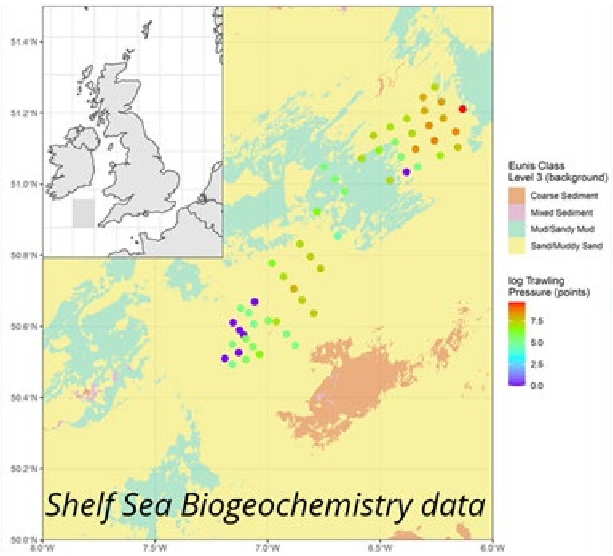


Figure 48. Location of 55 stations in the southern Celtic Sea where physical, biological and biogeochemical data was collected at each site.

Table 25. Biological traits related to bioturbation and bioirrigation potential of infaunal species.

Trait	***Attribute***	***Code***	***Trait***	***Attribute***	***Code***
Feeding mode	Suspension feeder	Fsp	**Mobility**	Sessile or slow moving	M1
	Surface deposit feeder	Fsf		Burrower	M2
	Sub-surface deposit feeder	Fss		Crawler	M3
	Scavenger or opportunist	Fsc		Swimmer	M4
	Predator	Fpr			
Bio-irrigation	iLow	Q1	**Sediment position**	Surface	Sd0
	iMedium	Q2		Shallow depth (0-5cm)	Sd1
	iHigh	Q3		Intermediate depth (5-10cm)	Sd2
Sediment reworking	Diffusive mixing	Rdif		Deep (>10cm)	Sd3
	Surface deposition	Rsf	**Maximum size**	<10mm	B1
	Upward conveyor	Rup		10-20mm	B2
	Downward conveyor	Rdow		21-100mm	B3
	Surface modifier	Rmod		101-200mm	B4
	Sediment regenerator	Rreg		>200mm	B5

Table 26. Biogeochemical data examined.

Biogeochemistry		
Chlorophyll *a*	µg/g	Quantity of phytodetritus
Phaeopigment	µg/g	Measure of phytoplankton degradation products
Organic carbon	%m/m	Quantity of organic carbon
Organic nitrogen	%m/m	Quantity of organic nitrogen
C:N ratio	Unitless	Proxy of carbon liability: high = old & refractory
Oxygen penetration depth	cm	Depth below which free oxygen is no longer present
Nutrient* slope upper	µmol/mm	Rate of change between 0 and 2cm depth
Nutrient* slope lower	µmol/mm	Rate of change between 2 and 5cm depth
Nutrient** concentration upper	µmol/L	Integrated concentration between 0 and 2cm depth
Nutrient** concentration lower	µmol/L	Integrated concentration between 2 and 5cm depth

Significant correlation between the suite of traits and the biogeochemical makeup was observed in both disturbed and undisturbed sites (undisturbed: n = 28, RV = 0.28, p-value = 0.0339*; disturbed: n=27, RV = 0.31, p-value=0.0192*). Sediment type described by % silt – OPD (axis 1) and Nutrient concentration – Carbon (axis 2) exerted a strong influence in driving the trait-biogeochemistry linkages. Correlations found three and four groups of trait-biogeochemistry linkages in the undisturbed and the disturbed set of sites respectively.

Segment size denoted the site-specific position in the CoIA reduced space (axis 1 and axis 2) of the infaunal trait suite (i.e., "trait space") relative to the local biogeochemical composition (i.e., "biogeochemistry space"). A short segment indicate a tight link between traits and biogeochemistry (similar position in the ordination) while longer size implies a looser connection between both set of variables. Undisturbed site segment sizes overall present a mixture of large and small segments indicating variable positions in the trait-space relative to the biogeochemistry space while disturbed site segment sizes have smaller overall difference between the longest and the shortest segments. This could be explained by lower redundancy within the disturbed sites due to fewer species overall.

6.2 Biogeochemical modelling: OMEXDIA model description

Presented by Justin Tiano

OMEXDIA is a benthic biogeochemical model, which can predict organic matter concentrations and degradation rate processes occurring within the sediment (Soetaert *et al.* 1996). This model uses estimates of organic matter (OM) influx (which can be estimated with oxygen/dissolved inorganic carbon [DIC] fluxes), and separates OM into fast and slow decaying fractions, which drive the recycling and sequestration of bioavailable carbon, nutrients, and oxygen within the top 10–20 cm of sediment (Figure 49). Oxic OM degradation and denitrification processes are explicitly modelled. The various anoxic OM degradation pathways and the compounds formed from them are combined in the model to create 'oxygen demand units'(ODU's) as they consume oxygen when they diffuse towards the sediment surface and are oxidized. The model output predicts for sedimentary OM, oxygen, nitrogen, phosphorus, DIC as well as their fluxes from the sediment to the overlying water. The model can be run dynamically to predict changes over time.

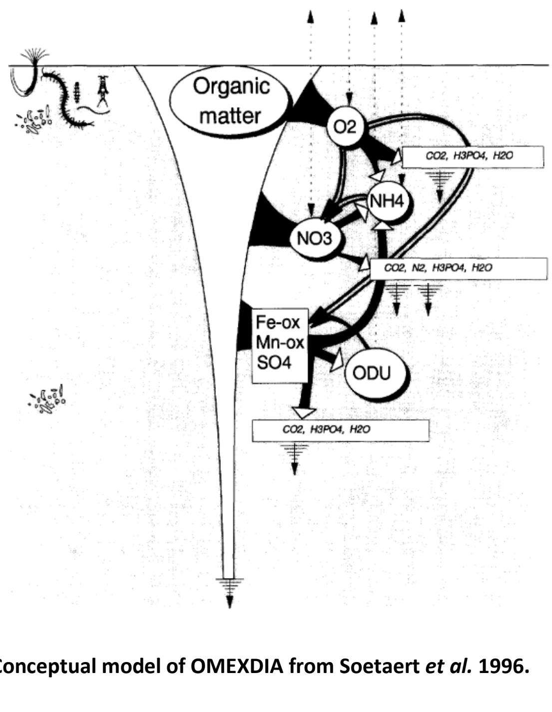


Figure 49. Conceptual model of OMEXDIA from Soetaert *et al.* 1996.

Trawling application

OMEXDIA can be used to assess disturbances by simulating different combinations of sediment erosion, mixing, and deposition. The model has been used to predict the effects of bottom trawl disturbances by simulating the removal (erosion) of the surface sediment layer and the homogenization (mixing) of the sediment underneath (Figure 50). Trawl disturbance scenarios from 5 North Sea habitats were published in Biogeosciences (De Borger *et al.*, 2021a). Several other North Sea habitats have been parameterized for OMEXDIA (De Borger *et al.*, 2021b) making them suitable to carry out trawling scenarios. Parameterization of sediments assumes that the sediments are in a steady-state conditions (whether they are historically disturbed or not) and recovery is based on how long it takes for parameters to return to this original steady state. It is important to note that, trawling scenarios have only been used to estimate effects of trawling on direct impacts (inside the trawl track) in idealized (no outside effects) circumstances. Effects of trawl induced sediment or OM deposition (indirect/regional effects), for example are very relevant but much more complicated to predict.

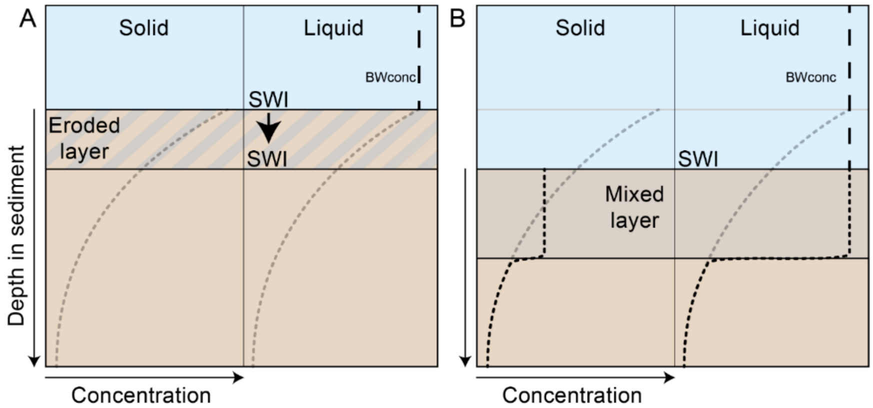


Figure 50. Simulated erosion and mixing caused from bottom trawling from De Borger *et al.* (2021a).

6.3 Next steps: Linking fauna functional traits to sediment biogeochemistry

On 24 November 2021, we held a hybrid (online/in person) brainstorm session on how to best to use biological traits to link trawling disturbance with ecosystem functioning. The original objective of this meeting was to create a conceptual model of how biological traits are linked to certain functions. To this end, three processes (biodeposition, bioturbation and bioirrigation) and their associated traits were identified as important to link with the depletion and recovery after trawling to best predict the effects on faunal-mediated ecosystem functioning. The main discussions and corresponding output of this session, resulted in a consensus to carry out (a) multivariate analysis to link biological traits to biogeochemical proxies and processes, and (b) methodological development of a biological model using trait-specific depletion (d) and recovery (r) values to examine effect of trawling on biogeochemical cycling.

6.3.1 Multivariate analysis to link traits to biogeochemical proxies and processes

We plan to explore the relationship between effect traits (and their modalities) and specific biogeochemical processes, using data sets where both species (trait) and biogeochemistry (bgc) data are available for the same sampling sites. The results will intrinsically include ecological effects such as density dependence, compensation, competition and other species interactions that in reality affect the net effect of community (trait) structure on bgc processes – something that is not currently captured by the proposed modelling.

Multivariate methods that allow the comparison and correlation of a species/trait matrix with a matrix of biogeochemical processes should be used; many are available, but examples include Canonical Correspondence Analysis or Co-Inertia Analyses (see 7.1.2).

In the first instance, we suggest starting with a broad set of possible effect trait modalities and bgc measurements, which relate to bioturbation (movement of particles within the sediment), bioirrigation (movement of solutes within the sediment) and biodeposition (movement of particles from the water column to the sediment) (i.e. a combination of those shown in Table 27).

Table 27. Suggested traits and trait attributes to use in multivariate correlation of traits and biogeochemical processes. Left side of table is from the CEFAS trait database (*). Right side of table is from Wrede *et al.* (2018) (¥).

*Trait	Attribute	¥Trait	Attribute
Feeding mode	Suspension feeder	Burrow type	Epifauna, internal irrigation (e.g. siphon)
	Surface deposit feeder		Open irrigation (e.g. U- or Y-shaped burrows)
	Sub-surface deposit feeder		Blind ended irrigation (e.g. blind ended burrows, no burrow systems)
	Scavenger or opportunist	Injection pocket depth	0–2 cm
	Predator		2–5 cm
Sediment reworking	Surface deposition		5–10 cm
	Upward conveyor		>10 cm
	Downward conveyor		
	Surface modifier		
	Sediment regenerator		
Mobility	Sessile or slow moving		
	Burrower		
	Crawler		
	Swimmer		
Sediment position	Surface		
	Shallow depth (0–5 cm)		
	Intermediate depth (5–10cm)		
	Deep (>10cm)		
Maximum size	<10 mm		

	10–20 mm	
	21–100 mm	
	101–200 mm	
	>200 mm	

Heavily vs. lightly trawled areas should be distinguished from each other to determine the trait-bgc relationships most affected. Data permitting, the analysis would ideally be carried out separately for sediment type and season, both of which are highly likely to influence the trait-bgc relationships (see 6.1.1).

In practice, the analyses will probably be determined by the availability of datasets with both fauna and bgc data. Datasets currently identified are:

- trawling experiments at the Frisian Front (Tiano *et al.* 2019, 2020)
- trawling experiments in the Dutch/Belgian coastal zone (Tiano *et al.*, in prep.)
- North-South transect in the North Sea ("NICO10", see de Borger *et al.* 2021 for information on the BGC data)
- southern Baltic Sea (Clare Bradshaw/Mattias Sköld) (currently unpublished)
- Kattegat (Clare Bradshaw/Mattias Sköld) (samples not yet analysed)
- Belgian part of the North Sea (Braeckman *et al.*, 2014; Toussant *et al.*, 2021)
- datasets from North Sea and Celtic Sea (Clement Garcia, Ruth Parker, CEFAS)
- Southern Aegean Sea (HCMR Team) (re-analysis of old project data, two sites: 100 mixed and 200 m soft sediment) (Chris / Nadia / Irini from HCMR)
- Southern Tyrrhenian Sea and western Ionian Sea (Maria Cristina Mangano, Valeria Mobilia) (samples still to be collected in 2022)

6.3.2 Methodological development of a biological model using trait-specific depletion and recovery

The logistic growth model used by the PD approach will be used to estimate how the biomass of each biological trait group changes with different trawling frequencies. This will predict how community trait composition will change at different (i) fishing intensity, (ii) fishing frequency, (iii) fishing gear (Figure 52).

Trait group-specific depletion and recovery rates will be estimated from meta-analysis of a literature database of trawling experimental and gradient studies up to 2014. If time permits this database will be updated to include studies published after 2014. Depletion estimates will be estimated for traits such as Sediment position and Mobility (Table 26) as this describes species' sensitivity to trawling, whereas recovery rates will be estimated for species in different Longevity classes.

Trait-based indices such as the BPc and IPc will then be calculated using the sum of trait biomass/densities displayed at a given time step before or after trawling. Changes in BPc (proxy for bioturbation rate) will be implemented in OMEXDIA to obtain a more comprehensive (faunal and physically induced) estimate of trawling effects on nutrient and carbon dynamics.

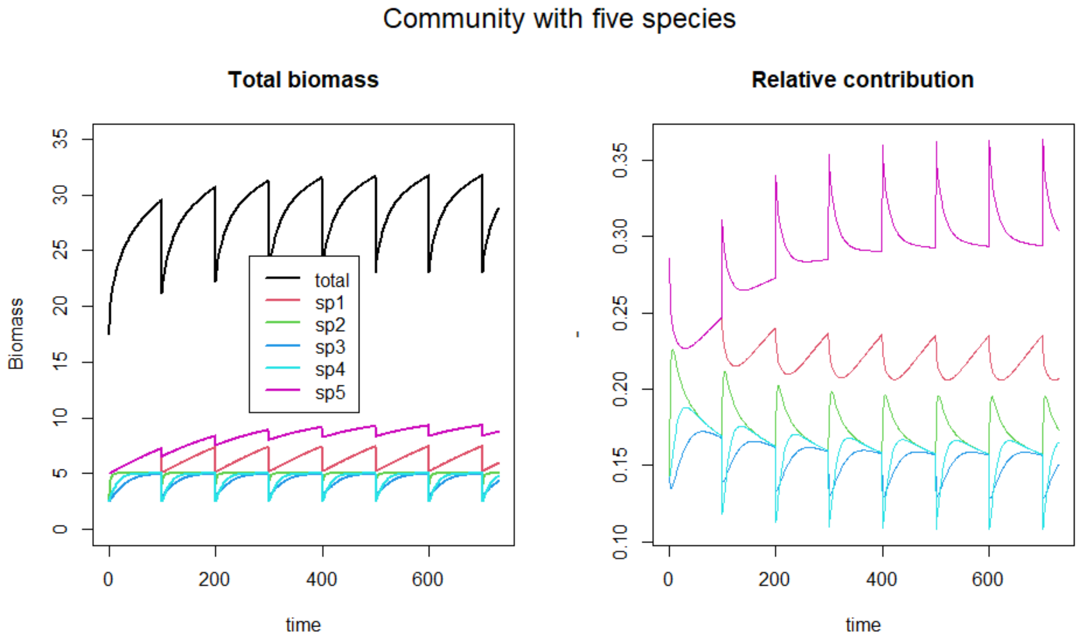


Figure 51. Hypothetical example of trawling impact on community composition using taxon-specific depletion and recovery parameters. In this example, a trawling disturbance happens every 100 days.

6.3.3 Parameterizing OMEXDIA for different sediment types and regions

Available biogeochemical data from a number of areas could be used to parameterize the model and examine the biogeochemical vulnerability to trawling around Europe. Model parameterization will need measures for 1) porosity (can be estimated with grain size) to convert between solid and liquid substances, 2) porewater ammonium, nitrate, phosphate, and oxygen (microprofiles preferred), 3) bottom water nutrient concentrations, and 4) an estimation of organic matter depositional flux into the sediment. The latter can be derived from oxygen consumption or DIC fluxes.

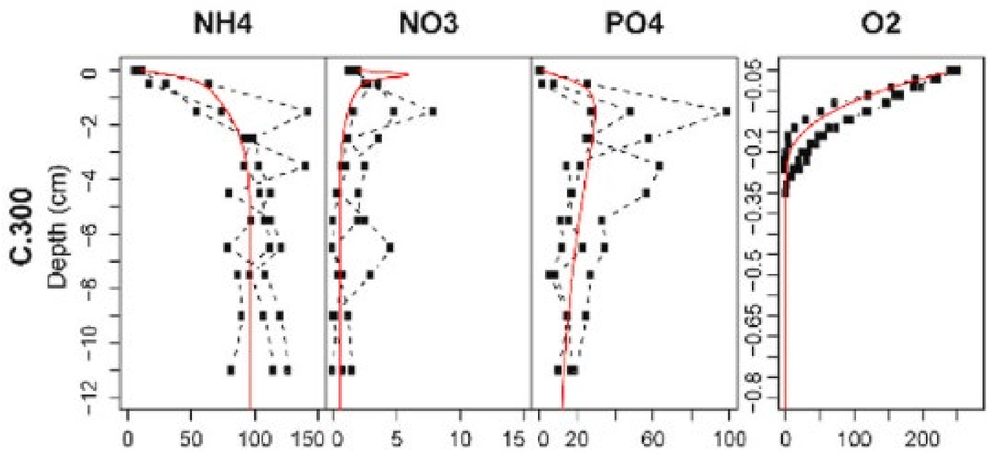


Figure 52. Examples of porewater nutrient profiles data used to parameterize OMEXDIA (De Borger *et al.*, 2021b).

Potential datasets suitable for parameterization and trawl prediction scenarios include the bgc datasets from:

- the Baltic and North Sea identified in section 6.3.1;
- biogeochemical datasets from the northwest Mediterranean (Sandrine Vaz, IFREMER);
- 5 North Sea stations already parameterized in De Borger *et al.* (2021);
- Southern Aegean Sea (Chris / Nadia / Irini HCMR);
- Celtic Sea and North Sea (temporal and spatial data); (Clement Garcia, Ruth Parker CEFAS).

Improvements to the model include the incorporation of the trait-mediated changes in bioturbation and bioirrigation discussed in section 6.3.2 and accounting for indirect trawl-induced OM and sediment deposition. Depositional effects can be estimated by the model, however, finding realistic values for deposited (previously resuspended) OM and potential changes in lability are current knowledge gaps.

6.4 Additional resources

6.4.1 Mapping of macrofaunal traits

CEFAS (contact: Stefan Bolam) is working on generating maps of macrofauna assemblages (based on taxonomic structure) and biological traits (based on trait composition). These consist of continuous maps (raster layers) generated using random forest modelling of point sample data available in 'OneBenthic' database. OneBenthic is an open source database with >44 000 macrofaunal samples pertaining to 809 surveys and provided by 106 data providers (global in scope). Available at https://openscience.cefas.co.uk/obdash/.

Two main trait maps have been generated so far; one focusing on 'effect traits' such as longevity, feeding mode, bioturbation and body size that may give insight on differing functional potential, the other one based on 'response traits' such as morphology, sediment position and mobility reflecting the sensitivity of the assemblage to a pressure or disturbance. Importantly this assessment method:

- can be undertaken to produce a single trait map or a combination of traits map
- generate raster layers which can be related to various fishing pressure metrics and data layers
- can be undertaken to produce trait maps for areas with no fishing, low fishing, high fishing, etc. Comparison of these maps and what traits drive the differences might be useful in inferring which traits respond to fishing

Caveat: Only abundance (not biomass) data has been used for this research and so there are potential complications with using this for RBS which works with biomass. This may be alleviated with using mean individual biomass for each individual, to calculate estimated biomass.

6.4.2 Published database: Worldwide measurements of bioturbation intensity, ventilation rate and the mixing depth of marine sediments

Solan *et al.* 2019 provides a comprehensive georeferenced database of measured values of bioturbation intensity (Db, n = 1281), burrow ventilation rate (q, n = 765, 47 species) and the mixing depth (L, n = 1780) of marine soft sediments compiled from the scientific literature (1864–2018). These data provide reference information that can be used to inform and parameterise global, habitat specific and/or species level biogeochemical models. Metadata includes information relating to the source, timing and location of each study, the methodology used, and environmental and experimental information. Access from:

https://www.nature.com/articles/s41597–019–0069–7

6.4.3 Published database: The SCOC database

Stratmann *et al.* 2019 provides a freely available database of sediment community oxygen consumption (SCOC) rates. The database is comprised of 3540 georeferenced SCOC records from 230 studies that were selected following the procedure for systematic reviews and meta-analyses. Each data record states whether the oxygen consumption was measured ex situ or in situ, as total oxygen uptake, diffusive or advective oxygen uptake, and which measurement device was used. SCOC) rates provide important information about biogeochemical processes in marine sediments and the activity of benthic microorganisms and fauna. Access from: https://www.nature.com/articles/s41597–019–0259–3.

7 General issues

7.1 Update technical report

The technical report on the WGFBIT assessment approach is revised and available in Annex 5.

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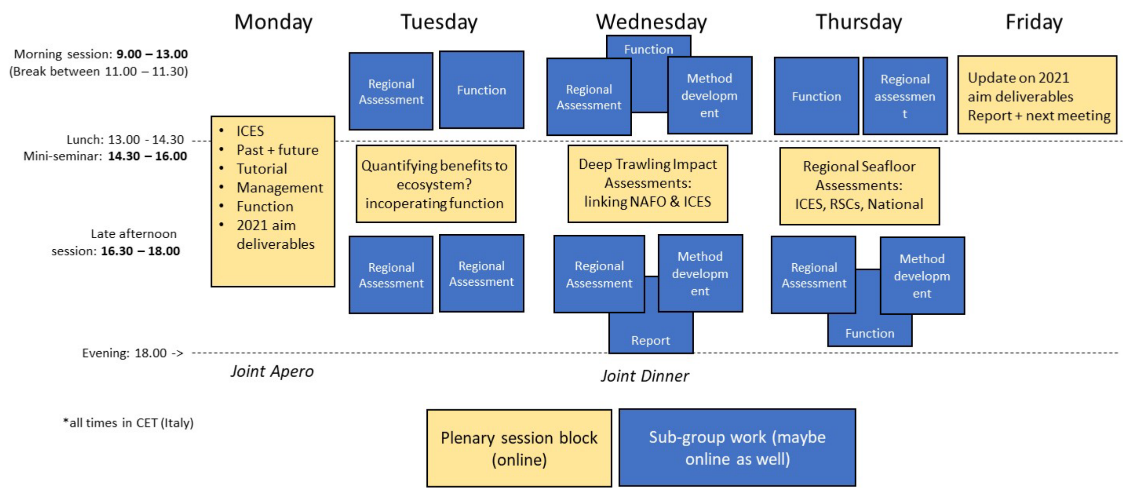
WGFBIT agenda, 22–26 November 2021



Annex 2: WGFBIT resolution

The **Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT)**, chaired by Gert van Hoey, Belgium; Jan-Geert Hiddink, UK; and Marija Sciberras, UK, will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2021	22–26 November	Palermo, Italy		
Year 2022				
Year 2023			Final report by DATE to SCICOM	

ToR descriptors

ToR	Description	Background	Science Plan topics addressed	Duration	Expected Deliverables
a	**REGIONAL ASSESSMENTS** Apply and improve theseafloor assessment framework developed by WGFBIT (2018–2020) to produce (sub-)regional assessments for the North, Celtic, Baltic, Arctic (Icelandic, Norwegian Barents sea), Mediterranean Seas and the Bay of Biscay and the Iberian Coast.	Produce a worked example of how science can operationalize EBM (ecosystem based management) and contribute towards IEAs (intergrated ecosystem assessment) as ICES advice products. I.e. develop an EU MSFD D6/D1 assessment with management options that can be applied also by non-EU ICES countries. Links (avoiding overlaps) will be established with key experts also attending WGECO, WGDEC, WGSFD, BEWG, MHWG, WGIMM, WGMBRED, and WGMPCZM.	1.9; 2.1; 2.4; 6.3	3 years	Year 1: a worked example for all regional seas, based on the preliminary achievements in the period 2018–2020. Initiating the 'pipeline process' for inclusion of relevant outputs to ecosystem overviews, starting with North and Baltic Sea. Year 2: Updating of the regional and sub-regional assessments for the different regions. Year 3: Final regional assessments of the impact of bottom abrasing fisheries for all regions in the ToR, which can feed into the ICES fishery and ecosystem overviews.
b	**UPDATES FOR ASSESSMENT FRAMEWORK** Explore and potentially implement options to improve the parameterisation of the	These updates can focus on following aspects: E.g. through; i) standardisation of benthos data sampled with different gears, ii) development of	2.3; 2.4	3 years	Year 1- 3: Stepwise progress for the different aspects that can be tackled. Updates or adaptations need to feed in ToR A, to improve the regional assessments. If

	WGFBIT seafloor assessment framework components, in shallow waters and deep-sea areas.	methods to predict benthos longevity biomass in data poor areas, iii) integration of environmental drivers in the predictions, iv) improve the resolution of gear-specific depletion rates, v) estimation of parameter uncertainty			appropriate progress or results, research paper(s) will be conducted.
c	**WGFBIT AND THE WIDER WORLD** Alignment of the WGFBIT seafloor assessment framework with other assessment methods for benthic habitats under relevant EU directives.	The WGFBIT seafloor assessment framework (based on assessing the relative benthic state) is not the only way to assess benthic impacts from physical disturbance. Therefore, alignment with other methods needs to be explored.	2.3; 2.4	3 years	Year 1–3: Research paper(s)
d	**ECOSYSTEM FUNCTIONING** Explore if ecosystem functioning can be incorporated more explicitly into the WGFBIT seafloor assessment methodology.	This can be done through examining the direct influence of bottom fishing on sediment parameters related to ecosystem functioning (e.g. apparent redox discontinuity potential layer). The link between total benthic community biomass and/or particular traits (e.g. longevity or sediment position) with biogeochemical parameters that are related to particular benthic ecosystem functions will also be explored – for this part links to work by BEWG and WGECO will be sought.	1.3; 1.9; 2.3	3 years	Year 1–3: Research paper(s)

Summary of the Work Plan

ToR a) **REGIONAL ASSESSMENTS**. Apply and improve the EU MSFD D6/D1 assessment framework related to bottom abrasion of fishing activity at the regional / subregional scale, which was developed by ICES WGFBIT (2018–2020). Priority will be given to improve the parameterisation of framework components at regional and sub-regional scale and with that also improve the overall assessment of benthic status and of alternative management options to achieve good environmental status (GES). The framework should remain generic enough that it allows cross regional comparison and specific enough that it addresses regional-specific trade-offs (i.e. incorporating other pressures than fisheries).

ToR b) **UPDATES FOR THE ASSESSMENT FRAMEWORK.** Explore and potentially implement options to improve the parameterisation of framework components. This can be done through the below action points.

i) The default WGFBIT seafloor assessment framework uses data collected by grab or box corer and therefore targeting the infauna. For some regions, such infauna data is not always available , and assessments are therefore based on epi-benthic data from trawl samples. The use of different sampling methodologies, with subsequent assessment focus on different parts of the ecosystem, has influence on the outcome. Therefore, these differences or commonalities in a regional context, need to be investigated,

ii) The determination of grid cell recovery values are based on longevity compositions sampled from unfished areas. In some regions this type of data is sparse, so alternative approaches/data are needed. A thorough investigation of this aspect will enlarge the WGFBIT assessment framework applicability and increase the confidence of the assessments,

iii) Application of the WGFBIT assessment framework for regional areas requires the development of statistically robust relationships between the benthic biomass longevity distribution and environmental drivers, such as depth, sediment, bottom shear stress, salinity, temperature, primary production, etc. For some regions it has been difficult to obtain meaningful relationships that distinguish sensitive and less sensitive areas spatially, and improved modelling (inclusion of more and better enviromental data across larger cross-regional scales) could potentially solve this,

iv) The gear-specific depletion rate of the assessment method is currently based on only 3 different metiers; beam trawl, otter trawl and dredges. Recent approaches have provided the basis for having a finer gear resolution of the depletion rates (cf Rijnsdorp *et al.*, 2020) and this should be pursued. Methodology to estimate the seabed disturbance area of passive fishing gears is on its way and inclusion of these gears in the assessment framework can be explored in alignment with ICES WGSFD, where these aspects are already being investigated,

v) It is necessary to quantify the uncertainty in the risk assessment methodology developed by WGFBIT. This is required to a) identify which input parameters and modelling steps account for the majority of the uncertainty, and therefore will benefit from efforts to reduce it (e.g. by carrying out further studies), and b) to map the distribution of the overall uncertainty in the assessment area in order to consider it when evaluating management scenarios. The utility of a bootstrapping approach will be explored.

ToR c) WG**FBIT AND THE WIDER WORLD**

i) Alternative EU MSFD D6/D1 assessment frameworks are under development. Comparing different methods has several advantages; 1) Multiple assessments with similar outcomes will increase the confidence of the assessment within a region, as locations with a low or high state/impact should be clearly distinguishable across assessment methods. Areas that differ between assessments, need more investigation, 2) Multiple assessments will help to improve approaches and the guiding of decision making. A more profound decision can be made, when it is based on several outputs.

ii) Threshold Values for determining adverse effects (and loss) and GES is highly requested for policy purpose in relation to: 1) impacts of physical pressures (and bio-geo-chemical pressures); 2) specific indicators (and response value levels) and 3) areal protection – what, where, how much and how strict? (securing ecosystem functioning). The lack of empirically based threshold values is an upcoming and increasingly urgent concern internationally (TG Seabed, HELCOM, OSPAR) and at the national level concerning the implementation of the EU MSFD D6C3 and D6C5, as well as for the D1 and D5. The options to integrate GES threshold values in WGFBIT will be explored by looking to current practices under the WFD and NATURA 2000 management at the national level.

ToR d) **ECOSYSTEM FUNCTIONING**

The WGFBIT seafloor assessment framework uses total benthic community biomass as key metric to assess seabed impacts under the assumption of a strong correlation with ecosystem functions such as carbon mineralization and nutrient cycling. We propose to test this assumption and investigate how ecosystem functioning can be incorporated into the PD methodology. This will not only ascertain that RBS is a good way forward, but also help us in setting thresholds for acceptable ecosystem impacts. This can be done through examining the direct influence of bottom fishing on sediment parameters related to ecosystem functioning (e.g. apparent redox discontinuity potential layer). The link between total benthic community biomass and/or particular traits (e.g. longevity or sediment position) with biogeochemical parameters that are related to particular benthic ecosystem functions will also be explored – for this part links to work by BEWG and WGECO will be sought.

Year 1	ToR a, b, c, d
Year 2	ToR a, b, c, d
Year 3	ToR a, b, c, d

Supporting information

Priority	The activities of this Group will lead ICES into issues related to the ecosystem effects of fisheries, especially with regard to the application of the Precautionary Approach. Consequently, these activities are considered to have a very high priority.
Resource requirements	Experts that provide the main input to this group have been involved in successful EU funded projects (BENTHIS). It is envisoned that future funding will be availble and that this ICES working group experts can also provide an international platform to establish a consortium. This would allow to commit future resources to the group’s work.
Participants	The Group is normally attended by around 30 members and guests.
Secretariat facilities	Standard support
Financial	No financial implications

Linkages to ACOM and groups under ACOM	Advice products and working groups (e.g. WGECO and WGDEC)
Linkages to other committees or groups	There is a very close working relationship with all the groups under the Ecosystem Pressures and Impacts Steering Group. It is also very relevant to the Workings Groups WGECO, WGDEC, WGSFD, BEWG, WGMHM, WGIMM, WGMBRED, WGMPCZM.
Linkages to other organizations	EU (DG-ENV, DG-MARE), RSCs (Baltic's HELCOM, North Atlantic's OSPAR, Mediterranean's Barcelona Convention and Black Sea's Bucharest Convention), JRC, STCEF.

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Annex 4: Advice sheet template

ICES seafloor assessment of mobile bottom fishing: XXYY ecoregion

Assesment summary

This is an assessment of [UU] for region [VV] it is based on [XX] data and follows the methods described in [ZZ]. Bottom fishing is the single most important impact on the seafloor in this area. Impact from other sources which are important in this area are [XX], [YY] and [ZZ], but their impact is only a fraction of that of bottom fisheries (ICES 2019). [Which threshold is used (arbitrary or GES)? What is this advice to be used for?] References to the full assessment and advice documentation can be found below under 'Format of the assessment'.

Assessment results

Status in year [XX]

Map of sensitivity	*Map of abrasion (fishing and/or other)*
Map of Impact	*Map of uncertainty, preferably analogous to coefficient of variation (blank if not available)*

Figure 1 Variation across assessment of [UU] for region [VV]. Sensitivity (a), pressure (b) and impact (c) with uncertainty of estimate presented (d). The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2021). n/a = not analysed.

Table 1 Summary of the pressure and impact indicators by (sub-)region for 0–200 and 200–800 m depths. The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2021). n/a = not analysed.

Habitat type (Eunis lvl X)	Area km2 (fraction of total)	Fraction un-trawled (+-CI)	Mean SAR (+-CI)	Fraction SAR>[X] (+-CI)	Mean Impact (+-CI)	Fraction with im-pact below [X] (+-CI)
A	x (y)	..(..)	..(..)	..(..)	..(..)	..(..)
B	..(..)	..(..)	..(..)	..(..)	..(..)	..(..)
C	..(..)	..(..)	..(..)	..(..)	..(..)	..(..)
..	..(..)	..(..)	..(..)	..(..)	..(..)	..(..)
Total	..(..)	..(..)	..(..)	..(..)	..(..)	..(..)

Time trends

Plot of mean abrasion for each habitat type and total area over time	*Plot of mean impact for each habitat type and total by time (with conf limits)*	*Plot of fraction below specific threshold impact [X], for each habitat type and total, by time (with conf limits)*

Figure 1 Temporal trends for the assessment of [UU] for region [VV]. (a) Pressure presented as abrasion for each habitat type and total area over time, (b) mean impact for each habitat type and total by time (with conf limits), and (c) fraction below specific threshold impact [X], for each habitat type and total, by time (with conf limits). The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2021). n/a = not analysed.

Interpretation of results

[Brief interpretation of results (max ½ page). A verbal reference to factors in ecology, management and/or fishing practices which are important in understanding the indicated results. Whether the trends are related to changes in specific locations or not. Special emphasis on uncertainty map and significance of trends.]

Validity and limitations

[Summary of limitations and caveats, listed in the more detailed online assessment sheet, should be taken into account when considering the advice. These relate for example to issues concerning the provision of vessel data and their interpretation, the scale at which the data are informative, other important developments in the area (e.g. unfishable areas due to anoxia) and the information used to assess impact.]

Format of the assessment

This seafloor assessment of [UU] for region [VV] it consists of this PDF assessment text and a data product, consisting of a series of interactive maps and regional assessments and the VMS aggregated fishing data [REFS]. The seafloor assessment text should be read in conjunction with the interactive maps and can also be informed by the regional assessments. Within the text, references to the interactive maps and regional assessments and their specific "sections" are made. The limitations and caveats described in [VV] should be considered before using the data products.

The data product is [UU website].

[Diagram showing the various components of this seafloor assessment [UU] for region [VV]: the seafloor assessment text in PDF format and a ZIP file containing interactive maps, regional assessments, and the VMS aggregated fishing data in CSV and shapefile format. The aggregated CSV data products are provided by ICES to allow elements of this seafloor assessment to be incorporated into spatial analysis software, e.g. GIS software.]

Download the ZIP file.

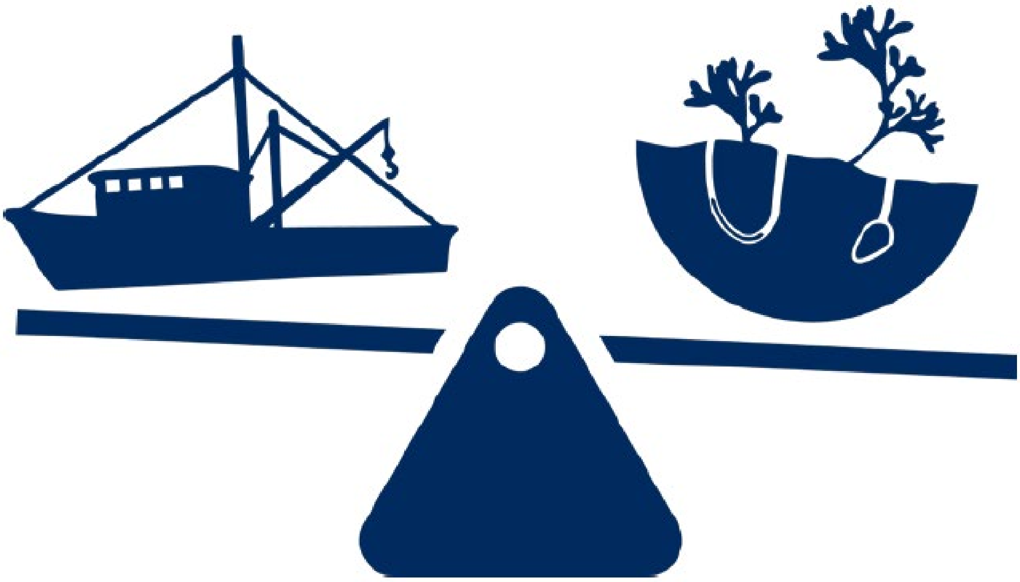
Sources and references

ICES. 2019. EU request to advise on a seafloor assessment process for physical loss (D6C1, D6C4) and physical disturbance (D6C2) on benthic habitats. In Report of the ICES Advisory Committee, 2019. ICES Advice 2019, sr.2019.25, https://doi.org/10.17895/ices.advice.5742.

Annex 5: Technical guidelines document for assessing fishing impact from mobile bottom-contacting fishing gears. Version 2

Technical guidelines document for assessing fishing impact from mobile bottom-contacting fishing gears.

Version 2



Intended use

The target audience for this guidance document are experts involved in assessing the seafloor across ICES and EU areas, for example national level implementation (and reporting) of MSFD, experts from regional seas conventions (Baltic Sea, North–East Atlantic, Mediterranean and Black Sea areas), as well as, other regions and stakeholders. The document presents an overview of the ICES seafloor impact assessment framework to promote understanding and dissemination of an assessment method that can be applied at the regional scale and across European Seas.

The document comes together with open-source code and data products to run the assessment (https://github.com/ices-eg/FBIT), following the guiding principles of ICES Transparent Assessment framework (TAF). The assessment framework has been developed through an iterative process of open workshops that have been peer-reviewed, evaluated by an advice drafting group and approved by ICES Advisory Committee, ACOM (ICES 2016, 2017, 2021a).

Please note that this document, as well as, the underlying code to run the assessment will be updated based on feedback and further developments. Ownership of this guidance document is with the ICES working group on Fisheries Benthic Impact and Trade-offs (WGFBIT).

Recommended format for purposes of citation:

ICES. 2022. Technical guideline document for assessing fishing impact from mobile bottom-contacting fishing gears (version 2, 27 February 2022). *within*: Report from the working group on Fisheries Benthic Impact and Trade-Offs

1. Introduction

Seafloor ecosystems in the ICES area (Northeast Atlantic and the Baltic Sea) account for > 14.348.000 km^2, an area 1.4 times larger than continental Europe. The seafloor ecosystem is home to >2500 species of benthic organism that represent virtually all known phyla. These species and their populations form a wide variety of communities across distinct habitats types. The management goal for the seafloor is to safeguard both benthic community structure and function. Structure and function are not mutually exclusive of one another, they are both vital. They ensure that viable populations of native species exist across the seafloor, representative habitats are distributed across their natural range of variation, ecological processes (e.g. nutrient cycles) are maintained and, ecoregions and benthic species are able to respond to short- and long-term environmental change.

The overarching aim of safeguarding benthic community structure and function can be linked with two broadly cited management objectives. The first is the protection of unique or vulnerable seafloor species and associated habitat that are valued due to their intrinsic value to global biodiversity. The second is to ensure sustainable use of seafloor habitats that are not as rare or sensitive and mainly valued for their contribution towards ecosystem functions and services that are essential to our lives. There is thus a general wish to avoid further degradation of these habitats by, for example, fisheries that regularly tow bottom contacting gears across the seafloor. In European waters, the Marine Strategy Framework Directive (MSFD) has been introduced as one of the main legislative instruments to implement sustainable use of seafloor habitats and safeguard benthic community structure and function through Ecosystem-based Management (EBM).

EBM is a tool used to manage human activities affecting marine ecosystems, which aims to find a balance between conservation and sustainable use. For descriptor 6 (D6) of the MSFD, the aim is to maintain the integrity of the seafloor to ensure marine biodiversity and the provision of living resources. The overarching goal of D6 is for seafloor integrity to be at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected. The D6 requirement have led to the development of methods to assess impact on benthic habitats from anthropogenic activities, particularly bottom trawl fisheries, across EU member countries and Regional Sea Conventions (RSCs). In parallel to D6, such methods are also used to assess impact in relation to Descriptor 1 (D1) that has as overarching goal to maintain biological diversity.

ICES role is to provide the evidence for ecosystem-based decision making for the management of fisheries and other sectors in the ICES area. The evidence is required to explore the consequences of likely trade-offs between the services these human activities provide and the impacts these activities have on biodiversity of species and habitats. For MSFD D1 and D6 purposes, ICES has acted as a facilitator for setting methodological standards that ensure operationalizing of a regional assessment of the seafloor (ICES 2016, 2017). In relation to the two broad management objectives, ICES noted (ICES 2016):

1. The first objective is the protection and conservation of particularly valued and sensitive habitats and communities in shallow and deep waters. In a global context, some of these habitats and communities have been described and defined as Vulnerable Marine Ecosystems (VMEs). Other sensitive and/or valued habitat in shallower waters that are closer to land (e.g. Zostera, Maerl and Oyster beds, sea-pen and burrowing megafauna communities, Charales) are regulated by national level legislations. The sensitivity of areas holding these sensitive and/or valued habitat such as VME indicator species and/or habitat is such that any bottom-impacting fishing may severely or permanently damage and degrade them. Consequently, many become closed to these forms of fishing. Once particularly valued and sensitive habitats and communities have been defined, the main scientific activity needed for such

areas is to find and map them – the main management need is to bring forward appropriate control measures. ICES recommended therefore that the state of these areas be assessed separately from the state of other seabed habitats (e.g. ICES 2021b).

2. The other objective relates to the state of more widespread habitats and communities that are not covered by the category of particularly valued and sensitive habitats and communities. These seafloors consist of benthic communities and habitats that are not as rare or sensitive and mainly valued for their contribution towards essential ecosystem functions (nutrient cycling, CO_2 exchange, primary and secondary productivity) and ecosystem services (food and nutrition, waste disposal and detoxification, mining, oil and gas). The MSFD aim for these areas is to allow sustainable use at a level that maintains vital ecological processes, and native ecosystem habitats and species across their natural range. ("*structure and functions of ecosystems are safeguarded and that benthic ecosystems are not adversely affected*").

This document presents the technical guidelines for an assessment framework that can be used to assess the state of these more widespread habitats and communities (**Figure 54**). The document will be annually evaluated during the WGFBIT meeting and updated when needed. We refer to ICES 2018 for definitions of all conceptual and technical terms related to the assessment that might invoke confusion.

1.1. Use of the assessment framework

The document describes the methodology of an assessment approach that can be used to derive a set of indicators for assessing physical disturbance pressures from bottom-contacting fishing gears and their environmental impacts on seabed habitats (**Figure 54**). The framework allows for the evaluation of trade-offs between catch/value of landings per unit area and the environmental impact and recovery potential of the seafloor. The assessment framework is able to derive the indicators at the spatial scale of biogeographic subdivisions of the MSFD regions and subregions, and per MSFD broad habitat type (or more finely-defined habitat types), and, can be assessed over time.

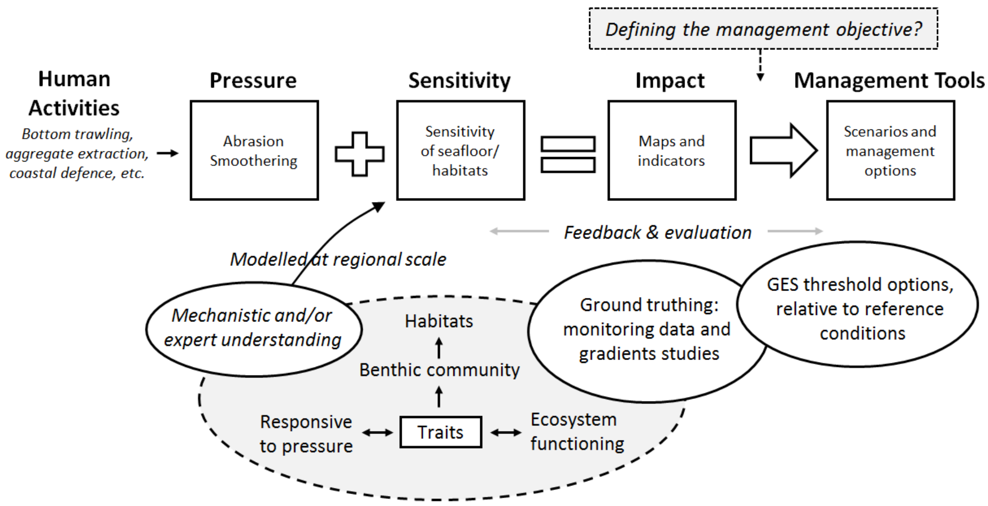


Figure 53. Conceptual diagram of the steps taken in developing management tools for assessing pressure and impact on the seafloor from human activity.

2. Assessment framework – pressure: fishing activity data

Bottom trawling is a type of fishing in which a net, or other collection device, is dragged over the seabed to catch demersal fish, crustaceans and shellfish. Bottom trawl fisheries are a key human activity in the EU waters that cause physical disturbance to the seafloor (Eigaard *et al.*, 2017, Amoroso *et al.*, 2018). The most commonly used gears for bottom trawl fishing are beam trawls, otter trawls, seines and dredges. To estimate fishing pressure from these bottom contacting gears, the different fishing activities (gear types) have been translated into a common fishing pressure metric. This allowed to describe the spatial and temporal distribution of fishing activities – and simultaneously consider their characteristic ecological footprint (Figure 55). To derive the fishing pressure metric, data has been used from satellite tracking of fishing vessels (Vessel Monitoring by Satellite data - VMS) and fisheries logbooks.

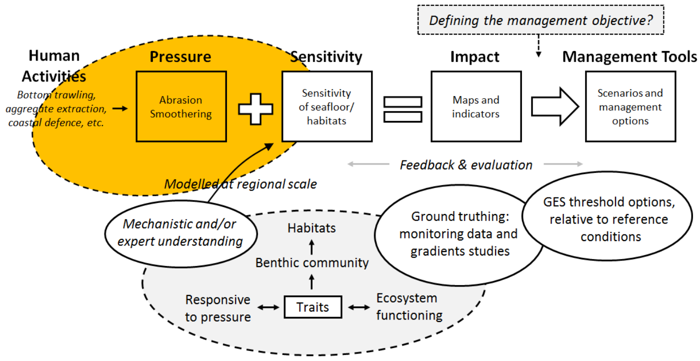


Figure 54. Conceptual diagram of the steps taken in developing management tools for assessing pressure and impact on the seafloor from human activity. Pressure part is highlighted in orange.

2.1. Estimating fishing pressure

To estimate fishing pressure, it is necessary to provide a spatially resolved index of fishing intensity for mobile bottom contacting gears. Fishing intensity is defined 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. Fishing intensity is based on VMS and fisheries logbook data. 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 vessel flag country, gear code (equivalent to Data Collection Framework (DCF) level 4), fishing activity category (DCF level 6), average fishing speed, fishing hour, average vessel length, average engine power (kW), total landings weight and total value of all species caught. Following some analytical steps to identify e.g. misreported pings (ICES WGFSD 2015), the vessel state (steaming, fishing or floating) is identified using the speed information. Only data, which are assumed to represent fishing activity, are then assigned to a 0.05 x 0.05 degrees C-square grid, about 15 km² at 60°N latitude (Rees 2003), hereafter termed C-square.

To calculate the fishing intensity values, certain assumptions about the spread of the gear, the extent of bottom contact and the fishing speed of the vessel need to be made (ICES 2015). Submitted VMS datasets usually contain 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) are used to approximate the bottom contact (e.g. gear width). To do this, it is necessary to aggregate métier level 6 to lower and more meaningful gear groups (so-called "Benthis métiers"), for which assumptions regarding the extend of bottom contact were robust. Following this, fishing effort (hours) is aggregated per c-square for each métier and year. Fishing speeds are 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. Similarly, vessel length and engine power are submitted through the data call but where missing, average vessel length/engine power values are taken from the BENTHIS survey (Eigaard *et al.*, 2016). Parameters necessary to approximate the missing information are listed in Table 27.

Fishing intensity values per gear group, grid cell and year are afterwards calculated. For towed gears (otter trawls, beam trawls, dredges), fishing intensity is described by:

$$SA = \sum evw \quad (1)$$

for Danish seines as:

$$SA = \sum(\pi(w2\pi)^2(e/2.591234)) \quad (2)$$

and for Scottish seines as:

$$SA = \sum(1.5\pi(w2\pi)^2(e/1.91125)) \quad (3)$$

where SA is the swept-area, π the number pi, e is the time fished (h), w is the total width (m) of the fishing gear (gear group) causing abrasion (Table 27), and v is the average vessel speed during fishing (m/h; Table 27).

The swept-area information is additionally aggregated across métiers for each gear class (otter trawl, beam trawl, dredge, demersal seine) To account for varying cell sizes of the C-square grid, swept-area values are additionally divided by the grid cell area:

$$SAR = SA/CA \quad (4)$$

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

Table 28. Parameter estimates of the relationship between vessel size (LOA as length in m) or power (kW) and gear width, the average gear width 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 metier	Model	Gear width causing abrasion (m)	Subsurface proportion (%)	Fishing speed (knots)
Otter trawl	OT_CRU	$5.1039\ kW^{0.4690}$	78.92	32.1	2.5
	OT_DMF	$9.6054\ kW^{0.4337}$	105.47	7.8	3.1
	OT_MIX	$10.6608\ kW^{0.2921}$	61.37	14.7	2.8
	OT_MIX_CRU	$37.5272\ kW^{0.1490}$	105.12	29.2	3.0
	OT_MIX_DMF_BEN	$3.2141\ LOA + 77.9812$	156.31	8.6	2.9
	OT_MIX_DMF_PEL	$6.6371\ LOA^{0.7706}$	76.21	22	3.4
	OT_MIX_CRU_DMF	$3.9273\ LOA + 35.8254$	113.96	22.9	2.6
	OT_SPF	$0.9652\ LOA + 68.3890$	101.58	2.8	2.9
Beam trawl	TBB_CRU	$1.4812\ kW^{0.4578}$	17.15	52.2	3
	TBB_DMF	$0.6601\ kW^{0.5078}$	20.28	100	5.2
	TBB_MOL	$0.9530\ LOA^{0.7094}$	4.93	100	2.4
Dredge	DRB_MOL	$0.3142\ LOA^{1.2454}$	16.97	100	2.5

Demersal	SDN_DMF	1948.8347 $kW^{0.2363}$	6536.64	5	NA
seines	SSC_DMF	4461.2700 $LOA^{0.1176}$	6454.21	14	NA

2.2. Calculating weight and value of fisheries landings

In the workflow for answering the ICES datacall, the function splitAmongPings from the Vmstools R package can be used to distribute landings or value of landings among the VMS positions where fishing activity is assumed. There are some choices within the function to distribute the landings either according to the time interval between the VMS pings or to split equally out on the pings. This can be done either by day, by ICES rectangle or by trip. As there are different options in the function, it might be implemented differently by nations.

2.3. Fishing pressure indicators

ICES (2017) advised on the use of five indicators to assess the pressure from mobile bottom-contacting fishing gear: four annual indicators and one multiple year indicator (Table 28). The indicators can be applied by (sub-)regional, subdivision sea, or broad habitat type within that sea, and assessed by total bottom-contacting fishery, a métier, or a combination of métiers. Four of these indicators rely on gridding the considered area, and the results of especially indicators 2 and 5 strongly depend on the spatial resolution of the used grid. Each indicator can also be assessed separately for specific depth ranges.

Table 29. Fishing pressure indicators that are applied to (sub-)regional seas, or broad-scale habitat types within that sea.

Annual pressure indicator	Description
1 – Intensity	Average number of times the area is swept by bottom-contacting fishing gears. Estimated as the sum of swept area for all vessels using bottom-contacting gears or by métier divided by the total area of the considered area (regional/ subregional sea, or broadscale habitat type within that sea).
2 – Proportion of grid cells fished	The number of grid cells (c-squares) fished at least once (irrespective of the swept area within the cell), divided by the total number of grid cells (c-squares) within the considered area.
3 – Proportion of area fished	The sum of swept area across all grid cells in a considered area, where swept area in a specific grid cell cannot be greater than the area of that grid cell, divided by the summed area of all grid cells.
4 – Aggregation of fishing pressure	The smallest proportion of the grid cells (c-squares) where 90% of the total swept area occurs.
Multiple year indicator	**Description**
5 – Persistently unfished areas	In order to understand the length of time that grid cells remain unfished, Indicator 2 could be evaluated over six years.

3. Assessment framework – Habitat sensitivity

To convert patterns of fishing pressure into patterns of impact, the underlying seafloor sensitivity needs to be estimated (Figure 56). WGFBIT uses the so called "*PD method*" to assign sensitivity and derive impact. PD stands for 'Population Dynamics model'. WGFBIT uses the PD method, mainly due to the following advantages:

- The method is strongly rooted in general concepts of population dynamics and summarizes impact across the entire benthic community with a single indicator.
- The method is based on a large body of scientific work, which has been published in peer-reviewed scientific journals (Hiddink *et al.*, 2017; Pitcher *et al.*, 2017; Hiddink *et al.*, 2018; Rijnsdorp *et al.*, 2018).
- The method uses habitat- and gear-specific mortality and recovery dynamics to derive local impact scores.
- The method lends itself to the Transparent Assessment Framework (TAF) standard adopted by ICES because it can be applied in an identical way across regions.

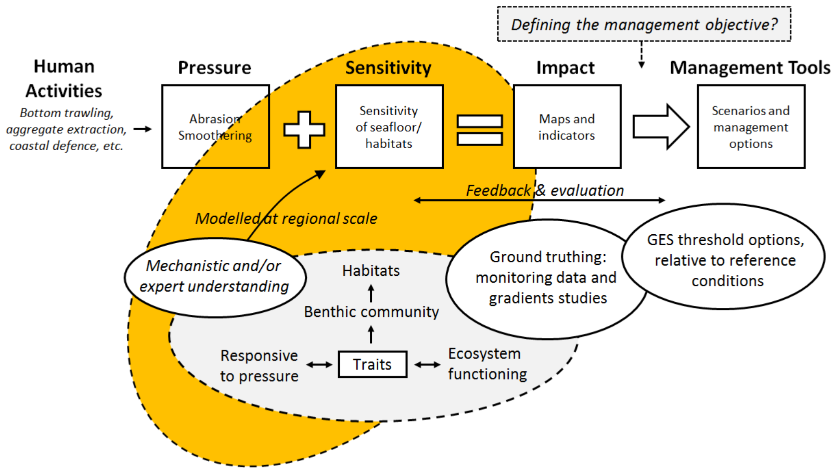


Figure 55. Conceptual diagram of the steps taken in developing management tools for assessing pressure and impact on the seafloor from human activity. Sensitivity part is highlighted in orange.

Below we describe how the PD method can be used to assess the impact of bottom trawling on the state of the seabed. An overview of the pieces of information required to perform an assessment, and how they are combined into a final estimate of benthic status is shown in **Figure 57**. The assessment methodology consists of a trawl impact model and its parameter estimates that are based on a generic understanding of trawl impacts and applicable for any fishery (**Figure 57**A), and a region and habitat-specific estimate of the longevity distribution of benthic biota (**Figure 57**B) that is used to derive the recovery rate in **Figure 57**A. Together with the pressure (section 2), this sensitivity leads to an estimate of the impact (**Figure 57**). The sections below explain how these are derived and applied.

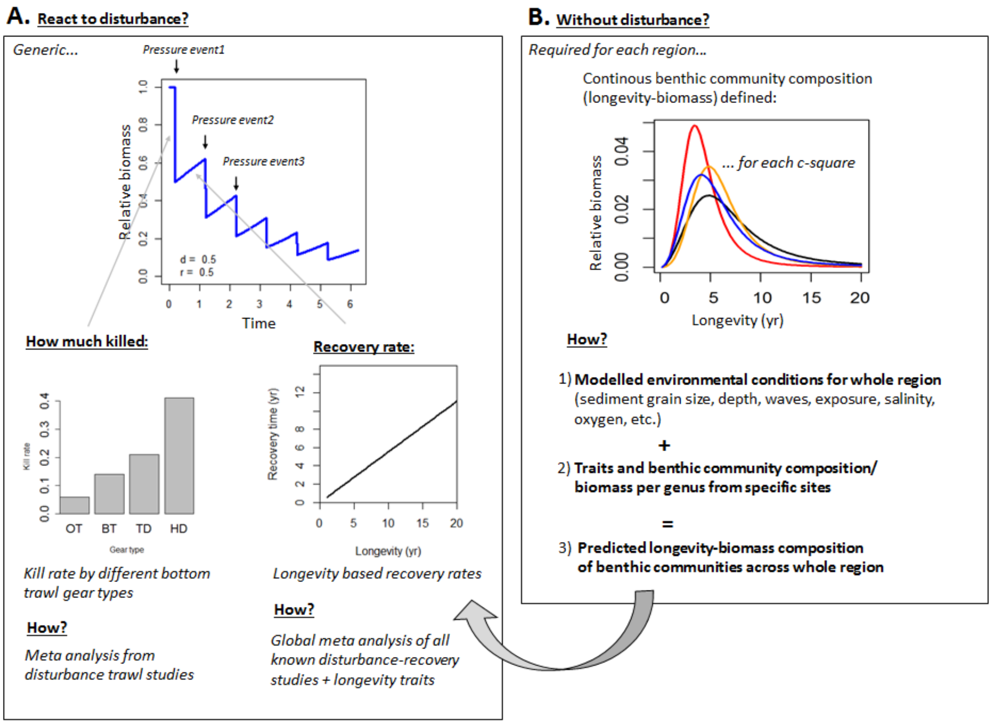


Figure 56. A flow diagram of how data layers and relationships derived from synthesis and analysis of the literature are combined to determine RBS (Relative Benthic Status) in the FBIT framework.

3.1. Population model

This section explains how the recovery rate and the fraction of biota killed by different gears are combined to estimate trawling impacts (top figure in **Figure 57**A). The PD method is a quantitative method for assessing the risks to benthic habitats by towed bottom-fishing gears. The method is based on a simple equation for relative benthic status (RBS, defined as the biomass *B* relative to the carrying capacity *K*), derived by solving the logistic population growth equation for the equilibrium state (Pitcher *et al.*, 2017).

RBS = B/K = 1- F d/r

Here, trawling effort (F = SAR) is defined as the total area swept by trawl gear within a given area of seabed in one year divided by that area of seabed (units y^{-1}, see 2.1). Depletion *d* is the fraction mortality per trawl pass estimated from experimental trawling studies, and *r* is the intrinsic rate of population increase.

The impact of trawling on benthic biota depends on both d and r (Figure 58), and sensitivity to trawling depends on the ratio of d over r, and is therefore proportional to the reciprocal of the recovery rate r.

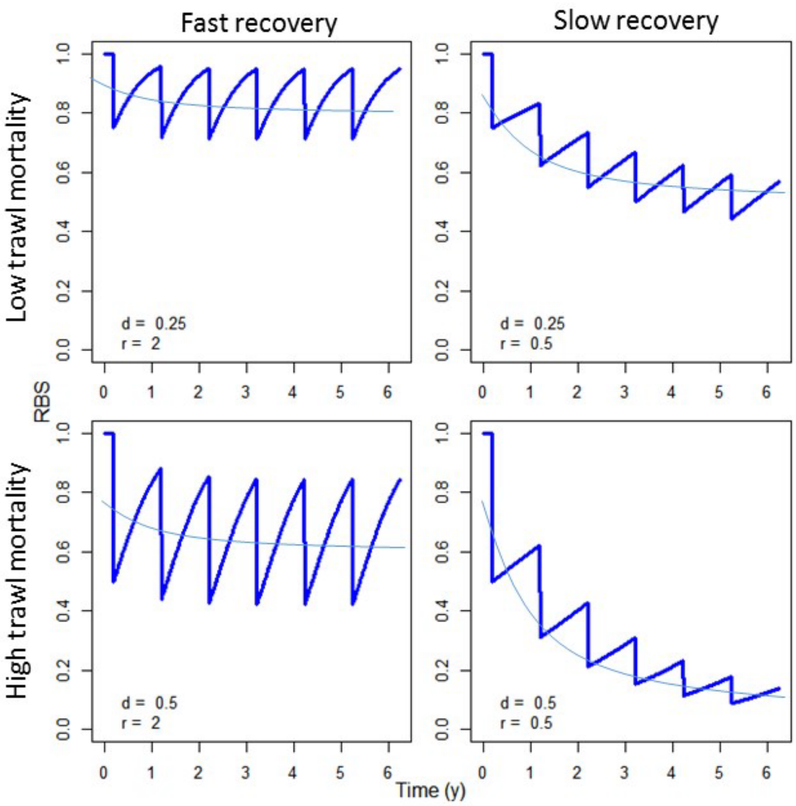


Figure 57. The effect of trawling depends on the trawl mortality (depletion *d*) and the recovery rates (*r*) of the benthic community. In this example, trawling occurs once a year, and after trawling recovery of the relative benthic state (RBS) occurs.

Previous work aiming to categorise the impact of human pressure on ecosystems has been using a variety of terminology to typify the sensitivity to pressure (e.g. https://www.marlin.ac.uk/sensitivity/sensitivity_rationale). 'Resistance' as used in such frameworks is equivalent to (1-*d*), while 'resilience' is equivalent to *r*, and 'Sensitivity' is generally defined as the 'product' of resistance (i.e. (1-*d*) * *r*) and often categorised in limited number of categories. The RBS equation above shows that sensitivity in our approach is equivalent to *d*/*r*, and that *d* and *r* are quantified based on empirical estimates rather than categorised based on expert opinion.

Estimating RBS therefore requires only maps of fishing intensity and habitat type – and parameters for impact and recovery rates, which have been taken from meta-analyses of all available studies of towed-gear impacts. The assessment produces a relative benthic state estimate (RBS) for each grid cell (C-square) in the assessed region, based on just two parameter values (depletion *d* and the intrinsic rate of population increase *r*, a metric of recovery rate) and the fishing intensity.

3.2. Systematic review of the evidence

The parameter estimates for *d* and *r* and their uncertainties were based on a collation from published experimental and comparative studies of the effects of bottom trawling on seabed habitat and biota following a systematic review protocol (Hughes *et al.*, 2014), thereby avoiding selection bias. Studies were included if the abundance *B* (as numbers or biomass) of benthic species, genera and families, of either infauna and/or epifauna, was reported. This includes all studies that passed the quality selection criteria, and covers both infauna and epifauna sampled using grabs, dredges, trawls, photo and video, and a wide variety of habitats, although most studies were from the temperate northern hemisphere. The parameter estimates are therefore applicable to benthic communities in general, and constitute a synthesis of all the evidence available.

The validity of the estimates of *d* and *r* depends on the quality and design of the included studies, and the extent to which the control locations in the studies used to estimate *r* representing unfished reference conditions. If studies are carried out in areas where unfished control stations represent a situation that is different from the pristine state from 100s of years ago (e.g. where oyster reefs were lost), the carrying capacity estimate, and RBS estimates, produced using this method will describe the state of the seabed as it could currently be without fishing and not an unknown state in which it could have been at some historic point in time.

3.2.1. Response variable: total community biomass

This methodology estimates RBS, which is estimated here as the benthic biomass of the whole benthic community relative to its carrying capacity. This metric is used because it is expected to be a proxy for the structure and function of benthic ecosystems. A high community biomass will coincide with communities where the body size distribution, age structure as well as numbers of the benthic fauna are close to natural, and community biomass correlates to the energy flow through food webs and other ecosystem processes that are linked closely to biomass (e.g. nutrient cycling, bioturbation and food provisioning for fish and sea birds). Recovery in numbers is driven more strongly by recruitment than recovery of biomass, which is driven by increases in the size and age structure of the population through growth of individuals.

A comparison of different response variables using all studies from our systematic review showed that community biomass is the most sensitive indicator of trawling impacts as it is most responsive, while community abundance and species richness were less sensitive, and diversity indices were not suitable as state indicators for monitoring the effect of bottom trawling (Figure 59, Hiddink *et al.*, 2020).

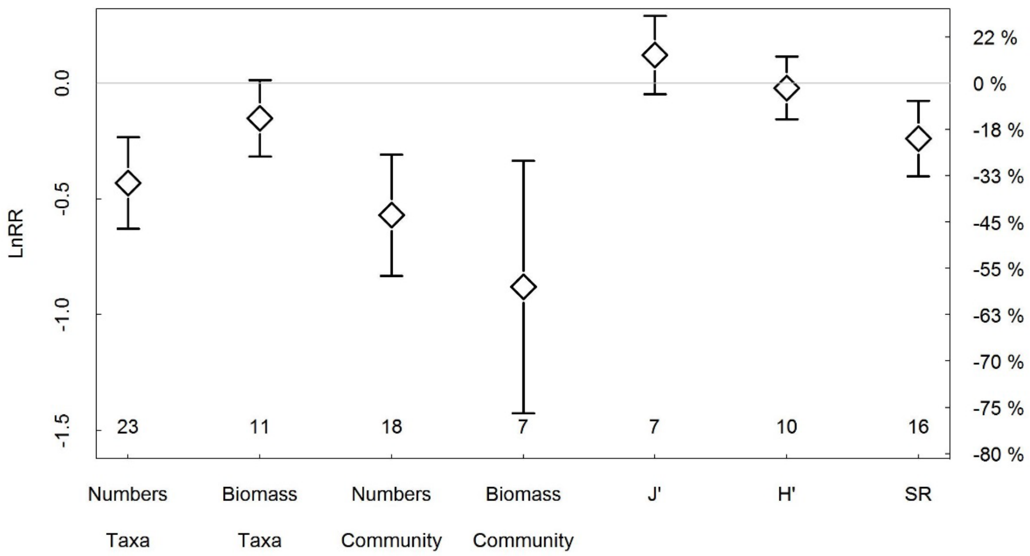


Figure 58. Outputs of the meta-analysis of control-impact studies with 95% confidence intervals. If the 95% confidence interval overlaps 0 the effect was not significant. The right-hand axis gives % changes for ease of interpretation. J': Evenness, H': Shannon-Wiener diversity index, SR: species richness (from Hiddink *et al.*, 2020).

3.2.2. Depletion, *d*

This section explains how we estimated values for 'How much killed' in **Figure 57**A. Bottom trawls [here defined as any towed bottom-fishing gear, including otter trawls (OTs), beam trawls

(BTs), towed (scallop) dredges (TDs), and hydraulic dredges (HDs)] are used to catch fish, crustaceans, and bivalves living in, on, or close to the seabed. The meta-analysis in Hiddink *et al.* (2017) provided estimations of the depletion *d* for the biomass of the whole community of benthic invertebrates. Estimates of depletion d and penetration depth *P* by gear type were very closely correlated (Figure 60) (Pearson's r = 0.980, P = 0.020). OTs had the smallest impact, removing on average 6% of organisms per trawl pass and penetrating on average 2.4 cm into the sediment. Median penetration depths were 2.7 and 5.5 cm for BTs and TDs, respectively, and the corresponding median depletion rates per trawl pass were 14 and 20%, respectively. HDs had the largest impact, removing on average 41% of organisms per pass and penetrating 16.1 cm. These values are generic estimates over all habitats.

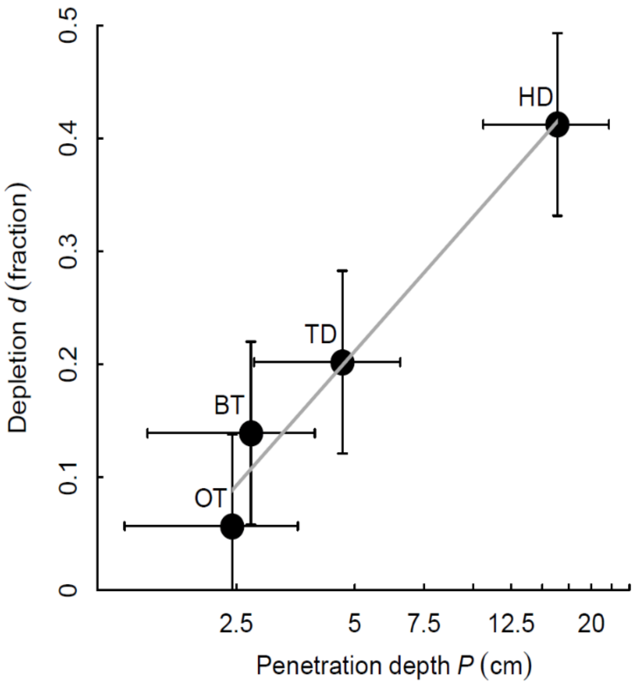


Figure 59. The relationship between the penetration depth P and depletion d of macrofaunal community biomass and numbers caused by a single trawl pass for different trawl gears (means ± SD) (Hiddink *et al.*, 2017).

FBIT assessments originally used the *d* estimates presented in Figure 60by mapping the different metiers available in the ICES VMS database (Table 29) onto these broad gear categories. Recent work by Rijnsdorp *et al.* (2020) estimated *d* for 10 different metier types based on the relationship between *d* and *P* from Figure 60. These 10 metiers follow the groupings available in the ICES VMS database and are currently used to estimate metier-specific depletion (Table 29). The *d* estimates presented here are for whole benthic communities, and do not differentiate between sediment type.

More specific estimates for different sediment types, and different components of the benthos are available in Sciberras *et al.* (2018) and may be appropriate to use for assessments of particular components of the ecosystem. Moreover, work is underway to provide *P* and *d* estimates that depend on gear as well as sediment type, which generally suggest a deeper *P* in mud and gravel compared to sandy sediments (Pitcher *et al.* accepted). These estimates could be integrated in the FBIT assessment when available.

Table 30. Gear types, target species and depletion rates for the 10 different metier types (Rijnsdorp *et al.* 2020).

Metier	Main gear type	Target species assemblage group	Main target species	Depletion rate
DRB_MOL	Dredge	Molluscs	Scallops	0.200
OT_CRU[1]	Otter trawl	Crustaceans	Nephrops, Pandalus, mixed fish	0.100
OT_DMF	Otter trawl	Demersal fish	Cod or plaice	0.026
OT_MIX[2]	Otter trawl	Mixed fish	Mixed fish	0.074
OT_SPF	Otter trawl	Small pelagic fish	Sprat or sandeel	0.009
SDN_DMF	Danish seine	Demersal fish	Plaice, cod	0.009
SSC_DMF	Flyshooter (seine)	Demersal fish	Cod, haddock, flatfish	0.016
TBB_CRU	Beam trawl	Crustaceans	Brown shrimp	0.060
TBB_DMF	Beam trawl	Demersal fish	Flatfish	0.140
TBB_MOL	Beam trawl	Molluscs	Whelk, snails and scallops	0.060

[1] including OT_MIX_CRU and OT_MIX_CRU_DMF

[2] including OT_MIX_DMF_BEN, OT_MIX_DMF_PEL

3.2.3. Longevities trait information

The PD method assumes that the sensitivity to trawling is proportional to the reciprocal of the longevity of species and communities, as explained in the next section. This approach therefore requires estimates of the longevity of all species in a community.

Owing to scarce data and high uncertainty in longevity (T_{max}) estimates for individual species, longevities were assigned to taxa with a fuzzy-coding approach following Bolam *et al.* (2017). Fuzzy coding can assign fractional scores to different T_{max} categories, depending on the affinity of the species with these categories, and sums to one. This allows taxa to exhibit multiple T_{max} categories to different degrees, and helps to address the uncertainty in and absence of direct T_{max} measurements for many benthic invertebrate species and expected differences in T_{max} within species linked to latitude and environment. Most of the longevity database applied four T_{max} categories: <1, 1–3, 3–10, >10yr, which are chosen to encompass the range of possible attributes of most taxa but for some regions, T_{max} categories were changed to better represent the composition of their fauna. For example, for the Barents Sea and Norwegian Shelf, six T_{max} categories (<2, 2–5, 5–10, 10–20, 20–50 and > 50 yr) were included.

3.2.4. The intrinsic rate of population increase *r* (recovery rate)

This section explains how we estimated values for 'Recovery rate' in **Figure 57**A. The effect of any given rate of trawl mortality on a population will depend on its life-history, whereby populations with low *r*, low natural mortality rates (*M*) and greater longevity (T_{max}) have an increased sensitivity to trawling disturbance (Duplisea *et al.*, 2002). For example, Tillin *et al.* (2006) demonstrated that benthic epifauna with T_{max} >10yr decreased in abundance with trawling, but that no such reduction occurred for fauna in the same areas with T_{max} <2yr. Hiddink *et al.* (2018) showed that the effect of bottom trawling in comparative studies increased with longevity, with a 2–3× larger effect on biota living >10yr than on biota living 1–3yr. We attribute this difference to the slower recovery rates of the longer-lived biota. This work showed that *r* closely relates to the inverse of longevity of benthic fauna, and that this matches theoretical expectations (Figure 61).

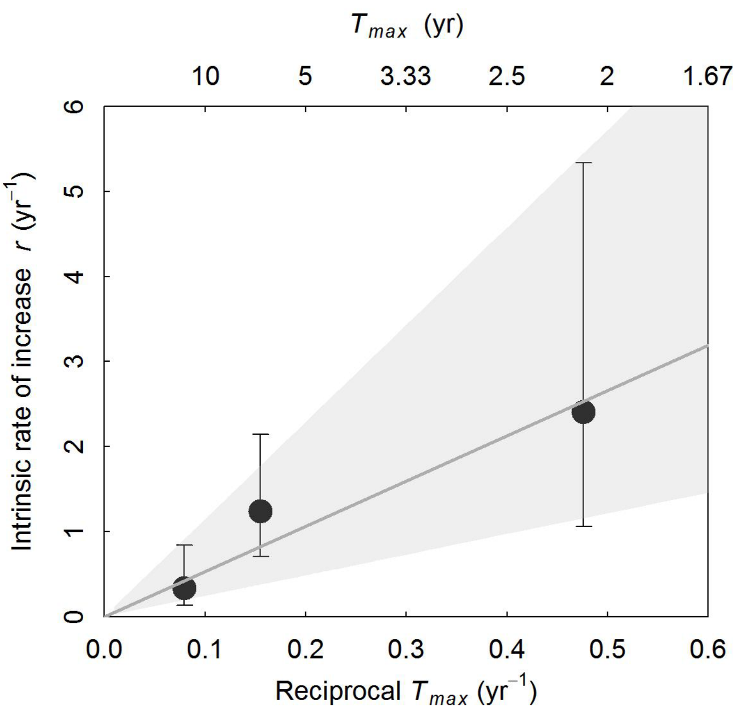


Figure 60. Relationship between *r* and longevity T_{max} estimated from gradient studies (*r* = 5.31 / longevity, $R^2 = 0.96$, $F_{1,1} = 73.9$, P = 0.013). The points and error bars are *r* estimates and their 95% confidence intervals, while the solid line is the fitted regression line. The shaded areas indicate the regression fits through the upper and lower confidence intervals of the data (upper: *r* = 11.44 / longevity, lower: *r* = 2.43 / longevity); (Hiddink *et al.*, 2018).

3.2.5. Habitat sensitivity

The distribution of longevities can then be used to estimate the sensitivity to trawling of a habitat. A benthic community with many long-lived species will have a lower mean *r* than a community with many short-lived species. Because the effect of trawling is proportional to the ratio of *d*/*r*, a lower *r* will result in a higher impact at the same intensity of trawling. Figure 62 illustrates this, using two hypothetical habitats. A habitat will be sensitive to trawling if a large fraction of the biomass of the community, in an untrawled community, is made up of long-lived species with a low *r* (Figure 62a). A habitat will be less sensitive to trawling if a large fraction of the biomass of the community, in an untrawled community, is made up of short-lived species with a high *r* (Figure 62b). This results in sensitivity of habitats to bottom trawling being higher in habitats with higher proportions of long-lived organisms (Figure 62). Because the biomass of the high *r*, short-lived, species will respond less to trawling that the biomass of the low *r*, long-lived, species, total community biomass will respond differently depending on the longevity composition of the community at no trawling.

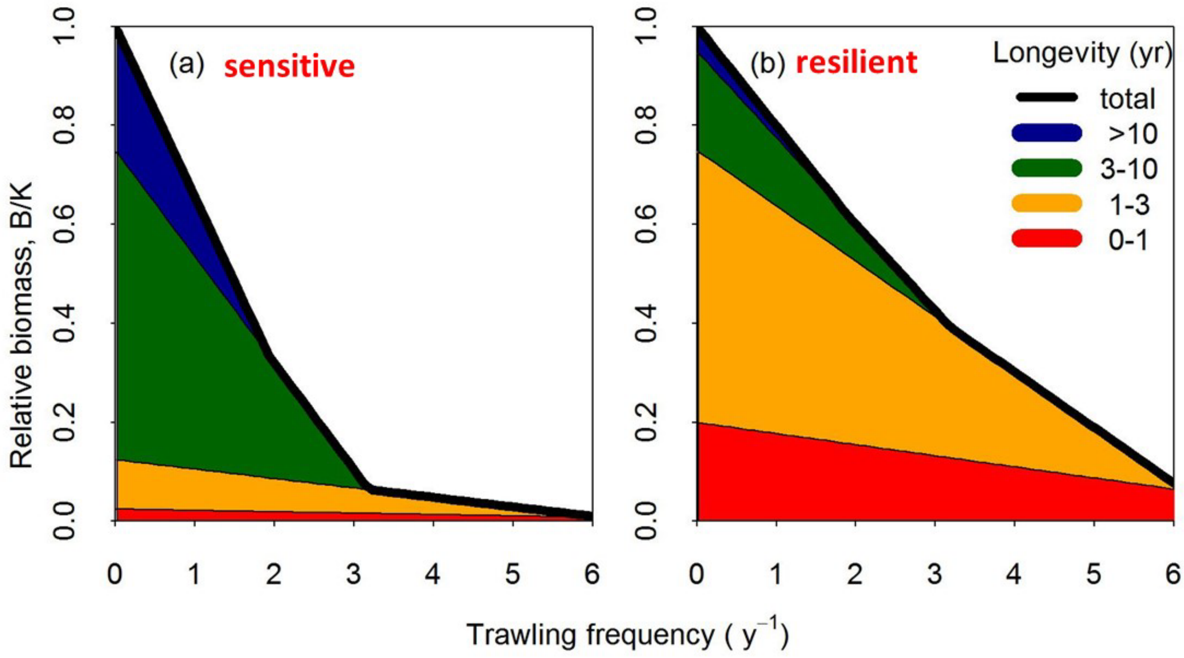


Figure 61. An example of how the longevity distribution of a benthic community at no trawling affects the response of total community biomass to bottom trawling.

Differences in longevity distribution of benthic communities are likely to be related to the environment they live in. Habitats with high levels of other disturbance, for example by waves, or hypoxia, are likely to have a low fraction of long-lived species as these disturbances will have already led to the loss of such species, and are instead dominated by short-lived fauna. As a result, communities in high natural-disturbance environments with shorter-lived fauna will be less sensitive to anthropogenic disturbance, as shown in several previous studies (Hiddink *et al.*, 2006; van Denderen *et al.*, 2015; Rijnsdorp *et al.*, 2018).

This means that where the longevity of a species or the longevity distribution of a community is known or can be inferred, our estimates of depletion and intrinsic rate of increase can be combined with high-resolution maps of trawling intensity to assess trawling impacts at the scale of the fishery or other defined unit of assessment.

3.2.6. Estimating the biomass-longevity distribution of untrawled communities

This section explains how we estimated the continuous benthic community composition in **Figure 57**B. To apply the PD approach, the biomass-longevity distribution of untrawled communities will need to be estimated in relation to environmental variables (i.e. the reference state). This will require samples (which can include grabs, cores, video, photo, dredges or trawls) of benthic communities over the main environmental gradients. To estimate a reference state, Bolam *et al.* (2017) showed that it is possible to use both samples from untrawled (i.e. a zero fishing pressure estimate) locations and locations with low trawling intensity. They found that for the more sensitive shelf habitats locations with trawling intensities up to 0.1 per year could be used for estimating the reference state, whereas locations with even higher fishing intensities could be included in areas less sensitive.

WGFBIT currently uses the method described in Rijnsdorp *et al.* (2018) to estimate a reference state that represents the biomass-longevity distribution of untrawled communities. This is done based on the below four steps:

1) Estimate the fraction of benthic community biomass per T_{max} category for each sampling location
2) Convert the T_{max} longevity categories into a continuous scale by assuming that in each sample the biomass proportion with longevity smaller than or equal to the upper range of T_{max} (e.g. T_{max} 1–3 = 3, 3–10 = 10) is a sigmoidal (logistic) function of longevity, which starts at 0 and approaches 1 when longevity becomes large (Figure 63).

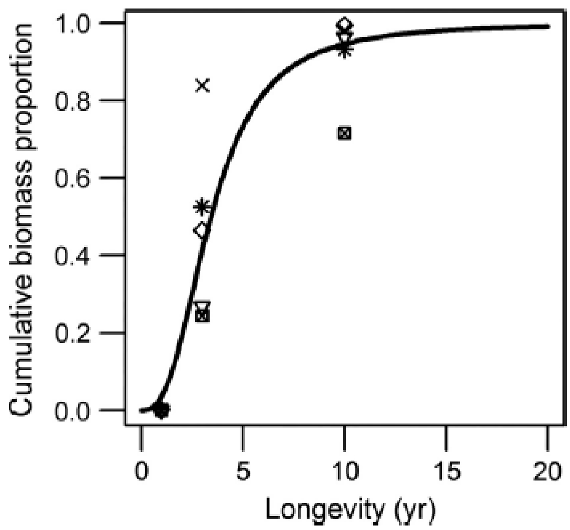


Figure 62. An example of the cumulative biomass–longevity relationship estimated from the observed cumulative biomass by longevity class (1, 1–3, 3–10 yr) in five sampling stations. Different symbols indicate the five different locations. Figure taken from Rijnsdorp *et al.* (2018).

3) Fit a statistical model to estimate a biomass-longevity distribution. The model used is a logistic mixed effect model with the cumulative biomass proportions (*Cb*) as the response variable and longevity (*l*) and environmental conditions (*H*) as the predictor variables. The model has a random intercept per location to take account of the dependency of the cumulative biomass proportions within a sample:

$$Cb \sim \beta_0 + \beta_1 \ln(l) + \beta_2 H + \beta_3 \ln(l) * H + \varepsilon_1 + \varepsilon_2$$

where longevity (l) is ln transformed, the first error term ($\varepsilon 1$) has a binomial distribution, and the second normally distributed error (ε_2) represents the random effect on the intercept per sampling location.

Main effects and two-way interaction terms between longevity and environmental conditions can be examined. In all statistical procedures, model fits are evaluated using the Akaike Information Criterion (AIC). The best candidate model is the model with the lowest AIC (yet with a difference of <2 AIC units, the model with the fewest parameters is chosen).

4) Predict the longevity distribution for each c-square in the region using the best candidate model and the prevailing environmental conditions.

If environmental data layers (e.g. sediment composition, bottom shear stress, salinity, …) are not available but EUNIS classified habitat maps are available, it may be possible to derive a longevity distribution by EUNIS habitat instead.

If some sampling locations are trawled, trawling intensity has to be included in the statistical model after which an untrawled “reference” biomass-longevity distribution can be obtained, see for example Rijnsdorp *et al.* (2018). Only where a large number of stations with no or very low trawling intensity are present, trawling intensity does not need to be included in the models.

3.3. FAQ on benthic sensitivity

- Why was the PD assessment method chosen?

A good indicator to assess GES for D6 of the MSFD should relate to the biodiversity, structure and function of the benthic community (ICES, 2016, 2017). The PD methods response variable captures the structure and function of the benthic community to a greater extent than other assessment methods. The PD method combines information on total benthic biomass (which is linked to the overall functioning of the ecosystem, see 2017 WGFBIT report section 3.2.1 on page 57) with the relative abundance of different longevity classes (that in turn relates to the structure and biodiversity).

The PD method is a mechanistic model that is based on the logistic population growth equation, which is generally applied in ecology and fisheries to describe how populations change in size in response to exploitation. The model needs depletion (d) and recovery (r) parameters, which were estimated from all globally available trawl impact studies for infauna and epifauna. The method and its parameter estimates are therefore applicable globally. In the PD method, the recovery rate of a community depends on the longevity distribution of an untrawled community. The response variable presented by the PD method is the relative benthic biomass (RBS), which is the whole community benthic biomass relative to carrying capacity (i.e. the sum of the biomass of fauna of all different longevities relative to what it would have been with no fishing).

The PD method is considered more suitable to assess GES of the seabed at a European scale because of its mechanistic nature means that it can be flexibly applied to areas outside the area it was developed (North Sea). FBIT has now successfully operationalized the PD method for the North Sea, Baltic Sea, Celtic Sea, Bay of Biscay Iberian Coast, Northern Mediterranean, Iceland, Barents Sea and Norwegian Sea. Successful application of the PD method does not rely as heavily on any specific origin of the input, and can hence also be applied for more data-poor regions and subsequently improved when better data becomes available. For these reasons, WGFBIT has prioritised the PD model in its work plan over the coming years. The PD now serves as one common method or language for operationalizing the WGFBIT framework (exploring options for thresholds, scale, cross-regional EU-wide guidance).

- The model estimates relative total community biomass, how does this relate to seafloor integrity, biodiversity, structure and function?

Community biomass is known to correlate to many ecosystem functions, and when local biomass is decreasing, local biodiversity and species richness will also be declining. Ecosystem processes that benthos provide such as bioturbation, nutrient cycling, and food provisioning for higher trophic levels such as fish and seabirds, are all tightly linked to benthic biomass.

- How did the underlying studies that provided the input data find unfished areas? Is not all of the seabed already trawled? How do we know what the pristine condition could be like?

Many of the studies that were used went through a careful process of site selection to ensure the true effect of trawling was detected. Unfished areas do occur in all seas, and have been used in many of the studies as ‘control’ locations. For example, Amoroso et al. (2018) showed that even in the most heavily trawled seas such as the North and Adriatic seas, around 20% of the areas is not trawled. Other studies have included ‘control’ locations that were infrequently trawled and were a large fraction of the seabed is likely to have been untouched by trawling for many years. Nevertheless, there may have been some loss of the most *sensitive fauna since 100s of years ago, and we cannot quantify how much using current methods. As a result, trawl impacts may be underestimated when there is uncertainty on how 'trawl-free' the control locations have been in the last century. However, managers will need to manage the ecosystem that is currently here, rather than one that might have been there a very long time ago, and this approach does provide the tools to do this.*

- How does the method deal with other pressures, such as aggregate dredging, invasive species and hypoxia?

The interaction of natural disturbance with trawl disturbance is considered through the untrawled longevity distribution of the fauna. Anthropogenic pressures besides abrasion from bottom trawling are currently not considered. Other pressures that cause abrasion, such as aggregate dredging, might be included relatively easy in future developments (ICES, 2019). Non-abrasion pressures are more difficult to incorporate. An approach to evaluate the interaction of hypoxia and trawling has been developed for the Baltic outside this WG (van Denderen et al. 2019).

4. Assessment framework – Fishing impact

Fishing impact is estimated by combining information from fishing pressure (see section 2) and benthos sensitivity (see section 3); (Figure 64). It is here assessed according to the PD method, which is a mechanistic model that estimates the total reduction in community biomass (B) relative to carrying capacity (K), corresponding to the estimated fishing intensity (1-B/K; Hiddink *et al.*, 2017, Pitcher *et al.*, 2017).

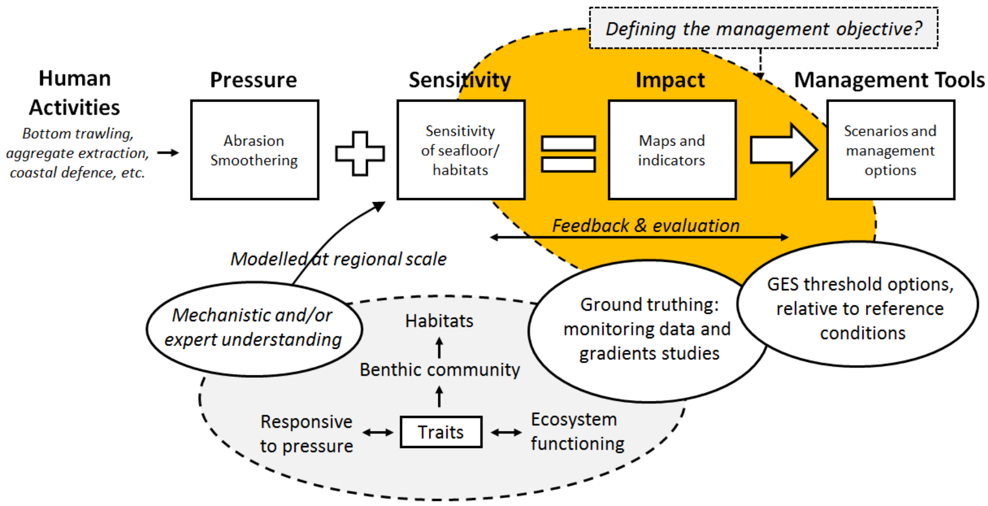


Figure 63. Conceptual diagram of the steps taken in developing management tools for assessing pressure and impact on the seafloor from human activity. Impact part is highlighted in orange.

4.1. Fishing impact indicator

Fishing impact is calculated on a spatial C-square grid of 0.05 x 0.05 degree resolution in accordance with the spatial resolution of the underlying pressure information (section 2.1). It is directly dependent on the local longevity distribution of the benthic community (see 3.2.6) and the annual surface abrasion from bottom contacting gears. This means that the indicator does not consider temporal changes in community sensitivity, nor does it estimate changes in benthic impact over continuous time.

Grid cell-specific annual impact indicator values are reported in a table per MSFD broad habitat type. ICES (2017) advised to use two area-specific annual indicators: First, the local impact indicator averaged across c-squares, and second, the proportion of c-squares with an impact below a predefined threshold level (Table 30). Both indicators are currently provided per year and ecoregion, the latter for an impact threshold value of 0.2. Each indicator can also be assessed separately for specific depth ranges.

Table 31. Indicators for assessing fishing impact.

Annual impact indicator	Description
1 – average impact	Annual average fishing impact across grid cells in the considered area (regional/ subregional sea, or broadscale habitat type within that sea)
2 – Area below impact threshold	The proportion of grid cells with an impact below a (chosen) impact threshold in the considered area (regional/ subregional sea, or broadscale habitat type within that sea

Furthermore, C-squares and thus impact indicators of assessed ecoregions can be aggregated by broad habitat types, i.e. EUNIS habitat types (level 2). All habitat types associated with each C-square are considered and the relative proportion of habitat types within each grid cell is estimated. Similarly, impact indicators are calculated separately for the 10 métiers (Table 29), thus indicating their relative contribution to the overall benthic impact and providing the opportunity to relate métier-specific impacts to other indices like catch and landings.

4.2. Running the assessment and input data

Documentation (R-code) for assessing pressure and impact is available on GitHub (see Appendix 2).

The following input data are currently used to calculate fishing impact on a 0.05x0.05 degrees grid and aggregate estimates to regional and subregional indicator values:

1. Seabed depth: average depth per C-square as taken from EMODnet bathymetry data as downloaded in April 2020: https://www.emodnet-bathymetry.eu/
2. MSFD broad habitat types: Taken from EMODNET EUSEAMAP as downloaded in September 2021 http://www.emodnet.eu/
3. Bottom trawl fishing SAR values (available for all Atlantic regions through the ICES VMS database using the R package icesVMS)
4. Seafloor sensitivity, i.e. longevity composition of the benthic community, estimated by each sub-regional assessment group within FBIT – each sub-group maintains and archives statistical outputs and underlying environmental data layers.
5. Shapefiles of ICES ecoregions as downloaded in June 2018 http://gis.ices.dk/shapefiles/ICES_ecoregions.zip

4.3. Uncertainties in impact estimates

The confidence intervals of model parameters d and r have been estimated based on their observed variability and this uncertainty can be propagated into the final model impact outputs. A Monte Carlo approach to estimate this uncertainty in the assessment output will be implemented intersessional. An example of such an analysis is shown in van Denderen *et al.* (2019) for the

Baltic Sea, where besides uncertainty in parameter *d* and *r*, statistical uncertainty in the predicted biomass-longevity distribution was propagated into the final outputs for each grid cell.

Other sources of uncertainty come from the environmental data layers, the fishing pressure maps and the broad habitat type maps, and currently no methods have been applied to propagate this uncertainty.

The PD approach to estimate fishing impact provides a relative value, relating the total reduction in community biomass (B) due to abrasion (currently only from fishing) to the locally assumed carrying capacity (K). Thus, impact values cannot be directly validated with empirical measures of biomass.

4.4. Assumptions and limitations

The outputs of this work come from a model, and the outputs are only as good as the simplifications, assumptions and parameter estimates used. The logistic population growth model that is used is one of the simplest ecological models and is used here exactly because of this simplicity. The simplicity makes the approach transparent and allows the robust estimation of the parameter values. More complex approaches are available (e.g. Hiddink *et al.*, 2006), but the much higher parameter demands of such models make it very difficult to extend them to larger areas.

The parameter estimates used here are as robust as the current state of knowledge allows given that they synthesize all available evidence. Nevertheless, these parameter estimates are only applicable to the studies that they were based on, and at the moment most studies were carried out in temperate sedimentary habitats on infauna and epifauna, and studied the impact of towed bottom gears.

The approach creates a spatial prediction of fishing impacts, but does not include spatial ecological processes. This means that processes like recruitment and dispersal are not included, and that the state of a C-square does not depend on the state of the C-squares around it. Likewise, any functions that are provided by a specific species that could affect surrounded species, for instance reef building or bioturbation capacities, are not taken into account by the model.

The method predicts the relative community biomass, which is the biomass as a fraction of what it would be without bottom trawling. This has the advantage that it is easy to compare states between the different habitats, and that the data demands of the approach are lower. It does however also mean that in final products, all C-squares will be equally weighted regardless of the amount of biomass they can support, and areas that can support a high biomass are not given more importance. If a data layer predicting biomass carrying capacity can be provided, absolute biomass can be predicted using this approach.

4.5. FAQ on benthic impact

- Some opportunistic species will increase in abundance in response to trawling, how does this approach capture this?

After trawling, smaller, short-lived species may increase in abundance when they are released from competition and predation by the larger, long-lived species. The availability of discards may also provide a small food subsidy to some species, although this has been shown to be a very minor fraction of the diet for benthos. Because the species that can increase in abundance are generally small, the total community biomass will largely reflect as loss in the larger species, and an increase in smaller opportunistic species will hardly affect total community biomass. These emergent effects are already incorporated in our parameter estimates as they will have been present in the studies that were used to estimate the parameters. In cases *where the increase in opportunistic species has a large effect on total community biomass, it is recommended to examine model predictions (and validation) with and without the dominant species as the current methodology is unable to account for non-negative responses with trawling.*

- Is a complete change in the biological assemblage with trawling within the same physical habitat seen as habitat loss? How does the approach handle this?

Following ICES (2019), loss is defined as any human-induced permanent alteration of the physical habitat from which recovery is impossible without further human intervention. An alteration of the physical habitat refers to a change from one EUNIS level 2 habitat type to another EUNIS level 2 habitat type. A change in the biological assemblage is therefore not seen as habitat loss, but as disturbance. The PD model may estimate this as a community that is 100% impacted – no species of the original community are expected to be present.

- Can the approach estimate the reduction in biomass of sensitive taxa, rather than total community biomass?

The PD method does not separately account for declines of rare, sensitive and fragile species that managers may want to protect (e.g. within MSFD Descriptor 1: biodiversity). Rare and sensitive species are potentially heavily affected by trawling even though total biomass, linked to the structure and function of a community, is less affected. The PD model can be used to model the vulnerable part of the benthic community. For example, the model can be used to estimate relative biomass decline for all taxa with longevities > 10 yr. This will result in a different benthic impact indicator than currently used in WGFBIT.

5. Assessment framework – Trade-offs

5.1. Assessment of trade-offs

The evaluation of trade-offs between human activities and environmental impact is an integral part of Ecosystem-based management. For bottom trawl fishing, trade-offs relate to the distribution of impact and recovery potential of the seafloor with factors that are important for management (e.g. fisheries economics).

The WGFBIT seafloor assessment framework allows for evaluation of trade-offs between catch/value of landings per unit area and the environmental impact and recovery potential of the seafloor (e.g. ICES 2021). Such information will be required in the exploration of management scenarios under different policy requirements (e.g. MSFD, CFP, and the deep-sea access regulation EU 2016/2336); (Figure 65).

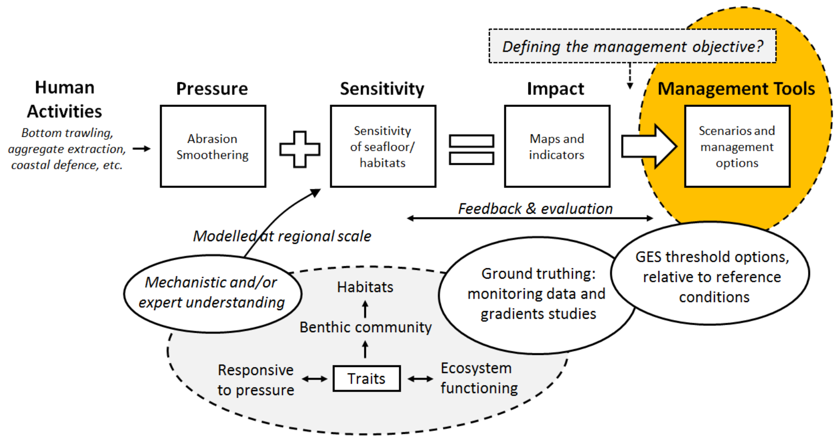


Figure 64. Conceptual diagram of the steps taken in developing management tools for assessing pressure and impact on the seafloor from human activity. Assessment of trade-offs part is highlighted in orange.

Investigations of the cumulative proportion of the swept area, total landings (kg), and value (€) in relation to the surface area of an ecoregion indicate that large proportions of each of the parameters occur in relatively small parts of the area (ICES, 2021). This pattern of smaller core and larger peripheral fishing areas is apparent at a (sub-)regional level, as well as for all métiers. It is thus feasible to estimate the change in fishing impact by reducing the fishing pressure to a varying degree.

In relation to the assessment of trade-offs, WGFBIT is currently

1) contrasting landings and value with the available pressure and state indicators per ecoregion and broad habitat types.
2) calculating a ratio between the gear type-specific impact indicator and landings respectively value, indicating which gear type causes the highest impact in relation to its relative economic importance.
3) ranking C-squares according to the level of fishing pressure they encounter, either per ecoregion, broad habitat type or other spatial area. As a result, options can be evaluated how much landings or value is generated in areas with the lowest fishing pressure (in %).

5.2. Development of trade-off scenarios

In the current state of the assessment framework, scenarios considering fisheries displacement and/or economic impacts cannot be properly developed. The framework can be used to evaluate changes in fishing impact and landings and value according to potential reductions in fishing pressure (as done in ICES, 2021a).

The following specific management scenarios have been taken forward for trade-off analysis:

- The progressive removal of fishing effort (from 5 to 99%) from c-squares for all bottom trawl métiers by either starting from the least or most trawled c-squares.
- Same as 1 but from each MSFD broad habitat type and only by starting from the least trawled c-squares.
- The removal of effort through specific spatial control until the estimated pressure/impact on each benthic habitat is reduced to the desired level.
- Gear modification in terms of reduced penetration depth, resulting in lower catch rate.
- The removal of fishing effort by particular individual métiers (métier prohibition).

Evaluations of each of these management scenarios is provided in the TRADE3 workshop report for the Greater North Sea in the period 2013–2018 (Section 5 in ICES, 2021a).

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Appendix 1: terminology and definitions

Definitions related to benthic impact from trawling

Different species' responses to disturbance over time can be defined. In the context of bottom trawl fishing, an important parameter is trawling frequency that modulates species' response. Instantaneously, a haul can damage or kill an organism depending on its sensitivity to the gear (e.g. degree of body fragility) and the magnitude of the disturbance. Then, in case of consequent demographic or biomass depletion, another type of response is recovery through adult migration or offspring settlement. Recovery depends on trawling frequency so that the higher the frequency, the slower the recovery. In case of a null degree of sensitivity, organisms are resistant, i.e. no damage or population depletion is consequent from a trawl disturbance. In the case of a non-null degree of sensitivity, two types of species can be characterised by combinations of sensitivity and recovery. A resilient species is primarily characterised by a fast recovery following damage or depletion, independently of sensitivity, so that juvenile or adult mortality do not impair population survival over time under a disturbance regime. By contrast, a vulnerable species experiences substantial damage or depletion following a minimum disturbance with a recovery time exacerbated by maintained or increased disturbance frequency.

Within the above context, and to ensure common understanding, WGFBIT have proposed the below set of definitions:

Activity: a human action or endeavour that has the potential to create pressures on the marine environment (e.g. aquaculture or tourism); where activities are usually grouped in sectors, each one of which encompasses many activities and sub-activities (e.g. fishing, bottom trawling, etc.) (Smith *et al.* 2016, Elliott *et al.* 2017).

Pressure: the mechanism through which an activity has an actual (or potential) impact on the ecosystem (e.g. for otter trawling or beam trawling fishing activity, one pressure would be abrasion to the seabed) (Robinson *et al.* 2008, Smith *et al.* 2016, ICES 2016).

Fishing 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).

Species 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

Impact: The effects (or consequences) of a pressure on an ecosystem component. The impact is determined by both exposure and sensitivity to a pressure (ICES 2016).

Degree of impact: The level of impact on the seabed should be considered in the ranking; where low impact activities are ranked below high impact activities for the same level of spatial/temporal coverage. Low impact activities are those which cause minor direct mortality/damage on benthic organisms, resulting in adverse effects/impacts that lie within the bounds evidenced across cycles of natural variation. High levels of impact can be considered to have occurred where the activity results in adverse effects/impacts to the benthic habitat and its communities beyond what might be expected from natural disturbances. Issues on sensitivity/resilience/recovery of specific benthic groups (faunal or traits) and functional habitats are discussed in the section on modelling and smothering.

Areal coverage: This must consider two aspects: the spread of the activities footprint at a regional scale and its spatial coverage within the footprint. For example, for a given degree of impact, if an activity occurring throughout the region is split into small, discrete areas, this would rank lower than similarly impactful activities that have a higher areal coverage but are not as widespread across the region. Activities that occur over the entire region, and are continuously distributed throughout this area, would be regarded as having the maximum areal coverage possible.

Recoverability (or resilience): The time that a receptor needs to recover from a pressure, once that pressure has been alleviated

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

Fishing intensity indicator: A characteristic of the footprint of the fisheries, on either spatial or temporal scales (or both).

Benthic impact indicator: A characteristic of a benthic habitat that can provide information on ecological structure and function

Above definitions related to benthic impact from trawling have been developed with the following ICES advice (and associated workshop work), as well as the ICES Ecosystem Overview in mind:

- ICES. 2021c. ICES Technical Guidelines Published 5 March 2021. ICES Advice 2021 – https://doi.org/10.17895/ices.advice.7916
- ICES. 2019. EU request to advise on a seafloor assessment process for physical loss (D6C1, D6C4) and physical disturbance (D6C2) on benthic habitats. In Report of the ICES Advisory Committee, 2019. ICES Advice 2019, sr.2019.25, https://doi.org/10.17895/ices.advice.5742
- ICES. 2017. EU request on indicators of the pressure and impact of bottom-contacting fishing gear on the seabed, and of trade-offs in the catch and the value of landings. ICES Special Request Advice, eu.2017.13. 27 pp. https://doi.org/10.17895/ices.advice.5657

How to differentiate between physical loss and physical disturbance?

The Commission Decision (EU) 2017/848 of 17 May 2017 defines physical loss and physical disturbance as:

"3. Physical loss shall be understood as a permanent change to the seabed which has lasted or is expected to last for a period of two reporting cycles (12 years) or more.

4. Physical disturbance shall be understood as a change to the seabed from which it can recover if the activity causing the disturbance pressure ceases."

With this in mind and based on ICES 2019 advice, WGFBIT agreed the following definitions of physical disturbance and physical loss:

Physical loss is defined as any human-induced permanent alteration of the physical habitat from which recovery is impossible without further human intervention. An alteration of the physical habitat refers to a change from one EUNIS level 2 habitat type to another EUNIS level 2 habitat type. Recovery indicates the re-establishment of the original natural EUNIS level 2 habitat by means of a human intervention.

Two types of physical loss are identified:

Sealed physical loss results from the placement of structures in the marine environment (e.g. wind turbines, port infrastructure) and from the introduction of substrates that seal off the seabed (e.g. dredge disposal).

Unsealed physical loss results from changes in physical habitat, either from human activities or from the indirect effects of the placement of man-made structures (e.g. aggregate extraction or a structure causing changes in water flows, ultimately changing the EUNIS level 2 habitat type).

Physical disturbance is defined as a pressure that disturbs benthic biota but does not permanently change the habitat from one EUNIS level 2 habitat type to another EUNIS level 2 habitat type. With sufficient time, recovery can be expected without human intervention.

Physical disturbance to physical loss can be regarded as a continuum, where the intensity of a physical disturbance may lead, in time, to a permanent change from one EUNIS level 2 habitat type to another and hence physical loss.

To identify the main human activities that disturb the seabed, four pressure subtypes were identified as the pathways through which physical loss and physical disturbance operate. These physical pressure subtypes were identified by ICES as the only pathways from activities to physical loss or physical disturbance. ICES (2019) defines these four pressure subtypes as:

Abrasion: the scraping of the substrate (e.g. by a trawl door or an anchor). Whilst abrasion could result in the mixing of sedimentary substrates, any sediment removal is considered a "Removal" pressure subtype. The abrasion pressure subtype can result in physical loss and/or physical disturbance.

Removal: the net transference of substrate away from the seabed resulting from human activities (e.g. either directly by human activities or indirectly through the modification of hydrodynamics). This pressure subtype can result in physical loss and/or physical disturbance.

Deposition: the movement of sediment and/or particulates to a new position on top of or in existing substrates (e.g. directly by human activities such as dredge disposal or indirectly through the modification of hydrodynamics). This pressure subtype can result in physical disturbance.

Sealing: the capping of the original substrate with structures (e.g. metal pilings, concrete footings, or blankets) or substrates (e.g. rock or stone fills, dredge disposal) which in and of themselves change the physical habitat. This pressure subtype can result in physical loss.

Appendix 2: R-documentation for assessing pressure and impact indicators

The workflow of the regional assessment of pressure and impact, with its respective R scripts, is publicly available on an open-source platform: https://github.com/ices-eg/FBIT

A tutorial for assessing pressure and impact following the WGFBIT methodology is available: https://github.com/ices-eg/FBIT/tree/master/TAF - ICES tutorial