# WORKING GROUP ON FISHERIES BENTHIC IMPACT AND TRADE-OFFS (WGFBIT; outputs from 2023 meeting)

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

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

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## Editors

Marija Sciberras • Gert Van Hoey • Jan Geert Hiddink

## Authors

Alessandra Nguyen Xuan • Alice Sbrana • Andrea Pierucci • Belén Calero • Chris Smith • Clare Bradshaw • Clement Garcia • Daniel van Denderen • Cristina Vina-Herbon • Elena Guijarro Garcia • Gert Van Hoey • Giada Riva • Hatice Onay • Irini Tsikopoulou • Jacob Bentley • Jan Geert Hiddink • Joanna Desmidt • Jochen Depestele • José Manuel González Irusta • Justin Christopher Tiano • Karline Soetaert • Kate Morris • Klaus Jürgens • Laura Seidel • Lorna McKellar • Luke Batts • Maria Cristina Mangano • Maria Teresa Farriols • Marija Sciberras • Marina Pulcini • Mats Blomqvist • Matteo Stefani • Mattias Sköld • Megan Parry • Melanie Hartley • Nadescha Zwerschke • Nadia Papadopoulou • Neve McCann • Olivier Beauchard • Pascal Laffargue • Philip Boulcott • Pierluigi Carbonara • Porzia Maiorano • Renato Mamede • Ruth Parker • Sandrine Vaz • Sebastian Valanko • Tommaso Russo • Walter Zupa

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# 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 (ToR A) are shown for the Spanish Mediterranean. For other regions, updates of the whole assessment or specific steps only are presented.

In relation to the updates on the assessment framework (ToR B), an alternative indicator to L1 was tested. It is based on the FBIT methodology but only estimates the relative decline in biomass of the 10% most long-lived biomass fraction of the community (PD-sens). The group examined the responsiveness of this indicator to 6 gradients of trawling pressure and compared it with the PD total biomass indicator and two empirically estimated indicators, SoS and long-lived fraction. The results show that the PD-sens is typically as responsive as SoS and long-lived fraction. Furthermore, the overview on the current methodologies used in the FBIT approach across regions is further updated and, in such way, forms the basis for the methodology section of the manuscript in development.

Regarding indicator comparability (ToR C), the work of the Workshop to evaluate proposed assessment methods and how to set thresholds for assessing adverse effects on seabed habitats (WKBENTH 3; ICES, 2022) is transformed into a publication. For certain regions, more indicator comparisons are executed, for example, in the Adriatic Sea.

The WGFBIT ToR D works towards an improved understanding of the link between species functional effect traits and parameters for specific ecosystem functions in order to improve our ability to predict the impact of fishing disturbance on benthic ecosystem functioning. A new assessment examining trawling-induced changes in benthic effect trait composition using multiple case-studies from the North Sea, Celtic Sea, Kattegat, Baltic Sea and the eastern Mediterranean is presented. Work continues to quantify relationships between species traits and biogeochemical parameters and to develop a data-driven mechanistic model to predict changes in the trajectories of species densities, bioturbation and bioirrigation potential over time due to trawling.

# 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** | 3/3 |
| **Chairs** | Marija Sciberras, UK<br>Gert Van Hoey, Belgium<br>Jan Geert Hiddink, UK |
| **Meeting venue and dates** | 20-24 November 2023; Tvarminne, Finland (hybrid), 50 participants |

# 1 Highlights from WGFBIT 2023 meeting

The major conclusions of the WGFBIT 2023 meeting are summarized as followed:

ToR A

> Further progress has been made with the regional assessments of bottom trawling impacts on seabed ecosystems in many regions, and we now have a preliminary map of sensitivity to trawling impacts that covers most of European continental shelf seas. The WG agreed to start working towards a manuscript that reports on the impacts of trawling on seabed ecosystems across all regions in Europe for which we have assessments.

ToR B & C

An alternative indicator, the PD-sens was tested. It is based on the FBIT methodology but only estimates the relative decline in biomass of the 10% most long-lived biomass fraction of the community.

The overview of the methodologies used in the FBIT approach across regions is further updated. Additional indicator comparability exercises are executed, as for example in the Adriatic Sea.

ToR D

> Results of a multiple case-study analysis by WGFBIT members is presented. The study focused on ecosystem functions ensured by benthic organisms (“ecosystem engineering”) through “effect trait” expression, and the possible impact of bottom trawling on those functions. Thirteen case-studies from European waters were used, allowing examination of different environmental contexts and trawling intensities. Bottom trawling was found to be a selective force of benthic effect trait composition in the majority of studied areas. In general, surficial species were more typical of low trawling frequencies, whereas deep burrowing species were more resistant at high trawling frequencies. Although we report significantly deleterious effects of trawling on benthic ecosystem functions, the effect trait pattern along the gradient was not related to life span. Therefore, although life span might be a key response trait to express taxon abundance recoverability following disturbance, it was not found to be a good indicator of ecosystem function vulnerability.

Publication: Beauchard, P., Bradshaw, C., Bolam, S., Tiano, J., Garcia, C., De Borger, E., Laffargue, P., Blomqvist, M., Tsikopoulou, I., Papadopoulou, N.K., Smith, C.J., Claes, J., Soetaert, K., **Sciberras, M**. (2023). Trawling-induced change in benthic effect trait composition – A multiple case-study. Frontiers in Marine Science, doi 10.3389/fmars.2023.1303909

Further work has been carried out on a data-driven mechanistic model that predicts species depletion and recovery between trawling events. This model calculates the changes in benthic species density or biomass, using the logistic growth formulation; its parameters are derived from in situ density or biomass data from a particular site combined with species trait information, including the longevity of the species, and the depth of occurrence in the sediment. Model was tested on two datasets from the Dutch part of the North Sea (macrofauna density and biomass data collected for the period 1995 till 2018 for 103 stations) and the oligotrophic eastern Mediterranean Sea.

# 2 General introduction

The objectives for the sixth meeting of the Fisheries Benthic Impact and Trade-offs working group (WGFBIT) 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 grouped 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.

Aims and Deliverable for 2023:

- Hybrid meeting with time for informal chats and catch up to strengthen links within the group and progress towards WGFBIT aims (ToR A, B, C, D).
- Progress integration into WGFBIT framework state of the art methods to quantify ecosystem goods and services using traits and ecosystem function (ToR D).
- Present and discuss the final FBIT regional assessments as input for ecosystem overviews (ToR A).
- Improving the methods (ToR B): Towards a more uniform application of the FBIT methods across regions.
- Progress regional specific calibration, ground truthing, and assessment sheets (ToR A, C).
- Updating ToRs and electing chairs for the next 3-year cycle of WGFBIT.

# 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. In Table 1, an overview is provided 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.

## 3.1 Regional advice sheet documents

These advice sheets are supplied for some regions, and for some regions summarise the information in section 3.2.

### 3.1.1 ICES seafloor assessment of mobile bottom fishing: Greater North Sea Ecoregion

**Assessment summary**

This is an assessment of mobile bottom fishing for the Greater North Sea Ecoregion. It is based on Vessel Monitoring by Satellite (VMS) fishing data up to 2022 and follows the methods described in ICES (2022a). 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 aggregate dredging and wind farm construction, but their impact is only a fraction of that of bottom fisheries (ICES 2019). The impact threshold used in this assessment is arbitrarily set at 0.2. References to the full assessment can be found below under ‘Format of the assessment’.

## Assessment results

### Status in year 2022

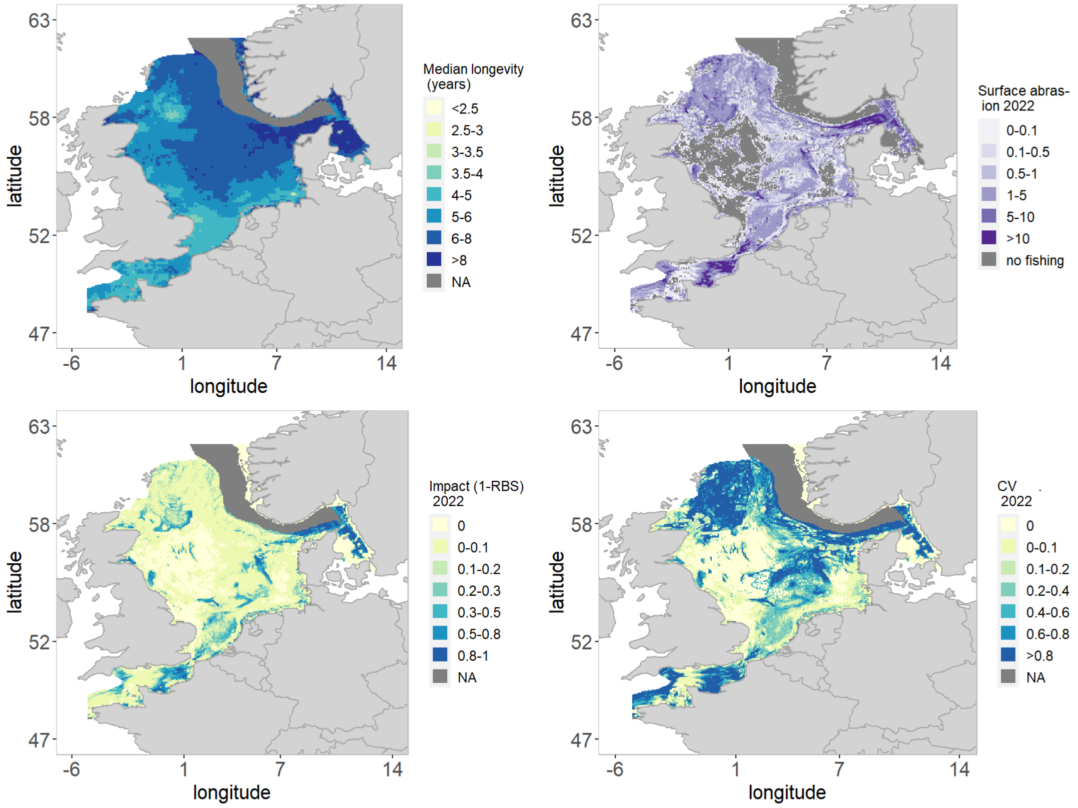

**Figure 1.** Assessment results for the Greater North Sea Ecoregion. Sensitivity (a), pressure (b) and impact (c) with uncertainty of estimate presented as the coefficient of variation CV (d). The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2021). n/a = not analysed/assessed. Areas deeper than 200m are masked out due to lack of longevity parameterisation.

**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 2022a). n/a = not analysed.

| MSFD broad habitat types | Area km2 (fraction of total) | Fraction untrawled (+-CI) | Mean SAR (+-CI) | Fraction SAR > 0.5 | Mean Impact (+-CI) | Fraction with impact below 0.2 |
|---|---|---|---|---|---|---|
| 0-200m | | | | | | |
| Offshore circalittoral sand | 239 (0.34) | 0.29 | 1.5 (0.05) | 0.41 | 0.09 (0.0023) | 0.91 |
| Offshore circalittoral mud | 105 (0.15) | 0.07 | 2.6 (0.07) | 0.75 | 0.19 (0.0052) | 0.65 |
| Offshore circalittoral coarse sediment | 76 (0.11) | 0.14 | 2.6 (0.15) | 0.56 | 0.12 (0.0044) | 0.77 |
| Circalittoral sand | 72 (0.1) | 0.21 | 1.7 (0.1) | 0.48 | 0.11 (0.0041) | 0.83 |
| Circalittoral coarse sediment | 30 (0.04) | 0.35 | 1.8 (0.16) | 0.27 | 0.09 (0.0049) | 0.89 |
| Infralittoral sand | 14 (0.02) | 0.57 | 1.5 (0.16) | 0.25 | 0.08 (0.0059) | 0.91 |
| Other | 32 (0.05) | 0.47 | 0.8 (0.04) | 0.26 | 0.07 (0.0028) | 0.86 |
| **Total 0-200m** | **639 (0.9)** | **0.3** | **1.7 (0.04)** | **0.45** | **0.1 (0.0019)** | **0.84** |
| 200-800m | | | | | | |
| Upper bathyal sediment | 61 (0.09) | 0.71 | 0.6 (0.07) | 0.17 | n/a | n/a |
| Other | 4 (0.01) | 0.97 | 0.1 (0.02) | 0.01 | n/a | n/a |
| **Total 200-800m** | **69 (0.1)** | **0.73** | **0.6 (0.06)** | **0.15** | **n/a** | **n/a** |

### Time trends

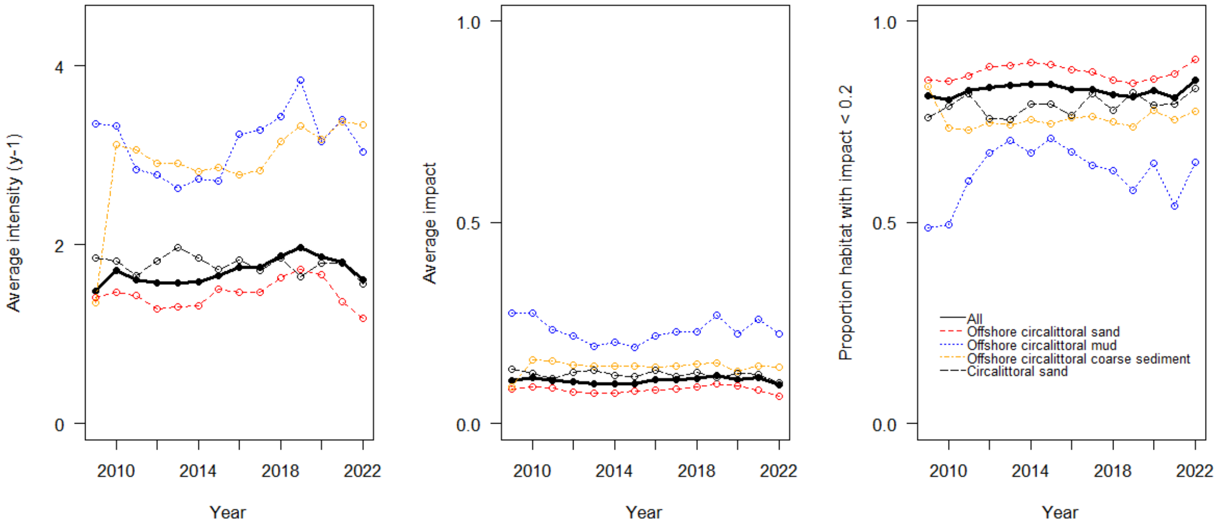

**Figure 2.** Temporal trends for the Greater North Sea Ecoregion. (a) Pressure presented as abrasion for four common habitat types and total area over time, (b) mean impact for four common habitat types and total by time, and (c) fraction below 0.2 threshold impact, for each habitat type and total, by time. The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2022a). n/a = not analysed.

## Interpretation of results

The Greater North Sea ecoregion includes the North Sea, English Channel, Skagerrak, and Kattegat. It is a temperate coastal shelf sea with a deep channel in the northwest, a permanently thermally mixed water column in the south and east, and seasonal stratification in the north.

The bottom fishing pressures vary spatially in the ecoregion (Figure 1a) with 30% of the grid cells untrawled in the depth zone 0–200m and 73% in 200–800m. The depth zone 0–200m is fished on average 1.7 SAR per year. Almost 45% of the region is fished > 0.5 SAR per year (Table 1).

The sensitivity of the Greater North Sea is highest in the northeaster North Sea and Kattegat and lowest in the southern North Sea. The southern North Sea is less sensitive mainly due to the high natural disturbance from tidal waves and storms.

The MSFD habitat type that experiences highest fishing pressure and impact is offshore circalittoral mud in 2022. This habitat type represents 15% of the Greater North Sea and is mainly targeted by Nephrops fisheries. Only 7% of the grid cells are untrawled and 75% of the area is fished with >0.5 SAR per year. Offshore circalittoral coarse sediment is the second most impacted habitat type (Table 1).

The fishing intensity in offshore circalittoral coarse sediment has increased since 2016. Fishing intensity in offshore circalittoral mud has been lower in 2020–2022 compared with 2019.

## Validity and limitations

Sensitivity and impact have not been calculated for grid cells > 200m depth because of data unavailability.

Temporal patterns in fishing activity are available from 2009 for vessels over 15m and from 2012 for vessels over 12m. Temporal variation in fishing activity hence represents vessels over 15m (2009–2011) and vessels over 12m (2012–2018).

Model validation is in an early stage but has been performed for Kattegat, the coastal area in the southern North Sea and Brown Bank. Further information can be found in ICES (2022b).

## Format of the assessment

This seafloor assessment of the Greater North Sea Ecoregion consists of this PDF assessment text, the technical guideline report (ICES 2022a) and a series of interactive maps, figures, tables, and text (ICES 2021).

The scripts used to produce the assessment are available: https://github.com/ices-eg/FBIT

## 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.

ICES. 2021. ICES advice to the EU on how management scenarios to reduce mobile bottom fishing disturbance on seafloor habitats affect fisheries landing and value. *In* Report of the ICES Advisory Committee, 2021. ICES Advice 2021. sr.2021.08. https://doi.org/10.17895/ices.advice.8191.

ICES. 2022a. 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

ICES 2022b. Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT; outputs from 2021 meeting). ICES Scientific Reports. 4:9. 133 pp. http://doi.org/10.17895/ices.pub.10042

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### 3.1.2 ICES seafloor assessment of mobile bottom fishing: Celtic Seas ecoregion

#### Assessment summary

This is an assessment of mobile bottom fishing for the Celtic Seas Ecoregion. It is based on Vessel Monitoring by Satellite (VMS) fishing data up to 2022 and follows the methods described in ICES (2022a). 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 aggregate dredging and wind farm construction, but their impact is only a fraction of that of bottom fisheries (ICES 2019). The impact threshold used in this assessment is arbitrarily set at 0.2. References to the full assessment can be found below under ‘Format of the assessment’.

#### Assessment results

**Status in year 2022**

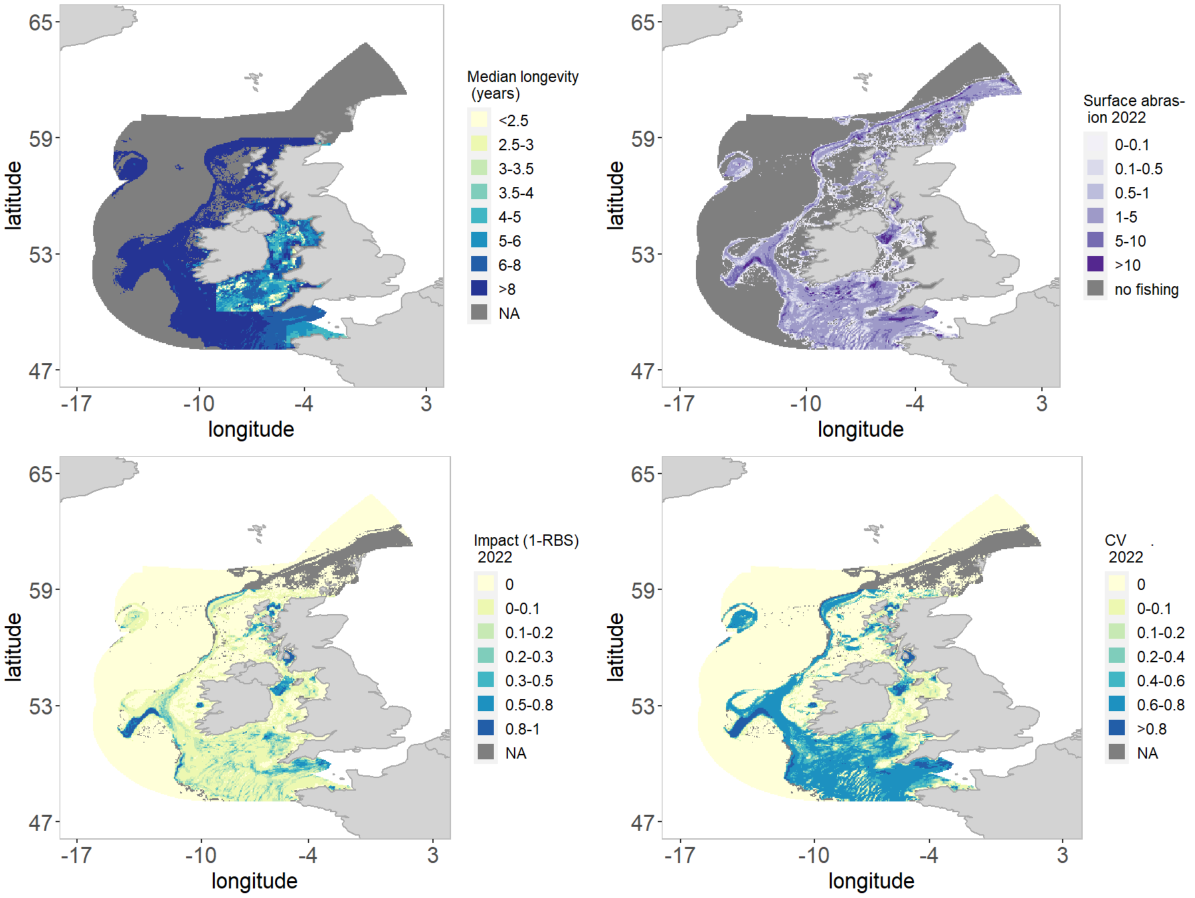


**Figure 1.** Assessment results for Celtic Seas Ecoregion. Sensitivity (a), pressure (b) and impact (c) with uncertainty of estimate presented as the coefficient of variation CV (d). The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2021). n/a = not analysed/assessed.

**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 2022a). n/a = not analysed.

| MSFD broad habitat types | Area km2 (fraction of total) | Fraction untrawled (+-CI) | Mean SAR (+-CI) | Fraction SAR > 0.5 | Mean Impact (+-CI) | Fraction with impact below 0.2 |
|---|---|---|---|---|---|---|
| 0-200m | | | | | | |
| Offshore circalittoral coarse sediment | 127 (0.14) | 0.31 | 1.3 (0.04) | 0.46 | 0.07 (0.0022) | 0.88 |
| Offshore circalittoral sand | 107 (0.12) | 0.17 | 1.4 (0.04) | 0.61 | 0.08 (0.0024) | 0.9 |
| Offshore circalittoral mud | 56 (0.06) | 0.05 | 2.4 (0.08) | 0.83 | 0.17 (0.0067) | 0.69 |
| Circalittoral coarse sediment | 20 (0.02) | 0.47 | 0.3 (0.04) | 0.13 | 0.03 (0.003) | 0.96 |
| Circalittoral sand | 11 (0.01) | 0.55 | 0.4 (0.06) | 0.14 | 0.04 (0.0051) | 0.96 |
| Other | 26 (0.03) | 0.59 | 0.5 (0.03) | 0.13 | 0.05 (0.0028) | 0.96 |
| Na | 41 (0.05) | 0.65 | 0.3 (0.03) | 0.14 | 0.03 (0.0027) | 0.98 |
| **Total** | **422 (0.48)** | **0.34** | **1.3 (0.03)** | **0.44** | **0.08 (0.0019)** | **0.89** |
| 200-800m | | | | | | |
| Upper bathyal sediment | 85 (0.1) | 0.43 | 1.6 (0.07) | 0.43 | 0.12 (0.0065) | 0.81 |
| Other | 22 (0.03) | 0.37 | 1.6 (0.11) | 0.43 | 0.12 (0.01) | 0.83 |
| **Total 200-800m** | **112 (0.13)** | **0.41** | **1.5 (0.06)** | **0.45** | **0.12 (0.0057)** | **0.82** |

## Time trends

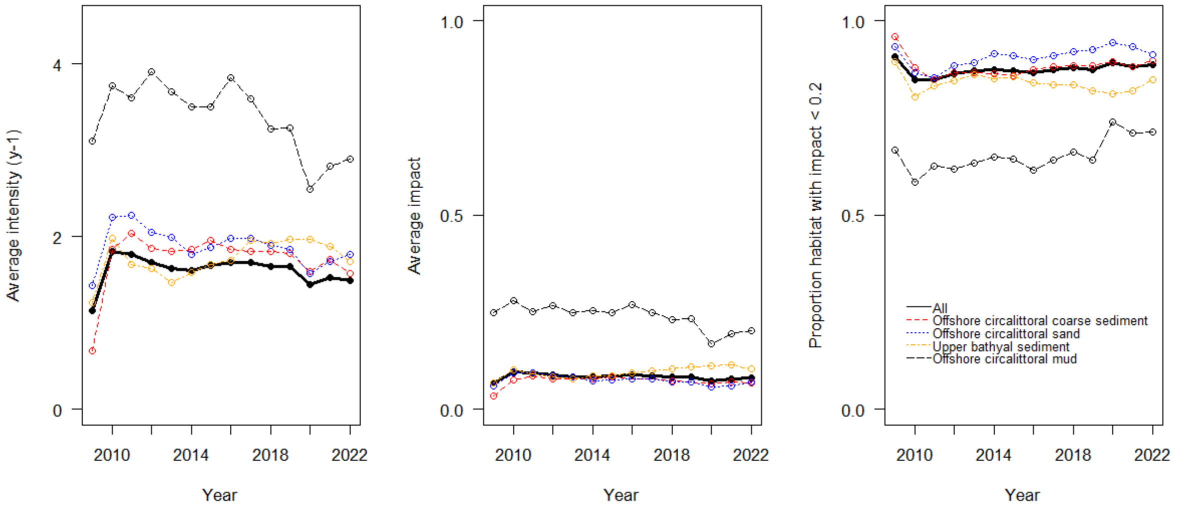


**Figure 2.** Temporal trends (in areas shallower than 800m) for the Celtic Seas Ecoregion. (a) Pressure presented as abrasion for four common habitat types and total area over time, (b) mean impact for four common habitat types and total by time, and (c) fraction below 0.2 threshold impact, for each habitat type and total, by time. The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2022a). n/a = not analysed.

## Interpretation of results

The Celtic Seas ecoregion covers the northwestern European continental shelf and seas, from western Brittany in the south to north of Shetland. The ecoregion can be considered to be split into four key areas: the west of Scotland region, the Celtic Sea continental shelf region (<200m), the continental shelf region to the west of Ireland, and the relatively shallow semi-enclosed Irish Sea. The oceanography and climate of the region is strongly influenced by conditions in the adjacent Atlantic Ocean, particularly along the continental shelf edge where water exchange occurs between the ocean and shallow shelf seas.

The bottom fishing pressures vary spatially in the ecoregion (Figure 1b) with 30% of the grid cells untrawled in the depth zone 0–200m and 35% in 200–800m. The depth zone 0–200m is fished on average 1.4 SAR per year. Almost 44% of the region is fished > 0.5 SAR per year (Table 1).

The sensitivity of the Celtic Sea ecoregion is highest to the west of the ecoregion closer to the shelf. The Irish Sea is less sensitive.

The MSFD habitat type that experiences highest fishing pressure and impact is offshore circalittoral mud in 2022. This habitat type represents 6% of the Celtic Seas ecoregion and is mainly targeted by Nephrops fisheries. 34% of the grid cells are untrawled and 44% of the area is fished with >0.5 SAR per year. Offshore circalittoral sand is the second most impacted habitat type (Table 1).

The fishing intensity in offshore circalittoral mud has decreased in recent years, with a similar but less pronounced trend across other habitat types (Table 1).

## Validity and limitations

The benthic sensitivity layer is based on two separate analyses. The sensitivity layer for the Irish Sea is based upon epifauna data from the international beam trawl survey (BTS) and the sensitivity layer for the remaining Celtic Seas ecoregion is based upon a preliminary analysis using epifaunal data from the Irish ground fish survey (Van Hoey *et al.*, 2023).

Temporal patterns in fishing activity are available from 2009 for vessels over 15m and from 2012 for vessels over 12m. Temporal variation in fishing activity hence represents vessels over 15m (2009–2011) and vessels over 12m (2012–2018).

Model validation is in an early stage. It should be noted model development is now focused on an extensive sensitivity layer modelled from multiple surveys across multiple ecoregions. See the most recent WGFBIT report for details.

## Format of the assessment

This seafloor assessment of the Celtic Seas Ecoregion consists of this PDF assessment text, the technical guideline report (ICES 2022a) and a series of interactive maps, figures, tables, and text (ICES 2021).

The scripts used to produce the assessment are available: https://github.com/ices-eg/FBIT

## 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.

ICES. 2021. ICES advice to the EU on how management scenarios to reduce mobile bottom fishing disturbance on seafloor habitats affect fisheries landing and value. *In* Report of the ICES Advisory Committee, 2021. ICES Advice 2021. sr.2021.08. https://doi.org/10.17895/ices.advice.8191.

ICES. 2022a. 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

ICES 2022b. Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT; outputs from 2021 meeting). ICES Scientific Reports. 4:9. 133 pp. http://doi.org/10.17895/ices.pub.10042

ICES. 2022c. Working Group on Fisheries Benthic Impact and Trade-offs - Sete

Van Hoey, G., Batts, L., Bolam, S., Carbonara, P., Clare, D., Depestele, J., Desmidt, J., Dinesen, G. E., Egekvist, J., Eigaard, O. R., Garcia, C., Kavadas, S., Lafarque, P., Maina, I., Mavraki, N., Olsen, J., Papadopoulou, N., Parker, R., Piet, G., Reid, D., Smith, C., Spedicato, M. T., Stounberg, J., Tsikopoulou, I., Zupa, W., and Rindorf A. 2023. SEAwise Report on the spatiotemporal benthic effects of fishing on benthic habitats relative to suggested threshold levels, both with respect to area impacted and impact intensity. Technical University of Denmark.

### 3.1.3 ICES seafloor assessment of mobile bottom fishing: Bay of Biscay and the Iberian Coast

## Assessment summary

This is an assessment of mobile bottom fishing for the Bay of Biscay and the Iberian Coast Ecoregion. It is based on Vessel Monitoring by Satellite (VMS) fishing data up to 2022 and follows the methods described in ICES (2022a). 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 aggregate dredging and wind farm construction, but their impact is only a fraction of that of bottom fisheries (ICES 2019). The impact threshold used in this assessment is arbitrarily set at 0.2. References to the full assessment can be found below under ‘Format of the assessment’.

## Assessment results

### Status in year 2022

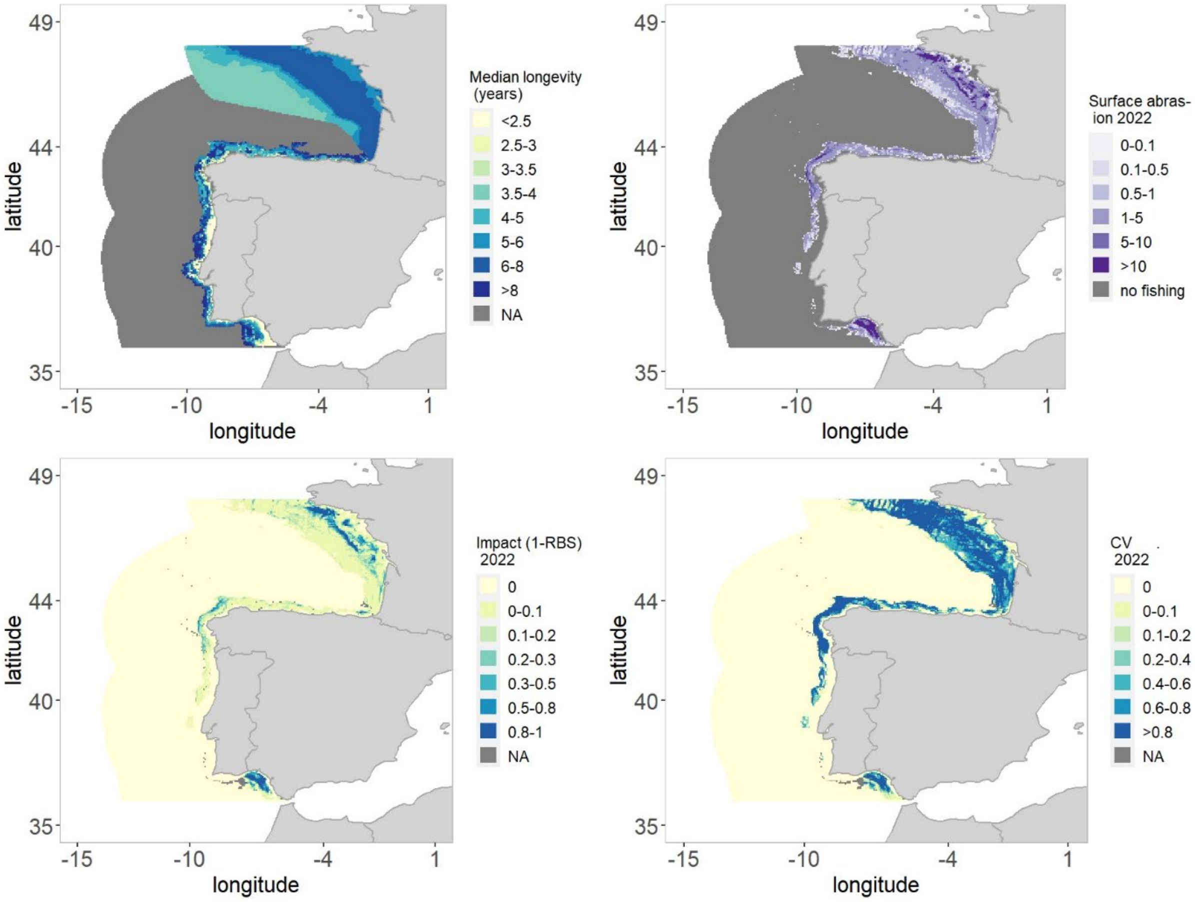


**Figure 3.** Assessment results for the Bay of Biscay and the Iberian Coast Ecoregion. Sensitivity (a), pressure (b) and impact (c) with uncertainty of estimate presented as the coefficient of variation CV (d). The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2021). n/a = not analysed/assessed.

**Table 2.** 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 2022a). n/a = not analysed.

| MSFD broad habitat types | Area km2 (fraction of total) | Fraction untrawled (+-CI) | Mean SAR (+-CI) | Fraction SAR > 0.5 | Mean Impact (+-CI) | Fraction with impact below 0.2 |
|---|---|---|---|---|---|---|
| 0-200m | | | | | | |
| Offshore circalittoral sand | 33 (0.04) | 0.06 | 1.8 (0.08) | 0.73 | 0.08 (0.0048) | 0.96 |
| Offshore circalittoral mud | 28 (0.04) | 0.19 | 3.1 (0.19) | 0.72 | 0.18 (0.0114) | 0.75 |
| Circalittoral sand | 17 (0.02) | 0.32 | 1.8 (0.18) | 0.52 | 0.08 (0.0073) | 0.82 |
| Offshore circalittoral coarse sediment | 10 (0.01) | 0.02 | 2.4 (0.16) | 0.76 | 0.1 (0.0087) | 0.92 |
| Circalittoral coarse sediment | 9 (0.01) | 0.07 | 3 (0.26) | 0.8 | 0.13 (0.0107) | 0.62 |
| Circalittoral mud | 6 (0.01) | 0.41 | 2.2 (0.38) | 0.45 | 0.11 (0.0144) | 0.7 |
| Other | 22 (0.03) | 0.51 | 0.8 (0.07) | 0.28 | 0.04 (0.0035) | 0.95 |
| **Total** | **143 (0.18)** | **0.29** | **2.4 (0.11)** | **0.56** | **0.11 (0.0053)** | **0.86** |
| 200-800m | | | | | | |
| Upper bathyal sediment | 25 (0.03) | 0.39 | 1.6 (0.19) | 0.39 | 0.08 (0.009) | 0.85 |
| Other | 11 (0.01) | 0.65 | 0.8 (0.15) | 0.19 | 0.03 (0.0055) | 0.99 |
| **Total 200-800m** | **42 (0.05)** | **0.43** | **1.4 (0.15)** | **0.36** | **0.07 (0.0071)** | **0.9** |

## Time trends

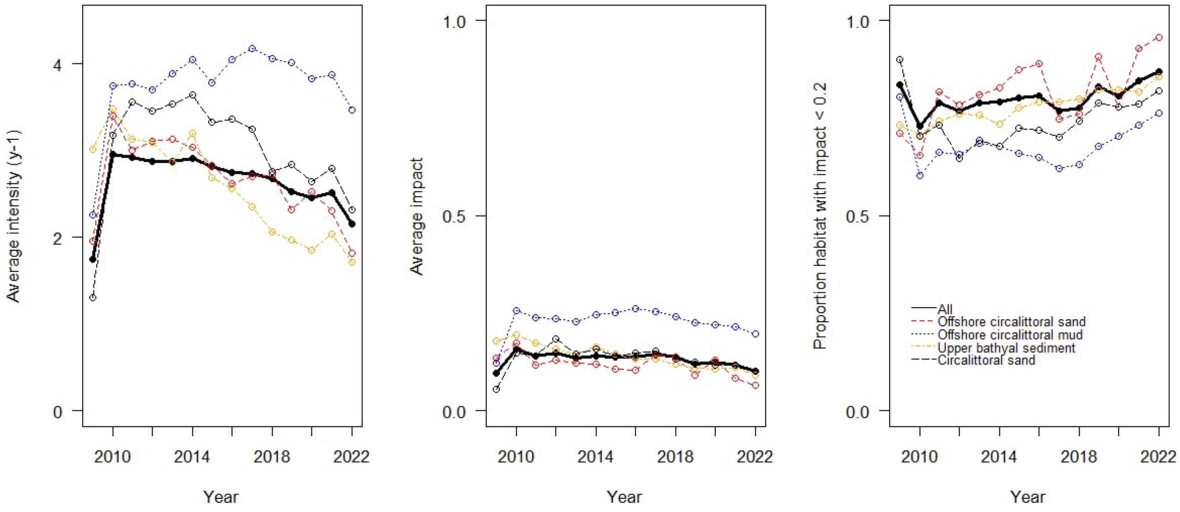


**Figure 4.** Temporal trends (in areas shallower than 800m) for the Bay of Biscay and the Iberian Coast Ecoregion. (a) Pressure presented as abrasion for four common habitat types and total area over time, (b) mean

impact for four common habitat types and total by time, and (c) fraction below 0.2 threshold impact, for each habitat type and total, by time. The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2022a). n/a = not analysed.

### Interpretation of results

The « Bay of Biscay and Iberian coast" ecoregion includes the whole Atlantic continental shelf from the northern part of the Irish continental shelf, the Bay of Biscay to the northern Spanish Atlantic shelf is an area of temperate continental shelves, characterized by a steep bathymetric gradient from the coast to the break in the continental shelf, integrating deep circalittoral and bathyal zones with depths reaching over 3000 m (although trawling is forbidden deeper than 800 m in the area). The spatial structure of the continental shelf is very pronounced, with contrasting habitat zones, particularly in hydrological and sedimentary terms, such as the central mudflats in the northern part of the Bay of Biscay, the oligotrophic sands of the southern part of the Bay, or the patchwork of habitats on the slope zone of the continental shelf with its alternating deep canyons.

Fishing pressure varies spatially in relation to the main habitats and species targeted for exploitation but overall, the untrawled part represents a low proportion whatever the habitat considered, with a maximum value above 40% for circalittoral mud and some deeper habitats. Offshore circalittoral habitats are the most heavily exploited, with unexploited fractions generally below 30%. As regards the temporal evolution of fishing pressure, data prior to 2012 cannot be considered valid.

The sensitivity of the marine subregion strongly follows a bathymetric gradient, with shallow areas less sensitive than habitats close to the slope of the continental shelf. High median longevity classes (>5 years) are very strongly dominant, mainly due to the benthic mega-epifauna dataset used to model distributions. Infralittoral areas and extrapolation beyond the shelf to deeper areas, particularly bathyal habitats, does provide very uncertain information particularly due to lack of biological information. Moreover, vessel coverage by VMS data in the more coastal areas (infralittoral) are very partial in the absence of data for vessels under 12m, which probably tends to significantly underestimate the impact values.

Only 29% and 43% of the grids cells are untrawled for the whole 0–200m and 200–800m area respectively, 56% and 78% is fished with >0.5 SAR. Offshore circalittoral mud, coarse sediment or sand and Circalittoral sand are the most impacted habitat types (Table 1). Generally offshore MSFD habitats experience the highest fishing pressure and impact. Only 2% to 19% of these habitat's grid cells are untrawled and 70% fished with >0.5 SAR. For example, "Offshore circalittoral mud" habitat type represents 28% of the subregion area and is mainly targeted by Nephrops fisheries.

### Validity and limitations

Benthic sensitivity layer is based on two separate analyses in Spain and France (WGFBIT report 2022). Estimates in Portugal are based on an extrapolation from Spanish information from two different data sources, north ("DEMERSALES" IBTS) and south ("ARSA" IBTS) of Portuguese waters. Therefore, especial care is needed when interpreting the results for Portuguese waters.

The results proposed for the Bay of Biscay area do not correspond to the most up-to-date version presented in the 2023 FBIT report. The model derived from previous work is based solely on the data available in this area, and does not enable a correct estimate of sensitivity (median longevity), due in particular to the very low proportion of observations corresponding to low or zero fishing levels, and the concentration of these data in specific habitats, notably deeper and on sandy bottoms. The results show a significant underestimation of the impact (1-RBS) compared with the 2023 models, which incorporate data from a much wider area, including the Irish continental shelf.

Temporal patterns in fishing activity are available from 2009 for vessels over 15m and from 2012 for vessels over 12m. Temporal variation in fishing activity hence represents vessels over 15m (2009–2011) and vessels over 12m (2012–2018). No VMS fishing data is available for Portugal since 2015. Particular care should be taken with results obtained in shallower areas (e.g. infralittoral habitats) where fishing activity based on <12m vessels is not well represented in VMS data. Model validation is in an early stage and should be improved for the next assessment period. For the bay of Biscay, the RBS and impact have been calculated in a simplified version, using only a standard depletion value that does not take into account possible variations in this rate according to fishing gear. Further information can be found in ICES (2023).

### Format of the assessment

This seafloor assessment of the Bay of Biscay and the Iberian Coast Ecoregion consists of this PDF assessment text and the technical guideline report (ICES 2022a).

The scripts used to produce the assessment are available: https://github.com/ices-eg/FBIT

### 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.

ICES. 2021. ICES advice to the EU on how management scenarios to reduce mobile bottom fishing disturbance on seafloor habitats affect fisheries landing and value. *In* Report of the ICES Advisory Committee, 2021. ICES Advice 2021. sr.2021.08. https://doi.org/10.17895/ices.advice.8191.

ICES. 2022a. 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

ICES 2022b. Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT; outputs from 2021 meeting). ICES Scientific Reports. 4:9. 133 pp. http://doi.org/10.17895/ices.pub.10042

ICES. 2022c. Working Group on Fisheries Benthic Impact and Trade-offs - Sete

## 3.1.4 ICES seafloor assessment of mobile bottom fishing: Baltic Sea Ecoregion

### Assessment summary

This is an assessment of mobile bottom fishing for the Baltic Sea Ecoregion. It is based on Vessel Monitoring by Satellite (VMS) fishing data up to 2022 and follows the methods described in ICES (2022a). The Baltic Sea Ecoregion is most impacted by eutrophication and eutrophication-induced hypoxia (ICES 2019). Bottom fishing occurs in the southern and southwestern Baltic Sea. The impact threshold used in this assessment is arbitrarily set at 0.2. References to the full assessment can be found below under ‘Format of the assessment’.

## Assessment results

### Status in year 2022

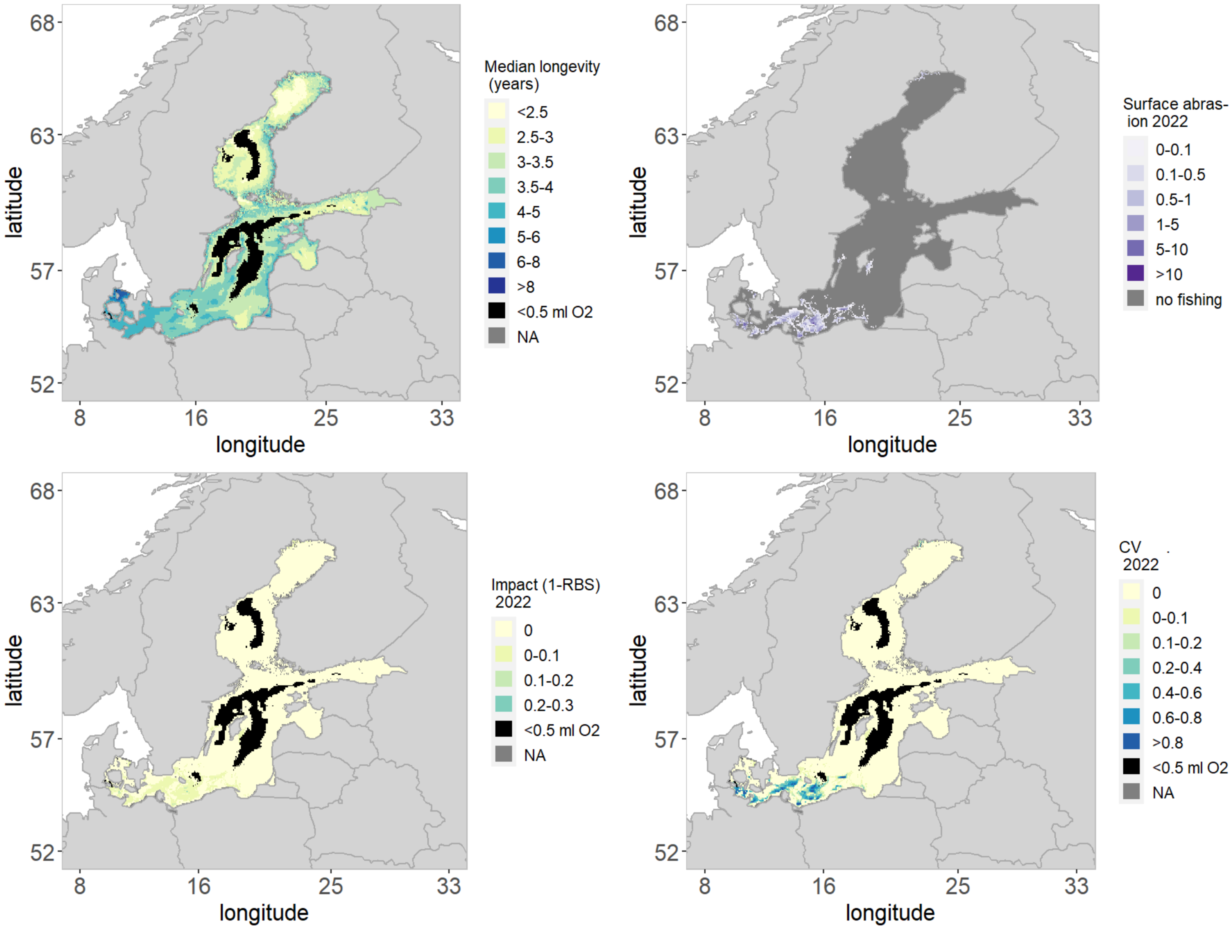


**Figure 5.** Assessment results for the Baltic Sea Ecoregion. Sensitivity (a), pressure (b) and impact (c) with uncertainty of estimate presented as the coefficient of variation CV (d). The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2021). n/a = not analysed. Black cells have seasonal oxygen concentrations <0.5 ml $O_2$ per liter, a concentration below which oxygen deprivation generates mass mortality in benthos.

**Table 3.** 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 2022a). n/a = not analysed. Areas with seasonal oxygen concentrations <0.5 ml $O_2$ per litter are classified as anoxic/hypoxic.

| MSFD broad habitat types | Area km2 (fraction of total) | Fraction untrawled | Mean SAR (+-CI) | Fraction SAR > 0.5 | Mean Impact (+-CI) | Fraction with impact below 0.2 |
|---|---|---|---|---|---|---|
| 0-200m | | | | | | |
| Circalittoral mixed sediment | 95 (0.26) | 0.97 | 0 (0) | 0.01 | 0 (1e-04) | 1 |
| Anoxic | 52 (0.14) | 0.99 | 0 (0) | 0 | 0 (1e-04) | 1 |
| Circalittoral mud or Circalittoral sand | 43 (0.12) | 0.99 | 0 (0) | 0 | n/a | n/a |
| Circalittoral sand | 31 (0.08) | 0.81 | 0.1 (0.01) | 0.06 | 0 (3e-04) | 1 |
| Circalittoral mud | 27 (0.07) | 0.91 | 0 (0.01) | 0.03 | 0 (2e-04) | 1 |
| Infralittoral sand | 21 (0.06) | 0.7 | 0.1 (0.02) | 0.1 | 0 (4e-04) | 1 |
| Other | 56 (0.15) | 0.93 | 0 (0) | 0.02 | 0 (1e-04) | 1 |
| **Total 0-200m** | **365 (0.99)** | **0.92** | **<0.01 (0)** | **0.02** | **0 (1e-04)** | **1** |
| 200-800m | | | | | | |
| **Total 200-800m** | **0 (0)** | **1** | **0 (0)** | **0** | **n/a** | **n/a** |

* Anoxic/hypoxic is included as a separate habitat to avoid averaging trawl impact over unfished but depauperate areas.

## Time trends

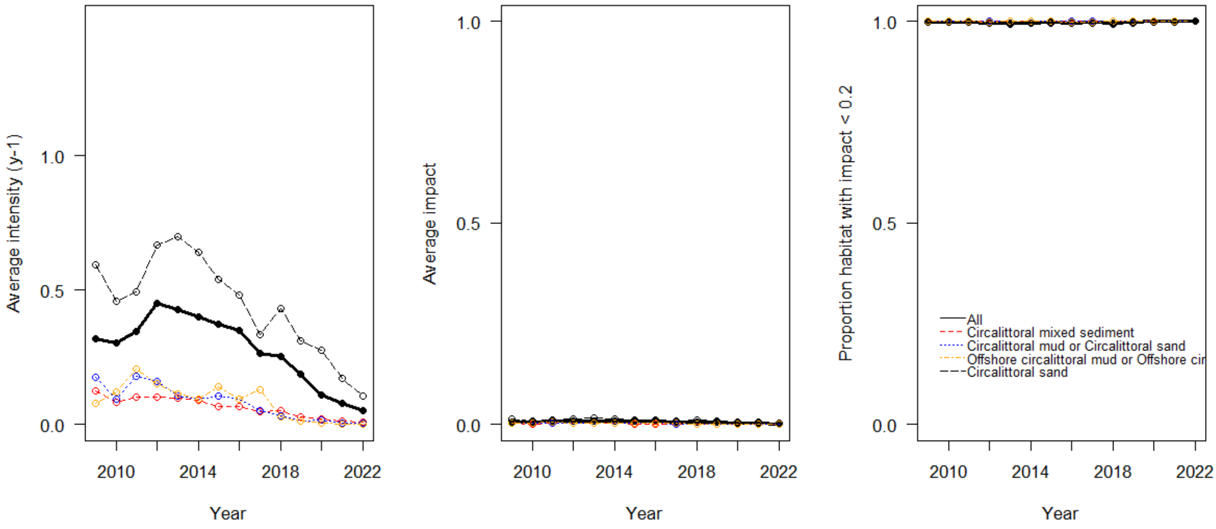


**Figure 6.** Temporal trends for the Baltic Sea Ecoregion. (a) Pressure presented as abrasion for four common habitat types and total area over time, (b) mean impact for four common habitat types and total by time, and (c) fraction below 0.2 threshold impact, for each habitat type and total, by time. The indicators are

explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2022a). Average trends exclude areas with seasonal oxygen concentrations <0.5 ml $O_2$ per litter.

## Interpretation of results

The Baltic Sea is one of the largest brackish water bodies in the world. It is a semi-enclosed shallow sea with an average depth of 60 m. This ecoregion is characterized by strong salinity gradients and large areas with low bottom oxygen concentrations.

Bottom fishing solely occurs in the southern and southwestern part of the ecoregion (Figure 5). More than 90% of the grid cells are untrawled and average fishing intensity is <0.01 SAR per year (Table 3).

The sensitivity of the Baltic Sea to bottom fishing disturbance is highest in the southwestern waters where species longevity is high (Figure 5). Sensitivity is lower in the deeper and northern parts of the Baltic Sea. 14% of the area experiences seasonal oxygen concentrations <0.5 ml $O_2$ per litter and benthic fauna in these areas is either absent or in a depauperate state.

Average fishing intensity has decreased significantly since 2013 due to the poor status of the Baltic cod stocks, and at present only a limited trawl fishery targeting flatfish is allowed. Average impact has been low since 2009 (Figure 6).

## Validity and limitations

Temporal patterns in fishing activity are available from 2009 for vessels over 15m and from 2012 for vessels over 12m. Temporal variation in fishing activity hence represents vessels over 15m (2009–2011) and vessels over 12m (2012–2018).

Model validation is in an early stage but has been performed for the Gotland basin and in the Southern Baltic Sea in Polish waters. Further information can be found in ICES (2022b).

## Format of the assessment

This seafloor assessment of the Baltic Sea Ecoregion consists of this PDF assessment text, the technical guideline report (ICES 2022a) and a series of interactive maps, figures, tables, and text (ICES 2021).

The scripts used to produce the assessment are available: https://github.com/ices-eg/FBIT

## 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.

ICES. 2021. ICES advice to the EU on how management scenarios to reduce mobile bottom fishing disturbance on seafloor habitats affect fisheries landing and value. *In* Report of the ICES Advisory Committee, 2021. ICES Advice 2021. sr.2021.08. https://doi.org/10.17895/ices.advice.8191.

ICES. 2022a. 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

ICES 2022b. WKBENTH3 workshop report xxx.

ICES. 2022c. Working Group on Fisheries Benthic Impact and Trade-offs - Sete

## 3.2 Regional assessment updates

### 3.2.1 Icelandic Waters, Norwegian Waters

No updates.

### 3.2.2 Celtic Seas, Bay of Biscay and the Iberian Coast

The FBIT workflow was applied to the western waters region (Celtic Seas, Bay of Biscay, Iberian Coast, Irish Sea). The results presented complement those obtained in the previous year but are still 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. As last year, we used standardized scripts for pre-processing 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 thus be able to propose a combined analysis of all or part of the data available on the "western waters" area.

For this report, in addition to a new analysis for certain sub-regions taken separately (Iberian and gulf of Cadix area), we also conducted analyses combining data from several sub-regions (Bay of Biscay, Celtic Seas and north Iberic shelves).

### 3.2.2.1 Workflow

Biological dataset

The epi-megafauna invertebrate data come from 6 benthic trawl surveys mainly carried out as part of the IBTS fisheries assessment surveys (Table 4, ICES IBTS 2023, https://doi.org/10.17895/ices.pub.23743989). The geographical area covered (Figure 7) extends from the south of Spain (Gulf of Cadiz) to the north of Ireland and the North Sea. However, this year's analysis is restricted to the continental shelves bordering Spain (Bay of Cadiz and North Iberian zone), the Bay of Biscay, and the Celtic and Irish Seas. Other areas are currently being analyzed and will be included in larger-scale results at a later date. The longevity data used are identical to those proposed in the previous FBIT report (2022).

**Table 4.** Source of megafauna datasets available to model median longevity. IGFS, EVHOE and DEMERSALES were the only datasets utilized for the analysis done in 2023.

| SURVEY | ICES areas | GEAR | Codend meshsize | Time series | Nb Stations | Depth range | REF / DOI |
|---|---|---|---|---|---|---|---|
| **IE-IGFS_Q4** | 6a;7a,b,g,j | **Otter trawl** | 20 mm | (2003) – 2022 | 3151 | [10, >700m] | |
| **EVHOE** | 8a,b ; 7ghj | **Otter trawl** | 20 mm | (2008)-2018 | 1482 | [20, >700m] | doi.org/10.18142/8 |
| **DEMERSALES** | 8c ; 9a | **Otter trawl** | 20 mm | 2013-2020 | 1047 | [15, >700m] | |
| *ARSA* | ***9a*** | *Otter trawl* | | | ***611*** | ***[17 , >700m]*** | |
| *IBTS-NS* | *4b,c ; 7d* | *Otter trawl* | *20 mm* | *2006-2021* | *1212* | *[4, 96m]* | doi.org/10.18142/17 |
| *CGFS* | *7e ; 7d* | *Otter trawl +rockhopper (western Channel)* | *20 mm* | 2014-2022 | 894 | [2, 114m] | doi.org/10.18142/11 |

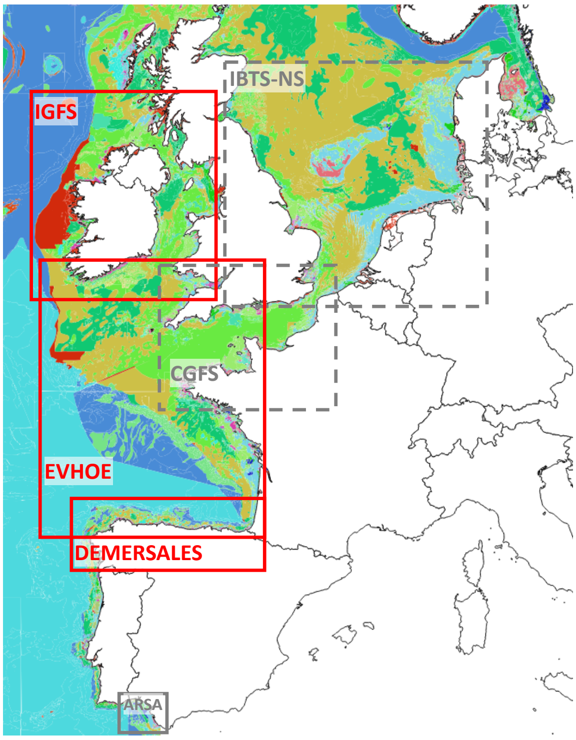


**Figure 7.** Location of megafauna datasets used for median longevity modelling. The grey/dashed boxes show the data not used this year in the combined modelling exercise at the scale of the western waters zone.

Fishing pressure variables

Fishing pressure layers were available for the whole area. We used data from the ICES 2023 data call covering the period 2009 to 2022. The annual SAR (Surface Area Ratio) variable was aggregated on different time scales to obtain an integrated average value over 1 to 5 years prior to the year of the biological sampling station. These SAR variables were used to test the effects when modelling median longevity. The stations providing the reference state for the biological variables were also selected according to different levels of « low » SAR: 1 or $2y^{-1}$.

Environmental variables

New set of environmental variables were selected (Table 5) in order to get standardized environmental layers at the scale of the whole western waters regions. Some derivatives of the initial environmental variables were also used for modelling (e.g. minimum, maximum value or standard deviation). On this basis, a selection of 5 major environmental variables was finally used to perform the analyses: depth, minimum of Chlorophyll, mean annual temperature and mean annual bottom current. Regarding substrate, we used a new computed variable based on the EUNIS substrate categories. To better reflect grain size we transformed the categorical variable provided from EUNIS into a pseudo granulometric one detailed into Table 5.

**Table 5.** List and source of environmental data used to model median longevity.

| Variable | Description | Source | Model/dataset | Covered period |
|---|---|---|---|---|
| **Depth** | Bathymetric data | **EMODNET**<br>https://portal.emodnet-bathymetry.eu/ | various | not relevant |
| **Temperature** | ⇒ Monthly bottom temperature<br>⇒ mean, standard deviation, minimum and maximum for each cell | **COPERNICUS**<br>https://resources.marine.copernicus.eu/product-detail/NWSHELF_MULTIYEAR_PHY_004_009/INFORMATION | NEMO-NEMOVAR. ERSEM NWSHELF_MULTIYEAR_PHY_004_009 cmems_mod_nws_phy-bottomt_my_7km-2D_P1M-m | 12/2018 to 12/2021 |
| **Current** | ⇒ "Kinetic energy due to currents at the seabed"<br>⇒ averages of annual percentiles 90th over the period 2010-2015 | **EMODNET**<br>http://gis.ices.dk/geonetwork/srv/eng/catalog.search#/metadata/0191e32e-6b0c-4967-9b96-f0ab37f19f3f | MANGA2500 IFREMER-DYNECO Hindcast | 2010 to 2015 |
| **Chlorophyl** | ⇒ North Altantic Chlorophyll Concentration from Satellite observations (daily average)<br>⇒ Monthly bottom data<br>⇒ mean, standard deviation, minimum and maximum for each cell | **COPERNICUS**<br>https://data.marine.copernicus.eu/product/NWSHELF_ANALYSISFORECAST_BGC_004_002/description | NEMO-NEMOVAR. ERSEM NWSHELF_MULTIYEAR_PHY_004_009 | 12/2018 to 12/2021 |
| **Substrate** | ⇒ Sediment categories from EUSeaMap2 (2016) Broad-Scale Predictive Habitat Map.<br>⇒ Transformation to pseudo-granulometric variable | **EMODNET**<br>https://www.emodnet-seabedhabitats.eu | EUSeaMap2021 | not relevant |

**Table 6.** Correspondence of substrate classes as obtained from EUNIS (2021 EUSeamap) with pseudo-granulometric variable (mean Grain Size).

| Substrate (EUNIS 2021) | mean Grain Size |
|---|---|
| **Fine mud** | 0,000275 |
| **Sandy mud** | 0,005854 |
| **Mud to muddy sand** | 0,013398 |
| **Sandy mud to muddy sand** | 0,015985 |
| **Muddy sand** | 0,026065 |
| **Sand** | 0,040506 |
| **Mixed sediment** | 0,081452 |
| **Coarse sediment** | 0,499763 |
| **Coarse and mixed sediment** | 0,581215 |
| **Rock or other hard substrata** | 0,786343 |
| **Cymodocea beds** | NA |
| **Dead mattes of Posidonia oceanica** | NA |
| **Cymodocea nodosa meadows** | NA |
| **Posidonia oceanica meadows** | NA |
| **Seabed** | NA |
| **Unknown** | NA |

#### 3.2.2.2 Combined Iberian coast, Bay of Biscay and Celtic Seas (ICES Divisions 8ab,7fghj)

The region is characterized by a broad dominance of offshore habitats, with a sedimentary range extending from mud to coarse sediments (Figure 8, Table 7). The bathyal zone accounts for a large proportion, particularly in the western part of Ireland. A total of 5637 megafauna observation stations were available for analysis (Figure 9A). Depending on the selection of the fishing threshold considered as low, this number of stations drops to 1081 and 1613 for fishing thresholds of 1y$^{-1}$ and 2y$^{-1}$ respectively. The distribution of observation stations is relatively heterogeneous, depending on the habitats and surveys considered (Figure 9B). Observation effort is relatively consistent with the relative surface area of soft-bottom habitats, although the bathyal zone is under-represented in relation to its surface area in the region under consideration.

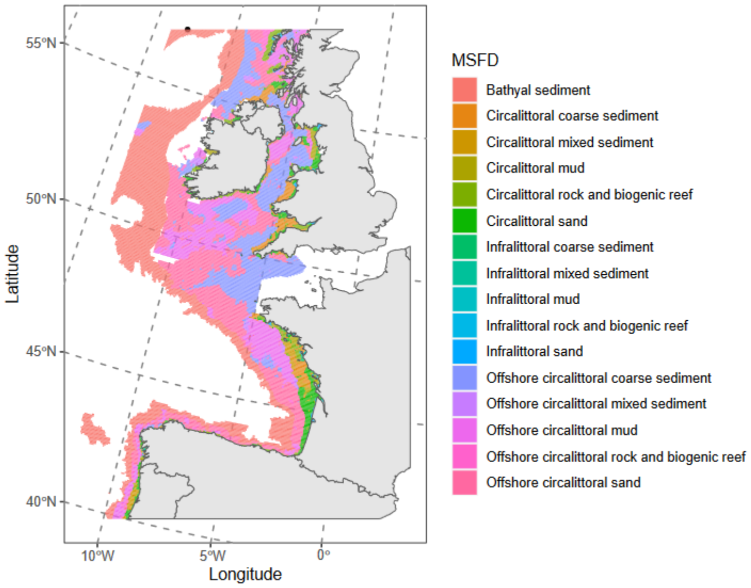


**Figure 8.** Distribution of MSFD habitats in the area selected for Western Waters.

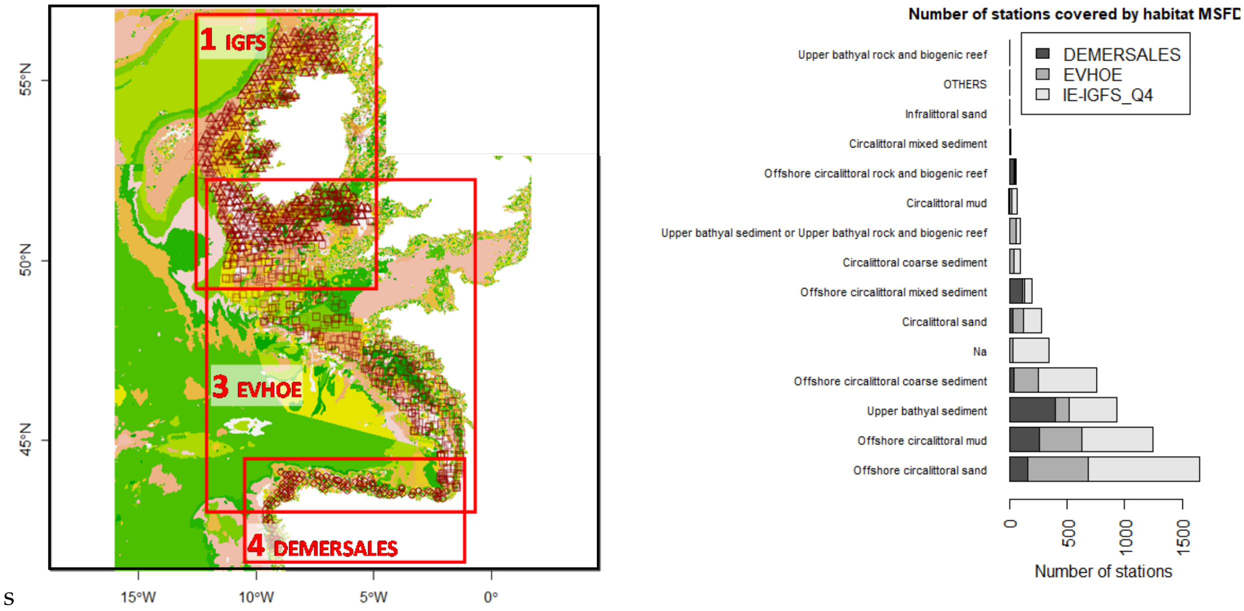


**Figure 9.** Distribution of stations for each of the surveys selected for analysis, A) spatial distribution, B) distribution within each MSFD habitat.

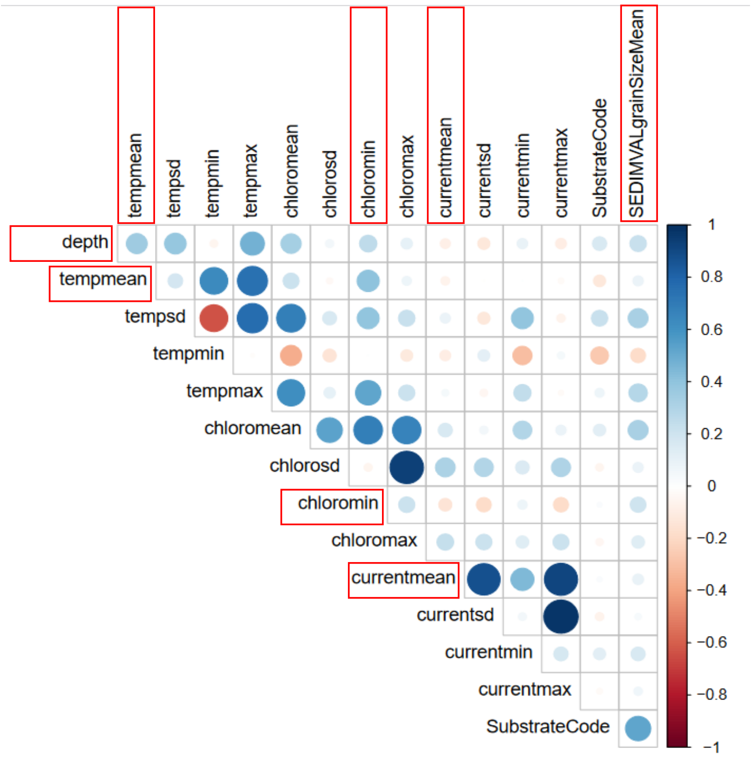


**Figure 10.** Correlation between environmental variables in the western areas. Variables retained for modelling are indicated (red rectangles).

Of all the environmental variables available (Figure 10), based on the results of modelling and analysis of correlations between variables, we retained 5 major environmental variables for the longevity models. Longevity modelling was carried out for all combinations of these variables. In addition to these combinations, different station selections based on different thresholds of low fishing pressure and SAR calculation were taken into account. The best models selected on the basis of the most reliable AIC criterion show strong correlations between the longevity maps, whatever the data selection criteria and models used (Figure 11). However, there are significant variations in the range of longevity values and contrasts depending on the criteria considered (Figure 12).

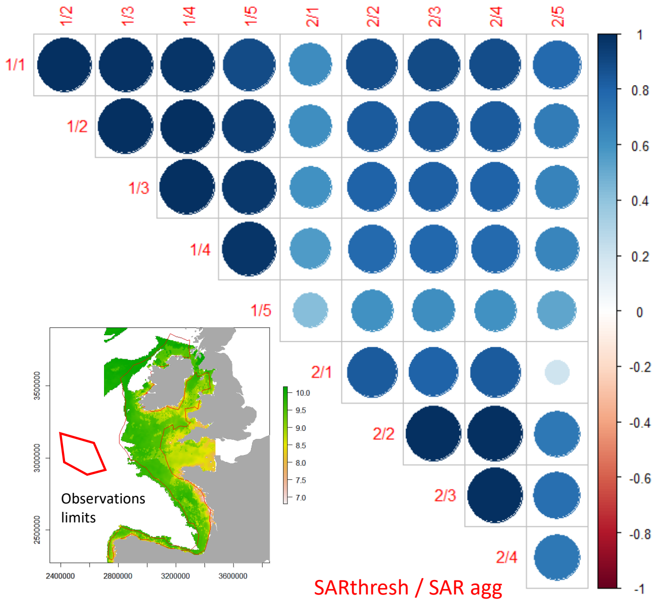
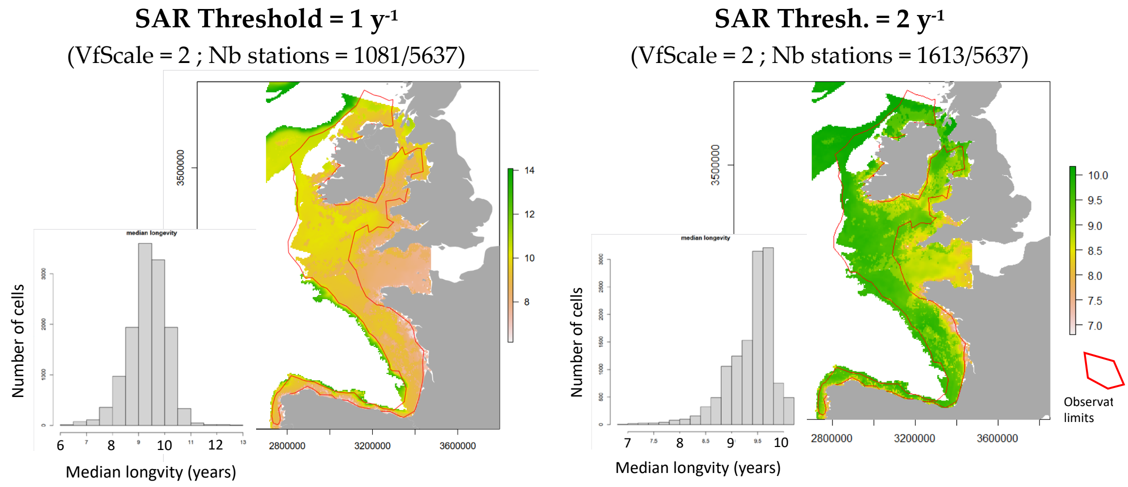


**Figure 11.** Correlation between the different median longevity maps obtained as a function of the choice of calculation criteria based on the SAR value considered as low or zero (SARthresh) and the number of years aggregated to calculate the SAR value of the observation stations (SARagg). The results presented correspond to the following model: Cumb ~ ll (+) Depth (+) Chloromin (+) Tempmean (+) Currentmean (+) SedimGrainSize + (1 | Station).



Cumb ~ ll + Depth + ChloroMin + ***TempMean*** + CurrentMean + SedimGrainSize + (1 | Station)

Cumb ~ ll + Depth + ChloroMin + CurrentMean + SedimGrainSize + (1 | Station)

**Figure 12.** Median longevity distribution including the "best" models retained as computed from biological data sets filtered on the basis of 2 criteria to select stations corresponding to “low” SAR thresholds: 1 or 2 years$^{-1}$. SAR calculated from ICES 2022 data sets as the average of the 2 years preceding each station observation year. Selected models are indicated with environmental variables described into Table 4 **(Cumb**: cumulated biomass; **ChloroMin**: yearly minimal bottom Chlorophyll concentration, **TempMean**: yearly mean of bottom temperature; **Current**: yearly mean energy from bottom current; **SedimGrainSize**: pseudo-granulometry of sediment).

Overall, the results show median longevities in a range restricted to high values (~6 to 14 years). These results are partly intrinsic to the data used, which concern megafauna with taxa whose longevities cover little or none of the lower longevity classes. However, the median longevity modelling exercise showed discrepancies between the different datasets used, and in particular with a wider range of longevities for DEMERSALES compared to the other datasets taken separately or analysed together. For these analyses, we did not consider the differences between surveys or the relative weight (e.g. difference in terms of number of stations) of the different data sets. On the basis of a binomial distribution of the longevity estimated by sample (Figure 13). We have highlighted a relatively patchy distribution of longevity. Moreover, median longevity shows annual variation (e.g. north of Ireland).

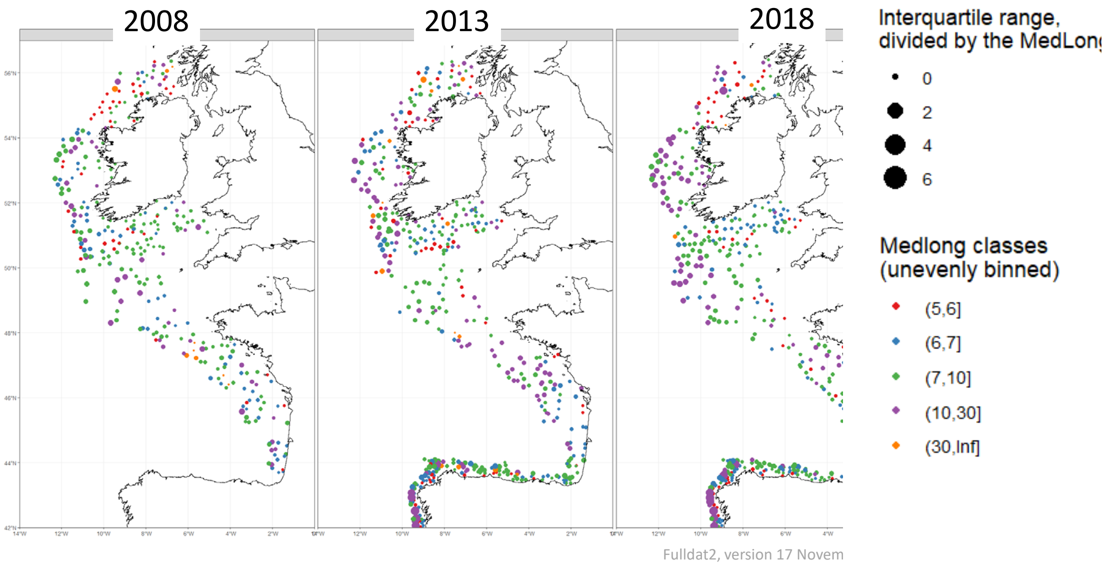


**Figure 13.** Yearly maps of median longevity classes based on binomial distribution of the median longevity estimated by sample. Variability (bubble size) is shown by the InterQuartile Range (IQR) divided by the median.

Median longevity modelling was tested by selecting stations with SAR levels 1 and 2 $y^{-1}$, considered to represent low fishing pressure. On the one hand, this selection leads to a strong restriction of the data eligible for modelling, so less than 20% of the available stations are retained for a "low" SAR threshold of 1 $y^{-1}$. On the other hand, the SAR threshold value still represents high fishing pressure, given the relatively high sensitivity and probably lasting impact of fishing pressure on the megafauna component considered here. A model including the SAR variable has therefore been considered; although preliminary tests were carried out during the FBIT 2023 exercise, the results will only be proposed in the next report. These results allow us to assess the relevance of the observed longevity distributions and encourage us to further analyse the influence of the sensitivity estimate on the final estimate of the RBS.

The RBS (Figure 14, Figure 15) was calculated on a preliminary basis, considering a standard median depletion rate (d=0.074) corresponding to the distribution of the main fishing gears operating in the area. The results show significantly contrasting situations between the various MSFD habitats, with, for example, the lowest RBS values for "Offshore circalittoral mud" and "circalittoral mixed sediment". (Figure 15C). The analysis enlightened the very conservative nature of the RBS calculation, with values that vary little whatever the data set or the conditions under which the estimation method is applied.

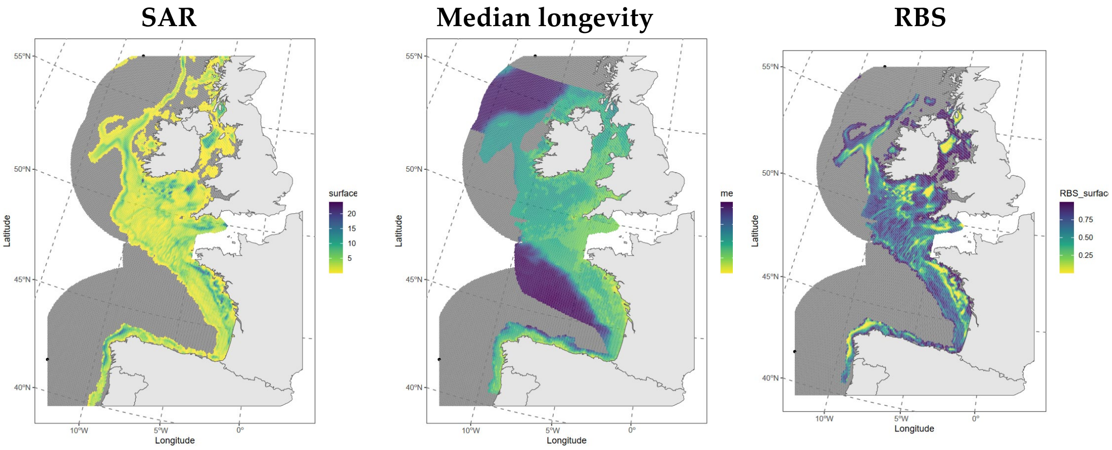


**Figure 14.** Mean surface SAR (A, 2009–2021), median longevity (B, modelled from stations with low SAR threshold of 1 years$^{-1}$) and Relative Benthic Status (C, RBS) for fishing pressure corresponding to mean surface SAR over the 2009–2021 period.

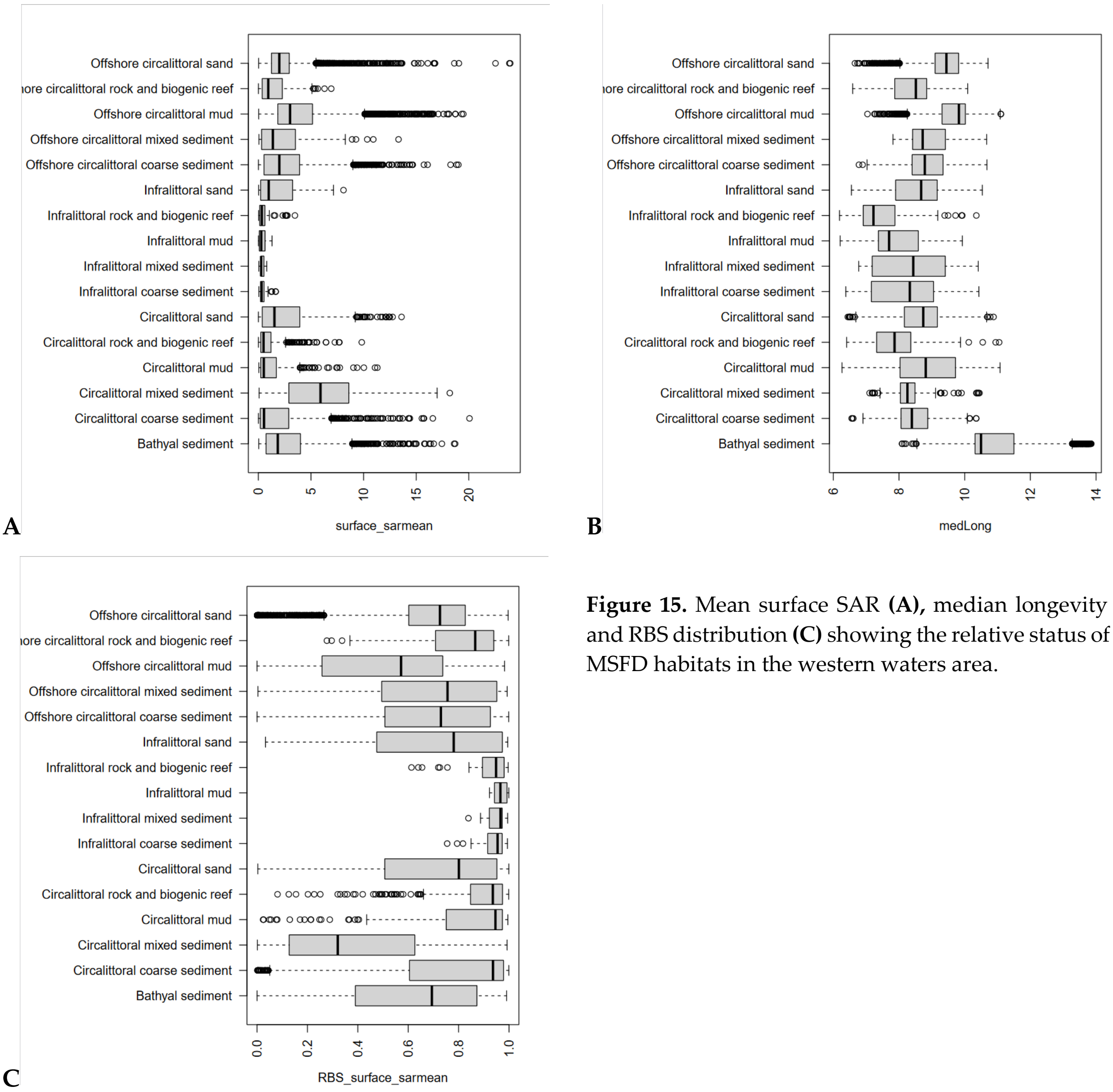


**Figure 15.** Mean surface SAR **(A),** median longevity **(B)** and RBS distribution **(C)** showing the relative status of the MSFD habitats in the western waters area.

**Table 7.** Summary of the pressure and impact indicators in the Western Waters areas (bay of Biscay and Celtic seas). The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2021).

| Habitat (MSFD) | Extent of habitat (1000 km2) | Area 1000 km2 (fraction of total) | Swept area 1000 km2 | Mean SAR (+-SD) | Fraction SAR>5 (+-SD) | Fraction SAR>2 (+-SD) | Mean Impact (+-SD) | Fraction with impact below 0.3 (+-SD) |
|---|---|---|---|---|---|---|---|---|
| **Bathyal sediment** | 194.47 | 0.29 | 11.56 | 2.64 (+/− 2.47) | 0.07 | 0.21 | 0.38 (+/− 0.29) | 0.17 |
| **Circalittoral coarse sediment** | 22.72 | 0.03 | 1.55 | 2.2 (+/− 3.33) | 0.13 | 0.19 | 0.24 (+/− 0.32) | 0.4 |
| **Circalittoral mixed sediment** | 6.53 | 0.01 | 1.25 | 5.97 (+/− 3.9) | 0.4 | 0.57 | 0.61 (+/− 0.3) | 0.13 |
| **Circalittoral mud** | 9 | 0.01 | 0.42 | 1.35 (+/− 1.87) | 0.03 | 0.15 | 0.17 (+/− 0.23) | 0.44 |
| **Circalittoral rock and biogenic reef** | 18.05 | 0.03 | 0.44 | 1.03 (+/− 1.37) | 0.01 | 0.08 | 0.13 (+/− 0.17) | 0.32 |
| **Circalittoral sand** | 28.65 | 0.04 | 2.16 | 2.52 (+/− 2.64) | 0.11 | 0.3 | 0.3 (+/− 0.28) | 0.32 |
| **Infralittoral coarse sediment** | 1.46 | <0.01 | 0.02 | 0.44 (+/− 0.4) | 0 | 0 | 0.07 (+/− 0.06) | 0.33 |
| **Infralittoral mixed sediment** | 0.74 | <0.01 | <0.01 | 0.37 (+/− 0.26) | 0 | 0 | 0.06 (+/− 0.05) | 0.19 |
| **Infralittoral mud** | 3.16 | <0.01 | 0.01 | 0.37 (+/− 0.35) | 0 | 0 | 0.03 (+/− 0.03) | 0.08 |
| **Infralittoral rock and biogenic reef** | 3.93 | 0.01 | 0.05 | 0.54 (+/− 0.68) | 0 | 0.03 | 0.09 (+/− 0.11) | 0.16 |
| **Infralittoral sand** | 5.52 | 0.01 | 0.12 | 2.15 (+/− 2.38) | 0.03 | 0.08 | 0.31 (+/− 0.31) | 0.1 |
| **Offshore circalittoral coarse sediment** | 113.65 | 0.17 | 11.8 | 2.65 (+/− 2.59) | 0.13 | 0.39 | 0.32 (+/− 0.27) | 0.38 |
| **Offshore circalittoral mixed sediment** | 6.66 | 0.01 | 0.63 | 2.21 (+/− 2.31) | 0.1 | 0.37 | 0.3 (+/− 0.26) | 0.37 |
| **Offshore circalittoral mud** | 88.89 | 0.13 | 17.45 | 3.98 (+/− 3.03) | 0.25 | 0.71 | 0.5 (+/− 0.28) | 0.27 |
| **Offshore circalittoral rock and biogenic reef** | 8.52 | 0.01 | 0.35 | 1.47 (+/− 1.43) | 0.02 | 0.19 | 0.2 (+/− 0.17) | 0.31 |
| **Offshore circalittoral sand** | 147.64 | 0.22 | 16.32 | 2.35 (+/− 1.85) | 0.06 | 0.48 | 0.31 (+/− 0.2) | 0.51 |

### 3.2.2.3 Iberian Peninsula and the Gulf of Caddiz

The Gulf of Cadiz was also included in the scope of the WGFBIT assessment by using combined data of the Spanish IBTS of northern coast of Spain and Gulf of Cadiz (ICES 2023). The studied area encompasses all Iberian Peninsula although their results in Portugal waters are the result of extrapolation of data sampled in area covered (Figure 16) and therefore its direct use to assessment is not recommended. In fact, as previously mentioned in the extended assessment these results, although an improvement in relation with previous years are still preliminary and should not be considered as a relevant assessment for the area under consideration.

**Figure 16.** Haul distribution across the studied area of the DEMERSALES (norther coast of Spain) and ARSA (Gulf of Cadiz) surveys. There were not available data for Portugal coast.

For the analysis of the Iberian Peninsula, we used data of invertebrate biomass from the surveys DEMERSALES (northern coast of Spain) and ARSA (Gulf of Cadiz) for the years 2013–2020 and a set of environmental variables, including depth, sediment type, sea stress, chlorophyl and temperature near bottom (see ICES (2021) for a complete description of the environmental layers). Trawling effort for the period 2009–2020 was also included by using data provided by ICES. To each sample, we assign the value of each explanatory variable in the mean point of the haul. For trawling effort to each sample, we assigned the mean effort in the mean point of the haul during the 4 years before sampling and the sampling year (e.g. for a sample of 2015, we assigned the mean effort in the period 2011–2015). The longevity values were assigned using the same trait database than in the rest of region.

To model the distribution, the mean longevity across the studied region we tried two different approaches. In the first approach, we use as a proxy to reference conditions all areas of the seabed with values lower than 0.5 SAR during the four-year period before sampling (including the year of sampling, as previously described). In this approach, from the initial 1572 samples, we reduced the analysis to 113 samples in reference conditions, 76 from DEMERSALES survey and 36 for ARSA survey (Figure 17).

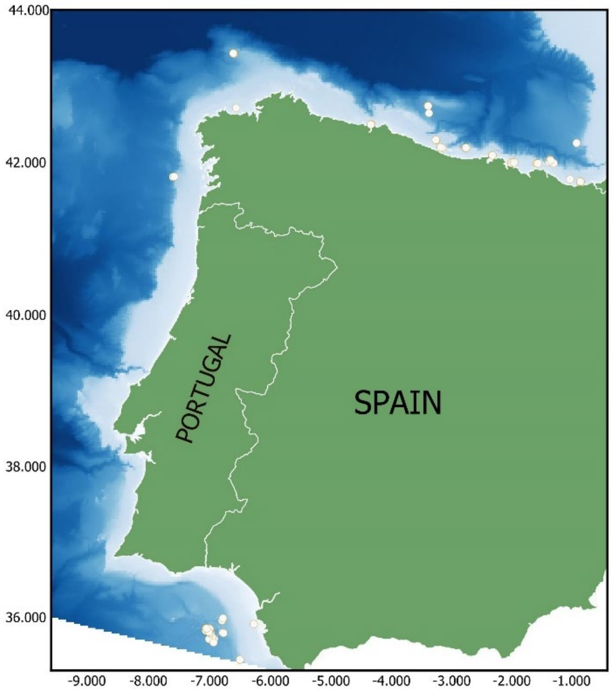


**Figure 17.** Haul distribution in seabed areas exposed to values of trawling lower than 0.5 SAR values (during the last 4 years before sampling and including sampling year) in both norther coast of Spain and Gulf of Cadiz.

In the second approach we did not model the distribution based on sampled from reference conditions. On the contrary, we used all available data (Figure 16) and we included trawling as an explanatory variable. Then, once the effect of trawling on mean longevity was quantified, we predict the distribution of longevity in an “alternative scenario” without trawling (so raising trawling to 0 in the raster layer).

For each dataset (data for SAR <0.5 and all data) we test all the models using all potential combinations of the environmental layers (without including interactions between variables) and we choose the model with the lowest AIC value. In the first approach, the effect of trawling for values between 0 to 0.5 of SAR was considered to be NILL and it was not included into the model.

The selected models were:

**SAR <0.5** Cumb ~ ll + as.factor(Substrate) + Chl +AllEnergy + Temp + (1 | Station)

**All data** Cumb ~ ll + TrawlingEffort + Depth + Chl +AllEnergy + as.factor(Substrate) + Temp + (1 | Station)

Both models coincide in including temperature near bottom, chlorophyl, energy and substrate as explanatory variables with a a significant effect on mean longevity of benthos invertebrates. Temperature near bottom have a negative effect on the mean longevity in both models, generating a depth and latitudinal gradient in longevity (higher in deeper and northern areas) even without include depth as explanatory variable (model for SAR <0.5). On the contrary, chlorophyl and seabed stress were included differently in both models. Whereas in the model of SAR <0.5 the energy and Chlorophyl had a negative impact on longevity (animals live longer in areas with low primary productivity and low seabed stress) in the model including trawling these variables have a positive effect. Both models also differ in how substrate was included, generating some patches of high longevity in some of the prediction that are not visible in the other (see Figure 18). Despite these differences both models offer similar results of longevity distribution across the study area, with a clear depth trend in longevity (higher as deeper) and with low longevity areas in the shallower part of the Gulf of Cadiz (an area heavily trawled). In general, the prediction based on including trawling in the model and then predict the longevity values in a scenario without trawling offered higher values than the model based on analysed only areas with SAR values lower than 0.5.

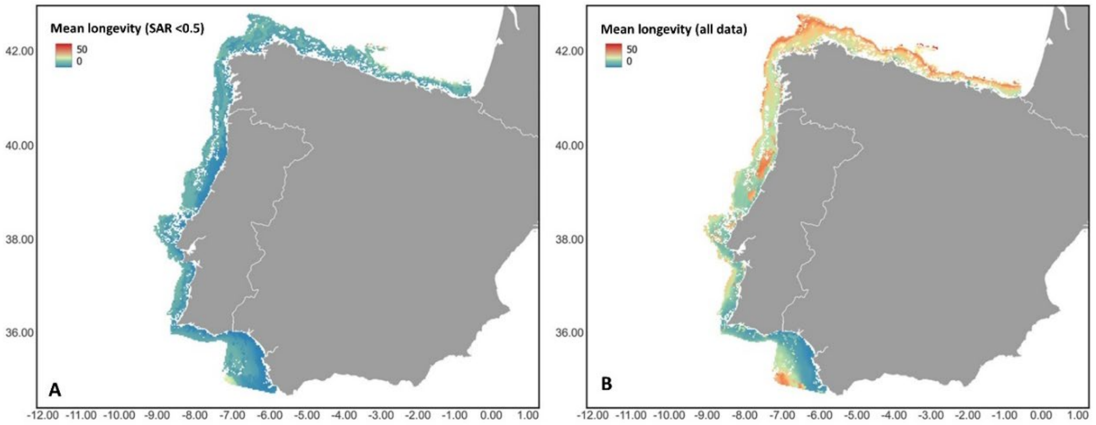


**Figure 18.** Predicted longevity across the studied area for both models. A) Prediction based on data sampled in low trawling effort areas (SAR < 0.5). B) Prediction bases in all data, with trawling as explanatory variable and generated after replace all trawling effort values by 0.

With the longevity maps, the PD was applied for both models using the mean trawling for the years 2016–2022. The results are shown in Figure 19.

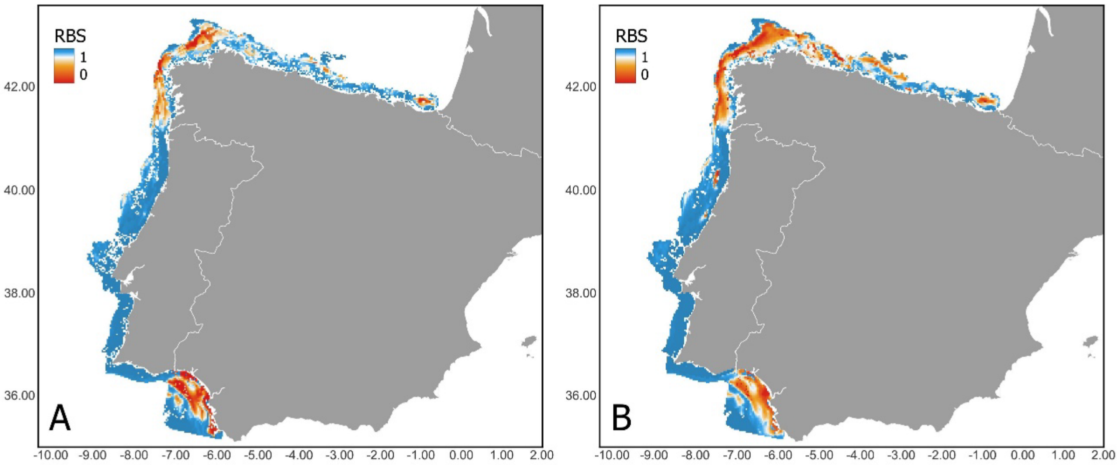


**Figure 19.** Predicted Relative Benthic Status (RBS) across the studied area for both models. A) Prediction based on longevity prediction shown in Figure 18. B) Prediction based on longevity prediction shown in Figure 18. Predicted Relative Benthic Status (RBS) across the studied area for both models. Please be aware that trawling effort did not included Portuguese fleet for the studied period (2016–2022).

As expected because of the different longevity maps, the final output showing the Relative Benthic Status (RBS) are quite different between approaches. Currently is not possible to establish one of these models reflect better the reality of benthic habitats in the Iberian Peninsula, being the selection of models and approaches for mapping the distribution of mean longevity across the assessed area probably one of the biggest challenges in the frame of the WGFBIT work.

## 3.2.3 Mediterranean Sea

### 3.2.3.1 Regional Assessment for Levantino-Balear Demarcation (Spanish Mediterranean)

Belén Calero & M. Teresa Farriols

MEDITS scientific surveys have been carried out since 1994 by the Spanish Institute of Oceanography to assess demersal resources along the entire peninsular coast in the Spanish Mediterranean (Spedicato *et al.*, 2019). From 2001, a series of surveys also began in Mallorca and Menorca, which are currently part of the MEDITS surveys. These surveys sample sedimentary bottoms with the experimental bottom trawl GOC-73. In the Marine Strategy Framework Directive, the Levantino-Balear (LEBA) Demarcation covers from Cabo de Gata to Cap de Creus and the Balearic Islands.

A total number of 1125 stations between 34 and 756 m depth have been used to conduct the regional assessment in the LEBA Demarcation (Figure 20). To do that standardized biomass (g/km$^2$) of benthic sessile megafauna from the MEDITS surveys carried out from 2014 to 2021 has been used. Highly mobile species have been excluded from the analysis.

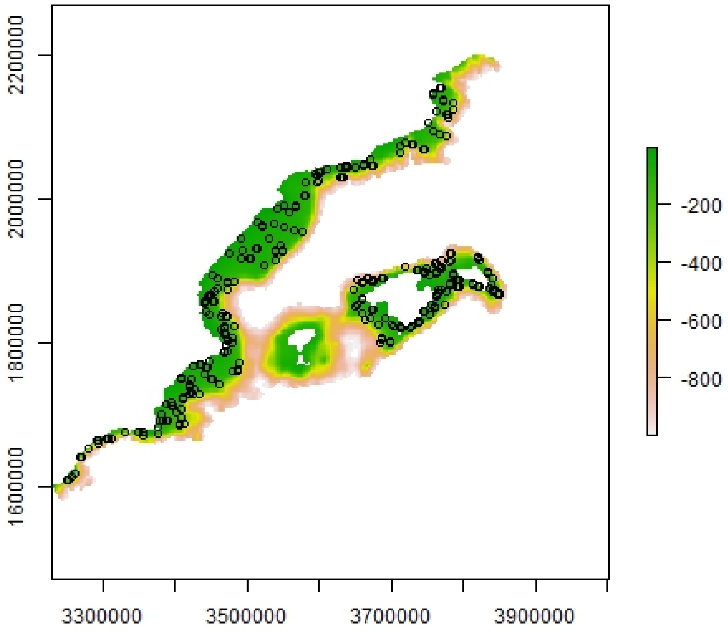


**Figure 20.** Map of the stations sampled during the MEDITS bottom trawl scientific surveys from 2014 to 2021 in the Levantino-Balear Demarcation.

Fuzzy longevity coding was implemented for each species. When datum for a species was not available, longevity of the upper taxonomic level was assigned. However, this work is still ongoing, with the aim of incorporating the longevity of all species at the lowest taxonomic level.

The Spanish SAR from 2010 to 2021 have been used to estimate fishing effort in the area, with the exception of 2019, for which year no SAR data is available in the LEBA Demarcation. A value of SAR lower to 0.5 has been used to identify the reference stations (Figure 21).

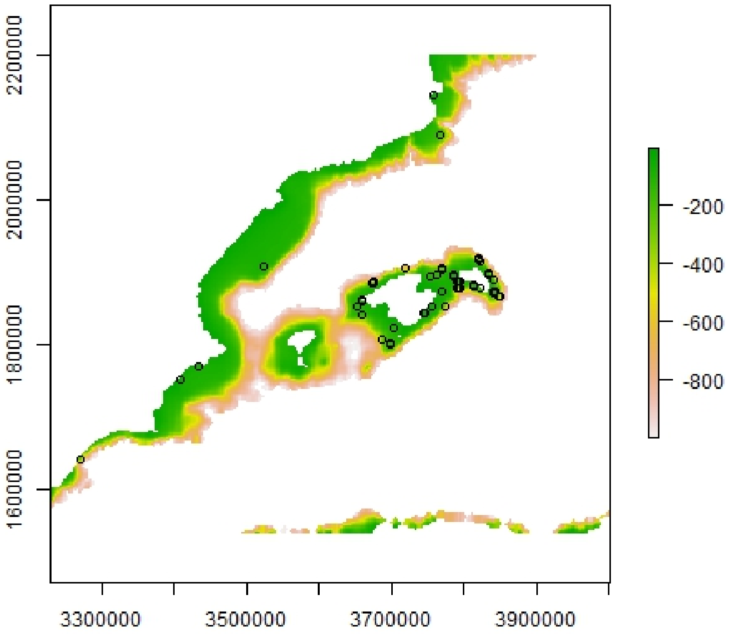


**Figure 21.** Map of the stations sampled during the MEDITS bottom trawl scientific surveys from 2014 to 2021 in the Levantino-Balear Demarcation under reference conditions (SAR<0.5).

The environmental layers used for this first approach have been obtained from EMODNET and they are depth, temperature, substrate type, currents and waves. A preliminary analysis shows that the environmental layer that correlates best with longevity is depth. However, these layers are being revised and the possibility of including better environmental information is currently explored.

In addition, work is ongoing to include data from the Alborán Sea that would allow to cover the entire Spanish Mediterranean in the Regional Assessment.

## References

ICES. 2023. International Bottom Trawl Survey Working Group (IBTSWG). ICES Scientific Reports. 5:80. 204 pp. https://doi.org/10.17895/ices.pub.23743989

Spedicato MT, Massutí E, Mérigot B, Tserpes G, Jadaud A, Relini G. 2019. The MEDITS trawl survey specifications in an ecosystem approach to fishery management. Scientia Marina 83(S1):9–20.

### 3.2.3.2 Eco-Region: Ionian and Central Mediterranean Sea

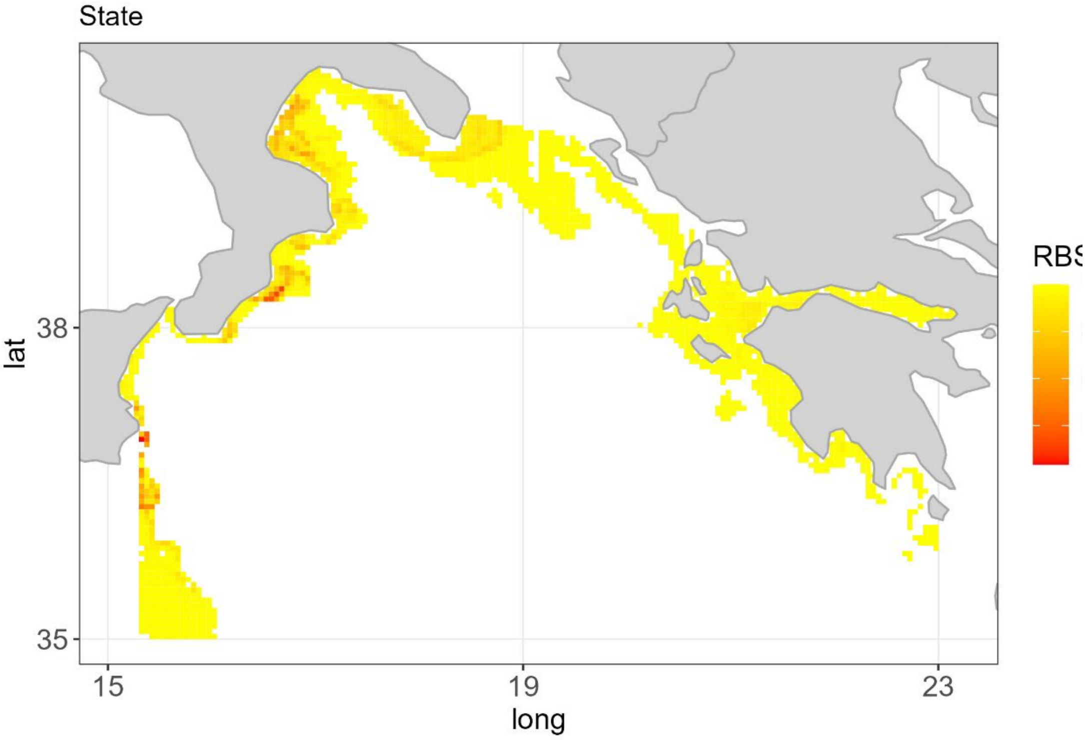


**Figure 22**. Ionian Sea joint RBS assessment. Western Ionian assessment based on AIS-SAR and epifaunal longevity. Eastern Ionian based on based on VMS-SAR and macrofaunal longevity

The assessment shown in Figure 22. Is the first eco-region assessment, joining separate assessments from the west (Italian) and east (Greek work) completed in the SEAWISE project (with habitat, SAR, longevity and state maps, data for MSFD BHTs with confidence). The separate parts are based on different sources with the western area having SAR calculated from AIS, using longevity estimates from trawl caught epifauna, whilst in the East SAR is based on VMS data (average 2015–2018) and longevity on macrofaunal grab sampling.

The northern part of the eco-region is characterised by deep water (>1000 m) relatively close to the coasts which reflects SAR result distribution and consequently the distribution of RBS. The analysis was restricted to shallower than 1200 m depth (limit for upper bathyal BHT). From the joined assessments, trawling impacts are generally higher in the West than the East. Hotspots of activity are found in several areas of the south Italian coast and south-east of Sicily. Hotspots in Greek waters, were found in the islands of Cephalonia and Zakynthos and the mainland – although this area still had much higher status that the Italian hotspots.

As noted above, the individual RBS assessments have been completed for these two parts based on available longevity data, with trawl-sampled epifauna in the West and grab-sampled macrofauna in the East. It is proposed, in the coming period, to complete separate estimates for the whole ecoregion for both sensitivity layers. This would be facilitated by COISPA and HCMR sharing longevity data (curve slope data for each BHT available), in the first step with COISPA assessing RBS for western waters using HCMR macrofaunal longevity and HCMR assessing eastern waters using COISPA epifaunal longevity. The east and west assessments would then be combined for each of the 2 sensitivity analyses. This would both complete assessment of the eco-region as well as a comparison of the assessment of the two faunal groups in one area. The work will need efforts to a) ensure grid compatibility (COISPA currently use a 0.01 degree grid and

HCMR a 0.05 degree grid), b) acquire environmental co-variate data to calculate habitat sensitivity curves (using the models already selected), c) estimate sensitivity layers, d) estimate RBS. Existing habitat and SAR data would be used.

### Levantine Eco-region Assessment and Work Done

The assessment of Greek waters for 2015–2018 was completed and published in Smith *et al.* (2023). Further work was completed on annual variations on SAR. The spatial distribution of RBS in relation to bottom trawling is shown in Figure 23 with data constrained to 1200 m depth. Values are high (>0.95, blue and green) across most of the area, with some constant hotspots in shallower coastal areas and gulfs. There was very little annual variability and difference between years was never higher than 0.07% (Table 8). Similar homogeneity was shown when aggregating between years (2015–2017 and 2018–2020) to represent two difference MSFD cycles. Figure 24 shows the annual RBS for the different Broad Scale Habitats analysed. The different habitats show very little interannual variability, mostly less than 0.25%, with the greatest variation in the Circalittoral Sand habitat, which is related both to low habitat coverage and variable fishing in this habitat.

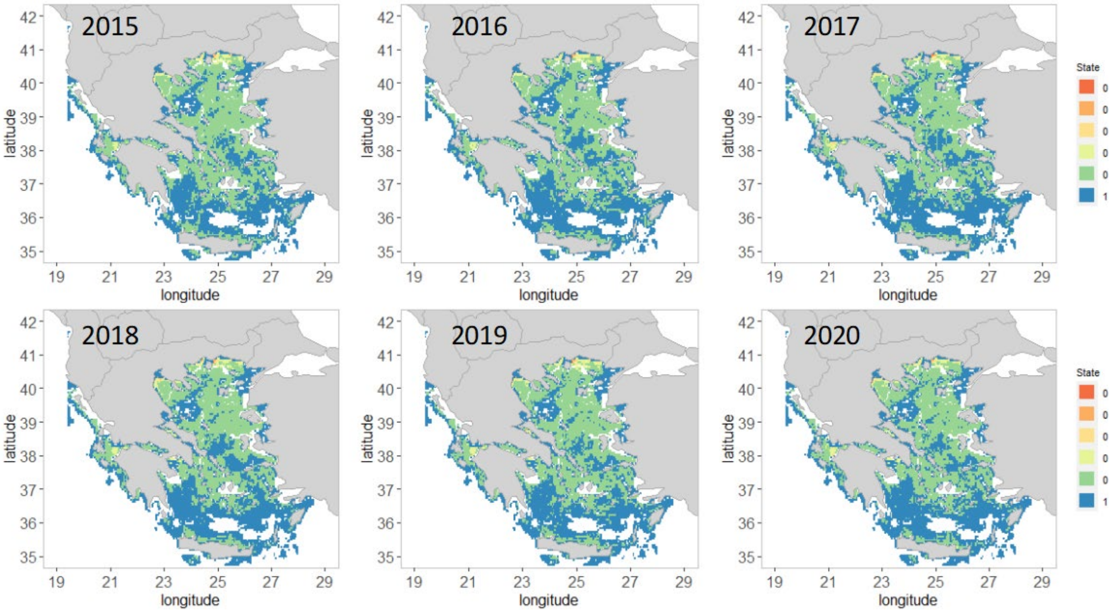


**Figure 23.** Ionian Sea joint RBS assessment. Western Ionian assessment based on AIS-SAR and epifaunal longevity. Eastern Ionian based on based on VMS-SAR and macrofaunal longevity

**Table 8.** Percentage difference for aggregated RBS in Greek waters (Aegean and Eastern Ionian) between consecutive years (2015 to 2020) and difference between each year and 2015.

| Year | % Diff per yr | % Diff 2015 |
|---|---|---|
| 2015 to 2016 | 0.00 | -0.062 |
| 2016 to 2017 | -0.07 | -0.064 |
| 2017 to 2018 | 0.01 | -0.052 |
| 2018 to 2019 | -0.01 | -0.063 |
| 2019 to 2020 | 0.03 | -0.035 |

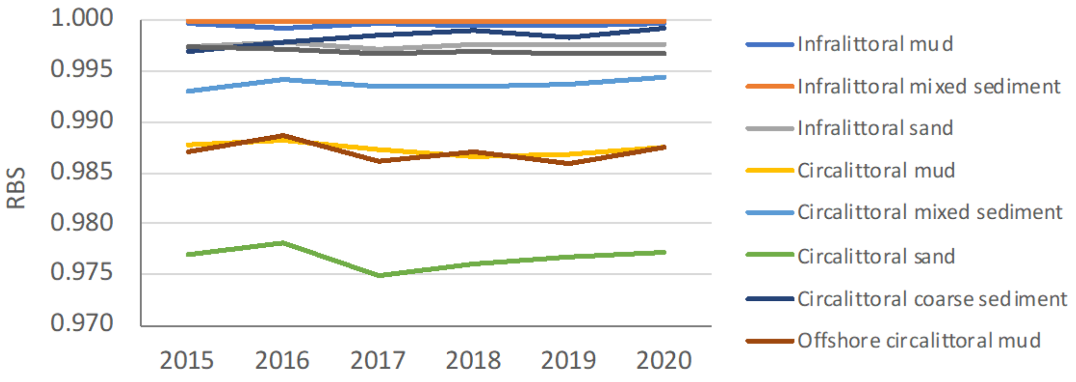


**Figure 24**. Ionian Sea joint RBS assessment. Western Ionian assessment based on AIS-SAR and epifaunal longevity. Eastern Ionian based on based on VMS-SAR and macrofaunal longevity.

With the new division of work for the eco-regions, the Ionian Sea data will be removed from the Greek waters analysis and new analysis will be run to complete a separate part of the Aegean-Levantine Sea. New work on higher resolution (0.05 to 0.01 degree cells), acquisition of new data for epifaunal sensitivity in RBS assessment, improvements to SAR with inclusion of AIS data, and comparison of indicators are foreseen for the future clarification steps.

### 3.2.3.3 Adriatic and Western Ionian Sea

The benthic state assessment was for both Adriatic Sea and Wester Ionian Sea was conducted in the frame of the SeaWise project. Biologic information on benthic species biomass distribution were collected from MEDITS scientific trawl survey data (AA.VV., 2017; Spedicato *et al.*, 2019) conducted from the years 2017–2021 (2021 survey data were available only for the Southern Adriatic Sea, GSA 18) and 2017–2020 for the Western Ionian Sea (GSA 19). Such source of data provides valuable information on epibenthic fauna, even if the MEDITS bottom trawl survey is not specifically designed to collect benthic species. It is facilitated by the 20mm codend mesh size of the GOC 73 sampling gear adopted in the survey that allows even to collect small individuals.

Longevity trait information was derived from the longevity database, built in the frame of the FBIT working group in 2022 (ICES, 2022), merging seven different longevity databases available for Mediterranean and Atlantic areas.

Fishing intensity pressure layer was estimated in terms of swept area ratio (SAR): the area contacted by a fishing gear within a grid cell over one year. Fishing effort information were derived from aggregated AIS data freely provided by the Global Fishing Watch (GFW) website. In particular, the benthic state assessment analysis was conducted using bottom trawl vessels' activity, reported as fishing hours at a 0.01°x0.01° resolution, further aggregated at 0.05°x0.05° c-squares grid to fit the grid resolution adopted in FBIT assessments. SAR was estimated by multiplying the vessel activity for the total gear width (door spread), estimated for OTB vessels using Eigaard *et al.* (2016) equations, and assuming a mean trawling speed of 2.5 knots.

The 0.05°x 0.05° c-squares reference grid used covered the bathymetrical depth range of 0–1000m (EMODnet DTM, 2021; https://emodnet.ec.europa.eu/geoviewer) and ranged between 12.25°E – 20.0° E in longitude and 39.7° N – 45.8° N range of latitude for the Adriatic Sea, and 15.0°E – 19.15° E range of longitude and in the 35.0° N – 40.5° N range of latitude for the Western Ionian Sea (Figure 24). The grid covered the bathymetrical depth range of 0–1000m.

The approach used for modelling cumulative biomass as function of log-longevity (null model) was based on the use of Generalized Linear Mixed Effect Models (GLMM) (Rijnsdorp *et al.*, 2018) with a binomial distribution. The basic relationship between the two variables described by the null model was expanded with the inclusion of different pressure and environmental covariates as fixed effects, while sampling stations (ID) were included as random effects. Environmental covariates were extracted from E.U. Copernicus Marine Service Information (Escudier *et al.*, 2020; Cossarini *et al.*, 2021), while the depth profiles, was derived from EMODnet (EMODnet, 2022). Furthermore, the pressure effect was included in the modelling approach in the form of swept area ratio, while the factorial covariate of benthic habitat classification was derived from EMODnet EUSeaMap habitat layer (Vasquez *et al.* 2021).

The environmental covariates tested to be included in the modelling analysis were:

- Sea water salinity at bottom level (botso);
- Sea water potential temperature at sea floor (botT);
- Sea water velocity at bottom level, as resultant of the eastward and northward components (botcur);
- Mole concentration of dissolved molecular oxygen in sea water at bottom level (botDox);
- Mole concentration of nitrate in sea water at bottom level (botNit);
- Mole concentration of phosphate in sea water at bottom level (botPho);
- Mass concentration of chlorophyll a in sea water (chl).

The GLMM models were estimated using the *lme4* package in R (Bates *et al.*, 2015) testing all possibles combinations of fixed effect covariates. SAR variavle was mantained in each model tested in order to allow the estimation of median longevity sensitivity layer. All the possible combinations of fixed terms, excluding combinations with correlated variables, were generated with the *MuMIn* package (Barton, 2022).

The best models, identified using a ΔAIC threshold of 3 were further validated by mean of a train/test procedure iteratively (20 iterations) training the models re-fitting them on 70% of the data to explore their fitting capability, and testing their predictive performance on the remaining 30% of the data. The models were then validated selecting the model minimizing the estimated mean AIC values (Akaike, 2011).

The slope and the intercept of the best model selected in this way were used to estimate the median longevity, extrapolating the binomial model to SAR=0 and then used to predict the Relative Benthic State (RBS) by mean of the Population Dynamics method (PD) (Pitcher *et al.*, 2017) adopted in the ICES FBIT framework (ICES, 2022).

### 3.2.3.4 Adriatic Sea

The SAR layer reported in Figure 25 shows that the higher pressure in the Adriatic Sea is mainly observed in the western side of the ecoregion. On the other side, the southern-eastern part appeared to be less impacted by trawling, even if this picture could be likely due to the lower number of fishing vessels equipped with the AIS device.

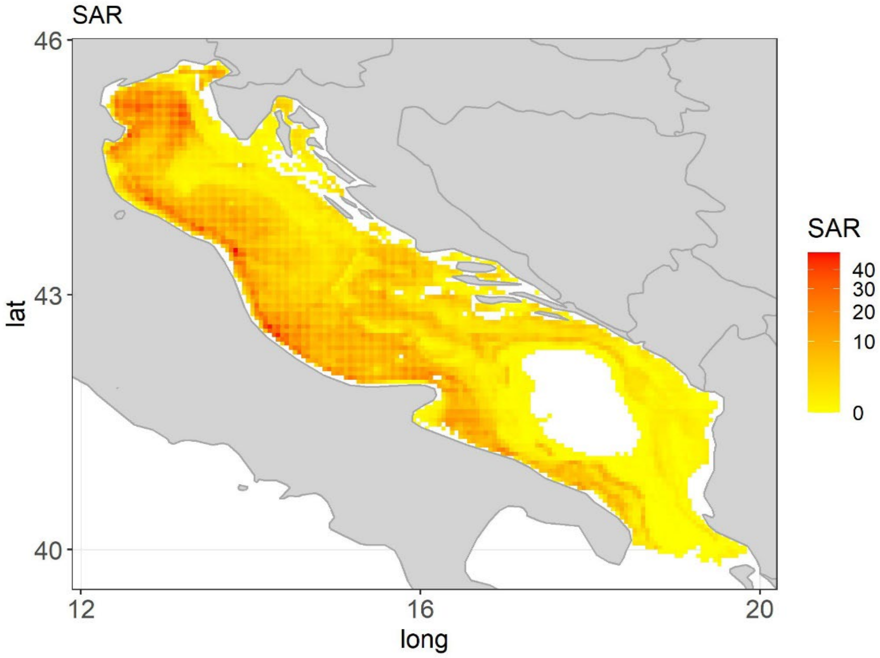


**Figure 25**. Extent of the average swept area ratio (SAR) estimated in the Adriatic Sea from 2017–2021, based on AIS data and plotted on a 0.05° x 0.05° grid.

The best model, selected among a total of 384 models (Table 9), and validated by mean of the training/testing procedure (Figure 26), was built including the following covariates: includes temperature, current and dissolved oxygen at the sea floor as environmental covariates. The contribute of the environmental variables to the improvement of the model performances is marginal (~1.16% of $R^2$).

**Table 9.** Results relative to the best 20 models with Δ(AIC)<3. For each model the AIC, Δ(AIC) and R2 values are reported. The results related to the NULL model are also included in the table, in the first row (Cumb: cumulative biomass; botso: bottom salinity; botT: bottom temperature; botcur: bottom water velocity; botDox: bottom dissolved oxygen; botNit: bottom nitrates; botPho: bottom phosphates; chl: chlorophyll a concentration; ll: log-longevity; MSFD: EMODnet EUSeaMap habitat; SAR: swept area ratio; ID: sampling station code).

| | Models | AIC | Δ(AIC) | Adj.$R^2$ |
|---|---|---|---|---|
| *0* | *NULL MODEL (ll)* | 1136.2 | 53.8 | 0.8460 |
| **1** | Cumb ~ botcur + botDox + botT + ll + MSFD + SAR + (1 ∣ ID) | 1082.4 | 0.0 | 0.8577 |
| **2** | Cumb ~ botcur + botDox + botNit + botT + ll + MSFD + SAR + (1 ∣ ID) | 1082.8 | 0.6 | 0.8576 |
| **3** | Cumb ~ botcur + botDox + botT + Depth + ll + MSFD + SAR + (1 ∣ ID) | 1083.0 | 1.0 | 0.8576 |
| **4** | Cumb ~ botcur + botDox + botso + botT + ll + MSFD + SAR + (1 ∣ ID) | 1083.1 | 1.2 | 0.8559 |
| **5** | Cumb ~ botcur + botDox + botT + ll + SAR + (1 ∣ ID) | 1083.3 | 1.3 | 0.8562 |
| **6** | Cumb ~ botcur + botDox + botT + Depth + ll + SAR + (1 ∣ ID) | 1083.4 | 1.5 | 0.8578 |
| **7** | Cumb ~ botcur + botDox + botNit + botT + Depth + ll + MSFD + SAR + (1 ∣ ID) | 1083.4 | 1.6 | 0.8575 |
| **8** | Cumb ~ botcur + botDox + botT + chl + ll + MSFD + SAR + (1 ∣ ID) | 1083.5 | 1.6 | 0.8568 |
| **9** | Cumb ~ botcur + botT + ll + MSFD + SAR + (1 ∣ ID) | 1083.6 | 1.7 | 0.8575 |
| **10** | Cumb ~ botcur + botDox + botPho + botT + ll + MSFD + SAR + (1 ∣ ID) | 1083.7 | 1.8 | 0.8562 |
| **11** | Cumb ~ botcur + botDox + botNit + botT + ll + SAR + (1 ∣ ID) | 1084.0 | 1.9 | 0.8564 |
| **12** | Cumb ~ botcur + botDox + botNit + botT + Depth + ll + SAR + (1 ∣ ID) | 1084.0 | 2.2 | 0.8577 |
| **13** | Cumb ~ botcur + botDox + botso + botT + Depth + ll + MSFD + SAR + (1 ∣ ID) | 1084.1 | 2.2 | 0.8571 |
| **14** | Cumb ~ botcur + botso + botT + ll + MSFD + SAR + (1 ∣ ID) | 1084.3 | 2.3 | 0.8577 |
| **15** | Cumb ~ botcur + botDox + botNit + botPho + botT + ll + MSFD + SAR + (1 ∣ ID) | 1084.4 | 2.5 | 0.8577 |
| **16** | Cumb ~ botcur + botDox + botT + chl + Depth + ll + MSFD + SAR + (1 ∣ ID) | 1084.6 | 2.6 | 0.8563 |
| **17** | Cumb ~ botcur + botDox + botso + botT + Depth + ll + SAR + (1 ∣ ID) | 1084.6 | 2.8 | 0.8570 |
| **18** | Cumb ~ botcur + botNit + botT + ll + MSFD + SAR + (1 ∣ ID) | 1084.8 | 2.8 | 0.8570 |
| **19** | Cumb ~ botcur + botT + Depth + ll + MSFD + SAR + (1 ∣ ID) | 1084.8 | 3.0 | 0.8560 |
| **20** | Cumb ~ botcur + botDox + botso + botT + ll + SAR + (1 ∣ ID) | 1081.8 | 3.0 | 0.8574 |

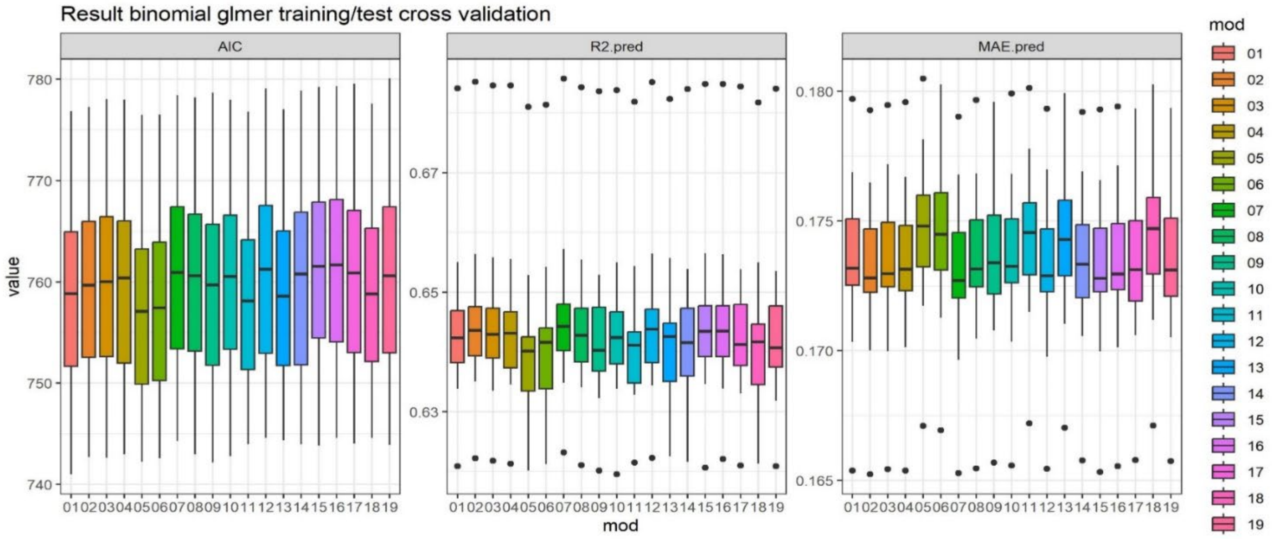


**Figure 26.** Results of the train/test conducted on the best models (Δ(AIC)<3): AIC, R² and MAE.

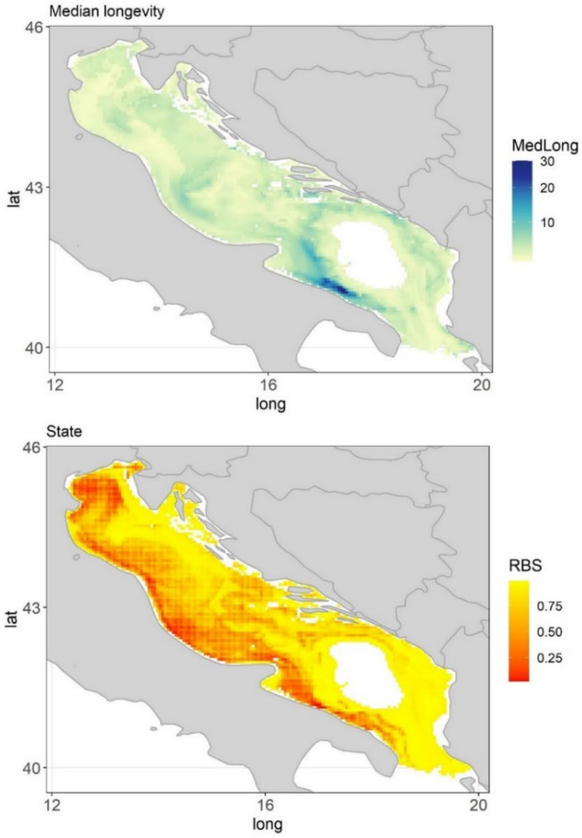


**Figure 27**. Maps of estimated sensitivity layer (median longevity on the left) and relative benthic state (RBS) (on the right) for the Adriatic Sea.

**Table 10.** Summary of the pressure and impact indicators by MSFD benthic broad habitat for 0–200 and 200–1000 m depths. The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2021). n/a = not analysed.

| MSFD broad habitat types | Area $10^3$ km$^2$ (fraction of total) | Fraction un-trawled | Mean SAR (±CI) | Fraction SAR > 0.5 | Mean Impact (±CI) | Fraction with impact below 0.2 |
|---|---|---|---|---|---|---|
| 0-200m | | | | | | |
| Circalittoral coarse sediment | 0.13(0) | 0.00 | 1.96(1.55) | 0.83 | n/a | n/a |
| Circalittoral mixed sediment | 0.56(0) | 0.20 | 0.57(0.65) | 0.12 | n/a | n/a |
| Circalittoral mud or Offshore circalittoral mud | 0.61(0.01) | 0.17 | 2.22(1.38) | 0.45 | n/a | n/a |
| Circalittoral mud | 29.42(0.24) | 0.07 | 7.16(0.4) | 0.79 | 0.37(0.01) | 0.34 |
| Circalittoral sand | 25(0.2) | 0.05 | 2.66(0.28) | 0.58 | 0.18(0.01) | 0.7 |
| Infralittoral coarse sediment | 0.21(0) | 0.54 | 0.14(0.19) | 0.08 | n/a | n/a |
| Infralittoral mixed sediment | 0.38(0) | 0.65 | 0.02(0.02) | 0 | n/a | n/a |
| Infralittoral mud | 1.89(0.02) | 0.56 | 0.21(0.13) | 0.12 | n/a | n/a |
| Infralittoral sand | 3.45(0.03) | 0.31 | 0.46(0.17) | 0.23 | n/a | n/a |
| Offshore circalittoral mixed sediment | 0.04(0) | 0.00 | 1.84(3.61) | 0.5 | n/a | n/a |
| Offshore circalittoral mud | 27.08(0.22) | 0.04 | 4.53(0.23) | 0.84 | 0.33(0.01) | 0.36 |
| Offshore circalittoral sand | 7.04(0.06) | 0.08 | 1.94(0.24) | 0.65 | 0.17(0.02) | 0.64 |
| Other | 3.56(0.03) | 0.60 | 0.3(0.16) | 0.1 | n/a | n/a |
| Upper bathyal sediment or Lower bathyal sediment | 0.14(0) | 0.33 | 0.98(1.12) | 0.33 | 0.09(0.09) | 0.67 |
| Total 0-200m | 99.51(0.81) | 0.11 | 4.12(0.17) | 0.66 | 0.29(0.01) | 0.41 |
| 200-1000m | | | | | | |
| Offshore circalittoral mud | 3.16(0.03) | 0.02 | 3.08(0.41) | 0.84 | 0.21(0.02) | 0.48 |
| Offshore circalittoral sand | 0.14(0) | 0.33 | 0.07(0.06) | 0.00 | 0.04(0.01) | 1.00 |
| Upper bathyal sediment or Lower bathyal sediment | 19.81(0.16) | 0.20 | 0.68(0.11) | 0.22 | 0.08(0.01) | 0.89 |
| Total 200-1000m | 23.11(0.19) | 0.18 | 1.01(0.12) | 0.31 | 0.1(0.01) | 0.84 |

The estimated RBS (Figure 27, Table 10 allows to recognise the circalittoral mud and offshore circalittoral mud as the more impacted habitats in the Adriatic Sea ecoregion, while coarse habitats, such as the circalittoral sands and the offshore circalittoral sands are less impacted than muddy environments. The least impacted habitat is the upper bathyal sediment or Lower bathyal sediment. There are also evidences of differences in RBS at depth strata level. Indeed, the mean impact is higher on the continental shelf area, that is the area in which the higher fishing pressure is registered.

### 3.2.3.5 Western Ionian Sea

The SAR layer reported in Figure 28 shows that the higher pressure in the Western Ionian Sea is mainly observed in the central part of the area, close the Gulf of Squillace, as well as in the southern part of Sicily island, offshore Siracusa.

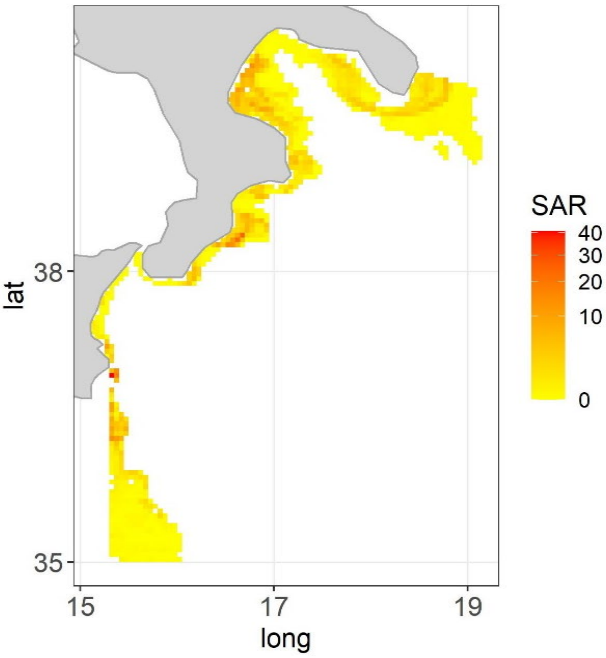


**Figure 28.** Extent of the average swept area ratio (SAR) estimated in the Wester Ionian Sea from 2017–2021, based on AIS data and plotted on a 0.05° x 0.05° grid.

The best model, selected among a total of 105 models (Table 11), and validated by mean of the training/testing procedure (Figure 29), was built including the following covariates: temperature, salinity and dissolved oxygen at the sea floor, as environmental covariates. The contribute of the environmental variables to the improvement of the model performances is marginal (~1.8% of $R^2$).

**Table 11.** Results relative to the best 5 models with Δ(AIC)<3. For each model the AIC, Δ(AIC) and R2 values are reported. The results related to the NULL model are also included in the table, in the first row (Cumb: cumulative biomass; botso: bottom salinity; botT: bottom temperature; botcur: bottom water velocity; botDox: bottom dissolved oxygen; botNit: bottom nitrates; botPho: bottom phosphates; chl: chlorophyll a concentration; ll: log-longevity; MSFD: EMODnet EUSeaMap habitat; SAR: swept area ratio; ID: sampling station code).

| | Models | AIC | Δ(AIC) | Adj.$R^2$ |
|---|---|---|---|---|
| | *NULL MODEL (ll)* | 239.7 | 23.2 | 0.8844 |
| **1** | Cumb ~ botDox + botso + botT + ll + SAR + (1 ǀ ID) | 216.5 | 0.0 | 0.9020 |
| **2** | Cumb ~ botDox + botso + ll + MSFD + SAR + (1 ǀ ID) | 217.6 | 1.1 | 0.9036 |
| **3** | Cumb ~ botDox + botso + botT + chl + ll + SAR + (1 ǀ ID) | 218.2 | 1.8 | 0.9021 |
| **4** | Cumb ~ botcur + botDox + botso + botT + ll + SAR + (1 ǀ ID) | 218.5 | 2.0 | 0.9020 |
| **5** | Cumb ~ botDox + botso + botT + ll + MSFD + SAR + (1 ǀ ID) | 218.8 | 2.4 | 0.9041 |

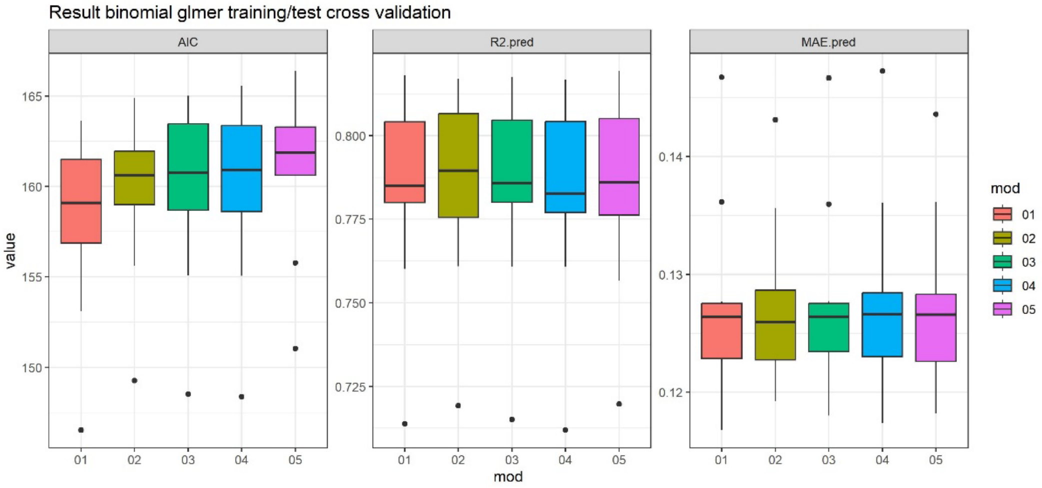


**Figure 29.** Results of the train/test conducted on the best models (Δ(AIC)<3): AIC, $R^2$ and MAE.

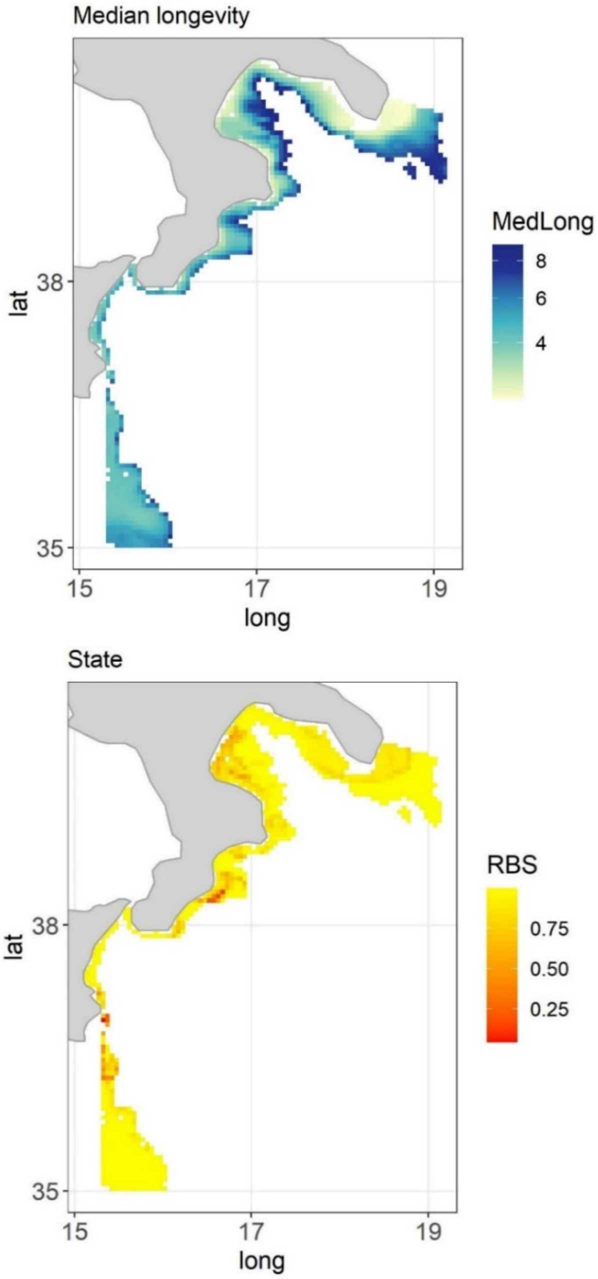


**Figure 30.** Maps of estimated sensitivity layer (median longevity on the left) and relative benthic state (RBS) (on the right) for the Western Ionian Sea.

**Table 12**. Summary of the pressure and impact indicators by MSFD benthic broad habitat for 0–200 and 200–1000 m depths. The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2021). n/a = not analysed.

| **MSFD broad habitat types** | **Area $10^3 km^2$ (fraction of total)** | **Fraction un-trawled** | **Mean SAR (±CI)** | **Fraction SAR>0.5** | **Mean Impact (±CI)** | **Fraction with impact below 0.2** |
|---|---|---|---|---|---|---|
| **0-200m** | | | | | | |
| Circalittoral mud | 0.05(0) | 0.00 | 0.13(0.2) | 0 | 0.07(0.01) | 1 |
| Circalittoral sand | 1.61(0.06) | 0.04 | 2.06(0.72) | 0.51 | 0.13(0.03) | 0.8 |
| Infralittoral mud | 0.02(0) | 0.00 | 1.88(n/a) | 1 | n/a | n/a |
| Infralittoral sand | 0.4(0.02) | 0.26 | 0.7(0.42) | 0.35 | n/a | n/a |
| Offshore circalittoral mixed sediment | 0.05(0) | 0.00 | 0.09(0.04) | 0 | n/a | n/a |
| Offshore circalittoral mud | 1.16(0.04) | 0.08 | 1.85(0.61) | 0.67 | 0.13(0.03) | 0.86 |
| Offshore circalittoral sand | 1.04(0.04) | 0.04 | 1.63(0.58) | 0.69 | 0.12(0.03) | 0.87 |
| Upper bathyal sediment or Lower bathyal sediment | 0.19(0.01) | 0.00 | 2.37(1.73) | 0.63 | 0.13(0.07) | 0.88 |
| Other | 1.17(0.04) | 0.46 | 0.24(0.19) | 0.2 | n/a | n/a |
| Total 0-200m | 5.68(0.21) | 0.16 | 1.4(0.28) | 0.49 | 0.13(0.02) | 0.73 |
| **200-1000m** | | | | | | |
| Circalittoral sand | 0.05(0) | 0.00 | 7(5.27) | 1 | 0.41(0.28) | 0 |
| Offshore circalittoral coarse sediment | 0.01(0) | 1.00 | 0(n/a) | 0 | n/a | n/a |
| Offshore circalittoral mixed sediment | 0.05(0) | 0.00 | 0.12(0.02) | 0 | n/a | n/a |
| Offshore circalittoral mud | 0.32(0.01) | 0.00 | 1.01(0.49) | 0.64 | 0.08(0.03) | 0.93 |
| Upper bathyal sediment or Lower bathyal sediment | 20.3(0.77) | 0.22 | 0.93(0.17) | 0.28 | 0.06(0.01) | 0.91 |
| Other | 0.05(0) | 1.00 | 0(n/a) | 0 | n/a | n/a |
| **Total 200-1000m** | **20.78(0.79)** | **0.22** | **0.94(0.17)** | **0.28** | **0.06(0.01)** | **0.91** |

The estimated RBS (Figure 30, Table 12) is globally high in the Wester Ionian Sea values along the whole area, with mean values at broad benthic habitat level always higher than 0.87, and reaching the higher value in the Upper bathyal sediment or Lower bathyal sediment habitat. Differences in RBS were also detected according to the depth strata. Indeed, the mean impact is higher on the continental shelf area, where the higher fishing pressure is observed, even if it represents only the 21% of the study area. Indeed, the most part of study area is included in the 200–1000m depth strata. The most impacted habitat on the slope is the circalittoral sand where the highest SAR values were observed.

### 3.2.3.6 Northern-Central Adriatic Sea (Italian GSA 17)

The Adriatic Sea is the most exploited sub-basin of the Mediterranean Sea with a high trawling intensity (Russo *et al.*, 2020). To perform the assessment, we used a benthic dataset derived from the integration of MSFD monitoring campaigns performed by Regional Environment Protection Agencies - ARPAs (2017–2020) and the Institute for Environmental Protection and Research - ISPRA (2019) in 316 sampling stations, SoleMON trawl survey (2014–2016; 168 sampling stations) and GAP2 trawl survey (2012–2014; 135 sampling stations), performed by ISPRA and CNR (Figure 31).

Sampling stations belonging to the MSFD monitoring campaigns are at a variable distance from the costaline, and SoleMON follows a random stratified approach and data used in this assessment spans from 1 nM from the the Italian coast to the midline (Scarcella *et al.*, 2011). GAP2 sampling stations comprised samples from trawl survey (collected along fixed distance from the coast) and randomly distributed hauls, with samples collected aboard of commercial trawlers (Piras *et al.*, 2015)

SoleMON trawl survey is a fishery-independent data collection carried out under Data Collection Framework - DCF established for collecting data in support of the stock assessment of benthic species and the sustainable management of resources, while GAP2 was aimed at acquiring fishery-dependent data (onboard commercial fishing vessels, i.e. beam and otter trawl) during fishing activities and fishery-independent data from scientific campaigns performed during the summer fishing period with otter trawl nets.

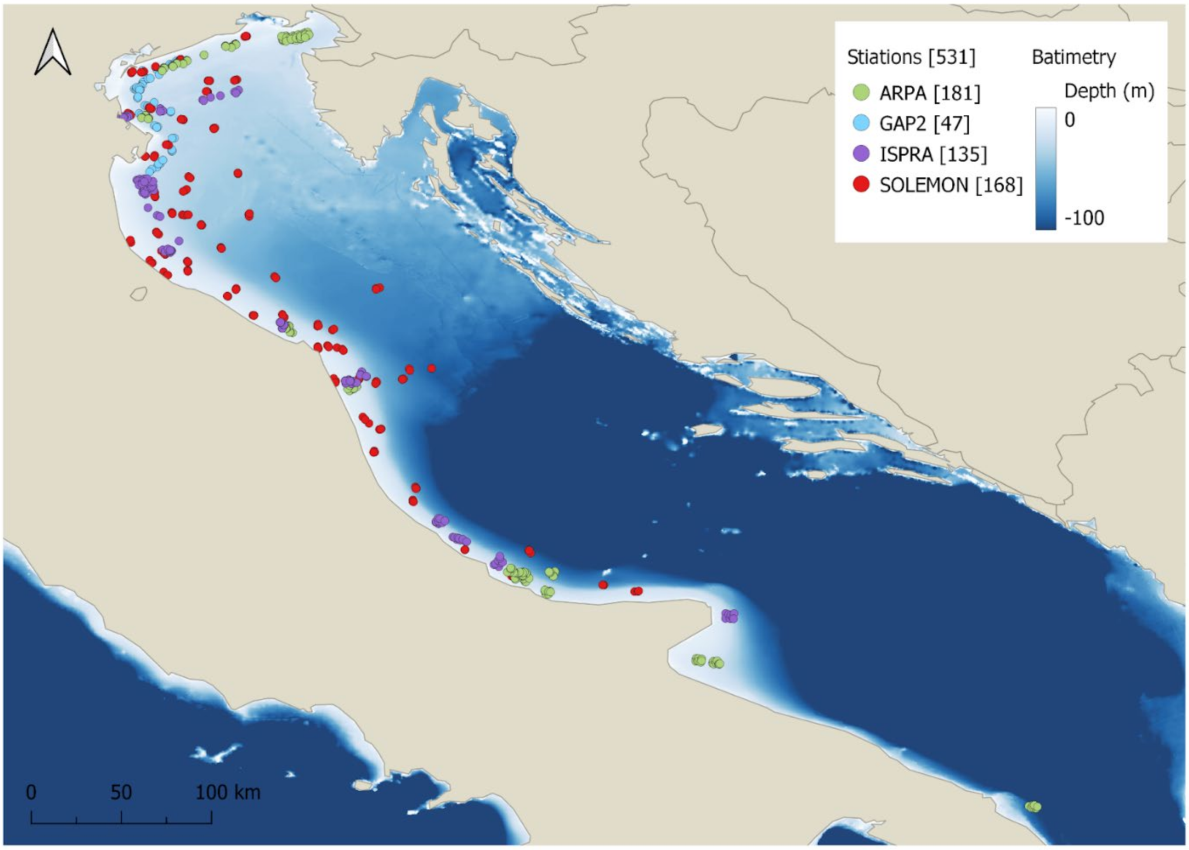


**Figure 31.** Sampling Stations distribution across the study area (GSA17 only Italian waters).

The assessment was based on biomass data of epi-mega benthos . In some cases, i.e. some stations of the MSFD campaigns, biomass data were estimated based on abundance, applying conversion factors derived from the closest sampling stations where biomass and abundance data were both available.

The bathymetric depth range of the sampling stations is 8–100 m (Figure 31). Taking into account the species for which FBIT longevity values were available, 282 species were identified; all the commercial species, pelagic, high mobility species (fish) and cephalopods were excluded from the assessment. Where the biomass information was missing, the average individual biomass per species was utilized together with abundance data.

Longevity trait information was derived from the longevity database, built in the frame of the FBIT working group in 2022 (ICES, 2022), merging seven different longevity databases available for Mediterranean Sea and Atlantic areas.

Fishing intensity pressure was estimated in terms of swept area ratio (cumulative area contacted by a fishing gear within a grid cell over one year) by integration of VMS and AIS data as SAR data on a grid with 1x1 km cell resolution. Within each grid cell the SAR average of the five yearly values (2015–2019) was estimated by fishing gear (OTB, TBB). The 1x1 km SAR data (average of a five-years period) was then plotted on a 0.05°x0.05° grid to run the RBS model, which provides the average of SAR of the corresponding 1x1 Km grid cells (Figure 32).

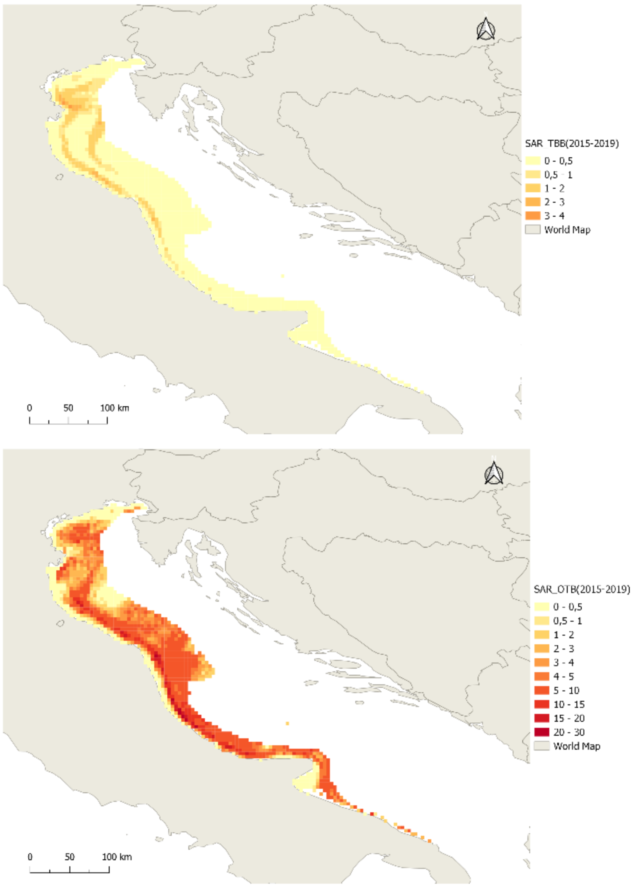


**Figure 32.** Extent of the average swept area ratio (SAR) estimated in the Adriatic Sea from 2015–2019, based on AIS and VMS data and plotted on a 0.05° x 0.05° grid for TBB - rapido trawls (top) and OTB - otter trawl (down).

Benthic habitat classification was derived from EMODnet EUSeaMap 2021 (Figure 33) which, according to the confidence assessment layer, has a moderate confidence.

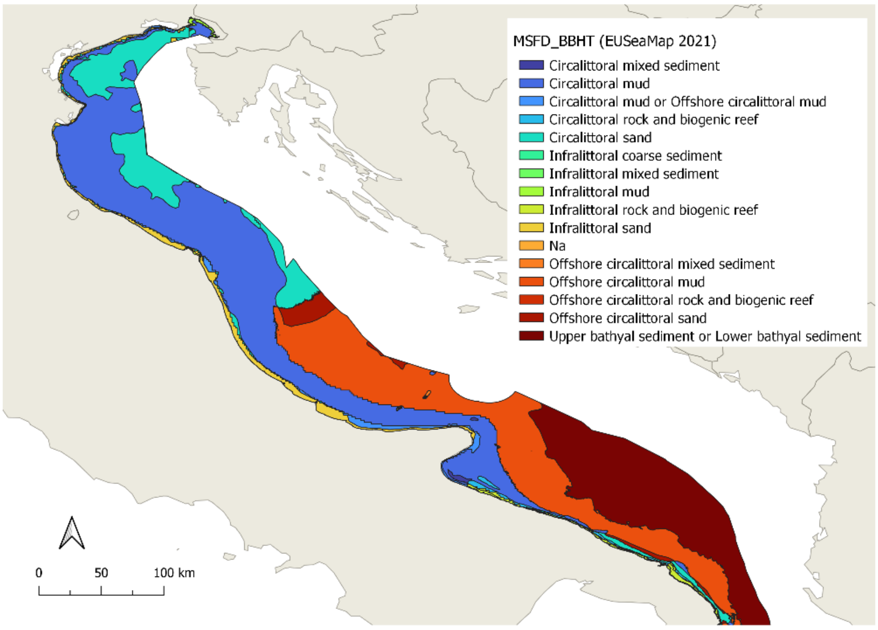


**Figure 33. Adriatic Sea MSFD BBHT as per EMODnet EUSeaMap 2021.**

Among all the MSFD BBHT of the Italian Adriatic waters, we considered in the assessment only those habitats for which a minimum number of 10 sampling stations.

Cumulated biomass was modeled by Generalized Linear Mixed-Effects Models (GLMM) with fixed effects described by Habitat, Depth and Longevity and random effect is defined by ID Station. As benthic data from sites with zero trawling pressure were not present in the dataset, to run the model we consider only stations with SAR < 1, where pressure was referred to the previous year. From the original dataset of 531 sampling stations we then used only 126 stations.

Tested models are the following:

```
mod1  <-  glmer(Cumb ~ ll + Depth + (1 | ID), data=fulldat, family=binomial)
mod2  <-  glmer(Cumb ~ ll + MSFD + Depth + (1 | ID), data=fulldat, family=binomial)
mod3  <-  glmer(Cumb ~ ll + MSFD + (1 | ID), data=fulldat, family=binomial)
mod4  <-  glmer(Cumb ~ ll + (1 | ID), data=fulldat, family=binomial)
```

The best model was identified using Akaike Information Criterion (AIC) and the higher quality of given models is obtained by mod2, considering Depth and Habitat as the main explained variables. The overall low variability of the median longevity (ranging from 4 to 6 yrs) may reflect the low environmental gradients of the study area. (Figure 34).

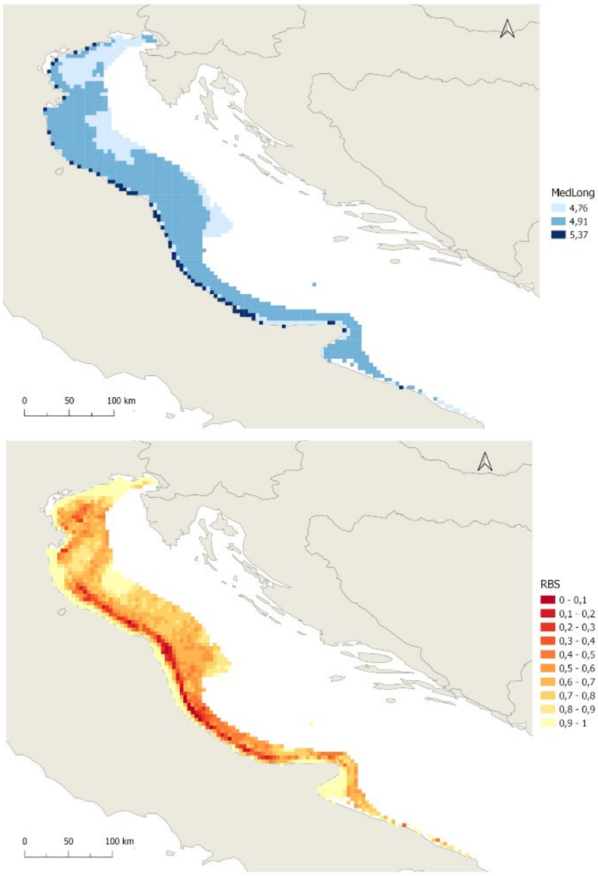


**Figure 34.** North and Central Adriatic Sea (Italian GSA 17) maps of: predicted median longevity (top) and relative benthic state (down). The indicators are described in the technical guidelines for WGFBIT seafloor assessment (ICES 2021).

**Table 13.** Summary of the pressure and impact indicators in the North and Central Adriatic Sea area. The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2021).

| Habitat type (EUSeaMap 2021) | Area (Km2) | Area untrawled (Km2) | Mean SAR_OTB (+-Dev.St) | Mean SAR_TBB (+-Dev.St) | Area SAR > 5 (Km2) | Mean Impact (+-Dev.St) | Area with impact below 0.3 (Km2) |
|---|---|---|---|---|---|---|---|
| Circalittoral mud | 21043.18 | 275 | 5.49 +3.40 | 0.31 +0.53 | 12875 | 0.37 +0.20 | 1675 |
| Circalittoral mud or Offshore circalittoral mud | 736.15 | 350 | 3.10 +3.82 | 0.10 +0.21 | 300 | 0.19 +0.22 | 25 |
| Circalittoral sand | 6771.55 | 1650 | 2.62 +2.32 | 0.38 +0.55 | 1500 | 0.20 +0.16 | 25 |
| Infralittoral sand | 1724.16 | 1025 | 1.29 +2.80 | 0.07 +0.18 | 150 | 0.09 +0.18 | 25 |

The assessment highlights the presence of high impact of trawling on benthic communities of the Northern and Central Adriatic Sea. Relative Benthic State (RBS) distribution (Figure 34) reflects strongly the SAR distribution. Indeed, the most impacted communities (RBS < 0.5) were located in the most exploited area, along the coastline, where trawling mostly occurred. The least impacted areas were located on the southeast side of Po outflow and in the Gulf of Manfredonia. Muddy habitats are the most impacted, possibly because of the higher trawling intensity and the large proportion of habitat affected (60% with SAR >5), while the infralittoral sandy habitat is the least impacted (60% of untrawled area; Table 13).

### 3.2.4 North Sea

See assessment sheet. No updates.

### 3.2.5 Baltic Sea

See assessment sheet. No updates.

## 3.3 Preparation of a paper on the outcomes of ToR a) and ToR b)

The WG agreed to start working towards a manuscript that reports on the impacts of trawling on seabed ecosystems across all regions in Europe for which we have assessments. The indicative title is "**Trawl impacts on the relative status of biotic communities of seabed sedimentary habitats in the NE Atlantic and Mediterranean Seas".** All contributors will be co-authors of the work. Jan Hiddink will write the first draft and will be first author, while Daniel van Denderen will take charge of the collation of results and analysis and will be last author. We will aim for a journal like Global Change Biology or Journal of Applied Ecology.

**Key messages**

Most detailed assessment to date taking account of spatial differences in seabed sensitivity that are customised to the drivers of sensitivity per region. Assessments for previously missing areas in Pitcher *et al.*, now contiguous area from Barents Sea to Black Sea. We will include a new assessment of the most sensitive species analysis (10% top of biomass).

**Time-line for completion of the work**

December 2023: JGH send out an email to invite participation explaining the process and expectations, and the collaborators confirm their agreement to participate.

January 2024: DvD will send out instructions on the format in which the sensitivity and effort layers should be submitted, so collaborators can start preparing their inputs.

January 2024: Where there are multiple overlapping assessments, regions will agree on how to integrate those (by integrating samples before fitting statistical models, or afterwards at the assessment level), and similarly when there are multiple SAR layers.

February 2024: Update meeting 1 to monitor progress and Q&A

April 2024: Update meeting 2 to monitor progress and Q&A

May 2024: Template from JGH for completing the Supplementary Materials

May 2024: All sensitivity and effort layers complete and submitted to DvD

July 2024: Supplementary materials template completed for all regions

November 2024: all outputs, figures, maps, tables ready for presentation at the FBIT meeting

December 2024: draft completed to circulate for feedback

February 2024: submit

**What figures to include?**

Map of all sample locations

Effort map, provided all permissions can be sorted

State/impact map: grab samples

State/impact map: trawl samples

Tables: By broad-scale habitat type and by depth zone (0–200 & 200–800m)

**We will need a big SM section to document all the choices and data sources.**

Tables with detailed information. Description of environmental layers used, samples taken, models fitted. We can also cite the ICES FBIT reports for some details. Sensitivity maps for each region in the SM

**Issues to solve**

Issues with SAR availability for ICES areas – for non-advice use

Standardize cell sizes to c-squares if possible.

Sasa & Walter: to discuss overlapping assessments

# 4 Thresholds

TG Seabed have proposed an extent threshold which states that 75% of an area must meet a 'good' quality threshold to be considered within Good Environmental Status under the Marine Strategy Framework Directive. Therefore, arbitrary quality thresholds from 55% to 95% at increasing intervals of 5% were applied to determine at what quality threshold the 75% extent threshold would be met for the Greater North Sea and Baltic Sea assessment regions. The five benthic broad habitat types (BHT) covering the largest area (km$^2$) within each region were assessed and the proportion of each habitat type with a relative benthic state (RBS) above the arbitrary quality threshold was calculated to determine whether the extent threshold was met (Figure 35).

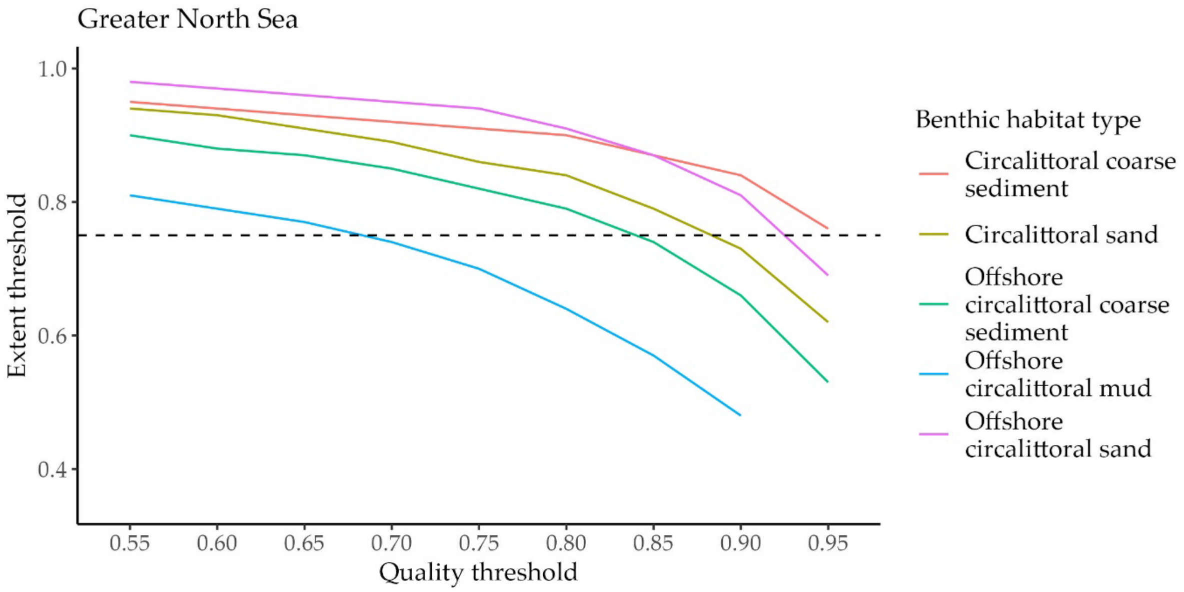


**Figure 35**. The proportion of benthic broad habitat types (BHT) that meet arbitrary quality thresholds in the Greater North Sea. The five benthic BHTs covering the largest area (km$^2$) in the Greater North Sea region were assessed. The 75% extent threshold proposed by TG Seabed is marked by the dashed line. For example, the 75% extent threshold is met for offshore circalittoral mud habitat at a quality threshold of 65%, whereas circalittoral coarse sediment habitat meets the extent threshold at a quality threshold of 95%.

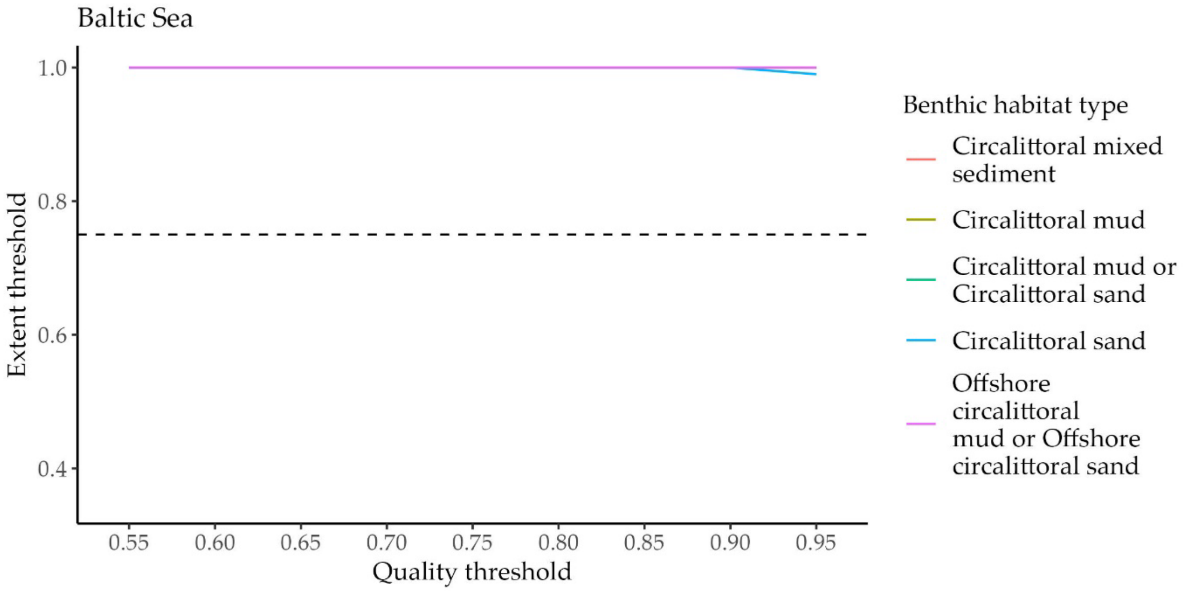


**Figure 36.** The proportion of benthic broad habitat types (BHT) meeting arbitrary quality thresholds in the Baltic Sea. The five benthic BHTs covering the largest area (km$^2$) in the Baltic Sea region were assessed. The 75% extent threshold proposed by TG Seabed is marked by the dashed line. All habitat types in the Baltic Sea region meet the 75% extent threshold.

To determine the proportion of fishing effort that would need to be removed for each benthic habitat type to meet the 75% extent threshold at different quality thresholds, the fishing effort within each habitat type was calculated for the Greater North Sea. Effort was determined through kw-fishing hours within c-square areas. This analysis, based on the detailed spatial and temporal information about effort and landing value (one of the best economic indicators used in this framework). This analysis (Figure 36), allowed to obtain, together with the value of extent, the corresponding of the effort that would be removed.

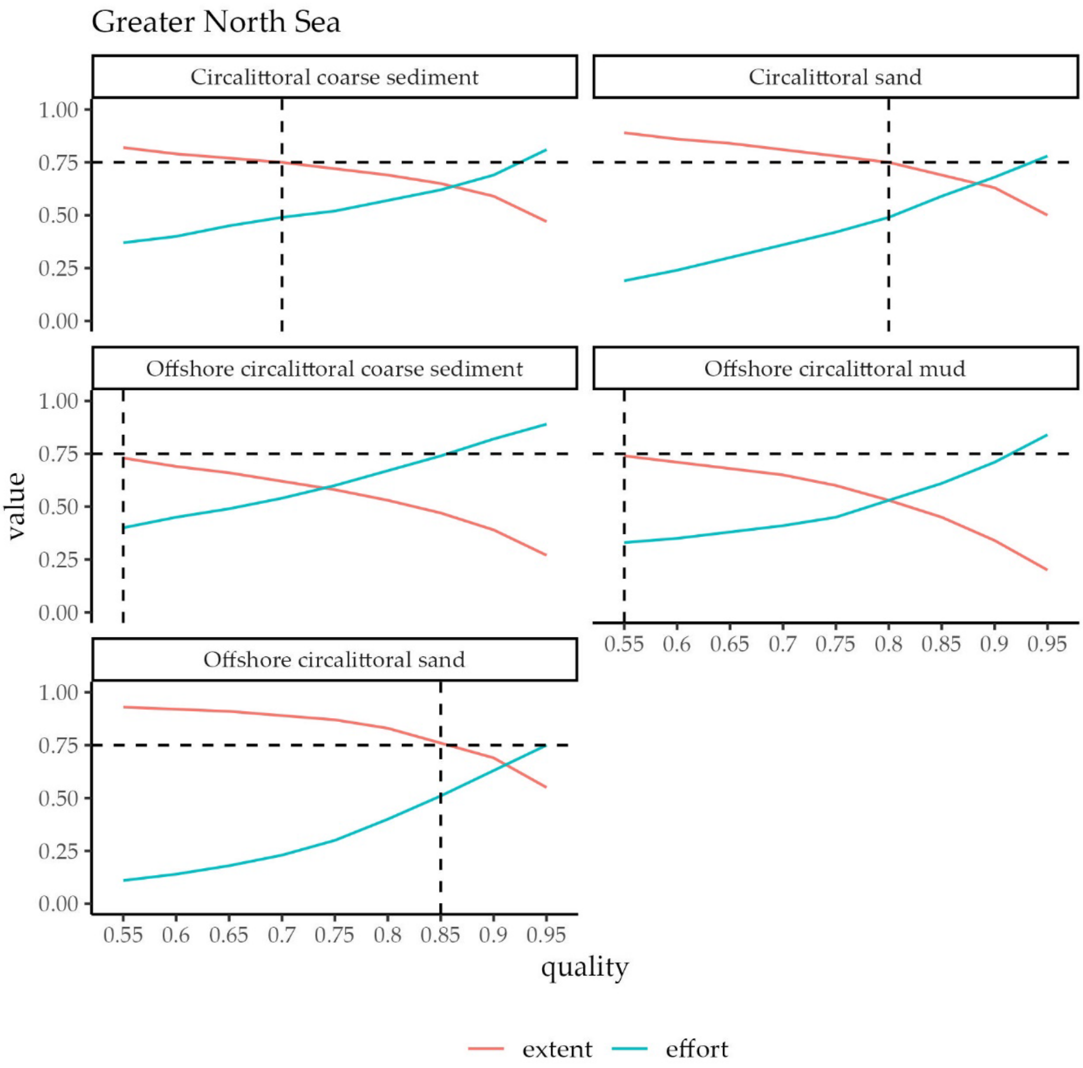


**Figure 37.** Fishing effort (kw fishing hours) that would have to be removed in order to reach the specified extent threshold at different quality thresholds.

Finally, the field total landing value was used in place of the effort value to determine what the associated costs would be in terms of lost landing value, as a result of removing fishing effort to reach the specified extent threshold at different quality thresholds.

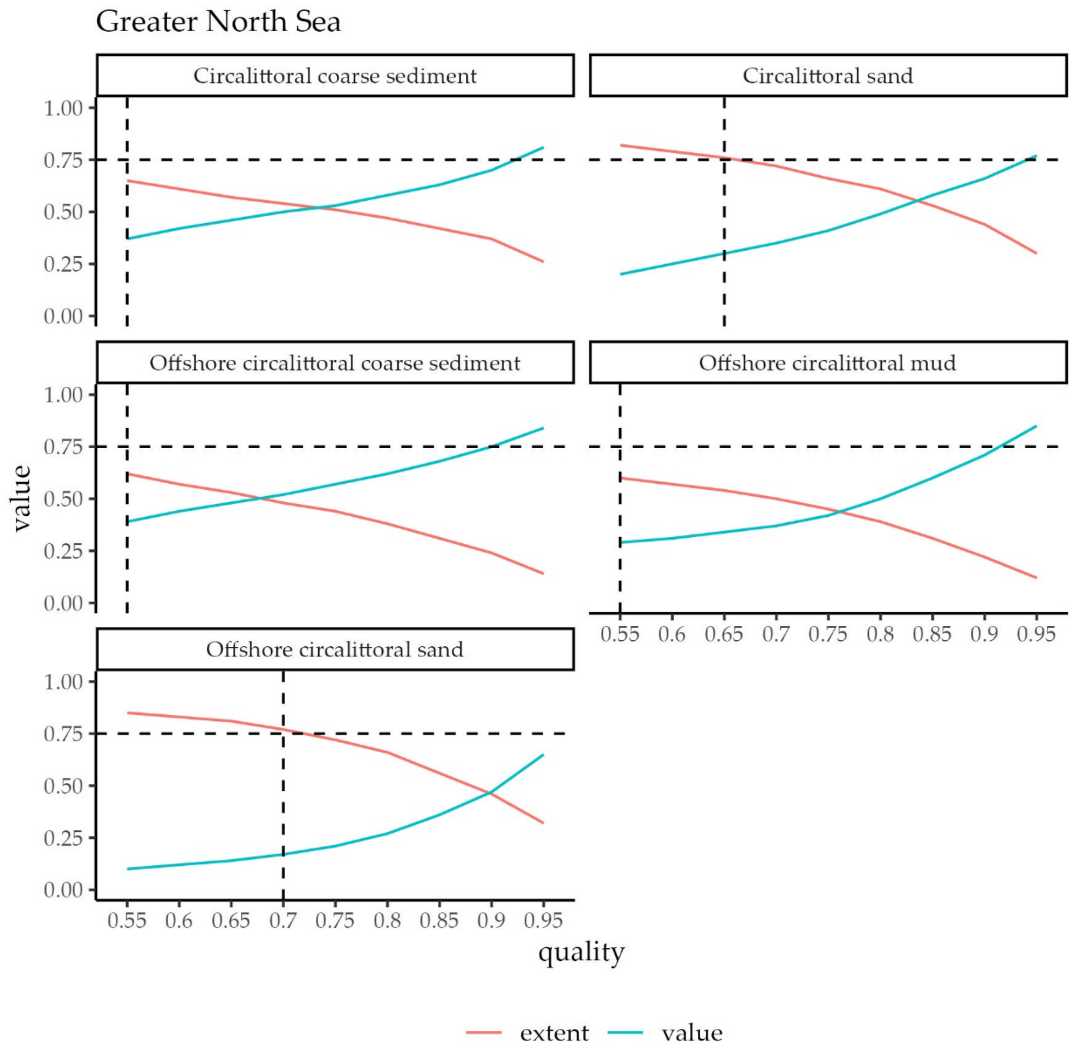


**Figure 38**. Associated costs in terms of lost landing value that would be incurred as a result of removing fishing pressure in order to reach the specified extent threshold at different quality thresholds.

**Assumptions and caveats**

This analysis was carried out by combining several information sources with different spatial resolutions. In particular, the low spatial resolution of the effort and landings data, which is not optimal for estimating performance indicators such as LPUEs, precluded the possibility of applying methods for estimating potential effort displacement (with consequent variation in landing values), making this approach 'frozen': in other words, it is only possible to estimate a cost in terms of effort and landings 'removed', but not reallocated.

# 5 Updates of assessment framework (ToR B)

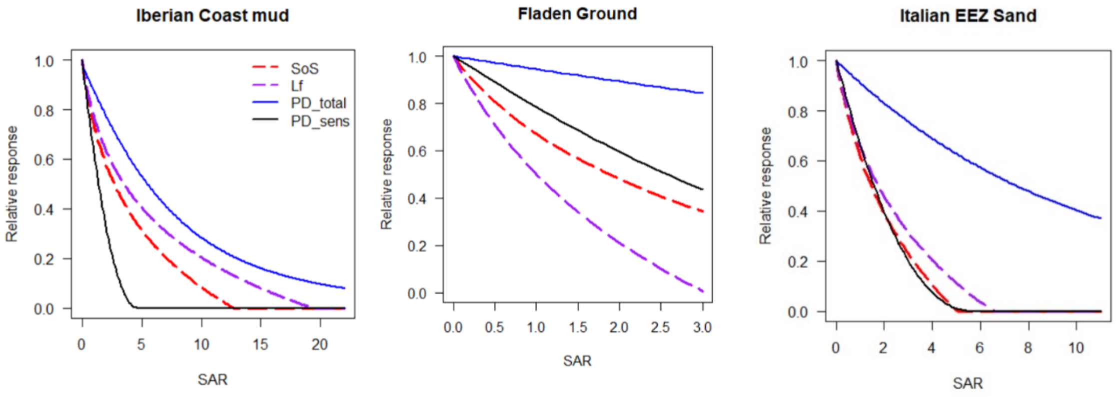
## 5.1 L1 change to PD-sens

ICES (2022) advised that regional assessments would ultimately best be carried out by applying different indicators in a complementary manner. It was further suggested to select indicators that cover different aspects of seabed habitat condition and benthic community.

ICES (2021) used two impact indicators to assess fishing impact abrasion. The first indicator was the PD indicator used in WGFBIT, which estimates the decline in total biomass. Since the PD indicator does not separately account for declines of rare, sensitive, and fragile species, ICES (2021) included a second benthic impact indicator, L1. This indicator is very precautionary as it assumes that all individuals of a species need to live to their maximum lifespan without encountering a trawl (Rijnsdorp *et al.* 2020).

The use of the L1 indicator has several disadvantages. First, the L1 method does not differentiate between gears, and this implied that any surface SAR, be it from a dredge or otter trawl, generates the same benthic impact in the assessment. In addition, the L1 indicator cannot be validated with benthic sampling data as the L1 indicator is a theoretical value that cannot be measured. This makes the L1 indicator difficult to use as a pressure-based indicator.

Here we test an alternative indicator to L1 to account for the declines of sensitive species. It is based on the FBIT methodology but only estimates the relative decline in biomass of the 10% most long-lived biomass fraction of the community (PD-sens). The new indicator can be implemented in all regions where the PD is estimated. We examined the responsiveness of the indicator to 6 gradients of trawling pressure and compared it with the PD total biomass indicator and two empirically estimated indicators, SoS and long-lived fraction (ICES 2022). The latter two indicators were chosen as they were found to best identify benthic community change with increasing bottom trawling pressure. The results show that the PD-sens is typically as responsive as SoS and long-lived fraction (Figure 39).



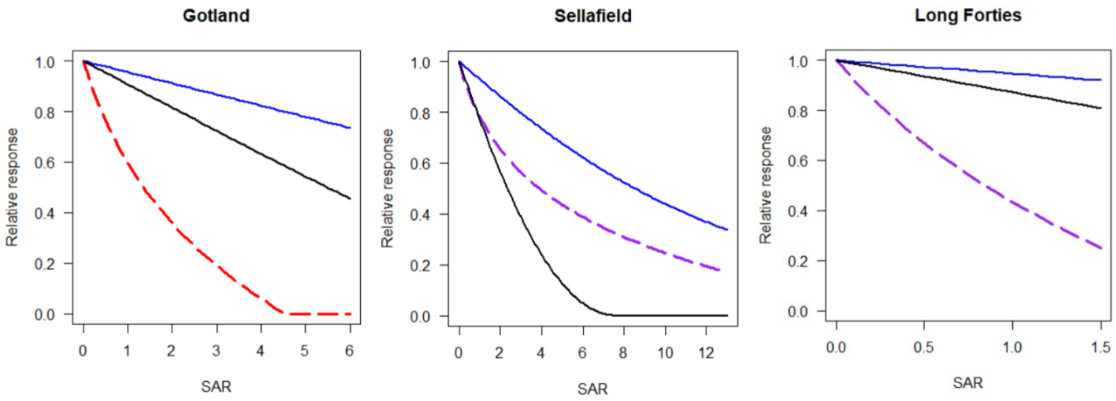


**Figure 39**. Relative declines of two empirically estimated indicators (SoS and long-lived fraction) and two pressure-based indicators (PD based on total biomass and the sensitive fraction). The PD declines are estimated by calculating impact from the predicted longevity composition from all reference stations (ICES 2022). Both SoS and long-lived fraction are scaled to 1 to make the relative response comparable to the pressure-based outcomes.

Impact maps based on the PD total biomass indicator as well as the PD-sens indicator are shown in Figure 42. As expected, PD-sens has a higher impact score. Average North Sea impact is 0.8 for PD-sens and 0.9 for PD total biomass. A correlation between the two indicators is shown in Figure 43.

WGFBIT recommends that the PD-sens is used instead of the L1 in future ICES advice.

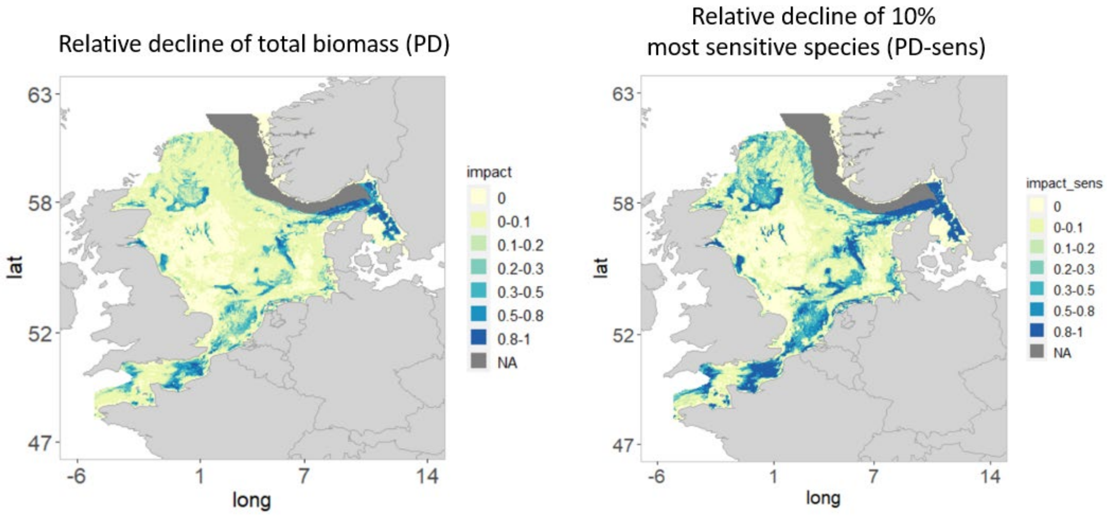


**Figure 42.** Impact maps based on the PD total biomass indicator (left) and the PD-sens indicator (right) using ICES VMS data from 2022.

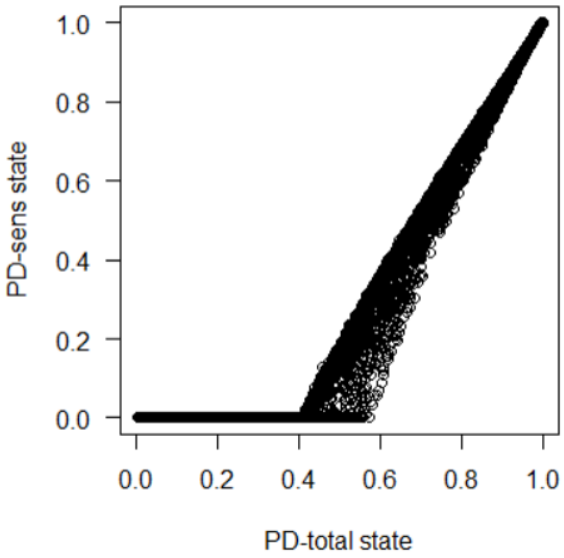


**Figure 43.** Correlation plot between PD-sens, estimating the relative decline in biomass of the 10% most long-lived biomass fraction of the community, and PD-total, estimating total biomass decline for the Greater North Sea Ecoregion using ICES VMS data from 2022.

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## 5.2 Overview of the methodologies used within the assessment framework: some standardisation

The FBIT approach is applied in all (sub-)regions, so we have an European wide assessment of fishery benthic impact. To accomplish this, the methodologies used in the different steps of the FBIT approach are slightly different among those regions (Table 1 & 2), related to variation in data availability, environmental characteristics and implementation possibilities among the (sub-)regions. Nevertheless, there will be strived to standardize some of the elements in the FBIT approach (where possible), step by step. This to have a more harmonized assessment of fishery benthic impact across the EU regions in the coming years. In this section, an overview is given on the current methodologies used and evaluated what standardisation is needed or can be done. This can be taken forward when updating the FBIT assessments.

### 5.2.1 Biological data

The inclusion/exclusion of certain fauna groups in the trawl or grab samples used for the longevity predictions shall play a role in the assessment outcomes, so some guidance is needed. Each equipment has a certain catch efficiency for certain fauna groups or in certain datasets not all taxa are taken into account (e.g. Hydrozoa or Bryozoa in grab sampling; Polychaeta in trawl samples) or determined to the lowest taxonomical level possible. Therefore, a common set of fauna groups should be used within the region (among subregional assessments) or even across regions (if possible) when using trawl or grab samples. This aspect is currently not clearly tackled in the FBIT assessments, except the advice to remove commercial species and cephalopods from trawl sample data (ICES FBIT report, 2021). An overview of excluded fauna groups in the (sub-)regional assessment is given in Table 14.

**Table 14.** Overview of the fauna groups included or excluded for the assessment.

| | Type of data | Fauna included/Excluded |
|---|---|---|
| Greece | Grab | Bigger fauna (X>biomass) out. |
| North/Central Adriatic | Trawl | Exclusion of commercial species, pelagic, high mobility species (fish) and cephalopods |
| Adriatic Sea | Trawl | Exclusion of commercial species, pelagic, high mobility species (fish) and cephalopods |
| Western Ionian Sea | Trawl | Exclusion of commercial species, pelagic, high mobility species (fish) and cephalopods |
| Sicily | Trawl | Exclusion of commercial species, pelagic, high mobility species (fish) and cephalopods |
| French Med. | Trawl | Exclusion of vertebrates, cephalopods and pelagic invertebrates |
| Iberian Coast | Trawl | Benthic taxa were restricted to Arthropoda, Mollusca, Echinodermata, Annelida, Cnidaria, Porifera, Platyhelminthes, Sipuncula, Priapulida, Nemertea, Acanthocephala |
| Bay of Biscay/Celtic Sea | Trawl | Exclusion of vertebrates, highly mobile cephalopods and gelatinous species |
| Celtic Sea/Irish Sea | Grab | Not yet defined/reported |
| North Sea | Grab/core | All fauna included from grab/core. Part of the data was converted from ash free dry weight to wet weight to make a more similar comparison of longevity between locations with wet weight and ash free dry weight observations. |
| Baltic Sea | Grab/core | All fauna included that were collated in Gogina *et al.* (https://doi.org/10.1093/icesjms/fsv265) |
| Islandic waters | Trawl | Not yet defined/reported |
| Norwegian Shelf | Video | Not yet defined/reported |

| | | |
|---|---|---|
| Barentz Sea | Trawl | Not yet defined/reported |

## 5.2.2 Trait dataset used

The longevity information per species is coming from different sources, also partially adapted over time. Therefore, we tried to summarize the data sources used for the trait data in Table 15.

**Table 15.** Overview of the sources used for the trait data (longevity).

| | Type of data | Source of trait data |
|---|---|---|
| Greece | Grab | HCMR trait database |
| North/Central Adriatic | Trawl | Merged Longevity database available on the WGFBIT 2022 Share-Point (ICES, 2022) |
| Adriatic Sea | Trawl | Merged Longevity database available on the WGFBIT 2022 Share-Point (ICES, 2022) |
| Western Ionian Sea | Trawl | Merged Longevity database available on the WGFBIT 2022 Share-Point (ICES, 2022) |
| Sicily | Trawl | Integration of Mediterranean available longevity datalists (ISPRA SIBM+MEDITS programme and HCMR trait database). Used longevity trait data as compiled by O Beauchard *et al.* 2018 and Bolam *et al.* 2014 for missing species |
| French Med. | Trawl | Merged longevity database (see below for details) |
| Iberian Coast | Trawl | Benthis plus some extra from a Spanish database when missing |
| Bay of Biscay/Celtic Sea | Trawl | Merge longevity trait data from Bolam, Beauchard and additional local additions |
| Celtic Sea/Irish Sea | Grab | Clare *et al.* (2022) |
| North Sea | Grab/core | Longevity trait data as compiled by Bolam *et al.* (2014). |
| Baltic Sea | Grab/core | Longevity trait data as compiled by Bolam *et al.* (2014) and Tornroos & Bonsdorff (2012). The trait data is available here: https://github.com/Dvandenderen/Baltic-benthic-status/tree/master/Benthic%20trait%20data |
| Islandic waters | Trawl | Existing longevity databases (Degen and Faulwetter 2019, the trait list from the BENTHIS project) and on expert judgment (ICES 2020). |
| Norwegian Shelf | Video | Existing longevity databases (Degen and Faulwetter 2019, the trait list from the BENTHIS project) and on expert judgment (ICES 2020). |
| Barents Sea | Trawl | Existing longevity databases (Degen and Faulwetter 2019, the trait list from the BENTHIS project) and on expert judgment (ICES 2020). |

## 5.2.3 Fishery data

The determination of the longevity curve should be based on data from reference stations, meaning locations which are not or little subjected to fishery disturbance in the last 3–5 years (more guidance in ICES FBIT REPORT 2020; Bolam *et al.*, 2017). It is possible to use both samples from untrawled (i.e. a zero fishing pressure estimate) locations and locations with low trawling intensity. In Bolam *et al.*, (2017), 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. If you have not enough reference stations, another solution is to include SAR (fishery pressure) into the longevity model. The advantage of using the latter is that you can use all your data. The availability of appropriate reference locations for the regional assessments seems not that straightforward, so several options were tested and/or applied, by using SAR threshold values of 0,1; 0,5 or 1. An overview is given in Table 16.

**Table 16.** Overview of origin of SAR data (AES, VMS, others…), which fleets are covered (countries) and any additional remark.

| | Origin of SAR data | Coverage of fleets (Countries) | Concluding remark |
|---|---|---|---|
| Greece | VMS | Greece | |
| North/Central Adriatic | VMS and AIS | Italy | SAR associated to bottom otter trawl (OTB) and rapido trawl (TBB) |
| Adriatic Sea | AIS data | ? | SAR associated only to bottom otter trawling |
| Western Ionian Sea | AIS data | ? | SAR associated only to bottom otter trawling |
| Sicily | VMS | Italy | SAR associated only to bottom otter trawling |
| French Med. | | Not reported yet | |
| Iberian Coast | VMS | Spain | |
| Bay of Biscay/Celtic Sea | VMS | Spain, France, UK, Ireland, Belgium | |
| Celtic Sea/Irish Sea | VMS | Spain, France, UK, Ireland, Belgium | |
| North Sea | VMS | Belgium, Netherlands, Germany, Denmark, UK, France | |
| Baltic Sea | VMS | Denmark, Sweden, Germany | |
| Islandic waters | | Not reported yet | |

| | | | |
|---|---|---|---|
| Norwegian Shelf | | Not reported yet | |
| Barentz Sea | | Not reported yet | |

**Table 22. Used SAR definition for selecting reference stations (overview of current practices). X = used method; x = tested approach.**

| | Type of data | SAR 0,1 | SAR 0,5 | SAR 1 | SAR in model | Concluding remark |
|---|---|---|---|---|---|---|
| Greece | Grab | X | x | x | | SAR levels tested to see the effect on availability for data for different MSFD habitats. However 0.1 chosen as it the least impacting (1 coverage every 10 years) |
| North/Central Adriatic | Trawl | | | X | X | Inclusion and exclusion of SAR in the model was tested. Stations with fishing intensity <1 were chosen for the longevity estimation. |
| Adriatic Sea | Trawl | | | | X | Inclusion or exclusion of SAR in the model was tested. Inclusion was chosen due to higher sample size and better fit to the data. |
| Western Ionian Sea | Trawl | | | | X | Inclusion or exclusion of SAR in the model was tested. Inclusion was chosen due to higher sample size and better fit to the data. |
| Sicily | Trawl | | x | | X | Inclusion or exclusion of SAR in the model was tested. Inclusion was chosen due to higher sample size and better fit to the data. |
| French Med. | Trawl | X | x | | X | |
| Iberian Coast | Trawl | | X | | | |
| Bay of Biscay/Celtic Sea | Trawl | | | x | | |
| Celtic Sea/Irish Sea | Grab | | | | X | Log-SAR (surface or subsurface SAR) |

| | | | | | | |
|---|---|---|---|---|---|---|
| North Sea | Grab | | | | X | Both surface and subsurface abrasion were tested in the model. Subsurface abrasion was selected based on AIC. Longevity responded as predicted to increasing levels of subsurface abrasion. |
| Baltic Sea | Grab | x | | | | Bottom fishing intensity is low in the Baltic Sea. Up to 1558 locations could be identified with intensity levels <0.1 (average SAR based on ICES data 2012-2016). Stations with bottom oxygen concentrations <3.2 ml per liter were also excluded in the estimation of longevity. |
| Islandic waters | Trawl | | | | | No selection yet of “untrawled” locations, or SAR included in the model. |
| Norwegian Shelf | Video | | | | | Model detail not reported yet |
| Barentz Sea | Trawl | | | | | Model detail not reported yet |

## 5.2.4 Environmental drivers / models

The biomass-longevity distribution of untrawled communities need to be estimated in relation to environmental variables (i.e. the reference state). This will require samples of benthic communities over the main environmental gradients. A statistical model is used 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.

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

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 above), 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.

In this section, an overview is given on the environmental predicators that are finally used in the model, see Table 17. With this overview, we see which are the main environmental drivers, where updates on environmental predicator layers are desirable and where model updates are needed.

**Table 17.** Environmental predictors used in model and final model selection.

| | Type of data | Predictor 1 | Predictor 2 | Predictor 3 | Predictor 4 | Selected model equation |
|---|---|---|---|---|---|---|
| Greece | Grab | MSFD habitat | Depth | | | Longevity + Habitat*Depth |
| North/Central Adriatic | Trawl | MSFD habitat | Depth | | | Cumb ~ ll + Depth + MSFD_hab + (1 \| station) |
| Adriatic Sea | Trawl | MSFD habitat | Bottom current speed | Bottom dissolved oxygen | Bottom temperature | Cumb ~ botcur + botDox + botT + ll + MSFD + SAR + (1 \| ID) |
| Western Ionian Sea | Trawl | Bottom dissolved oxygen | Bottom salinity | Bottom temperature | SAR | Cumb ~ botDox + botso + botT + ll + SAR + (1 \| ID) |
| Sicily | Trawl | Depth | SAR | | | Cumb ~ ll + ln(Depth) + ln(SAR+0.01)+ln(Depth):ln(SAR+0.01) + (1 \| ID) |
| French Med. | Trawl | | | | | Depending on habitat<br>Log(Longevity) + meanBtemp (circalittoral sand)<br>Or Log(Longevity) + stratification (upper bathyal sediment)<br>Environmental layers available: A bathymetry (m), B Seabed stress (N.m-2), C sediment average grain size (mm), D mean bottom temperature (°C), E mean surface Chlorophyll a concentration (mg.m-3), D mean bottom dissolved oxygen concentration (mmol.m-3), Stratification index<br>The dredge-function of the R-package MuMIn was used to evaluate all possible model formulations based on the Bayesian information criterium (BIC). |

| | | | | | | |
|---|---|---|---|---|---|---|
| Iberian Coast | Trawl | Depth | Substrate | | | LL + Depth + Subst + D<br>Available environmental layers: Depth: bathymetry, Chl: mean annual Chlorophyll concentration, Temp: mean annual temperature, Energy: mean annual hydrodynamic energy, Substrate: sediment type |
| Bay of Biscay/Celtic Sea | Trawl | MSFD habitat | Depth | Bottom mean temperature | Bottom current | Cumb ~ ll + Depth + Chloro + Temp + Current + Substrate + (1 \| Station) |
| Celtic Sea/Irish Sea | Grab | | | | | Top 10 models reported, but no selection made |
| North Sea | Grab | Mud% | Gravel% | Bed shear stress | Subsurface abrasion | Log(Longevity) + log(subsurf. Abras) + mud, + gravel + log(shear stress) + log(subsurf. Abras) x log(shear stress) + log(longevity) x gravel |
| Baltic Sea | Grab | Salinity | Depth | Wave exposure at bottom | | Log(longevity) + salinity + log(depth) + log(wave expos) + log(longevity) x salinity + salinity x log(depth) + log(longevity x log(depth) |
| Islandic waters | Trawl | Depth | Temperature | | | ll + temp*ll + depth + (1/ID) |
| Norwegian Shelf | Video | | | | | Model details not reported yet, but those used are: Depth, temperature, sediment composition |
| Barentz Sea | Trawl | | | | | Model details not reported yet, but those used are: Depth, temperature, sediment composition |

### 5.2.5 Grid scale

The grid scale to be used for the FBIT assessment is minimum 0.05°. This is the case for the North-East Atlantic regions, the Adriatic and Ionian Seas. For the French Med a grid scale of 0.016° is used.

### 5.2.6 Habitat data layer

As habitat data layer for the FBIT assessment the EUSEAMAP 2021 should be used to delineated the MSFD broad habitat types. The habitat layer limit is 1200m (upper bathyal) and rock habitats should be excluded. Regarding the depth layer, there is still a discrepancy with the legislative depth boundary limit for fishery, which is 800m (Atlantic) and 1000m (Med). It does not imply that fishery fish that deep as the practical limit seems to be 500/800m.

## 5.3 Way forward

At the meeting two methodological aspects (integration of assessments; model validation) were discussed in more detail to determine the way forward on those aspects.

In relation to integrating different assessments for certain eco-region, following process is proposed:

- If there are separate, overlapping analyses within the same eco-region, the maps can be put together, by applying the precautionary approach and use the maximal impact value or minimal status value when combining.
- If there are separate, but not overlapping analyses, the outcome can be integrated in one map, but clearly indicated in the caption the discrepancy.
- In the next step, when sampling efficiency for benthos is comparable, the data should be integrated to run one integrated analyses. If the data source is not integrable, a separate analyses is executed (E.g. trawl versus grab based data assessment).

In relation to the validation of the FBIT output, some guidance is discussed, summarized as:

- Use 80% of the data (20% as validation data set) to run the models to predict median longevity.
- Cross-validation with existing data is tricky as it is in many cases data subjected to a certain fishing pressures (sampled state), so are less relevant as modelled ones should be those without fishery. How to deal with it … (see chapter 4.3).

Next to it, the start is made to develop and use the PDsens approach instead of the L1, as the latter has several shortcomings. It will be implemented in the FBIT R-script, so the PDsens can be calculated for the regional assessments in the coming ICES FBIT cycle.

For the next ICES FBIT cycle, ToR B will be merged with ToR A, as the methodological updates goes in parallel with the assessment updates.

# 6 FBIT and the wider world (ToR C)

## 6.1 Comparison between SoS and PD methods for Adriatic Sea

Two methods to assess the sensibility of epi-benthic communities and estimate the impact of trawling were compared in the context of the North and Central Adriatic Sea. In detail, we considered the 'Sentinel of Seabed' indicator (SoS; Serrano *et al.*, 2022), which detects changes and assesses the state of the benthic community according to the proportion of "sentinel species" (selected by the BESITO score, Gonzalez-Irusta *et al.*, 2018) and the approach proposed by ICES based on the PD2 model. The relative benthos state (RBS) was evaluated considering the decrease in biomass of benthic communities in response to trawling and the recovery rate according to their relative growth rate (Rijnsdorp *et al.*,2020; ICES, 2022). The assessments were carried out at the BBHT level in order to highlight consistencies and differences between the indicators' output (ICES, 2022).

Input data

Benthic data were acquired during the GAP2 project from 2012 to 2014 (Mion *et al.*, 2015) and the SoleMON trawl survey from 2014 to 2016 (Scarcella *et al.*, 2014), expressed as biomass standardized per swept area (Kg/Km2). Commercial, pelagic, and high mobility species were removed. Fishing effort was estimated based by integrating VMS and AIS data on a grid with 1 km2 cell resolution for otter trawlers (OTB) and rapido trawlers (TBB) and expressed as Swept Area Ratio (SAR) considering the average value of 3 years (2014–2016). Two other environmental parameters were used: depth (m) and MFSD broad habitat types (from EMODnet EUSeaMap 2021).

SoS assessment

A List of Sentinel Species was defined for each BBHT according to their frequency (based on the relative contribution of species to intra-habitat similarity, SIMPER analysis) and relative sensitivity (based on the BESITO index; Riva, 2022).

The pressure-state curve was defined by investigating the relationship between the Sentinel species proportion and the fishing effort (SAR) per each habitat type. The proportion of the most sensitive species was then estimated by GAMs using the SAR as the only response variable, the same model was applied separately for each BBHT. The predicted values were interpolated on a grid of 0.5° cell resolution to obtain the map of the predicted percentage of sentinel species across the study area.

PD2 assessment

The relative benthos state index (RBS) was assessed following the scripts developed by Van Denderen (https://github.com/ices-eg/FBIT). For each species, fuzzy-coding longevity was defined using a 4-level classification (<1ys; 1–3ys; 3–10ys; >10ys) based on the database available on the group SharePoint (WGFBIT/2022 Meeting Docs/06. Data/TorA_data files/FR_MED_merged_lon-gevity_v2.zip). The relationship between species' longevity and environmental variables was investigated by estimating the cumulative biomass-longevity distribution by Generalized Linear Mixed Models (GLMMs) with MSFD Broad habitat type, Depth, and Trawling effort (SAR) as fixed effects and assuming stations as a random effect. The swept area ratio was included in the model due to insufficient reference unfished samples. Longevity distribution reflects the depth gradient with lower depth along the coast associated with a lower longevity class. The overall low variability of the median longevity (ranging from 4 to 6 ys) may reflect the lower environmental gradients of the study area.

Risk-based comparison

The sensitivity and impact values were estimated for each habitat based on both indicators according to the methods reported in the WKBENTH3 report:

| | Sensitivity estimation | Impact estimation |
|---|---|---|
| PD2 | Estimated as the average median longevity value across grid cells (higher values are more sensitive habitats). | Estimated as the average decline in B/K (biomass divided by carrying capacity) across grid cells (1-RBS). |
| SoS | Sensitivity is estimated from the pressure-state curve per habitat type. The pressure-state curve is compared with five theoretical sensitivity curves (i.e. five theoretical curves on how the state can change with pressure) and the most similar is selected. Highest score is the most sensitive. | Estimated as the average proportional decline of sentinel species by trawling across grid cells (1-SoS). |

Both indicators identified 'Circalittoral sand' as the most sensitive habitat; indeed, it is characterized by a higher percentage of sensitive and long-lived species that strongly decrease in response to trawling. The 'infralittoral sand' appears to be the least sensitive habitat as the benthic communities are characterized by fast recovery and recolonization rates. PD2 (sensitivity range from 4 to 6) than by SoS (sensitivity range from 1 to 4; Table 18).

All indicators identified 'Circalittoral mud' as being the habitat most impacted by physical abrasion pressure due to the higher fishing intensity that occurred in this area and 'Infralittoral sand' as being the least impacted (Table 18), showing consistency between indicator outputs.

Despite that, the impact values varied between indicators. According to the SoS assessment, a very impacted scenario was estimated where, in almost the entire study area, the biomass of the most sensitive species represents only 10–20% of the benthic community. The Relative Benthic State (RBS) distribution correlates strongly with trawling effort; indeed, the most impacted communities (RBS < 0.5) were located in the most exploited area, along the coastline (out of the 3 nM), where trawling mostly occurred.

**Table 18.** Indicator sensitivity and Impact information from North and Central Adriatic Sea (GSA17).

| | Sensitivity estimation | | Impact estimation | |
|---|---|---|---|---|
| Broad Habitat Type | PD2 | SoS | PD2 | SoS |
| Infralittoral sand | 4 | 1 | 0.1 | 0.7 |
| Circalittoral mud | 5 | 3 | 0.4 | 0.9 |
| Circalittoral sand | 6 | 4 | 0.2 | 0.8 |

Observed variations on the impact scores assessed by the different indicators, were likely related to the fact that the two benthic indicators have been developed for unique applications varying in design and structure and they consider distinct factors to assess benthos state. The scale on which sensitivity was estimated and the traits considered are different (e.g. SoS uses a range of traits to assess sensitivity based on BESITO, while PD2 uses only longevity). Thus, the observed outputs may reflect variations in method design and data availability. The higher impacted scenario estimated according to the SoS index is possible due to the higher emphasis given to the most sensitive part of the community. The two risk-based indicators, reflecting different properties of the communities, could be used complementary to obtain a more complete risk-based assessment when assessing environmental change in response to seabed physical pressure (ICES, 2022).

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# 7 Ecosystem functioning (ToR d)

The marine offshore seabed provides a wealth of ecosystem goods and services which are fundamental in supporting human livelihoods and wellbeing, such as the provision of resources, regulating carbon and cultural activities. The maintenance of those goods and services can be insured by sufficient levels of ecosystem functioning which reflect the collection of life activities (plants, animals, microbes) and the effects of those activities on the physico-chemical conditions of their environment. Seabed ecosystem functioning has commonly been evaluated through the lens of biogeochemical processes which drive the cycling of organic matter (carbon and nutrient). Those processes are mediated by both abiotic (sediment type, depth, temperature) and biotic (respiration, feeding, bioturbation) drivers. Mechanical disturbance due to trawling has thus a direct impact route on the physico-chemical compositions of the seabed through sediment mixing and resuspension as well as an indirect impact route through the mortality of the fauna present in and around the seabed.

Why incorporating seabed ecosystem functioning in the FBIT assessment?

- Link to climate regulation and global warming mitigation
- Link to waste removal and support resources
- Understanding the conditions, status and variability of these services
- Trade-offs and synergies between multiple service (beyond fishing) and provide advice as to how marine space can be designed to increase overall benefits to multiple stakeholders with different objectives.

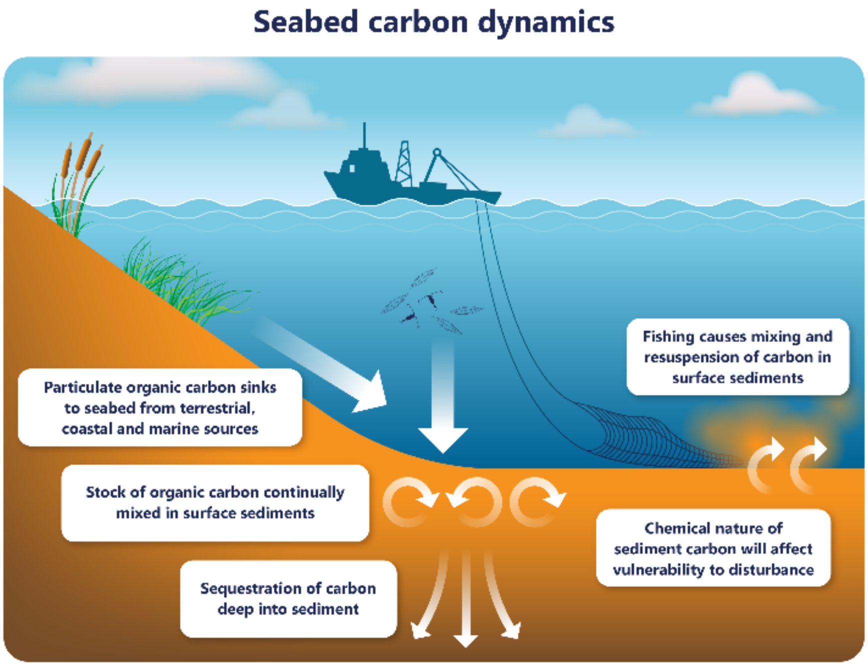


**Figure 44.** Infographic showing interaction of bottom trawling with seabed and consequences for carbon sequestration and storage.

## 7.1 Workflow for ToR d

By depleting fauna and changing the species composition, bottom fishing can result in alterations in the functional effect traits (sediment mixing, bioirrigation, and habitat creation and maintenance) of a community, which in turn may have broad implications for the overall ecosystem performance. The goal of ToR d is to explore whether ecosystem functioning can be incorporated more explicitly in to the WGFBIT seafloor assessment methodology.

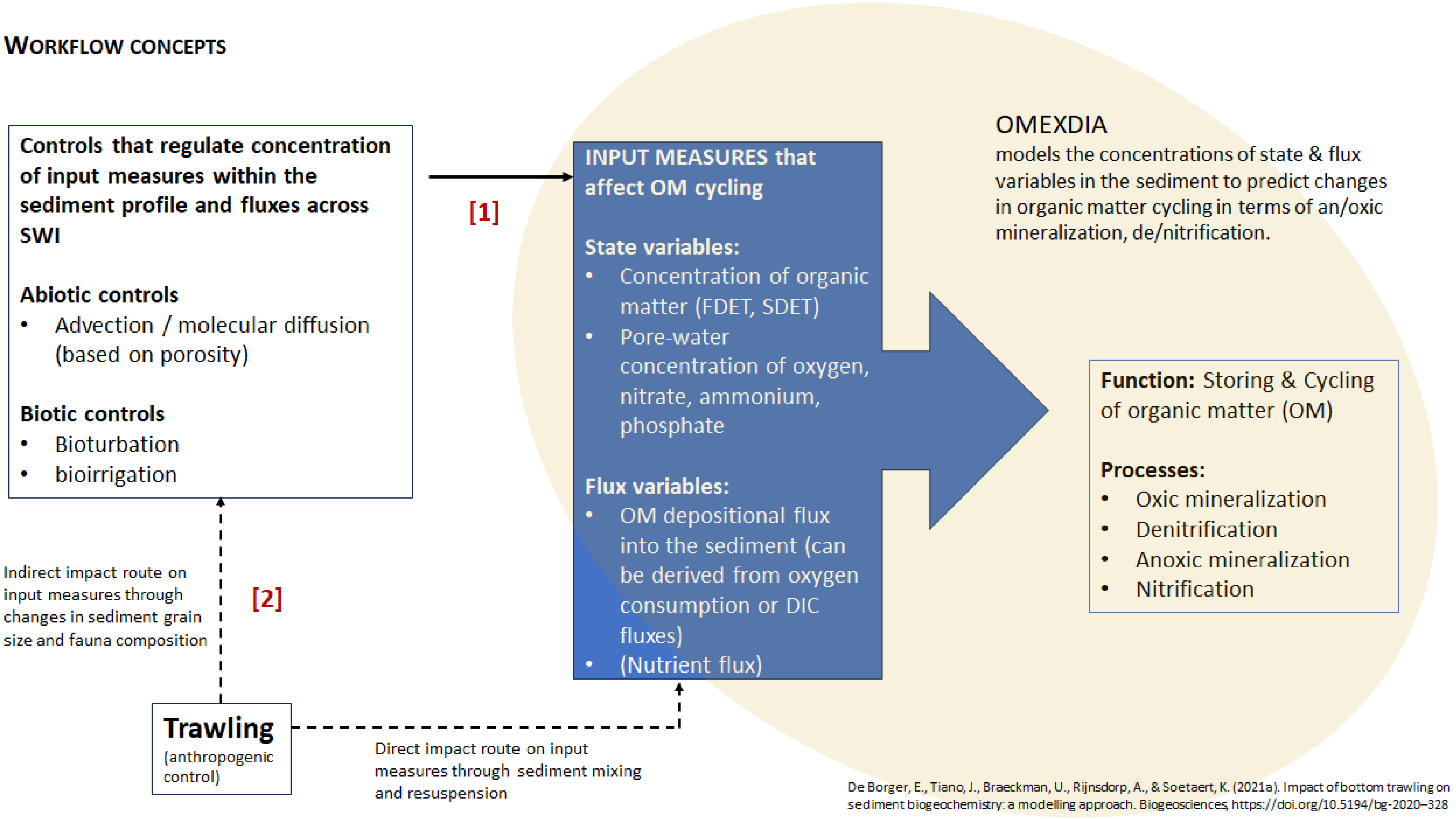
The current PD method utilized in the WGFBIT assessment method combines information on total benthic biomass with the relative abundance of different longevity classes to estimate the relative impact of different types of fishing on the seabed. The working assumption of this method is that high community 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. Hence, when exploring bottom trawling impact on the benthos, changes in species functional composition may prevail on changes in total biomass. Functional traits have often been advocated as proxies for predicting ecosystem functioning responses to anthropogenic perturbations.

In ToR d we aim to:

[1] determine the relationship between macrofauna and ecosystem functioning (ecosystem engineering, sediment biogeochemistry) and examine how this is influenced by trawling. Macrofaunal parameters such as total biomass, sediment mixing potential, bioirrigation potential, and species functional traits are considered. A combination of multivariate and univariate analyses is undertaken (a) to examine influence of trawling on effect trait composition, (b) to relate traits to biogeochemical state (e.g. organic matter and chlorophyll-a concentrations) and flux (e.g. oxygen flux) variables, and (c) to examine trawling influence on this relationship,

[2] develop a method to predict changes in species composition due to trawling (following principles of PD model used in FBIT) to estimate changes in bioturbation potential of a community known to affect ecosystem functioning. A modelling approach (logistic-growth model) is undertaken. Results from this model can be linked to a biogeochemical model such as OMEXDIA to estimate changes in the biogeochemical nature of the sediment due to sediment erosion, mixing or deposition as a result of trawling.

## WORKFLOW CONCEPTS



**Controls that regulate concentration of input measures within the sediment profile and fluxes across SWI**

**Abiotic controls**

- Advection / molecular diffusion (based on porosity)

**Biotic controls**

- Bioturbation
- bioirrigation

[1]

**INPUT MEASURES that affect OM cycling**

**State variables:**

- Concentration of organic matter (FDET, SDET)
- Pore-water concentration of oxygen, nitrate, ammonium, phosphate

**Flux variables:**

- OM depositional flux into the sediment (can be derived from oxygen consumption or DIC fluxes)
- (Nutrient flux)

OMEXDIA

models the concentrations of state & flux variables in the sediment to predict changes in organic matter cycling in terms of an/oxic mineralization, de/nitrification.

**Function:** Storing & Cycling of organic matter (OM)

**Processes:**

- Oxic mineralization
- Denitrification
- Anoxic mineralization
- Nitrification

Indirect impact route on input measures through changes in sediment grain size and fauna composition

[2]

**Trawling**
(anthropogenic control)

Direct impact route on input measures through sediment mixing and resuspension

De Borger, E., Tiano, J., Braeckman, U., Rijnsdorp, A., & Soetaert, K. (2021a). Impact of bottom trawling on sediment biogeochemistry: a modelling approach. Biogeosciences, https://doi.org/10.5194/bg-2020-328

## 7.2 Trawling-induced change in benthic effect trait composition: A multiple case-study

*Publication:* Beauchard O., Bradshaw C., Bolam S., Tiano J., Garcia C., de Borger E., Laffargue P., Blomqvist M., Tsikopoulou I., Papadopoulou N.K., Smith C.J., Claes J., Soetaert K., Sciberras M., 2023. Trawling-induced change in benthic effect trait composition – A multiple case study. Frontiers in Marine Science, accepted.

A multiple case-study analysis was carried out to examine the consequences of disturbance by bottom trawl fisheries on benthic effect trait composition. The study focused on ecosystem functions ensured by benthic organisms ("ecosystem engineering") through "effect trait" expression, and the possible impact of bottom trawling on those functions (Beauchard *et al.* 2023). Thirteen case-studies from European waters were used, allowing examination of different environmental contexts and trawling intensities (Figure 45). Partial RLQ analysis was applied to derive a gradient that solely account for trawling-induced disturbance.

Bottom trawling was found to be a selective force of benthic effect trait composition in the majority of studied areas. In general, surficial species were more typical of low trawling frequencies, whereas deep burrowing species were more resistant at high trawling frequencies (Figure 46). Although we report significantly deleterious effects of trawling on benthic ecosystem functions, the effect trait pattern along the gradient was not related to life span. Therefore, although life span might be a key response trait to express taxon abundance recoverability following disturbance, it was not found to be a good indicator of ecosystem function vulnerability. Furthermore, the work shows that trends in species multi-functionality and community functional diversity can be negative or positive along the trawling intensity gradient, but possible critical consequences were evidenced as most impacted species exhibit important role within the sea floor ecosystem.

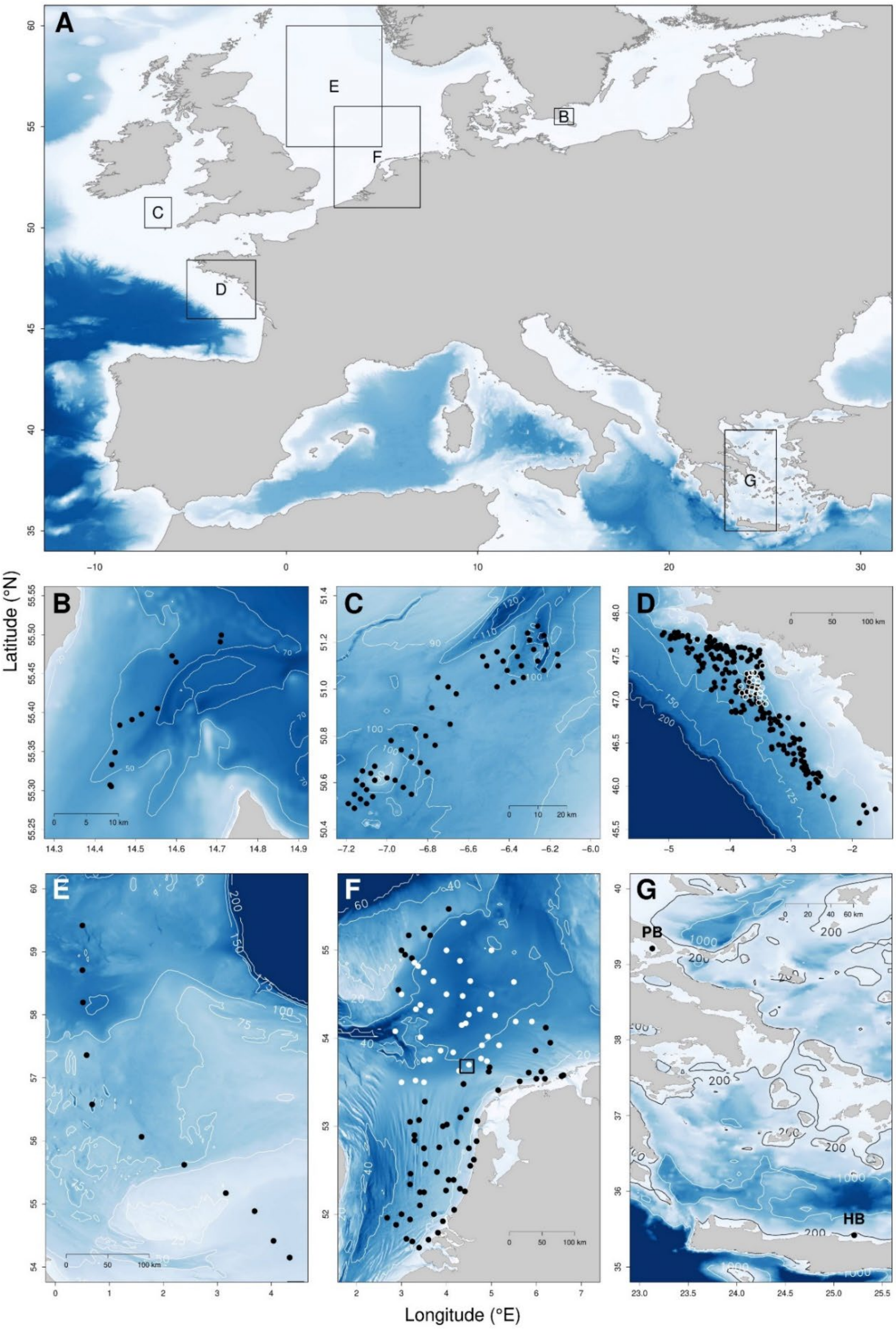


**Figure 45.** Case-study areas. A) Locations of the case studies in European waters; black frames delineate panels from B to G where sample positions (dots) are mapped. B) Baltic Sea (BS). C) Celtic Sea case study (CS). D) Bay of Biscay; black dots, BBL case; opened white circles, BBF case. E) North Sea transect (NST). F) Dutch sector of the North Sea (all dots, DSNS–WA); white dots, low dynamics case (DSNS – LD); black dots, high dynamics case (DSNS – HD); square in the middle, Frisian Front case (FF). G) Eastern

Mediterranean Sea (EMS); PB, Pagasitikos Bay case; HB, Heraklion Bay case; samples are aggregated at very small scale (45 and 50 for PB and HB respectively). Contour lines indicate depth in meters, with contrasts emphasized by blue background adapted to each area.

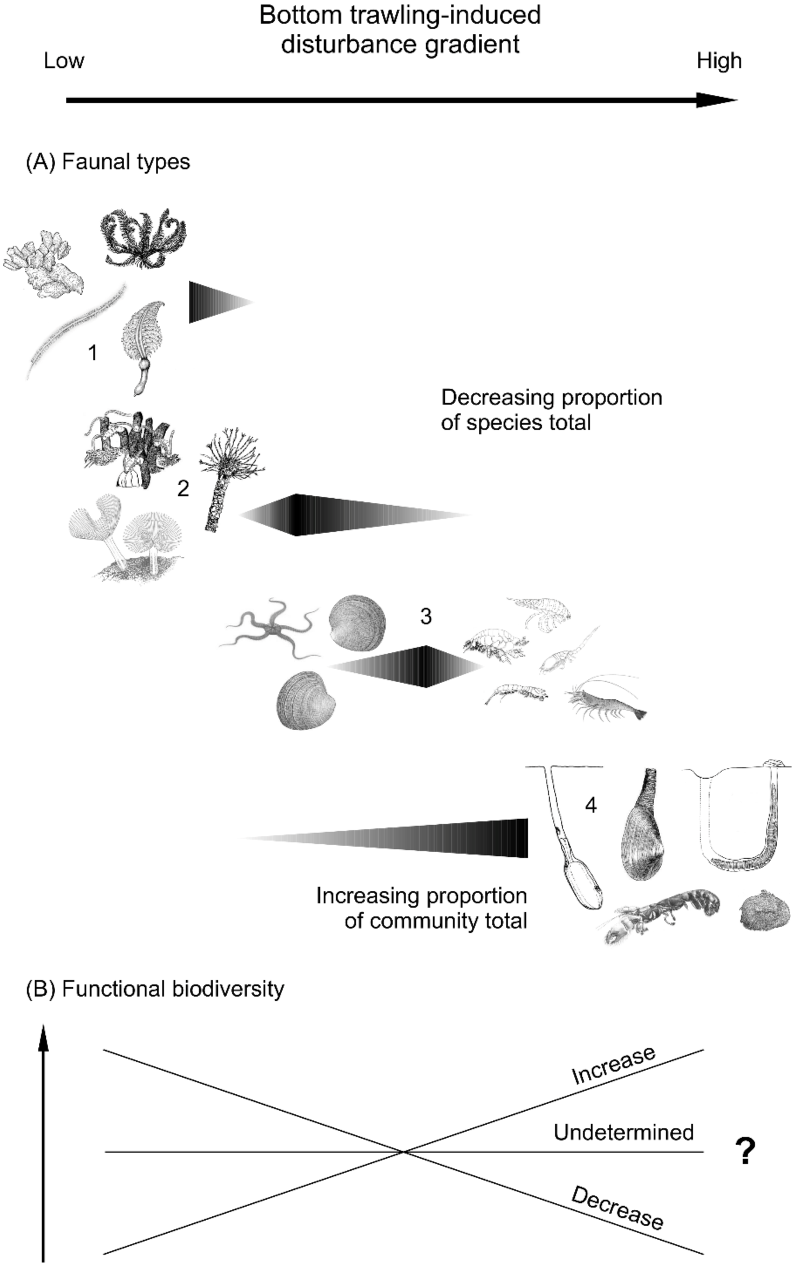


**Figure 46.** Bottom trawling consequences on ecosystem functions performed by benthic organisms. (A) From low to high trawling intensity, organisms living on the sediment surface or within the surficial layer (1 and 2) are more impacted than deep burrowing organisms (4). From left to right, while the frequencies of the former groups decrease, the latter groups, less exposed to trawling gears, represent a growing proportion of total community abundance. (1) extremely vulnerable biogenic structures (e.g. reef builders as habitat providers). (2) tubicolous species (sediment stabilisation, biodeposition and advective transfers of materials); (3) intermediately vulnerable (shell builders and mobile surficial sediment mixers); (4) deep burrowing engineers (bulldozing effect on the sediment, gallery building and bioirrigation). (B) Related functional biodiversity (FD) trend along the trawling gradient.In this context, FD increases with species trait dissimilarity within the community. As there is no general rule to predict functional composition along

gradients of soft sediment habitats (Beauchard *et al.* 2023), FD trend can be context dependent. FD is generated by species that ensure multiple ecosystem functions and that can occur anywhere along the trawling gradient. The indeterminacy in FD trend is explained by the large independence between species multifunctionality and vulnerability (Beauchard *et al.* 2023). A decrease in FD indicates that trawling intensity increases in areas of higher abundances in species that are both multifunctional and vulnerable. An FD increase along the trawling gradient does not indicate that trawling promotes FD, such a trend simply results from the removal of vulnerable and multi-functional species on the left side of the gradient while deep burrowers promoting FD persist on the right side (high trawling intensity). Hence, even impact on usually considered vulnerable species might have critical consequences on ecosystem function beyond a certain trawling frequency.

Correlations between effect trait group and trawling frequency identified by the multivariate analysis were further examined using univariate analyses. Results show a decrease in the proportion of surficial species of the community total abundance (Figure 47) and an increase in the proportion of deep burrowers of the community total abundance (Figure 48) with trawling. The latter is a consequence of the removal of the vulnerable epibenthic species. In some case-studies such as DSNS-WA and DSNA-HD this trend is less obvious as other species groups (e.g., highly mobile crustaceans) that are resistant to trawling are present.

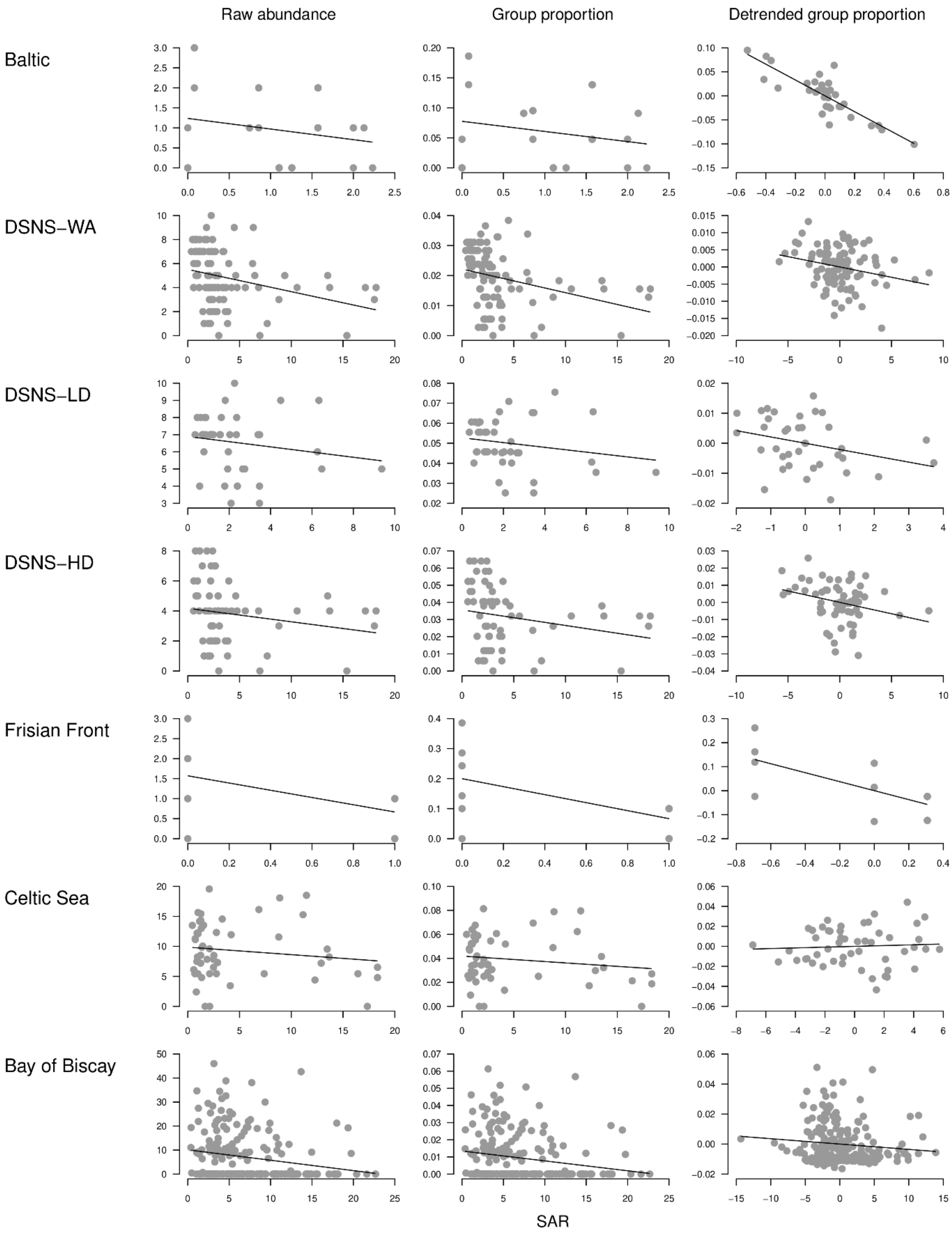


**Figure 47.** Relationship between surficial species abundance (y-axis) and trawling frequency (SAR, x-axis). Surficial species include tubiculous species and epibenthic groups producing biogenic structures. The first column displays the trends in absolute abundance (number of presences; Celtic Sea and Bay of Biscay, biomass density); the second column displays the trend in proportion of group total abundance; the third column displays the proportion after detrending from habitat influence. Note that SAR is *ln*(SAR + 1) in the Baltic.

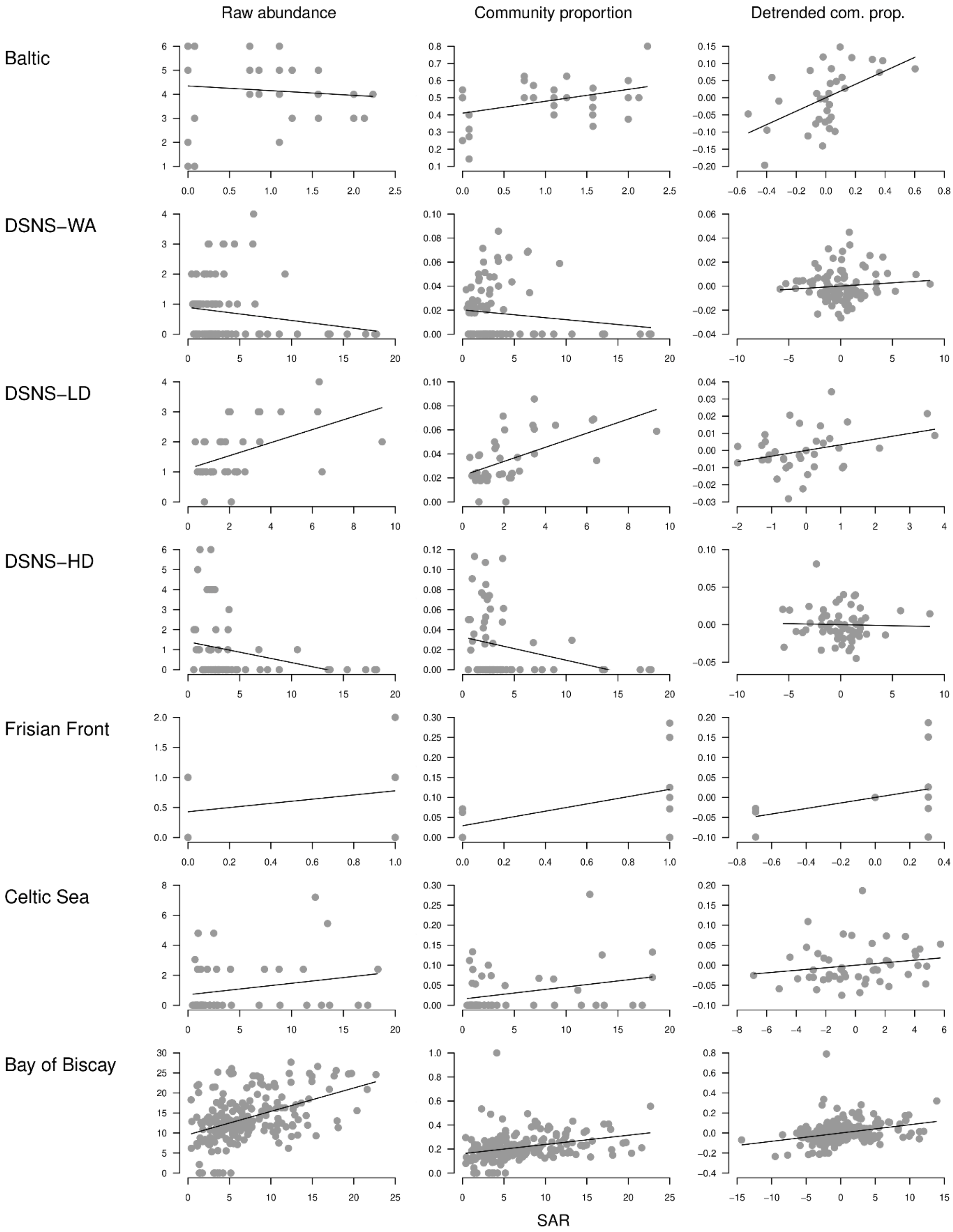


**Figure 48.** Relationship between deep burrowing species abundance (y-axis; number of presences; Celtic Sea and Bay of Biscay, biomass density) and trawling frequency (SAR, x-axis). Deep burrowing species include trait groups "Deep3D", "SesBiot" and "MajBiot" (Beauchard *et al.* 2023). The first column displays the trends in absolute abundance; the second column displays the trend in proportion of community total abundance; the third column displays the proportion after detrending from habitat influence. Note that SAR is *ln*(SAR + 1) in the Baltic.

## 7.3 Modelling trawling effects on ecosystem functioning

Karline Soetaert, Olivier Beauchard.

We present preliminary results of the modelling approach described in detail in ICES WGFBIT 2022 report to model the impact of bottom fisheries on sediment ecosystem functioning. In brief, the assessment method is a data-driven mechanistic model that predicts species depletion and recovery between trawling events. This model calculates the changes in benthic species density or biomass, using the logistic growth formulation; its parameters are derived from in situ density or biomass data from a particular site combined with species trait information, including the longevity of the species, and the depth of occurrence in the sediment. The outcome of this biological model describes trajectories of species densities over time. As the species densities change, so do the ecosystem functions that are delivered by the community. Sediment bioturbation and bio-irrigation are ecosystem functions that affect sediment biogeochemistry. These functions are estimated via the community bioturbation potential ($BP_c$) and bio-irrigation potential ($IP_c$) indices.

**Software**

The fishing impact models run in the open source framework R (R core team, 2022) and have been implemented in the Bfiat R-package (Soetaert *et al.*, 2022). Biological density and biomass data and trait composition data, used for the fisheries impact analysis on ecosystem functioning, are compiled in the R-package Btrait (Soetaert and Beauchard, 2022) that also contains functions to work on density and trait datasets. The package Btrait can be found on github (https://github.com/EMODnet/Btrait); the package Bfiat is still under construction; it will be made publicly available in 2024.

**Data**

The dataset comprises of macrofauna density and biomass data collected for the period 1995 till 2018 for 103 stations in the Dutch part of the North Sea (called the MWTL monitoring data) (https://www.emodnet-biology.eu) (Figure 49). Macrofauna sampling was performed yearly until 2010, then less frequently. Whereas individual organism density data are used to estimate the "carrying capacity" of the species at a particular site (i.e. the abundance of the species in the absence of fishing), biomass density data combined with individual density is used to estimate the mean weight of a species, which is necessary to estimate the ecosystem functions that affect sediment bioturbation: sediment mixing and bioirrigation.

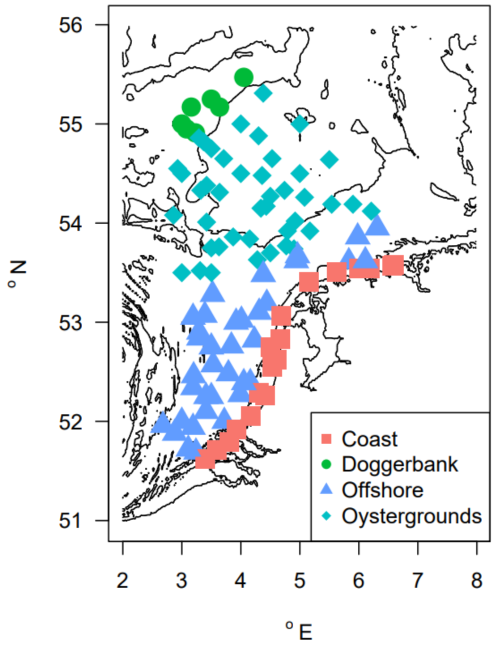


**Figure 49.** MWTL sampling stations with indication of the main areas.

The following species traits were compiled for each species in the dataset (Figure 50):

- life span (longevity) of species, used to estimate their “rate of increase” (ri),
- burrowing/sheltering depth, used to derive species vulnerability to bottom trawling and to calculated “depletion parameter” (di),
- reworking and mobility mode of species to estimate species “bioturbation potential” as defined in Queiros *et al.* (2013),
- feeding type, burrowing mode, injection depth to estimate species “bioirrigation potential” as defined in Wrede *et al.* (2018)

The traits database compiled by NIOZ was used to extract data on species life span, and living space (Beauchard *et al.*, 2021, 2023). The traits required for calculating the bioturbation potential were compiled in Queiros *et al.* (2013). Traits to estimate bioirrigation were described in Wrede *et al.* (2018).

Fishing intensity, expressed as the annual swept area ratio (SAR) was extracted for each sample using ICES SAR data layers. From the swept area ratio (hereafter denoted as S, units yr$^{-1}$), we calculate the time in between fishing events (yr) as 1/S.

## Model parameter estimation

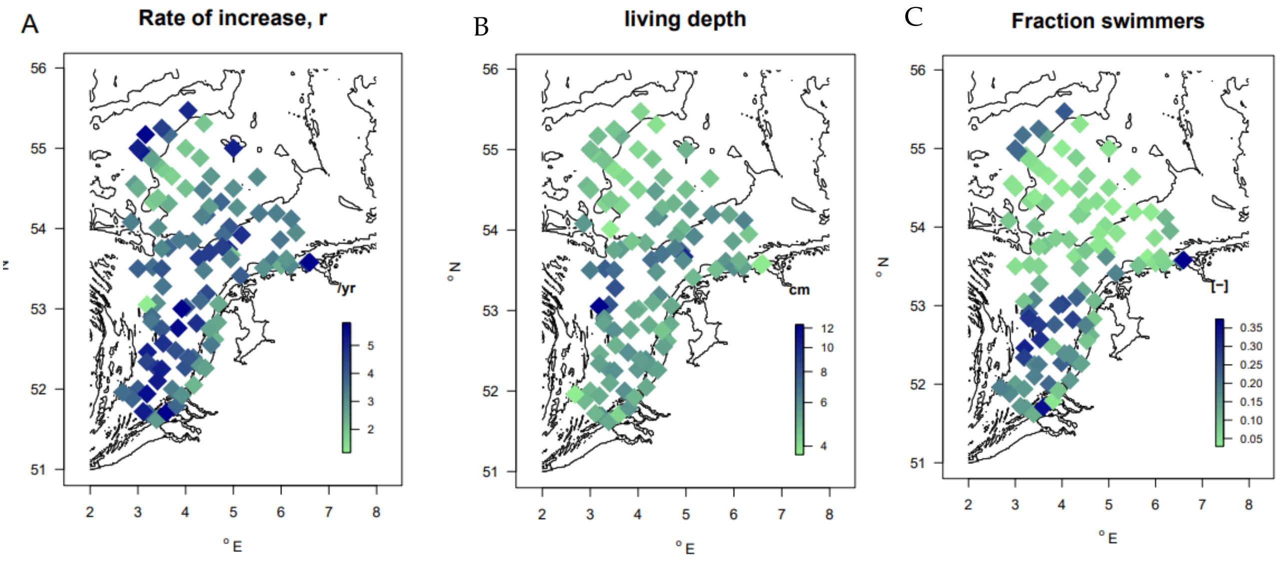


**Figure 50.** Maps of station-averaged (A) rate of increase (r), (B) depth of occurrence (species living in the upper 5 cm (0–5cm), from 5–15cm, from 15–30cm and deeper than 30 cm), (C) fraction of swimmers.

## Fishing impact estimation

The dynamic fisheries impact model is used to calculate the fishing impact for each species and station in the dataset using model parameters rate of increase (ri), depletion (di), and carrying capacity. The model reads:

$$\frac{dD_i^t}{dt} = r_i \cdot D_i^t \cdot (1 - \frac{D_i^t}{K_i})$$

where $t$ is time, $D^t_i$ is the density of species $i$ at a particular time, $K_i$ is the carrying capacity of species $i$, $r_i$ is the logistic growth parameter (units [/time]).

The model is run for a scenario where communities are exposed to 20 years of fishing, followed by 20 years of no fishing (i.e. recovery). For illustration purposes, results are presented for total community density and the 8 most abundant species densities in the Oyster grounds (OESTGND13) station (Figure 51). Results show that surface dwellers such as *Amphiura filiformis* and *Ophiura* sp. are more severely impacted than deep burrowers such as *Callianassa* sp.

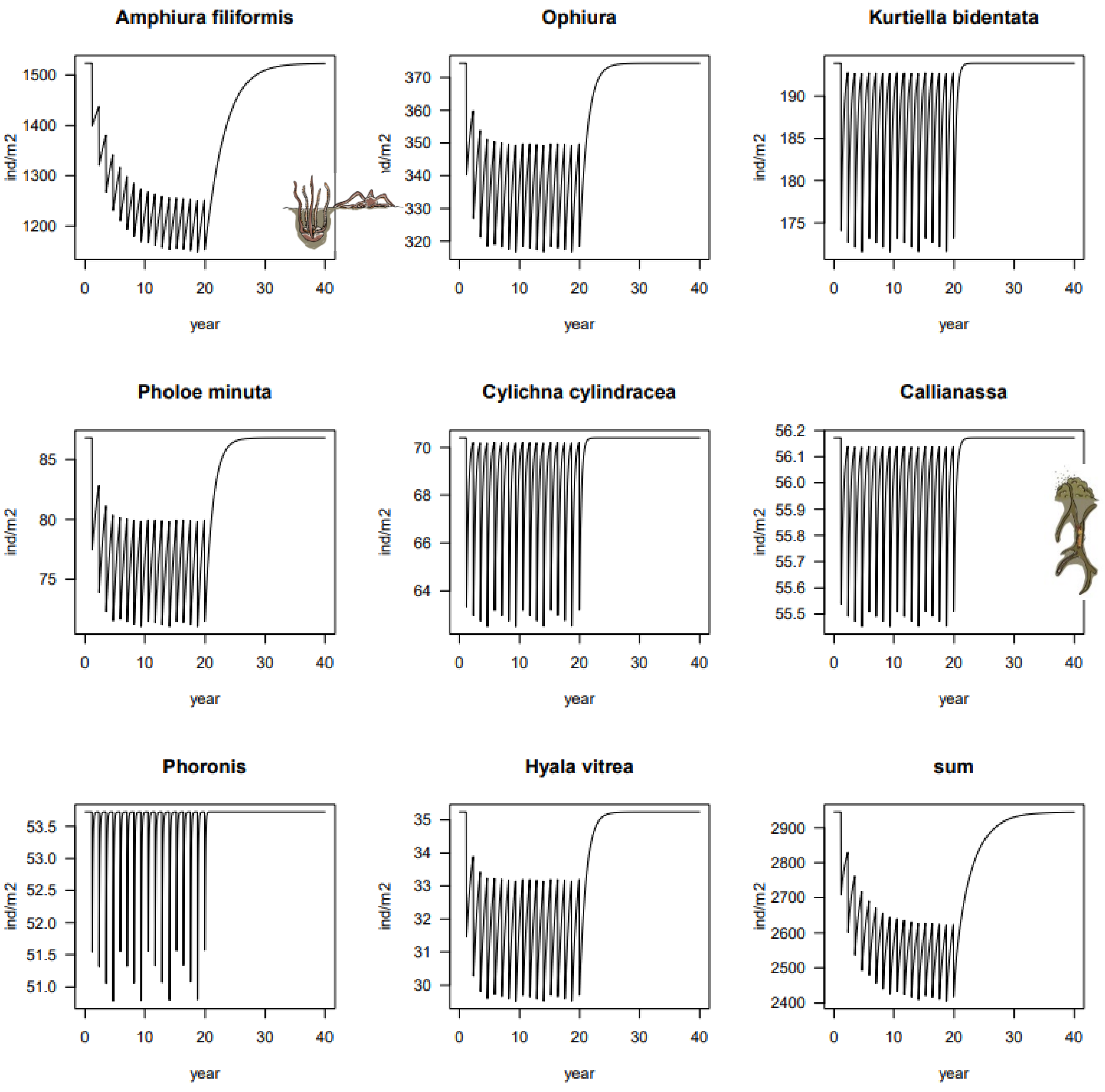


**Figure 51.** Fishing impact on the density of the 8 most abundant species, and the total density in station OESTGDN13; 20 years of fishing followed by 20 years without fishing.

The model is then run for all stations to estimate the impact of trawling on community total density and bioturbation potential. Results in Figure 52 indicate that trawling impact differs strongly across stations – those near the coast experience largest reduction in total community density and bioturbation potential.

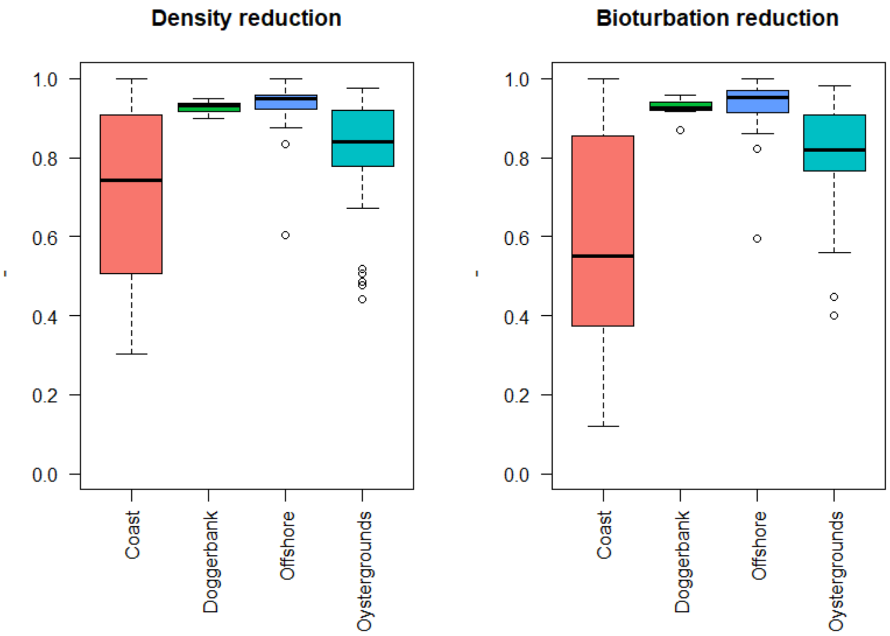


**Figure 52.** Fishing impact on total community density and the contribution to the bioturbation potential for a fishing scenario of 20 years of fishing followed by 20 years of no fishing.

## 7.4 Modelling trawling effects on ecosystem functioning: Eastern Mediterranean case study

Irini Tsikopoulou

This is the first attempt to apply the mechanistic model described above in the oligotrophic eastern Mediterranean. The purpose of this attempt is to get familiar with the R scripts and code developed for the model and also, to understand data requirements in order to model the impact of bottom fisheries on sediment ecosystem functioning.

### Data

For this preliminary analysis, only a single station was tested containing macrofauna density and biomass data collected in 2015 from Patraikos Gulf (Ionian Sea). The traits needed for the model were extracted from various databases, i.e., Beauchard *et al.* (2021, 2023), Clare *et al.* (2022), Queiros *et al.* (2013), Wrede *et al.* (2018). Fishing intensity, expressed as the annual swept area ratio (SAR), was provided by the Hellenic Ministry of Mercantile Marine and Island Policy and was analysed based on the methods and specifications further described in Maina *et al.* (2021) (and references therein).

### Results

The model run for a scenario where communities are exposed to 20 years of fishing, followed by 20 years of no fishing (i.e. recovery) is presented in Figure 53. The bivalve *Nucula nucleus* was the most impacted species in this site.

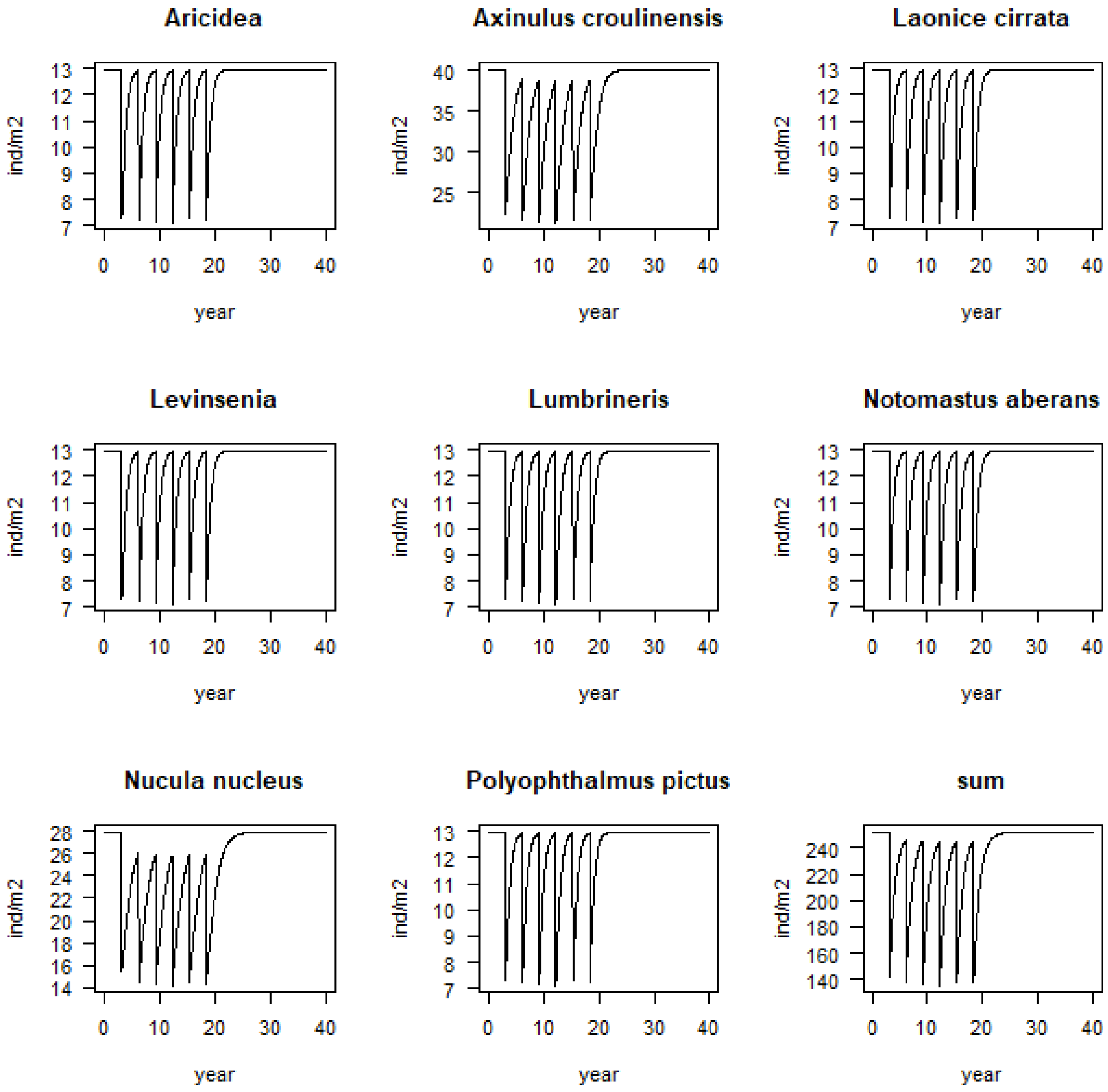


**Figure 53.** Fishing impact on the density of the 8 species, and the total density in the station; 20 years of fishing followed by 20 years without fishing.

## Discussion

The preliminary analysis revealed that the model can be applied in the Eastern Mediterranean. As a consequent, for the next WGFBIT we are going to apply this method for the Greek waters.

## 7.5 Bottom trawl model simulations on carbon mineralization

Justin Tiano, Karline Soetaert

For the bottom fishing impact assessment tool (BFIAT) project, model simulations were carried out to understand the long-term effects of bottom trawling on benthic biogeochemistry. In particular, different aspects of organic matter (OM) mineralization were investigated to assess how repeated beam trawl events affect carbon degradation rates and recovery.

### Methods

A one-dimensional biogeochemical model (OMEXDIA; Soetaert *et al.*, 1996) was used to explore how a sedimentary system may react to bottom trawl disturbance, following the methodology used in De Borger *et al.*, (2021). The effects of trawling were modelled as an erosion + a mixing event which has been observed in several in-situ trawling studies (Figure 54; Depestele *et al.*, 2016, 2018; Morys *et al.*, 2021; Tiano *et al.*, 2019, 2020).

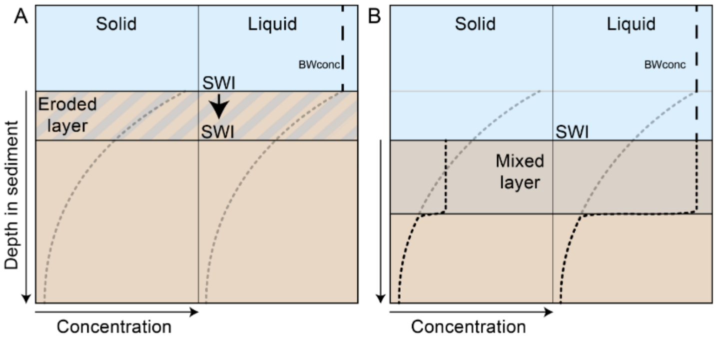


**Figure 54.** Implementation of a single trawling event in OMEXDIA as seen in De Borger *et al.*, (2021). Erosion removes a layer of sediment (A). Mixing of the sediment homogenizes the solid concentration over the mixed layer depth, whereas liquids are set to the overlying bottom water concentration (B).

Parameterized models derived from data collected at four sedimentary North Sea stations were selected to highlight divergent sediment types and mineralization characteristics (Figure 49). Sandy habitats: Dogger Bank (DB, low mineralization) and Vlakte van de Raan (VR, high mineralization), were compared to muddy sites: Frisian Front (FF, high mineralization), Fladen Grounds (FG, low mineralization). To enhance the connection between disturbances and biogeochemical changes, dynamic model runs were simplified by removing seasonal variability with OM imposed as a constant rate. Simulations were run for 10 years (daily resolution) with two trawl perturbations occurring annually.

### Results

The bi-annual trawl events had discernible impacts on mineralization, evident in distinct impact-recovery cycles. Total mineralization after the 10-year fishing simulation, showed notable decreases in both muddy sites (FL and FF) with only a slight decrease detected at the sandy DB (Figure 55). The sandy, high mineralization site VR exhibited an increase in total mineralization after 10 years (Figure 55).

Oxic mineralization recovered relatively quickly in all habitats after trawling disturbance while changes to anoxic mineralization were governed by sediment type. Muddy sediments exhibited clear declines in anoxic mineralization eventually showing annual values close to zero at approximately year 7 for FL and year 3 for FF (Figure 56). An initial decline in anoxic mineralization was observed in sandy sediments followed by a gradual increase in subsequent years (Figure 56).

Oxygen concentrations within the sediment increased for muddy sites at the end of the simulation but remained stable for sandy sites (Figure 57). The depth-wise spatial region of the sediment exhibiting anoxic mineralization decreased substantially during the simulation for muddy sediment sites but increased for the sandy DB site. The sandy VR site did not show a noticeable spatial expansion in anoxic mineralization, however, the rate of anoxic mineralization increased over time.

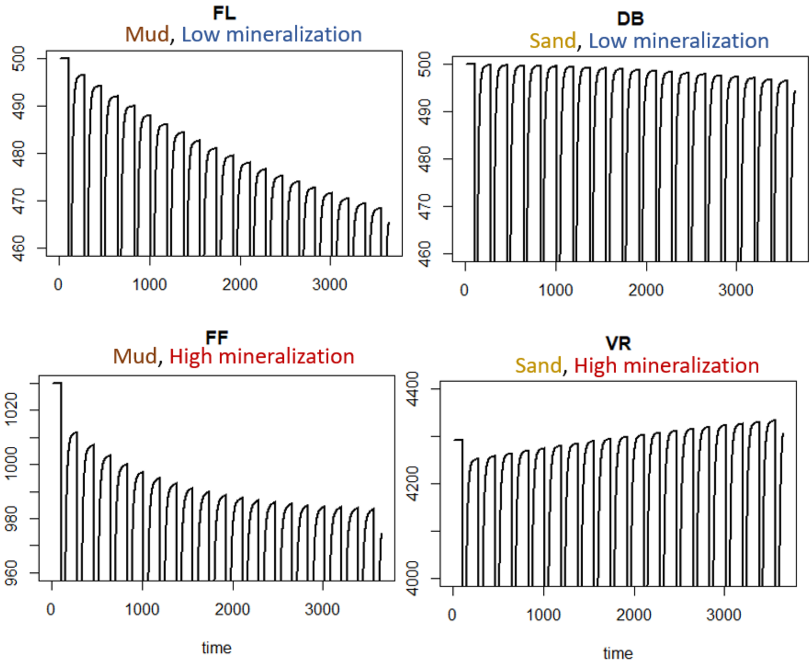


**Figure 55.** Total organic matter mineralization modelled over 10 years with bi-annual trawl events amongst the four sedimentary habitats.

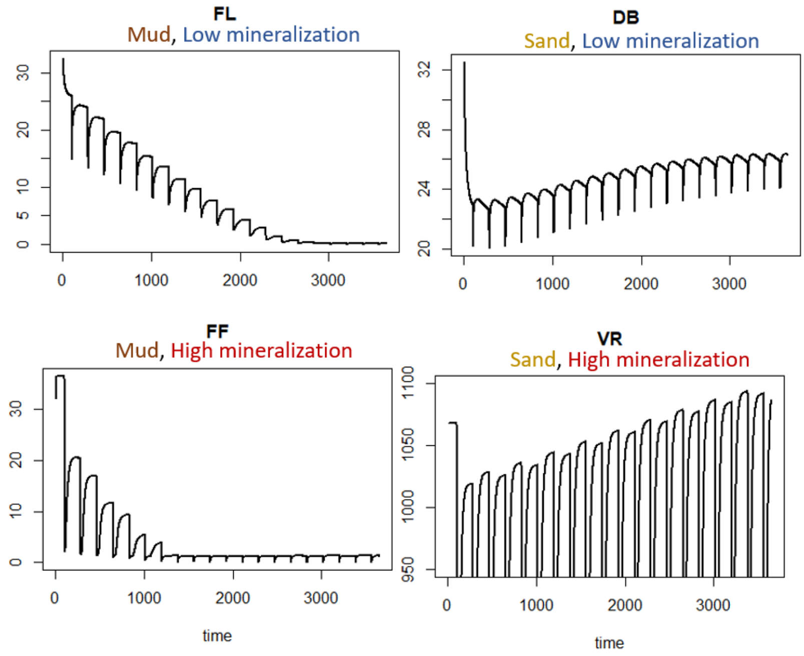


**Figure 56.** Anoxic mineralization modelled over 10 years with bi-annual trawl events amongst the four sedimentary habitats.

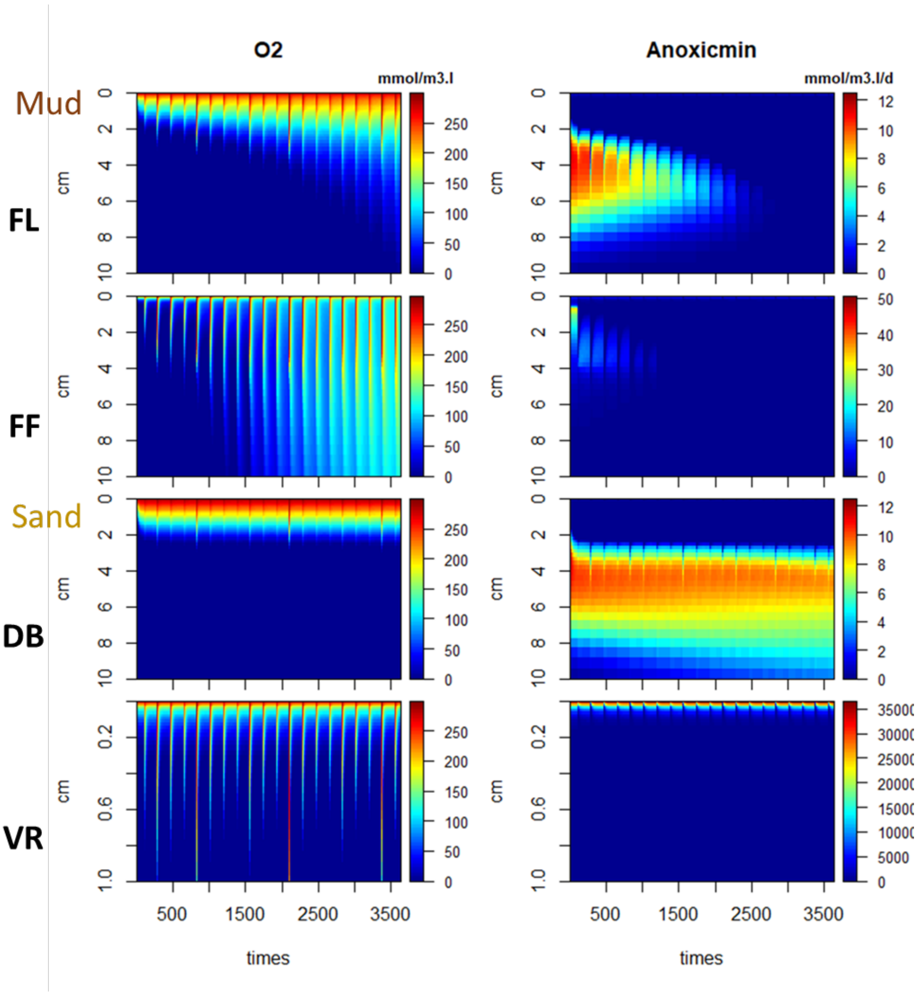


**Figure 57.** Oxygen concentrations and anoxic mineralization depth distributions. The VR site displays a different y-axis showing 0–1 cm unlike the 0–10 cm range for the other sites. This is due to the confinement of these biogeochemical characteristics to shallow layers at the VT site.

## Discussion

A shift towards oxic mineralization and $O_2$ content after trawling disturbance has been predicted by several modelling studies (Allen & Clarke, 2007; De Borger *et al.*, 2021; Duplisea *et al.*, 2001; van de Velde *et al.*, 2018). This increase in $O_2$ concentration in the sediment can be expected as disturbance-induced reductions in OM reduce the overall respiration within the sediment community (Tiano *et al.*, 2019, Morys *et al.*, 2021).

The results of this analysis are unique, however, in that they predict increased long-term mineralization in sandy sediments driven by the impacts of repeated bottom trawling on anoxic mineralization. The mechanisms driving this increase are slightly different between DB and VR. At DB, bi-annual disturbances lead to a spatial expansion of the depth distribution where anoxic mineralization is optimal, whereas disturbances at VR lead to an accumulation of slow-decaying recalcitrant OM fractions. Elevated oxygen concentrations observed at the muddy sites hinders anoxic mineralization, and in conjunction with trawl-induced reduction in OM, result in lower overall mineralization at the end of the simulations.

These findings suggest that although labile organic matter near the seabed surface may be more susceptible to immediate disturbances, changes to recalcitrant OM fractions and subsequent alterations to anoxic mineralization could drive longer-term chronic effects from bottom trawling. It is important to remember that these particular models use simplified biogeochemical dynamics to isolate cause-and-effect relationships and that the inclusion of more realistic characteristics such as seasonal effects, and changes to community bioturbation, may alter the outcomes of these results.

## 7.6 Other research efforts on seabed carbon response to pressure

Ruth Parker, Clement Garcia

**Shelf seabed blue carbon: What is the potential of the English seabed for climate mitigation under future marine management?**

The subtidal seabed sedimentary habitats in English Waters contain significant stores of carbon which are under pressure from climate forcing as well as various human activities, such as trawling. Management of these activities, including the protection or restoration of sedimentary habitats via various mechanisms may therefore provide a significant Nature-based Solutions (NbS) to climate change. A loss or degradation of sedimentary habitats and associated C stocks may cause additional greenhouse gas emissions, which means that protection or recovery of these habitats may represent avoided emissions. In addition, habitat restoration or protection (and associated recovery) may provide a mechanism by which additional carbon is removed from the atmosphere, representing an emission saving.

Recent work funded by Defra and conducted by Cefas provides an overview of the present available evidence on provision of the subtidal seabed sediments (both inshore and offshore) and marine protected area (MPA) network. This includes the carbon co-benefits as well as examining the response of carbon storage to impact (e.g. sea bed trawling) and the potential of spatial management measures of MPAs for climate mitigation.

Work on the seabed sedimentary particulate organic carbon (POC) stocks (0–10cms sediment depth) in English waters has shown that storage is calculated to range between 81–104 million tonnes POC (297–382 million tonnes $CO_2e$) and stocks range from 0.5 to 2.5 Kg C $m^{-2}$ . The highest stocks occur in muddier substrates and in deeper and colder areas or areas with high carbon inputs (usually close to terrestrial sources). For POC sequestration, the evidence in English Waters is very low, limited mainly by observations of sedimentation rates. Within the English North Sea, the seabed sediments sequester ~39 Kt C (143 Kt $CO_2e$) $yr^{-1}$, which is ~0.05% of the total stock (to 10cms depth) in this region.

Across English waters, 33% of total sediment POC stock occurs in MPAs. For the North Sea alone, the MPA network covers 64% of the seabed, which supplies 27% of the North Sea's total sequestration capacity. Despite not being designated for carbon considerations the existing MPA network does provide significant provision of carbon storage and sequestration. However, there are significant areas located outside the network and these include regions of the highest C stock density and potential sequestration (mainly coastal and deep/muddy regions). Behind any large-scale summary assessment for C stock and sequestration provision there will be considerable spatial variability at a regional scale which needs to be understood fully to assess importance of C provision at a specific MPA, region or network scale.

Overall, the net effect of trawling pressure on POC stock and sequestration rate is not clear due to the very low number of impact studies and will vary spatially due to factors including sediment carbon stability and predominance of main impact mechanisms; resuspension, faunal mortality, and sediment mixing (which is controlled by gear type, towing speed, substrate type and setting). This will vary according to seabed sediment status and environmental context.

Carbon – trawling pressure interaction areas are highly focused and often related to high carbon zones (Figure 58). A significant proportion (81 to 67%) of the total sediment POC stock (and potentially the highest sequestration regions) within English Waters occur outside (but sometimes in close proximity to) elements of the MPA network. These stocks are also exposed to approximately two-fold higher trawling pressure per annum than areas within the MPA network. Awareness of these higher carbon pressure areas is useful to inform future policy development and approaches.

Knowledge and predictions of displacement of activities, at local to regional scales, is important for understanding the full trade-offs for POC stock/accumulation under closure or pressure reduction scenarios if pressure moves to more vulnerable carbon areas.

It is mainly the unstable OC fractions (vulnerable OC portion) which is responsive to activity management, this will vary depending on regional stock differences and may be only a small part of total benthic OC. The approach to stock management (emission avoidance or savings) and also stock/sequestration recovery through differing activity management approaches (and NbS) will vary in differing shelf areas as dictated by carbon characteristics.

Key areas of evidence uncertainty remain and ongoing work is funded to address them. These include improved observations of carbon parameters and carbon vulnerability mapping; integrated C and biodiversity observations of baseline, impact and recovery conditions (linking R&D and monitoring); predictive tools to develop and test management scenarios and outcomes; data management and machine learning approaches to support an improved evidence base and provide underpinning carbon sediment understanding.

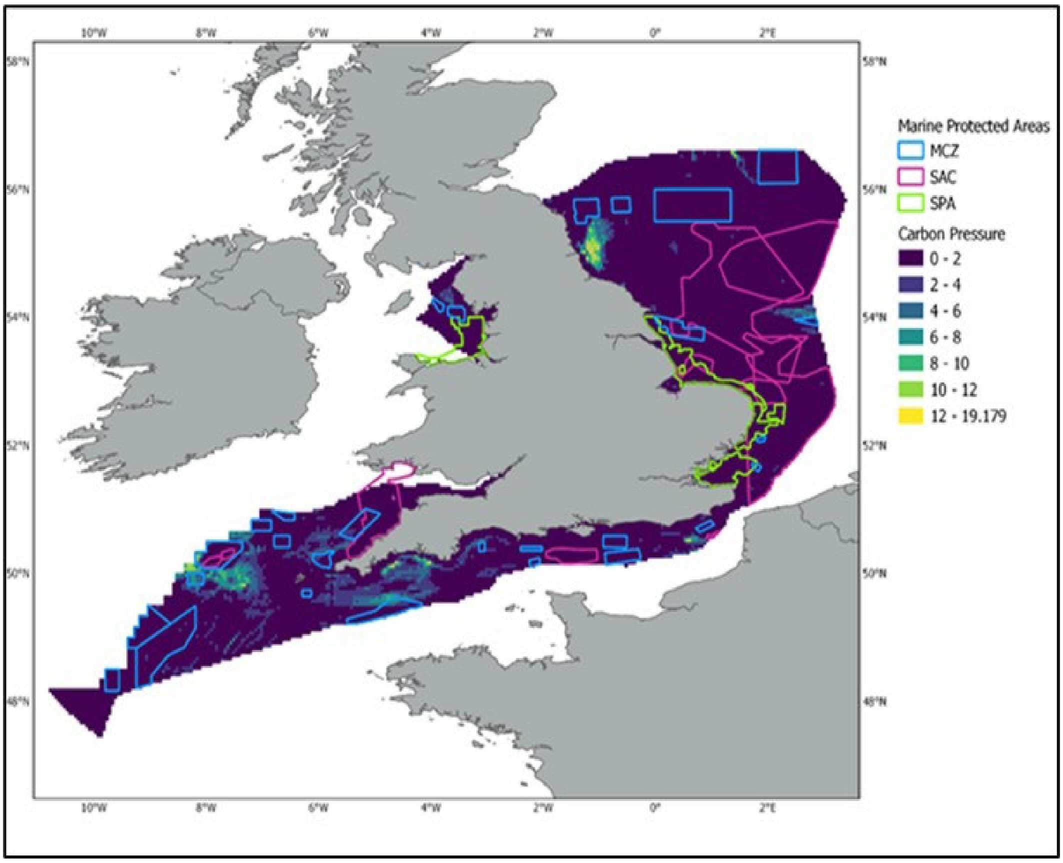


**Figure 58.** Comparative carbon stock – trawling pressure map (POC stock map (Diesing *et al.*, 2017) combined with trawling effort map (swept area ratio – 2016=2019, vessels > 12ms)). Yellow areas are higher POC – trawling pressure.

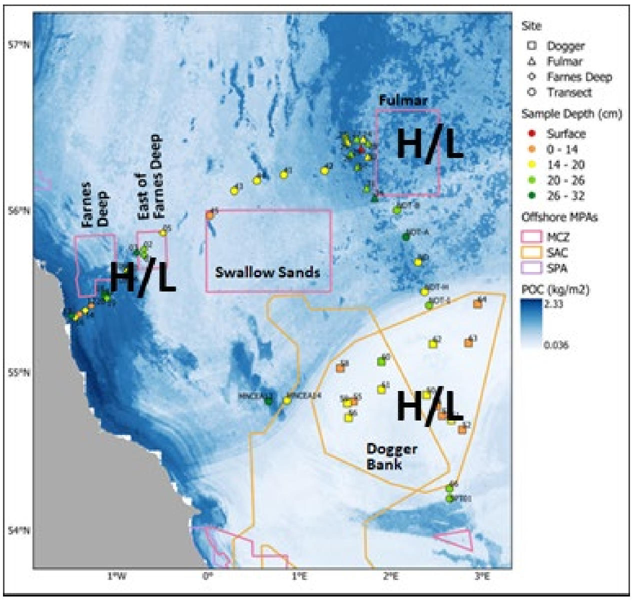
### Linking faunal metrics to biogeochemistry and Ecosystem Services: Ruth Parker and Clement Garcia

The seabed provides many interlinked ecosystem services (ES). These benthic ES can be viewed as measurable benefits for society and include climate regulation, nutrient cycling, waste remediation and storage and fish stock support. Biodiversity and the macrofaunal assemblage structure and function and integral in mediating these services. Benthic ES vary with space, time, and the impacts of human activity and climate. As one service changes, others will also be impacted. It is vital that the seabed system and the ES it provides are understood as a whole in order to be managed sustainably.

At present, only some components of the seabed system are measured in observational programmes.

This reductive approach creates a partial view of seabed ES and/or low confidence in any NC accounting or valuation as a result). It is therefore difficult to predict the full net effect of management scenarios across multiple ES. Additionally, inherent synergies and trade-offs across ES can lead to unexpected change which is difficult to mitigate and this may lead inadvertently to unexpected or unstainable outcomes of management decisions for some ES.

Various Defra Marine and Fisheries programmes (mNCEA and Carbon management projects ) are tackling the development of observational programmes, valuation and scenario testing models and tools to support and improved understanding of ES and links to biodiversity considerations moving forward. Observational work and new data from sampling programmes across the North and Celtic Seas (see figure left for North Sea sampling) are being undertaken in 2023 and 2024. These include measurements of water column and seabed parameters (oxygen, nutrients, carbon, fauna, contaminants) across differing regions of environmental drivers and sediment types. Sites include baseline conditions and also those with high chronic (>10 years) trawling impact from otter and beam trawls. These data will be used to improve our understanding of trawling impact on macrofaunal biodiversity and functioning as well as seabed state, functioning and ES and inform management measures (such as MPAs) which may promote protection or recovery.



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# 8 EO templates

Ecosystem Overviews are central to ICES approach to support evidence-based Ecosystem Based Management, the primary way of managing human activities affecting marine ecosystems. FBIT 2024 refined its input to the EO process by refining the advice sheet template for the assessment of mobile bottom fishing (Annex 3); advice sheets were produced for selected ecoregions (Annex 4).

FBIT also outlined approaches that might be used to include information on ecosystem services into the EO process. These approaches will be discussed with relevant ICES working groups in early 2024.

# 9 Mini symposium abstracts

### The Centre of Coastal Ecosystem and Climate Change research (CoastClim)

Presenter Anna Villnäs, scientific coordinator in CoastClim

The CoastClim Centre was established in September 2021 in response to the ongoing global climate change and biodiversity crises, with the aim to resolve what role our highly productive coastal ecosystems have for ocean-atmospheric carbon fluxes. Do healthy coastal ecosystems have a capacity to combat climate change? CoastClim forms a strategic partnership between the major marine and atmospheric units at the University of Helsinki (i.e. Tvärminne Zoological Station and the Institute for Atmospheric and Earth System Research) and Stockholm University (the Baltic Sea Centre and the Bolin Centre for Climate Research). The key objective is to quantify the role of healthy *versus* degraded coastal habitats for the life cycles of greenhouse gases and aerosols. To resolve this, we combine research fields within marine ecology, biogeochemistry, atmospheric sciences, marine physics, ecosystem modelling, policy and communication. Further information see https://www.coastclim.org/.

### A functional perspective on the factors underpinning carbon storage in coastal plant communities

Roel Lammerant, Alf Norkko, Camilla Gustafsson

Coastal ecosystems have received international interest for their possible role in climate change mitigation, highlighting the importance of being able to assess and predict how changes in habitat distributions and their associated communities may impact the greenhouse gas sink potential of these vegetated seascapes. To date, studies on aquatic plants have mainly focused on the role of mono-specific seagrass stands, typically ignoring that the coastal zone can be heterogeneous, where multiple species with a range of trait characteristics may influence carbon storage differently across seasons. With few studies having assessed how functional traits link to carbon storage in aquatic plant communities, we sought to explore (*i*) the relationship between functional community composition and biomass-bound carbon stocks, and (*ii*) seasonal fluctuations of non-structural carbohydrates in different plant species. We conducted multiple field surveys (i.e., October, March, June and August) in the Baltic Sea, Finland, where we sampled six soft-bottom communities dominated by aquatic vascular plants and measured nine traits that capture the key variation in plant life-history strategies. Functional diversity was associated with aquatic plant carbon stocks through mass ratio effects, highlighting that carbon stocks were positively influenced by the dominance of species with more acquisitive resource strategies. Moreover, the relationship between functional diversity and aquatic plant carbon stocks was mediated by seasonality. Species identity influenced seasonal patterns of non-structural carbohydrate concentrations, with the amount stored in leaf tissue throughout winter being tied to functional characteristics of the leaves. Our results indicate that the underlying biological mechanisms influencing carbon storage are affected by community trait composition, underlining the importance of using functional traits as a tool to assess the role of aquatic plant biodiversity for ecosystem functioning.

### Investigating the effects of heatwaves on seafloor community structure and ecosystem functioning – novel *in situ* approaches needed for realistic insights

Norman Göbeler, Laura Kauppi, Robin Gottberg, Göran Lundberg, Alf Norkko, Joanna Norkko

The frequency of abnormally warm water events is increasing not only in surface waters, but also in subsurface layers, with major impacts on benthic ecosystems. Previous insights on heatwave effects have been obtained through field observations or manipulative laboratory experiments. Here, we introduce a system capable of inducing elevated water temperatures in benthic habitats *in situ* over several days. The system consists of a commercially available electric boiler, usually applied in domestic underfloor heating, and custom-designed benthic acrylic glass chambers connected to individual thermostats. Furthermore, the chambers are semi-open, allowing constant water exchange, maintaining otherwise near-natural conditions, including oxygen concentrations, while the temperature is elevated. The water exchange can be stopped to facilitate incubations measuring changes in benthic fluxes. We conducted a 15-d trial study in July 2021 on a bare-sediment habitat at 2.5 m depth, exposing five chambers to water temperatures 5°C above ambient temperatures for 6 d and comparing with five control chambers. In this assessment, we demonstrate that the temperature control and stability were reliable while maintaining natural oxygen conditions. Furthermore, the induced MHW caused an increased metabolism, indicated by the doubling of respiration rates during night incubation, of the benthic community, which lead to amplified effluxes of phosphate, silicate and ammonium. This indicates a sublethal effect of MHWs, as the community structure demonstrated no changes. The modular character of the system permits adaptations for various benthic habitats, facilitating the investigation of elevated temperatures *in situ* for future climate change scenarios.

### Carbon sink potential in *Phragmites australis* across coastal archipelago reed belts

Margaret Williamson, Camilla Gustafsson, Tom Jilbert, Alf Norkko

Distribution of the common reed (*Phragmites australis*) has increased in coastal ecosystems of Finland and in other coastal ecosystems across the globe. Currently, there appears to be a gap in the literature on carbon (C) cycling and sequestration in reed beds though preliminary findings indicate these systems are unique, show great potential for C storage, and, therefore, should be taken into consideration while developing blue carbon (BC) budgets. The aim of our study is to quantify how much C is stored in reed bed biomass and sediment along the Pojo Bay system in coastal Finland. We selected 6 reed beds to sample along Pojo Bay covering a range of salinities and wave exposure from the northern-most part of the Bay to the southern-most part opening into the Baltic Sea. Within each reed bed, samples were taken from randomly selected sites within each of the 3 reed bed zones (terrestrial, intermittent, and littoral) and replicate samples were taken within each zone along a transect. Plant and sediment samples were collected and analysed for C content. Preliminary results from LOI (loss of ignition) within the sediment samples showed higher percentages of organic matter in the upper segments of sediment profiles and a general trend towards higher organic matter percentages in terrestrial and intermittent zones than littoral zones of reed beds. C profiles and isotope analysis on the sediment and plant samples are being analyzed. These findings are significant as they help rectify a gap in the literature on how much C is stored in reed bed biomass and sediment. Information on how much C is stored within this rapidly expanding coastal ecosystem type is important for the management of reed beds and greatly impacts calculations for coastal carbon budgets to combat climate change. Further information will be gathered from these field sites every 3 months for 2 years to show seasonal variability in the C storage, C isotope analysis, and methane emissions to get a more complete picture of C cycling in these reed bed systems.

### Effects of bottom trawling on benthic ecosystem structure and function in the southern Baltic Proper

Clare Bradshaw[1], Sven Iburg[1], Claudia Morys[1], Mattias Sköld[2], Antonio Pusceddu[3], Claudia Ennas[3], Patrik Jonsson[2], Francisco Nascimento[1]
[1]Stockholm University, Sweden, [2]Swedish University of Agricultural Sciences, [3]University of Cagliari, Italy

Bottom trawling in the Baltic Sea has occurred mainly in the southern Baltic Proper, using otter trawls to catch cod (*Gadus morhua*) and European flounder (*Platichthys flesus*). Although this fishing practice has occurred for many decades in the Swedish part of the southern Baltic and swept area ratios (SAR) there have commonly exceeded 10 $y^{-1}$ in some locations, potential benthic impacts have not been studied. We compared seabeds with high (SAR > 6 $y^{-1}$) and low (SAR < 1 $y^{-1}$) fishing intensity in terms of a) community structure of benthic macrofauna, meiofauna and bacteria, b) a range of sediment properties and c) ecosystem processes such as nutrient fluxes and carbon degradation rates, and evaluated these for the impact of both trawling and environmental factors. Trawling affected macrofauna community structure (in particular, deep burrowing worms were more common at high trawled sites) while meiofauna and bacteria communities were not affected. There was more labile carbon and higher extracellular enzyme activities and carbon degradation rates at highly trawled sites. Apart from trawling, site-specific characteristics, including bottom water conditions and physical and chemical sediment properties, were also important in determining benthic community structure and rates of benthic processes. The biomass and abundance of key macrofauna species were also highly correlated with ecosystem processes such as benthic oxygen consumption, N-fluxes and carbon turnover times. In summary, a complex interplay of environmental setting, ecology and trawling intensity interact to influence the patterns of benthic community structure and function that are found in this area of the southern Baltic Sea.
This work is in review in Science of the Total Environment (Nov 2023) and is available as a preprint.

### Sediment penetration by bottom contacting fishing gear components

Barry O'Neill, Morteza Eighani, Esther Savina
DTU Aqua, Denmark.

We report on experimental trials to investigate the penetration depth of towed cylindrical components into soft sediment seabeds. The experiments were carried out on RV Havfisken at three sites locations in Ålbæk Bay, Denmark, in the northern Kattegat, where the sediment types were classified as fine sand, muddy sand and mud and had respective silt fractions of 6.7, 20 and 87%. A towed sled similar to that used by O'Neill and Summerbell (2016) was used and was 1.0 m high, 2.1 m wide, 3.0 m long and weighed 530 kg. Three different sizes of cylindrical components were towed with radius x width dimensions of 0.3 x 0.3m, 0.3 x 0.6m and 0.2 x 0.6m, respectively. These components were mounted on an axle and attached to a framework that was free to move in the vertical direction. The vertical force exerted on the seabed by the components comprised the gravitational forces of the components, the part of the supporting framework that was free to move and additional weights that could be added to the framework. Hence, by adding weights, each component was tested having total vertical forces (in water) of approximately 855, 1365 and 1875 N. For each component – weight combination, the sled was towed for approximately ten minutes at three target speeds (1.25, 1.5 and 1.75 m/s), which was measured using the vessels GPS at a rate of 1Hz.

Linear fixed-effect models of the penetration depth in terms of aspect ratio, pressure force, towing speed and sediment type and their interactions were fitted to the data and the best model was that which had no dependence on aspect ratio and had interactions between pressure and speed, and pressure and silt. The analysis demonstrated that there was increased penetration with increased pressure, increased penetration on softer sediments, and reduced penetration with faster towing speed.

### Setting thresholds for ‘good’ status in marine ecosystem management

Lorna McKellar, Jan Geert Hiddink.
School of Ocean Sciences, Bangor University

Setting thresholds for 'good' status is an important part of effective marine ecosystem management and key to achieving marine sustainability goals. Thresholds are used to distinguish between ‘good’ and ‘bad’ ecosystem states for different indicators. Currently, a range of methods are used to estimate thresholds, but these are often chosen without a clear understanding of which methods will provide the most accurate and reliable estimations of 'good' status based on the available data. Therefore, this work has evaluated the statistical robustness of different methods for setting thresholds, using computationally simulated ‘indicator’ data, representing either pressure-state or reference condition/ baseline datasets. We examined the impact of varying levels of stochasticity, sample size (range), and the shape of the pressure-state relationship (linear, tolerant, sensitive) of ‘indicator’ datasets, on the thresholds estimated by different methods.

Methods using pressure-state datasets (tipping points and distance to degradation) estimated similar thresholds across varying levels of stochasticity and sample size but were unreliable, in that they frequently failed to estimate a threshold if ‘indicator’ datasets had high stochasticity levels or small sample sizes. Methods using reference condition datasets (range of natural variation and statistically detectable change) reliably estimated thresholds across datasets with low sample sizes and high stochasticity, but these were often estimated at a low state level, not representative of ‘good’ status. As a result, we recommend that methods using reference conditions are prioritized by decision-makers when estimating thresholds for ‘good’ status in ecosystem assessments, due to the unreliability of methods using pressure-state datasets. However, it is crucial that the accuracy of reference condition data in representing an indicator in ‘good’ condition is carefully considered to ensure the estimated thresholds are accurate, as well as reliable.

### Is there a need to manage the seafloor with spatial management measures: Examining an alternative from Alaska

PD van Denderen J Collie, D Boyce, G DePiper, S Gaichas, H Smati, H Uchida & K Hamon

We examined two distinct marine regions, Alaska and northwest Europe, in their fisheries strategy. We choose these regions as they have high levels of fisheries productivity and data availability, as well as clear differences in fisheries governance and level of cooperation between countries. We find that fisheries exploitation differs between regions in both historic exploitation as well as choice of acceptable level of current sustainable exploitation. Alaska has the lowest exploitation rates and overfished stocks and has largely mitigated indirect fishing effects, such as bycatch and seafloor degradation. On the other hand, northwest Europe has the most fishing operations with the highest weight of landings, number of KW sea days and sea days, the largest fleet, and most fuel consumption. Both regions have equal fisheries productive capacities, and this implies that northwest Europe would experience a reduction to less than half of its annual total landings if it were to adopt an Alaskan fisheries management strategy. Conversely, Alaska could potentially double its annual total landings if it were to implement a northwest European strategy.

Theory predicts that spatial management is more necessary in multi-jurisdictional areas, where it is more difficult to manage the fisheries. Our results corroborate this theory as we see many more spatial management measures to protect ecosystem components (both in spatial coverage and in absolute numbers) in northwest Europe, which is multi-jurisdictional with high overall exploitation. Spatial management seems less needed in Alaska which is a single-jurisdiction region with low catch diversity. Alaska has tighter catch limitations and gear restrictions to mitigate indirect fishing effects, such as bycatch and seafloor disturbance from bottom trawling.

### Trawling-induced change in benthic effect trait composition – A multiple case study

Olivier Beauchard[1], Clare Bradshaw[2] , Stefan Bolam[3] , Justin Tiano[4] , Clément Garcia[3] , Emil De Borger[1], Pascal Laffargue[5], Mats Blomqvist[6], Irini Tsikopoulou[7], Nadia Papadopoulou[7], Christopher Smith[7], Jolien Claes[8], Karline Soetaert[1], Marija Sciberras[8]

[1]Royal Netherlands Institute for Sea Research (NIOZ), Netherlands, [2]Stockholm University, Sweden, [3]Centre for Environment, Fisheries and Aquaculture Science (CEFAS), United Kingdom, [4]Wageningen Marine Research, Wageningen University and Research, Netherlands, [5]Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), France, [6]Hafok AB, Sweden, [7]Hellenic Centre for Marine Research (HCMR), Greece, [8]The Lyell Centre, United Kingdom.

The importance of the response-effect trait dichotomy in marine benthic ecology has garnered recent attention. Response traits, characterising species responses to environmental variations, have been a dominant focus in the development of ecological indicators for ecosystem health assessment. In contrast, effect traits, expressing effects of organism activities on the ecosystem, still do not benefit from an equal interest in spite of the complementary facet that they provide to complete our understanding of functional diversity and ecosystem vulnerability. In this study, we explore the consequences of disturbance by bottom trawl fisheries on benthic effect trait composition. To this end, we use different contexts of environmental and trawling conditions from thirteen case studies in European waters and apply the same analytical procedure to derive a gradient that solely account for trawling-induced disturbance (Partial RLQ analysis). Bottom trawling was found to be a selective force of benthic effect trait composition in a majority of case studies. In general, tube-dwelling species were more typical of low trawling frequencies, whereas deep burrowing species were more resistant at high trawling frequencies. Although we report significantly deleterious effects of trawling on benthic ecosystem functions, the effect trait pattern along the gradient was never related to life span, a key response trait generally assumed to express recoverability following disturbance. Furthermore, we show that trends in species multi-functionality and community functional diversity can be negative or positive along the trawling intensity gradient. We discuss the relevance of these results in light of recent developments in the framework of response and effect trait dichotomy, and provide guidelines of trait data analysis in context of trawl fisheries impact on the sea floor.

### The ABIOMMED Project: Portfolio of alternative measures to reduce pressures on the seafloor with key examples

Tommaso Russo

The modelling approaches applied in subtask 3.3.1 (Exploring alternative measures for reducing the fishing impact on the sea floor with spatially explicit models) of the ABIOMMED project simulated the application and estimated the potential effects of different management scenarios, based on combinations of networks of existing and/or new spatial closures. The work focuses on bottom trawling fleets in four different areas of the Mediterranean Sea. Two modelling frameworks to assess the effects of different spatial-based measures for the management of bottom trawling were applied. In both cases, the identification of fishing pressures on benthic habitats was based on the analysis of AIS, VMS, and Logbook data at the scale of individual vessels. The first modelling framework, inspired by the work carried out in the WKTRADE, represents a spatial analysis of fishing effort, resources productivity (i.e. the spatial LPUE) and of the main economic indicators associated with the observed exploitation patterns. This ultimately allows us to rank the spatial units and explore the "internal structure" of each fishery: where are located the main fishing grounds. This "static" analysis of the bottom otter trawling, based on individual VMS and Logbook data, was aimed at prioritizing the different areas to support the identification of the best trade-off between seafloor protection and economic sustainability of fishing activities. The second modelling approach deals with the estimation of the potential effects of different management scenarios, based on combinations of networks of existing and/or new spatial closures within the five case studies. The displacement of fishing efforts in alternative areas was also explored. This also allowed us to gain insight into the redistribution of catch by species as a consequence of the different management scenarios. These simulation-based methods provide indications (and warnings) of possible consequences (including negative ones such as increased fishing mortality for some stocks) that might be associated with the different scenarios explored. The economic outcome of the analyzed scenarios was significantly different depending on the case study. The explored scenarios demonstrate that 'one size does not fit all' and in addition to universal measures, further combinations of measures with national variations will be required (e.g. FRAs, MPAs, and spatial bans) to reach these targets, as well as the MSFD and Nature Restoration Law targets of achieving Good Environmental Status and/or where needed restoring degraded habitats. Taking into account redistribution of effort (or restricting this) would be critical to affording protection to habitats under consideration.

### Results of the BH1 application to the benthic habitats of the Western Mediterranean in the framework of the MSFD

Maria Teresa Farriols, Belén Calero, Elena Guijarro & Enric Massutí

Sentinels of Seabead (BH1) has been chosen as an indicator to assess benthic habitats condition in the Marine Strategy Framework Directive (Serrano *et al.* 2022). Sentinel Species are the most representative species sensitive to bottom trawling in non or low impacted areas. We have estimated the Sentinel of Seabed indicator for the benthic habitats of the Levantino-Balear Demarcation in the Western Mediterranean. In order to do that we have used standardized biomasses of epibenthic species proceeding from MEDITS bottom trawl scientific surveys during the period 2014 to 2021 and the Swept Area Ratio (SAR) obtained from VMS and logbook data during the period 2010–2021 in the area. Generalized Additive Models have been used to calculate state-pressure curves and elaborate prediction maps considering the proportion of Sentinel species and SAR in each Broad Habitat Type (BHT) obtained from EMODNET. Offshore Circalittoral Sand was the habitat showing highest sensitivity whereas Circalittoral Sand showed the lowest. Both Circalittoral Mixed Sediment and Circalittoral Coarse Sediment did not show significant resultsfor state-pressure curves. In general, we obtained a good correlation between proportion of Sentinel Species and fishing effort with higher proportion of Sentinel Species in low impacted areas. Lower fishing effort and higher proportion of Sentinel Species were obtained in the Balearic Islands compared to the Iberian Peninsula. We could not apply the BH1 to all BHT due to the scarce number of samples available in some of them. However, it should be taken into account that MEDITS surveys sampling strategy is designed to assess demersal resources and not to respond to this indicator.

Serrano, A., de la Torriente, A., Punzón, A., Blanco, M., Bellas, J., Durán-Muñoz, P., Murillo, F. J., Sacau, M., García-Alegre, A., Antolínez, A., Elliott, S., Guerin, L., Vina-Herbón, C., Marra, S., & González-Irusta, J. M. (2022). Sentinels of Seabed (SoS) indicator: Assessing benthic habitats condition using typical and sensitive species. Ecological Indicators, 140: 108979

# Annex 1: List of participants

| Name | Institute | Country | Email |
|---|---|---|---|
| Alice Sbrana | UNIROMA | Italy | alice.sbrana@uniroma2.it |
| Belén Calero | IEO | Spain | belen.calero@ieo.csic.es |
| Clare Bradshaw | Stockholm University | Sweden | clare.bradshaw@su.se |
| Clement Garcia | CEFAS | UK | clement.garcia@cefas.gov.uk |
| Daniel van Denderen | DTU Aqua | Denmark | pdvd@aqua.dtu.dk |
| Gert Van Hoey | ILVO | Belgium | gert.vanhoey@ilvo.vlaanderen.be |
| Jan Geert Hiddink | Bangor University | UK | j.hiddink@bangor.ac.uk |
| Joanna Desmidt | ILVO | Belgium | Joanna.Desmidt@ilvo.vlaanderen.be |
| José Manuel González Irusta | IEO | Spain | jmanuel.gonzalez@ieo.csic.es |
| Karline Soetaert | NIOZ | Netherlands | Karline.Soetaert@nioz.nl |
| Laura Seidel | Stockholm University | Sweden | laura.seidel@su.se |
| Lorna McKellar | Bangor University | UK | lorna.mckellar@bangor.ac.uk |
| Luke Batts | Marine Institute | Ireland | luke.batts@marine.ie |
| Maria Teresa Farriols | IEO | Spain | mt.farriols@ieo.csic.es |
| Marija Sciberras | Heriot-Watt University | UK | m.sciberras@hw.ac.uk |
| Mats Blomqvist | HAFOK | Sweden | mb@hafok.se |
| Matteo Stefani | UNIROMA | Italy | matteo.stefani.42@gmail.com |
| Mattias Sköld | Swedish University if Agricultural Sciences | Sweden | mattias.skold@slu.se |
| Neve McCann | Marine Institute | Ireland | nmccann@marine.ie |
| Olivier Beauchard | NIOZ | Netherlands | olivier.beauchard@nioz.nl |
| Pascal Laffargue | IFREMER | France | pascal.laffargue@ifremer.fr |
| Philip Boulcott | Marine Scotland | UK | philip.boulcott@gov.scot |
| Pierluigi Carbonara | COISPA | Italy | carbonara@fondazionecoispa.org |
| Sandrine Vaz | IFREMER | France | Sandrine.Vaz@ifremer.fr |
| Sebastian Valanko | ICES |  | sebastian.valanko@ices.dk |
| Tommaso Russo | UNIROMA | Italy | tommaso.russo@uniroma2.it |
| Walter Zupa | COISPA | Italy | zupa@fondazionecoispa.org |

| | | | |
|---|---|---|---|
| Andrea Pierucci | European Commission | | Andrea.PIERUCCI@ec.europa.eu |
| Alessandra Nguyen Xuan | ISPRA | Italy | alessandra.nguyenxuan@isprambiente.it |
| Chris Smith | HCMR | Greece | csmith@hcmr.gr |
| Dr Cristina Vina-Herbon | JNCC | UK | cristina.herbon@jncc.gov.uk |
| Elena Guijarro Garcia | IEO | Spain | elena.guijarro@ieo.csic.es |
| Hatice Onay | Recep Tayyip Erdogan University | Turkey | hatice.bal@erdogan.edu.tr |
| Irini Tsikopoulou | HCMR | Greece | itsikopoulou@hcmr.gr |
| Jochen Depestele | ILVO | Belgium | jochen.depestele@ilvo.vlaanderen.be |
| Justin Christopher Tiano | Wageningen Marine Research | Netherlands | Justin.Tiano@wur.nl |
| Kate Morris | Heriot-Watt University | UK | kjm2001@hw.ac.uk |
| Klaus Jürgens | Leibniz Institute for Baltic Sea Research | Germany | klaus.juergens@io-warnemuende.de |
| Maria Cristina Mangano | SZN | Italy | mariacristina.mangano@szn.it |
| Megan Parry | JNCC | UK | Megan.Parry@jncc.gov.uk |
| Nadia Papadopoulou | HCMR | Greece | nadiapap@hcmr.gr |
| Nadescha Zwerschke | Greenland Climate Research Centre | Greenland | nazw@natur.gl |
| Porzia Maiorano | University of Bari | Italy | porzia.maiorano@uniba.it |
| Marina Pulcini | ISPRA | Italy | marina.pulcini@isprambiente.it |
| Renato Mamede | University of Aveiro | Portugal | renatomamede@ua.pt |
| Ruth Parker | CEFAS | UK | ruth.parker@cefas.gov.uk |
| Giada Riva | University of Padua | Italy | giada.riva@studenti.unipd.it |
| Jacob Bentley | Natural England | UK | Jacob.Bentley@naturalengland.org.uk |
| Melanie Hartley | Natural England | UK | Melanie.Hartley@naturalengland.org.uk |

# 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 | 21–25 November | Sete, France | | |
| Year 2023 | 20–24 November | Tvarminne, Finland | Final report by 15 January 2024 to SCICOM | |

## ToR descriptors

| TOR | DESCRIPTION | BACKGROUND | SCIENCE PLAN TOPICS ADDRESSED | DURATION | EXPECTED DELIVERABLES |
|---|---|---|---|---|---|
| a | **REGIONAL ASSESSMENTS**<br>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.<br>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.<br>Year 2: Updating of the regional and sub-regional assessments for the different regions.<br>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**<br>Explore and potentially implement options to improve the | These updates can focus on following aspects: E.g. through; i) standardisation of benthos data sampled with different gears, ii) | 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 |

| | | | | | |
|---|---|---|---|---|---|
| | parameterisation of the WGFBIT seafloor assessment framework components, in shallow waters and deep-sea areas. | development of 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 | | | regional assessments. If appropriate progress or results, research paper(s) will be conducted. |
| c | **WGFBIT AND THE WIDER WORLD**<br>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**<br>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). Priortity 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 biogeo-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. |

# Annex 3: Advice sheet template

## ICES seafloor assessment of mobile bottom fishing: XXYY ecoregion

### Assessment summary

This is an assessment of [Mobile bottom-contacting fishing] for the [VV] ecoregion by broad scale habitat type. The assessment is based on [Vessel Monitoring by satellite (VMS) fishing] data and follows the methods described in [ICES (2022a).].

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'.

**<u>KEY signals:</u>** Mobile bottom-contacting fishing is the [single most widespread activity on the seafloor] in the ecoregion, with [xx] of the 0-200m assessed fishing cells having more than [xx] of their area within the footprint of fishing, and [xx] for 200-800m. By setting an arbitrary impact threshold of [xx] for this assessment, the proportion of broad scale habitat in the regions found to be below threshold state due to fishing abrasion within the 0-200m depth is [xx]. Assessment data is not currently available for the 200-800m depth range (accounting for [xx] of the ecoregion by area). Other important pressure causing activities in this ecoregion are [XX], [YY] and [ZZ], but their impact is only a fraction of that of bottom fisheries (ICES 2019). References to the full assessment 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). Grey areas are not analysed/assessed - areas deeper than 200m are masked-out due to the lack of longevity parameterisation.

**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 untrawled (+-CI) | Mean SAR (+-CI) | Fraction SAR>[X] (+-CI) | Mean Impact (+-CI) | Fraction with impact 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. An example is below ]

**Ecoregion**: The Greater North Sea ecoregion includes the North Sea, English Channel, Skagerrak, and Kattegat. It is a temperate coastal shelf sea with a deep channel in the northwest, a permanently thermally mixed water column in the south and east, and seasonal stratification in the north.

**Pressure:** Mobile bottom-contacting fishing pressures varies spatially across the ecoregion (Figure 1a) with xx% of the grid cells untrawled in the depth zone [range]m and xx% in [range]m. The depth [range]m is fished on average xx SAR per year. Only xx% of the grid cells (0 – 800m) are untrawled and xx% of this area is fished with [> 0.5 SAR] per year (Table 1).

**Sensitivity:** The sensitivity of the [xx] is highest in the [xx] and lowest in [xx]. The [xx] is less sensitive mainly due to the occurrence of habitat types that are resilient to prevailing natural disturbance from tidal waves and storms.

**Impact (key signal):** Within [range]m depth, xx% of the assessed area, due to fishing abrasion, was below threshold state. Assessment data is not currently available for the [xx]m depth range (accounting for xx% of the ecoregion by area).

**Impact (wider commentary on state):** The MSFD habitat type in [year] that experiences highest fishing pressure and impact, with xx% of its area below threshold, is [xx] ( Table 1). Fishing pressure in this habitat type is [adjective] distributed, with xx% of this habitat type experiencing [SAR>0.5]. This broad scale habitat type represents xx% of the Greater North Sea. Fishing pressure within [xx], mainly composing [xx] fisheries, is widely distributed, with xx% of the area experiencing [SAR >0.5].

**Trends of note:** Average fishing intensity and average fishing impact have [xx] since [xx] for the [xx] most common broad scale habitat types. However, the proportion of broad scale habitats with an impact greater that the [xx] threshold has [change] from [years]. The fishing intensity in [habitat type] has [change] since [year].

## 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 4: Example advice sheet

## ICES seafloor assessment of mobile bottom fishing: Greater North Sea Ecoregion

## Assessment summary

This is an assessment of mobile bottom fishing for the Greater North Sea Ecoregion by broad scale habitat type. The assessment is based on Vessel Monitoring by satellite (VMS) fishing data up to 2022 and follows the methods described in ICES (2022a).

**<u>KEY signals:</u>** Mobile bottom-contacting fishing is the single most widespread activity on the seafloor in the ecoregion, with 45% of the 0–200m assessed fishing cells having more than 50% of their area within the footprint of fishing, and 15% for 200–800m. By setting an arbitrary impact threshold of 0.2 for this assessment, the proportion of broad scale habitat in the regions found to be below threshold state due to fishing abrasion within the 0–200m depth is 0.16. Assessment data is not currently available for the 200–800m depth range (accounting for 10% of the ecoregion by area). Other important pressure causing activities in this ecoregion are aggregate dredging and wind farm construction, but their impact is only a fraction of that of bottom fisheries (ICES 2019). References to the full assessment can be found below under 'Format of the assessment'.

### Assessment results

### Status in year 2022

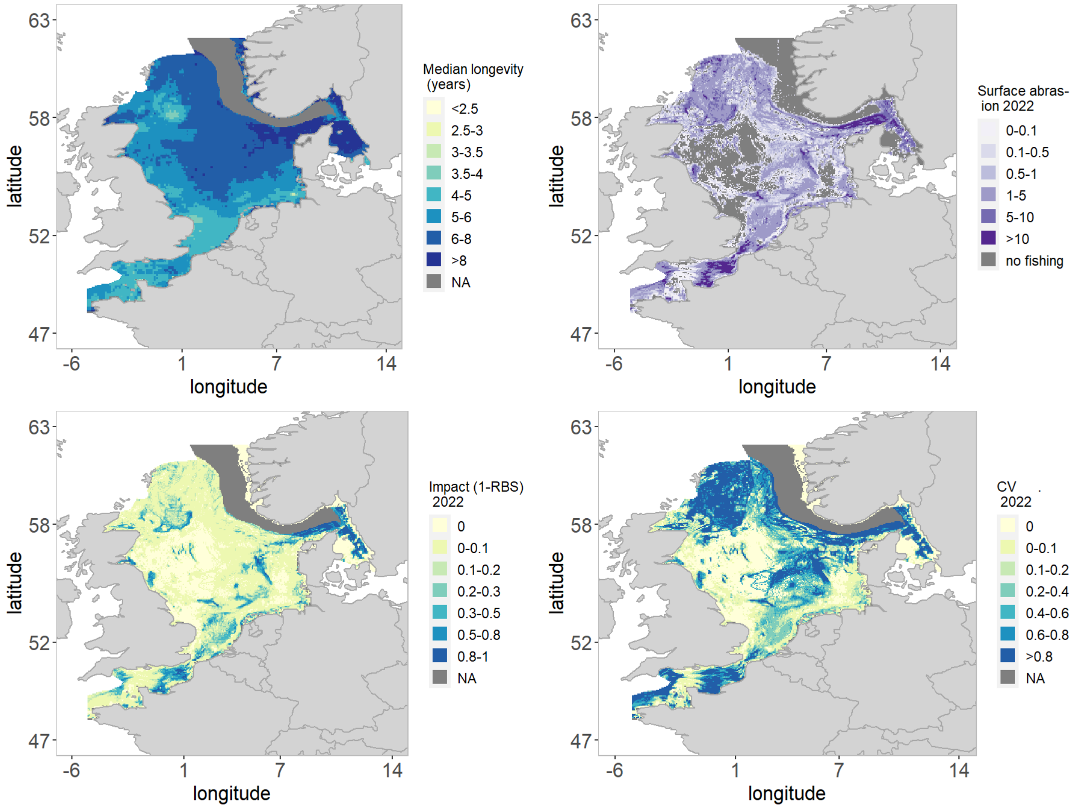


**Figure 1** Assessment results for the Greater North Sea Ecoregion. Sensitivity (a), pressure (b) and impact (c) with uncertainty of estimate presented as the coefficient of variation CV (d). The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2021). Grey areas are not analysed/assessed - areas deeper than 200m are masked-out due to the lack of longevity parameterisation.

**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 2022a). n/a = not analysed.

| MSFD broad habitat types | Area km$^2$ (fraction of total) | Fraction untrawled (+-CI) | Mean SAR (+-CI) | Fraction SAR > 0.5 | Mean Impact (+-CI) | Fraction with impact below threshold |
|---|---|---|---|---|---|---|
| 0-200m | | | | | | |
| Offshore circalittoral sand | 239 (0.34) | 0.29 | 1.5 (0.05) | 0.41 | 0.09 (0.0023) | 0.91 |
| Offshore circalittoral mud | 105 (0.15) | 0.07 | 2.6 (0.07) | 0.75 | 0.19 (0.0052) | 0.65 |
| Offshore circalittoral coarse sediment | 76 (0.11) | 0.14 | 2.6 (0.15) | 0.56 | 0.12 (0.0044) | 0.77 |
| Circalittoral sand | 72 (0.1) | 0.21 | 1.7 (0.1) | 0.48 | 0.11 (0.0041) | 0.83 |
| Circalittoral coarse sediment | 30 (0.04) | 0.35 | 1.8 (0.16) | 0.27 | 0.09 (0.0049) | 0.89 |
| Infralittoral sand | 14 (0.02) | 0.57 | 1.5 (0.16) | 0.25 | 0.08 (0.0059) | 0.91 |
| Other | 32 (0.05) | 0.47 | 0.8 (0.04) | 0.26 | 0.07 (0.0028) | 0.86 |
| **Total 0-200m** | **639 (0.9)** | **0.3** | **1.7 (0.04)** | **0.45** | **0.1 (0.0019)** | **0.84** |
| 200-800m | | | | | | |
| Upper bathyal sediment | 61 (0.09) | 0.71 | 0.6 (0.07) | 0.17 | n/a | n/a |
| Other | 4 (0.01) | 0.97 | 0.1 (0.02) | 0.01 | n/a | n/a |
| **Total 200-800m** | **69 (0.1)** | **0.73** | **0.6 (0.06)** | **0.15** | **n/a** | **n/a** |

### Time trends

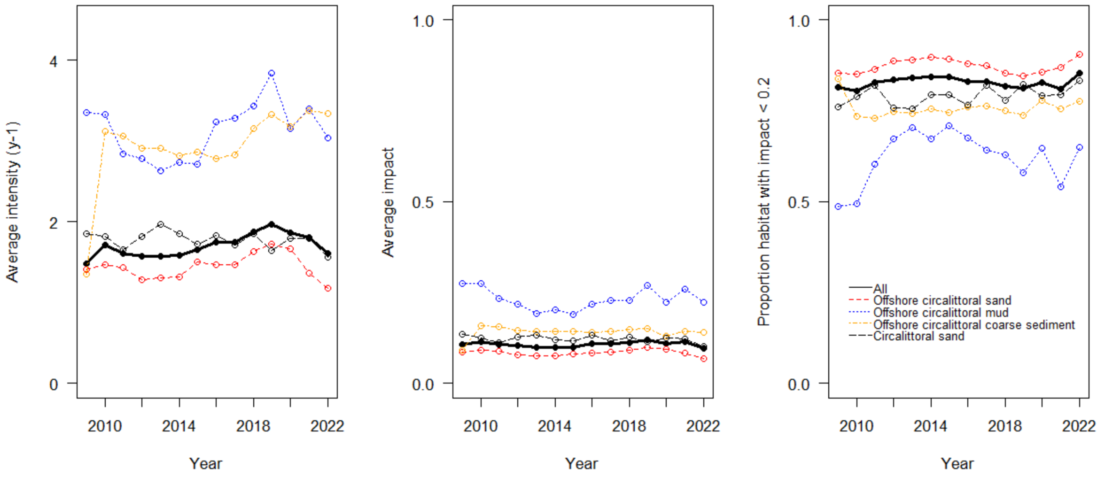


**Figure 2** Temporal trends for the Greater North Sea Ecoregion. (a) Pressure presented as abrasion for the four most common habitat types and total area over time, (b) mean impact for the four most common habitat types and total by time, and (c) fraction below the 0.2 threshold impact, for each habitat type and total, by time. The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2022a).

## Interpretation of results

**Ecoregion:** The Greater North Sea ecoregion includes the North Sea, English Channel, Skagerrak, and Kattegat. It is a temperate coastal shelf sea with a deep channel in the northwest, a permanently thermally mixed water column in the south and east, and seasonal stratification in the north.

**Pressure:** Mobile bottom-contacting fishing pressures varies spatially across the ecoregion (Figure 1a) with 10% of the grid cells untrawled in the depth zone 0-200m and 90% in 200–800m. The depth zone 0–200m is fished on average 1.7 SAR per year. Only xx% of the grid cells (0–800m) are untrawled and xx% of this area is fished with > 0.5 SAR per year (Table 1).

**Sensitivity:** The sensitivity of the Greater North Sea is highest in the northeaster North Sea and Kattegat and lowest in the southern North Sea. The southern North Sea is less sensitive mainly due to the occurrence of habitat types that are resilient to prevailing natural disturbance from tidal waves and storms.

**Impact (key signal):** Within 0-200m depth, 16% of the assessed area, due to fishing abrasion, was below threshold state. Assessment data is not currently available for the 200-800m depth range (accounting for 10% of the ecoregion by area).

**Impact (wider commentary on state):** The MSFD habitat type in 2021 that experiences highest fishing pressure and impact, with 35% of its area below threshold, is offshore circalittoral mud (Table 1). Fishing pressure in this habitat type is widely distributed, with 75% of this habitat type experiencing SAR > 0.5. This broad scale habitat type represents 15% of the Greater North Sea. Fishing pressure within offshore circalittoral mud, mainly composing Nephrops fisheries, is widely distributed, with 75% of the area experiencing SAR > 0.5. Offshore circalittoral coarse sediment is the second most impacted habitat type.

**Trends of note:** Average fishing intensity and average fishing impact have decreased since 2019 for the four most common broad scale habitat types. However, the proportion of broad scale habitats with an impact greater that the 0.2 threshold has increased from 2021 to 2022. The fishing intensity in offshore circalittoral coarse sediment has increased since 2016. Fishing intensity in offshore circalittoral mud has been lower in 2020 and 2021 compared with 2019.

## Validity and limitations

Sensitivity and impact have not been calculated for grid cells > 200m depth because of data unavailability.

Temporal patterns in fishing activity are available from 2009 for vessels over 15m and from 2012 for vessels over 12m. Temporal variation in fishing activity hence represents vessels over 15m (2009-2011) and vessels over 12m (2012-2018).

Model validation is in an early stage but has been performed for Kattegat, the coastal area in the southern North Sea and Brown Bank. Further information can be found in ICES (2022b).

## Format of the assessment

This seafloor assessment of the Greater North Sea Ecoregion consists of this PDF assessment text, the technical guideline report (ICES 2022a) and a series of interactive maps, figures, tables, and text (ICES 2021).

The scripts used to produce the assessment are available: https://github.com/ices-eg/FBIT

## 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.

ICES. 2021. ICES advice to the EU on how management scenarios to reduce mobile bottom fishing disturbance on seafloor habitats affect fisheries landing and value. *In* Report of the ICES Advisory Committee, 2021. ICES Advice 2021. sr.2021.08. https://doi.org/10.17895/ices.advice.8191.

ICES. 2022a. 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

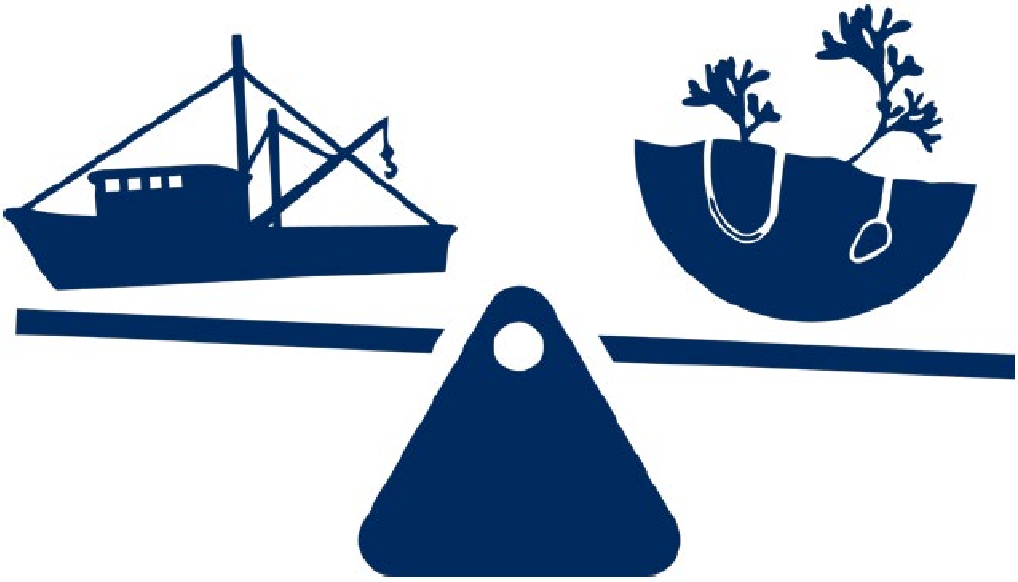
ICES 2022b. Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT; outputs from 2021 meeting). ICES Scientific Reports. 4:9. 133 pp. http://doi.org/10.17895/ices.pub.10042

ICES. 2022c. Working Group on Fisheries Benthic Impact and Trade-offs – Sete

# Annex 5: Draft Technical Guidelines document for assessing fishing impact from mobile bottom-contacting fishing gears. Version 3.0

## Draft Technical Guidelines document for assessing fishing impact from mobile bottom-contacting fishing gears.

## Version 3



**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. 2024. Technical Guidelines document for assessing fishing impact from mobile bottom-contacting fishing gears (version 3.0, 05/02/2024). *within*: Report from the Working Group on Fisheries Benthic Impact and Trade-Offs (WGFBIT)

# 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 draft technical guidelines for an assessment framework that can be used to assess the state of these more widespread habitats and communities (**Figure 1**). 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** 1). 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.

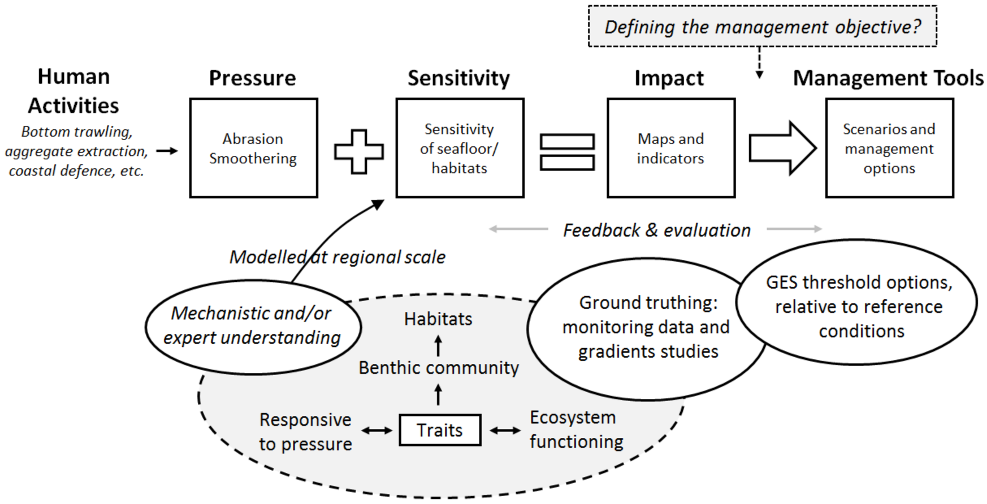


**Figure 1. Conceptual diagram of the steps taken in developing management tools for assessing pressure and impact on the seafloor from human activity.**

# 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 2). 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.

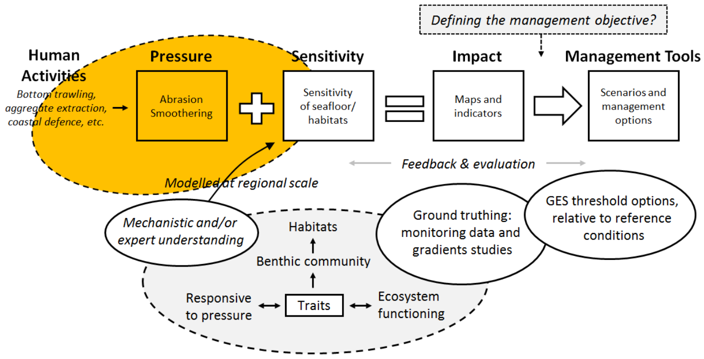


**Figure 22. Conceptual diagram of the steps taken in developing management tools for assessing pressure and impact on the seafloor from human activity. Pressure part is highlighted in orange.**

## 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 1.

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:

$$SA = \sum evw \tag{1}$$

for Danish seines as:

$$SA = \sum(\pi(w2\pi)^2(e/2.591234)) \tag{2}$$

and for Scottish seines as:

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

where $SA$ is the swept-area, $\pi$ the number pi, $e$ is the time fished (h), $w$ is the total width (m) of the fishing gear (gear group) causing abrasion (Table 1), and $v$ is the average vessel speed during fishing (m/h; Table 1).

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:

$$SAR = SA/CA \tag{4}$$

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 1. 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 seines | SDN_DMF | $1948.8347\ kW^{0.2363}$ | 6536.64 | 5 | NA |
| | 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 2). 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 2. 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 3). 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.

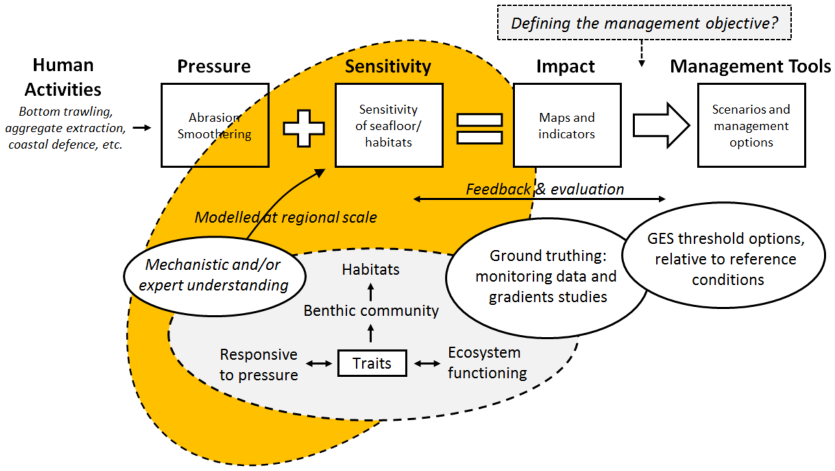


**Figure 3. Conceptual diagram of the steps taken in developing management tools for assessing pressure and impact on the seafloor from human activity. Sensitivity part is highlighted in orange.**

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 4**. 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** 4A), and a region and habitat-specific estimate of the longevity distribution of benthic biota (**Figure** 4B) that is used to derive the recovery rate in **Figure** 4A. Together with the pressure (section 2), this sensitivity leads to an estimate of the impact (**Figure 4**). The sections below explain how these are derived and applied.

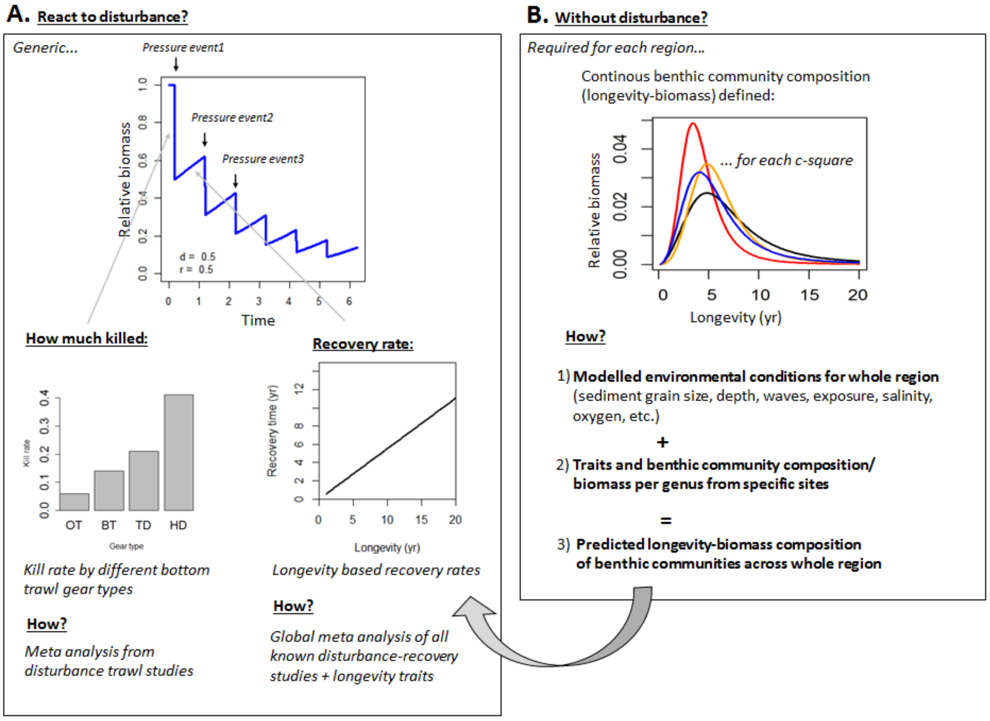


**Figure 4. A flow diagram of how data layers and relationships derived from synthesis and analysis of the literature are combined to determine RBS (Relative Benthic Status) in the FBIT framework.**

## 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** 4A). 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 5), and sensitivity to trawling depends on the ratio of d over r, and is therefore proportional to the reciprocal of the recovery rate r.

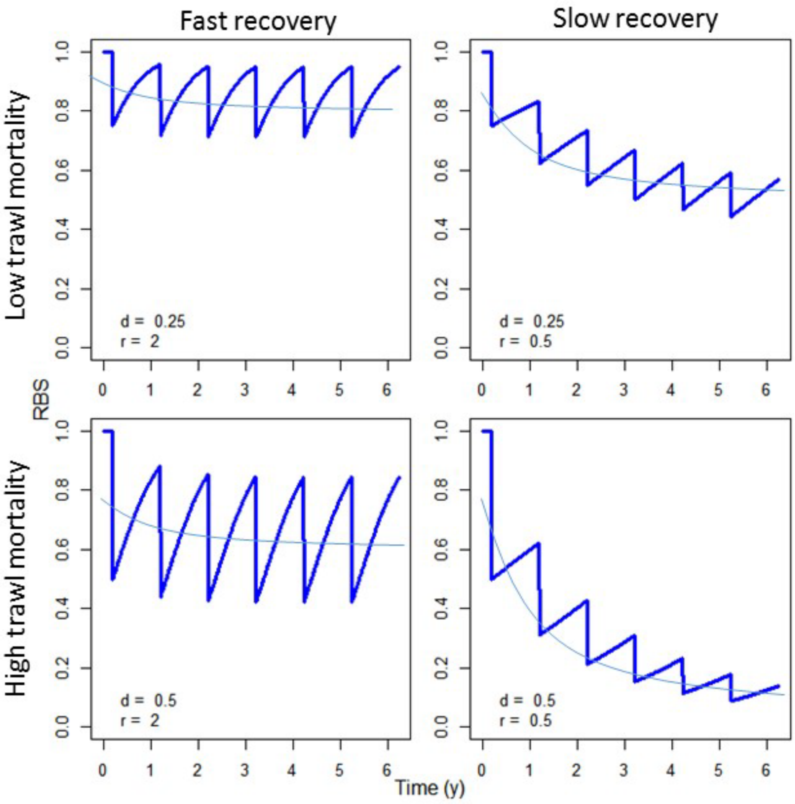


**Figure 5. The effect of trawling depends on the trawl mortality (depletion *d*) and the recovery rates (*r*) of the benthic community. In this example, trawling occurs once a year, and after trawling recovery of the relative benthic state (RBS) occurs.**

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 6, Hiddink *et al.*, 2020).

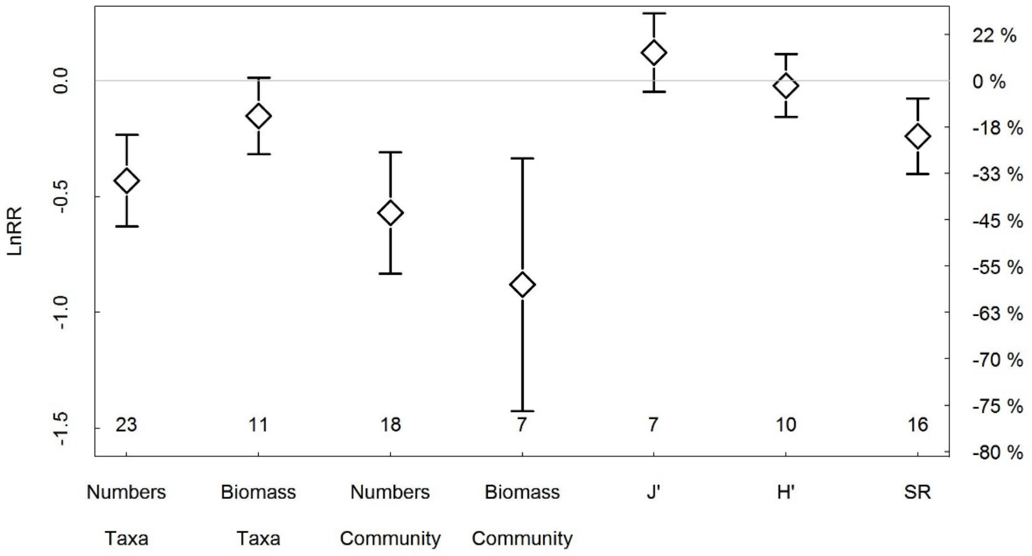


**Figure 6. Outputs of the meta-analysis of control-impact studies with 95% confidence intervals. If the 95% confidence interval overlaps 0 the effect was not significant. The right-hand axis gives % changes for ease of interpretation. J': Evenness, H': Shannon-Wiener diversity index, SR: species richness (from Hiddink *et al.*, 2020).**

### 3.2.2. Depletion, *d*

This section explains how we estimated values for 'How much killed' in **Figure 4**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 7) (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.

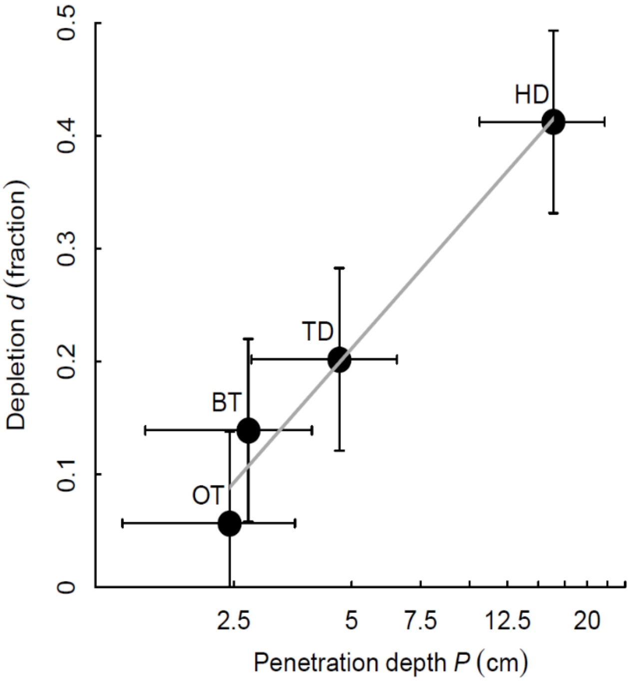


**Figure 7. The relationship between the penetration depth P and depletion d of macrofaunal community biomass and numbers caused by a single trawl pass for different trawl gears (means ± SD) (Hiddink *et al.*, 2017).**

FBIT assessments originally used the *d* estimates presented in Figure 7 by mapping the different metiers available in the ICES VMS database (Table 3) 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 7. These 10 metiers follow the groupings available in the ICES VMS database and are currently used to estimate metier-specific depletion (Table 3). 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 3. 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 $\mathrm{T}_{\max}$ 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 4**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 8).

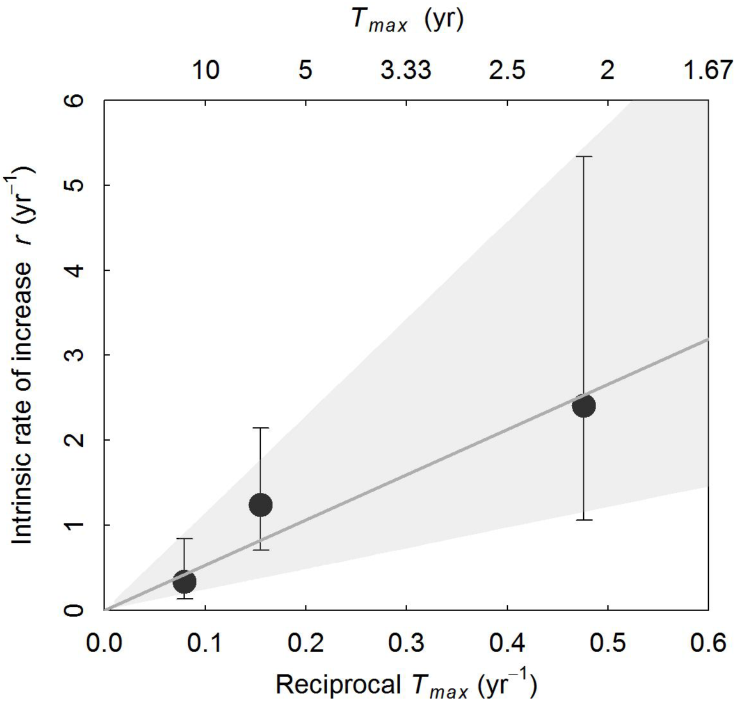


**Figure 8. Relationship between *r* and longevity $T_{max}$ estimated from gradient studies (*r* = 5.31 / longevity, $R^2 = 0.96$, $F_{1,1}$ = 73.9, P = 0.013). The points and error bars are *r* estimates and their 95% confidence intervals, while the solid line is the fitted regression line. The shaded 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 9 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 9a). 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 9b). This results in sensitivity of habitats to bottom trawling being higher in habitats with higher proportions of long-lived organisms (Figure 9). 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.

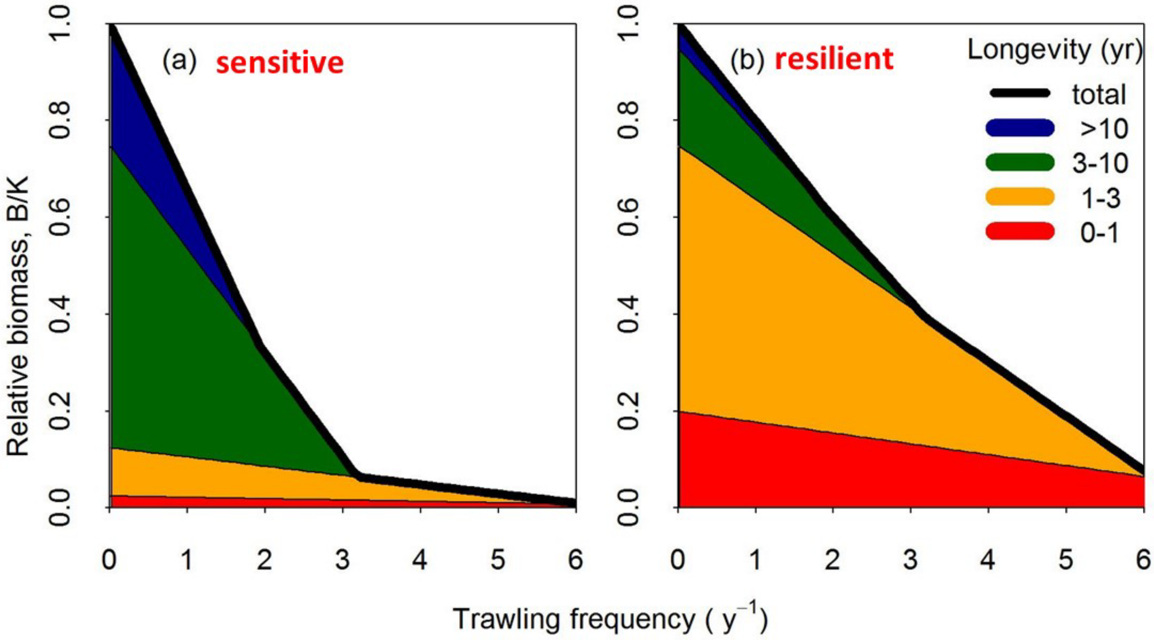


**Figure 9. An example of how the longevity distribution of a benthic community at no trawling affects the response of total community biomass to bottom trawling.**

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 4**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.

FBIT 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 10).

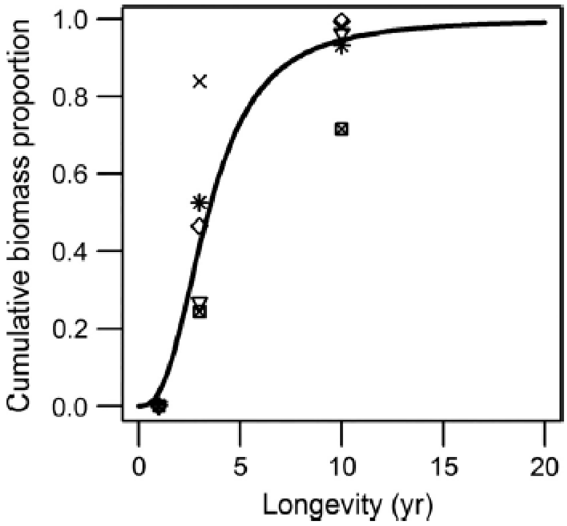


**Figure 10. An example of the cumulative biomass–longevity relationship estimated from the observed cumulative biomass by longevity class (1, 1–3, 3–10 yr) in five sampling stations. Different symbols indicate the five different locations. Figure taken from Rijnsdorp *et al.* (2018).**

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 ($\varepsilon_2$) 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.

# 4. PD-sens: an indicator for the most sensitive fraction of the community

ICES (2022) advised that regional assessments would ultimately best be carried out by applying different indicators in a complementary manner. It was further suggested to select indicators that cover different aspects of seabed habitat condition and benthic community.

The PD-sens indicator is an indicator that place more emphasis on declines of sensitive species. It is based on the FBIT methodology but only estimates the relative decline in biomass of the 10% most long-lived biomass fraction of the community (PD-sens). The indicator can be implemented in all regions where the PD is estimated. We examined the responsiveness of the indicator to 6 gradients of trawling pressure and compared it with the PD total biomass indicator and two empirically estimated indicators, SoS and long-lived fraction (ICES 2022). The latter two indicators were chosen as they were found to best identify benthic community change with increasing bottom trawling pressure. The results show that the PD-sens is typically as responsive as SoS and long-lived fraction (Figure 11).

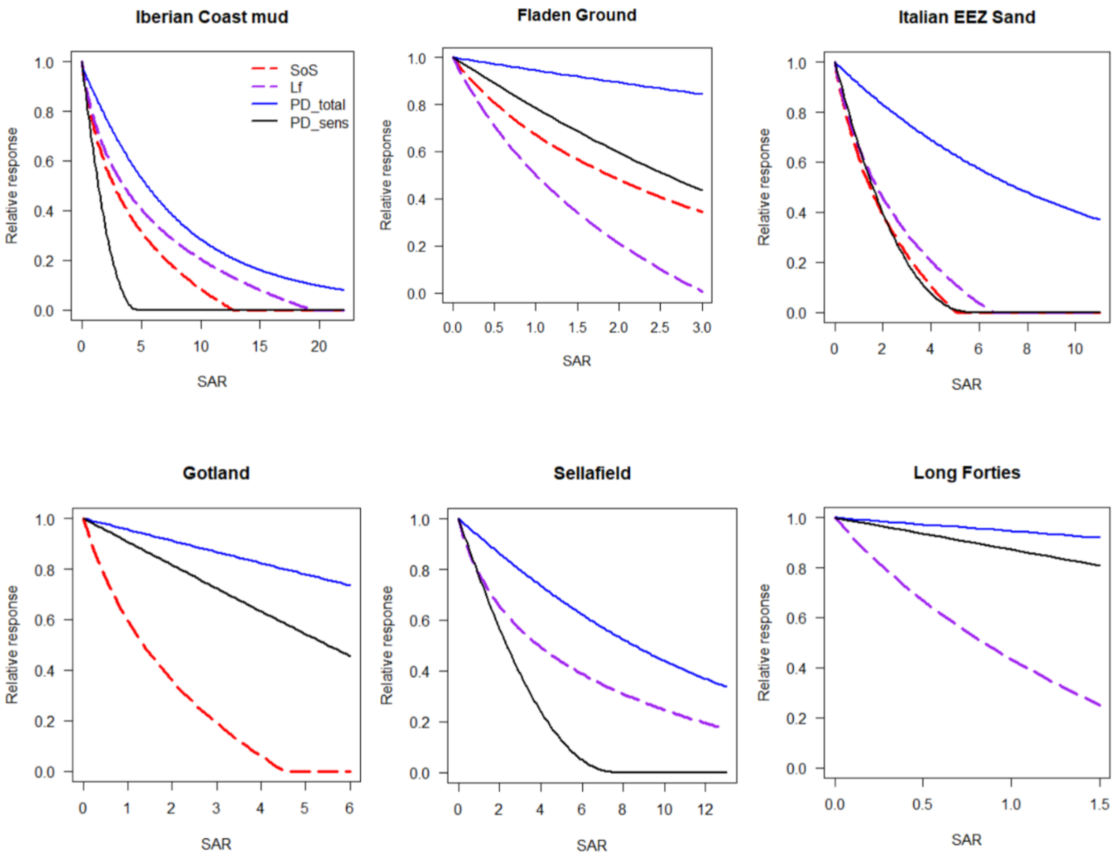


**Figure 11. Relative declines of two empirically estimated indicators (SoS and long-lived fraction) and two pressure-based indicators (PD based on total biomass and the sensitive fraction). The PD declines are estimated by calculating impact from the predicted longevity composition from all reference stations (ICES 2022). Both SoS and long-lived fraction are scaled to 1 to make the relative response comparable to the pressure-based outcomes.**

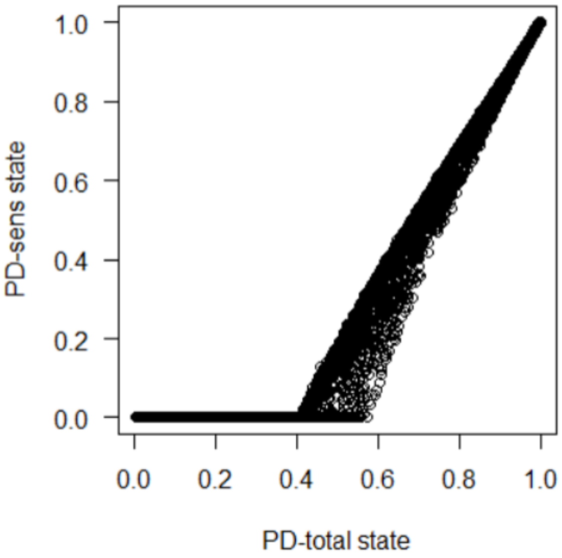


**Figure 12. Correlation plot between PD-sens, estimating the relative decline in biomass of the 10% most long-lived biomass fraction of the community, and PD-total, estimating total biomass decline for the Greater North Sea Ecoregion using ICES VMS data from 2022.**

## 4.1. 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).*

# 5. Assessment framework – Fishing impact

Fishing impact is estimated by combining information from fishing pressure (see section 2) and benthos sensitivity (see section 3); (Figure 13). 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).

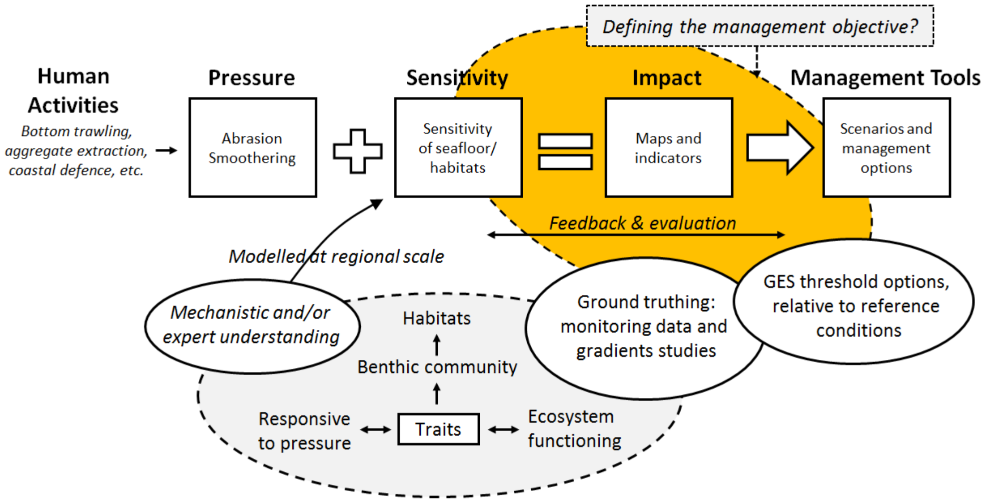


**Figure 13. Conceptual diagram of the steps taken in developing management tools for assessing pressure and impact on the seafloor from human activity. Impact part is highlighted in orange.**

## 5.1. 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 4). 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 4. 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 3), 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.

## 5.2. Running the assessment and input data

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

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

## 5.3. 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.

## 5.4. 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.

## 5.5. 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.*

# 6. Assessment framework – Trade-offs

## 6.1. 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 14).

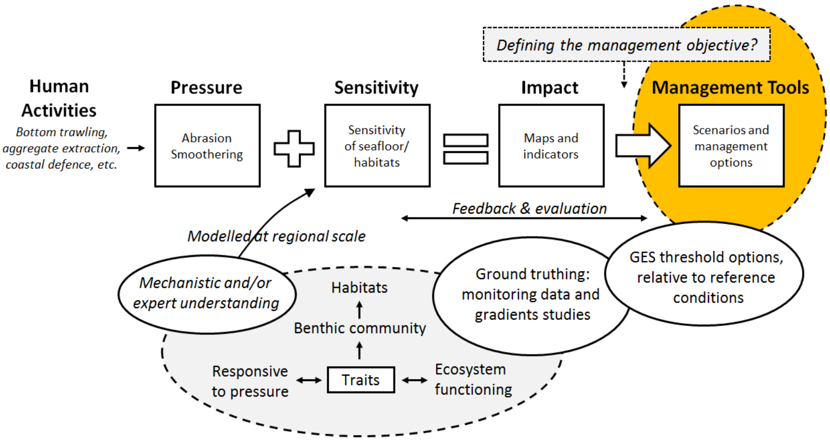


**Figure 14. Conceptual diagram of the steps taken in developing management tools for assessing pressure and impact on the seafloor from human activity. Assessment of trade-offs part is highlighted in orange.**

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 %).

## 6.2. 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).

# 7. References

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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 section 3.2 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.

# Annex 6: Report of the Review Group of FBIT products destined for the ICES Ecosystem Overviews (RGEOB)

**Mark Tasker, Judi Hewitt and Mike Elliott**
March 2024

The Review Group was asked to review draft benthic sections for four regional Ecosystem Overviews (Baltic, Greater North Sea, Celtic Seas and Bay of Biscay and Iberian Coasts) as well as the draft Technical Guidelines for making such assessments (v3).

## Draft Technical Guidelines

Overall, the draft Technical Guidelines document improves on the previous assessment methodology. However, it is highly dependent on numerical data on the activity (bottom fishing) being full and complete, and on some generally derived population dynamics and relationships between biomass and longevity used to indicate recovery. This dependency needs to be borne in mind when considering the assessments and any consequent advice. Some points:

- The draft Technical Guidelines do not give sufficient information to explain the data sheet.
- The section on VMS needs additional material to cover other forms of vessel monitoring, e.g. AIS, mobile phone reporting etc.
- The PD method is mentioned as "*strongly rooted in general concepts of population dynamics and summarizes impact across the entire benthic community with a single indicato*r". While this is backed up by some references, the concept of summarising community level impacts using population dynamics is not widespread in the ecological disturbance-recovery literature. Connectivity is more commonly seen as a controlling factor in both recovery and resilience and increasingly it is understood that a response footprint may differ from activity and stressor (ICES "pressure") footprints. This issue is acknowledged towards the end of the Guidelines: "*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*". This essentially means that a lot of effort has been put into quantifying the activity and using a population model while ignoring empirically-derived realities of disturbance-recovery ecology (e.g., connectivity, biodiversity landscape and facilitation). The RG recommends acknowledgement of this issue much earlier in the document and consideration at other places, for example just before Figure 5 r is defined as population increase. After figure 5 it is stated that it is equivalent to resilience. It is highly unlikely that either of these are not affected by connectivity. Relationships derived from fishing intensity and habitat type vary considerably in both directions.
- Introduction to PD, might mention that PD-sens is now also considered; PD-sens also missing at other points in the document where PD is considered
- Under Fishing Impact Indicator, unclear what "changes in benthic impact over continuous time" means.

- Unclear how "All habitat types associated with each C-square are considered and the relative proportion of habitat types within each grid cell is estimated." Is actually done
- Under Uncertainties in impact assessment, "A Monte Carlo approach to estimate this uncertainty in the assessment output will be implemented intersessional" is not really good enough in guidelines.
- Clarification is required on nomenclature. For example, climate change is described as a driver when it should be a pressure or, more accurately, a suite of pressures. It would also be better to use a 'socio-economic context' as Impact (on human Welfare) (I(W) in the DAPSI(W)R(M) framework) to complement State change on the natural environment. Similarly, it is better to split activities from pressures as indicated in Figure 3 which is not consistent with the text and the part of the framework DPSI/DAPSI.
- Other activities and pressures such as sea-bed mining and offshore energy generation are mentioned as being of significance in some areas; these activities and their pressures could be quantified to put fishing in context.
- The regional sea reports appear to reduce the benthos to the habitat maps and an implied assessment of the megafauna according to its longevity. It is unclear whether the sessile epifauna and the infauna are included in this assessment.
- The RG agrees that the spatial scale of the assessment strongly influences the results, especially of Indicators 2 and 5. A stronger logic for why the 0.5x0.5 c-square is usually chosen would be helpful and whether other scales could be used in other conditions.
- Habitat sensitivity is set at an ecoregion (possibly larger) scale. This will hide habitat heterogeneity (and therefore variation in sensitivity) at the smaller scale. It would be useful to assess the consequences of any such variation, as this might seriously affect the advice/ecosystem overview.
- It would be useful to describe why six years is used as the temporal scale for Indicator 5 (presumably the MSFD cycle? Or is it the similar but different HSD 6-year cycle?)
- The sentence "*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*" is long and confusing. Oyster reefs could recover if fishing was not occurring for a long enough period over a large enough area, taking into consideration connectivity (and supported perhaps by recent efforts to reseed areas of the North Sea). If the statement is not about recovery, it needs further rephrasing.
- The RG is unaware of a scientific reference that would support the phrasing on the response variable: total community biomass "*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)*". Could one be provided?
- The analysis of Figure 6 states "*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*". This is not completely true - the mean magnitude of the change for numbers of taxa (and numbers of community) are less, but also significant and less variable. The terms "taxa biomass" and "numbers community" on the x-axis of Figure 6 are unclear and need some description.
- The description of the assessment makes reference to a trawl impact model and its parameter estimates that are based on a generic understanding of trawl impacts and

applicable for any fishery. Maybe this should be rephrased to "any mobile bottom-contacting fishery"?

- The intrinsic rate of population increase r (recovery rate). This section references *Tillin et al. (2006) who demonstrated that benthic epifauna with Tmax >10yr decreased in abundance with trawling, but that no such reduction occurred for fauna in the same areas with Tmax <2yr.* This statement appears to confound longevity responses with living position in the sediment, and also probably with mobility of adults and juveniles.
- The RG is unsure as to whether "waves" cause "high levels of disturbance" in this sentence: "*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*". Rocky areas and biogenic reefs (including those that may grow in sandy areas) experience much wave impact and are not dominated by short-lived fauna.
- FAQ on benthic sensitivity. Text reading "*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.*" Successful operationalisation does not equate to validation. Most of the seafloor assessments state that validation is these other areas are still to occur. The RG recommends that this validation occurs as soon as possible.
- The RG agrees with "*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*" but would point out that management ought to be towards a return to a more functional system, that might have existed in a more immediate past, rather than a focus on a distant past. Rephrase?

## Common points on draft assessment texts

- It would be useful if Table 1 (mislabelled in at least one assessment) also had a column of mean longevity.
- A plot of the proportion of habitat below threshold (Figure 2c- although the figures need proper labelling), that there is also a plot of the inverse-proportion above the threshold. Basically, most people are really bad at doing that inversion themselves.
- There is a focus on MSFD habitats – can this be widened to include e.g. HSD habitats? Should there be an explanation of why MSFD and not e.g. EUNIS?
- Plainly there is a need to assess all benthic impacts cumulatively, and ICES is not there yet. Perhaps this needs more emphasis – as in "ICES regards this impact assessment as partial, and is aiming towards a full cumulative impact in due course"?
- The analyses all have the Impact Threshold set at an arbitrary level of 0.2 – this needs explaining in detail to make it defendable.
- In the figures, it may be better to use a broken and expanded axis for the ordinate (y-axis) to show the trends, i.e. it may be better to change the axis for each region and allow more interpretation.
- It may better for mean impact with a range to be given rather than the mean (+-CI). This is for two reasons: i) mean and CI implies statistical normality whereas min, mean, maximum gives some indication of where the mean is situated relative to the overall range (or use 10th and 90th percentiles instead); ii) an overview should make it easy for people

to see what is happening and getting them to add and subtract numbers is making them work harder than they have to.

- In Interpretation of Results it is noted that VMS data in the more coastal areas (infralittoral) are very partial in the absence of data for vessels under 12m. This would cause an underestimation (sometimes significant) of the impact values. This may be addressable to an extent by indicating the proportion of fleet under 12m.
- The absence of fishing data is assumed in places to equal no data which in turn is interpreted as leading to no impact and therefore no cv. The RG suspects this is an incorrect assumption, but the issue needs to be addressed.
- The drafts all tend to describe the data (albeit partly) rather provide explanations.
- Comparison between impacts need to state "whole ecosystem" – locally impacts may be higher from other activities than bottom trawling.
- In general, the benthos relates only to the epifauna. Hence any interpretation all depends on the quality of the benthic habitat mapping – in many areas, surveys are better inshore than offshore. In many cases, good data are available for the infaunal benthos, but these are not used.
- In all drafts, the layout and editing need improvement – for example, the scales on the maps are not self-evident and, for example, the legends do not indicate which are maps (a) to (d) and the use of the term Impact (I) is taken to be S (state change) in the DPSIR/DAPSI(W)R(M) framework.

## Bay of Biscay and Iberian Coast

The inter-country variability in supply of data in this region likely makes many results invalid. Thus, the lack of Portuguese VMS data since 2016, the discontinuity at the French/Spanish sea border and variance in reporting of the small vessel fleet, make all analyses for this region questionable. There is a statement that data prior to 2012 cannot be considered valid – yet this appears in the graphs. The RG notes also the important validation section, but is unclear as to why some of these issues have not been addressed. **The RG is of the opinion that these shortfalls mean that the analyses are not valid and cannot yet be used in advice**. The text may be useful in heavily caveated sections in the EO.

Should the ADG disagree with this, then above points need emphasis and the following points also need to be taken into account:

- The text notes a high median longevity characteristic – (>5 years) but this needs to be explained in the sheet (presumably for long-lived megafauna) and an indication given of why this should be the case in this area but not others (even though other areas are likely to have the same characteristics).
- Comparison between impacts need to state "whole ecosystem" – locally impacts may be higher from other activities than bottom trawling.

## Celtic Seas

This ecoregion shows similar trends to the Bay of Biscay even down to the anomalous trend in 2009–2010 – are the data valid before 2012 (when it was not in the BoB description)? This and other aspects need greater explanation given that the sheet mentions the data trend without giving any explanation. For example, the impact is highest in the offshore circalittoral area but is not that the area with no data?

## The analyses appear adequate and reliable enough to be used in advice

### Greater North Sea

This shows the evidence of better data sets although the Norwegian Trench is excluded (explain why – the text suggests that this is the result of the depth but does not the North Sea benthic study show this area?). Also, the text suggests a lack of longevity data but does it not exist or could they not make the same assumption as elsewhere?

More than the other three seas, there is variability in all parameters for this region. The large variability may reflect the variability in the area in the same way that the lack of variability in the other seas could be an artefact caused by high values in some sub-areas and low values in others leading to average patterns throughout. Hence, it might be better to have it separated in geographic sub-areas rather than as habitat overall.

In this region, the Offshore circalittoral mud is given as being most affected by fishing but this needs an explanation. For example, are they assuming that all habitats are affected in the same way and have the same powers of recovery? It is likely that, for example, mobile sands may recover more quickly for all disturbances than other types of habitat.

There is also the need to make sure the calculation of the area fished agrees with data in other ICES reports (e.g. indication that 85% of the Greater North Sea is fished).

In the brief Discussion, it is acknowledged that fishing intensity changes but it is only inferred that there is really an effect. They have to be sure that this really is the case and the conclusion is defendable.

## The analyses appear adequate and reliable enough to be used in advice

### Baltic Sea

All of the maps show the whole area rather than focussing on the area that is actually fished. This makes it very difficult to discern what is happening.

Hypoxic condition is often represented as mg/l rather than ml/L so we recommend providing both in the figure. Also Litre not liter.

The Table 3 column entries ‘Fraction with Impact below 0.2’ for the Baltic are all given as 1 which suggests that the whole area is like this, i.e. unimpacted – is this the case?

There is confusion regarding the habitat information – while not mentioned, it appears that this came from the EUNIS maps. Explain further what type of benthic information is included and why.

Figure 6 needs both correcting and explaining to allow greater interpretation and interrogation. For example, despite the fishing intensity decreasing markedly with time, with the scales used there is apparently no change in average impact unless the scale is misleading. Similarly, there is no change in the proportion of habitat with a given impact (again it is assumed which are (a), (b), (c) mentioned in the title) – if they used a suitable scale then a time-trend might be seen. If the graphs in all assessments have the same scale then there will be a loss of information.

Given the above, in the paragraph on Interpretation, they should indicate that the average impact does not reflect the effect of the decline in fishing (with the scales drawn as they are but this may be misleading).

In Validity and Limitations, the two sentences in paragraph 1 say the same thing and so the text could be shortened and simplified. Describe why the assumptions for 2 of the areas (Gotland Basins and Southern Baltic in Polish waters) should hold for the rest of the Baltic, given the differing characteristics of the different parts of the Sea.

Presumably there are no VMS data from Russia. Needs to mention risks from not including small vessel fleet. This though is not as big a problem as the lack of Portuguese data for the BoB&IC.

**The analyses appear adequate and reliable enough to be used in advice.**