WORKING GROUP ON FISHERIES BENTHIC IMPACT AND TRADE-OFFS (WGFBIT; outputs from 2024 meeting)

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Contents

i Executive summary

The Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT) develops methods and assessments to evaluate fisheries' benthic impact at a regional scale while considering trade-offs between fisheries and seabed health. This report summarizes progress on a European-wide assessment of bottom trawl impacts, presenting the first quantitative evaluation across the Baltic, Atlantic, Mediterranean, and Black Seas. Using indicators of seabed status—RBStot (biomass relative to fauna carrying capacity) and RBSsen (biomass of the 10% most sensitive fauna relative to carrying capacity)—significant regional and habitat differences in bottom trawling impacts were identified. Methods to differentiate between good and degraded states were further refined, including probability-based approaches for seabed condition assessment.

A roadmap was established to implement a Core Fishing Grounds Analysis (CFGA) across all EU marine regions within the 2024–2027 cycle. CFGs aim to balance sustainable fishing and environmental goals by protecting high-value fishing areas. Discussions addressed current limitations of CFGA and guidelines for defining scenarios in trade-off analyses. A preliminary exercise using Atlantic and Mediterranean data explored the effects of varying RBS values on surface area, landing value, fishing effort, and weight. Assuming RBS = 0.8 as the threshold for a "good" condition, the study assessed reductions in exploited areas and fishing efforts needed to meet EU marine targets (D6C5 Adverse Effects on Habitats).

The BFIAT (Bottom Fishing Impact Assessment Tool) model was advanced to predict trawling-induced habitat changes and their impact on biological processes like bioturbation. Case studies in the Celtic Sea, Greek waters, Baltic Sea, and Kattegat utilized datasets linking macrofauna traits to biogeochemical processes under different fishing and hydrodynamic regimes. Outputs from BFIAT are integrated with models like OMEXDIA to evaluate sediment carbon processing and with 3D models (NEMO/SPM-IOW, NEMO-ERSEM) to analyze carbon dynamics and deposition. Future work will examine the impacts of fauna reduction, sediment mixing, and carbon decay on ecosystem processes.

ii Expert group information

Expert group name	Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT)
Expert group cycle	Multiannual
Year cycle started	2024
Reporting year in cycle	1/3
Chairs	Jan Geert Hiddink, UK
	Marija Sciberras, UK
	Tommaso Russo, Italy
Meeting venue and dates	18–22 November 2024; Nantes, France (65 participants)

Summary of highlights 2024

- With 58 experts from >10 countries systematically contributing over the past 7 years, a Europe wide seafloor sensitivity to bottom trawling layer is close to completion
- This will the first Europe-wide quantitative assessment of bottom trawling effects, accounting for regional sensitivity drivers, across the Baltic, Atlantic, Mediterranean, and Black Seas. Using two indicators of seabed status—RBStot (biomass relative to seabed fauna carrying capacity) and RBSsen (biomass of the 10% most sensitive fauna relative to carrying capacity)
- Managers will need to agree what proportion of areas need to be above a quality threshold to provide essential functions such as nutrient cycling and carbon sequestration
- Experts from the Atlantic and the Mediterranean are helping to identify how to overcome various critical issues in the input data needed for trade-off analysis
- In parallel, methodologies are being consolidated for Core Fishing Ground Analysis that can be applied to all EU basins
- While preliminary assessments can be obtained at present, further work will be needed to consolidate the database and validate methodological aspects
- Together with information on fisheries economic of the fisheries, the working group is developing scenarios of management options
- In ToR D, the BFIAT model has been developed to incorporate predictions of trawling-induced habitat status changes on biological processes such as bioturbation in the WGFBIT seafloor assessment framework. Analyses are being conducted for case studies in the Celtic Sea, Greek waters, Baltic Sea, and Kattegat
- Empirical relationships between macrofauna traits and biogeochemical processes are also being explored.
- Work is underway to integrate BFIAT predictions with advanced modelling approaches to assess trawling-induced changes in sediment carbon processing and storage.

1 Regional assessments

Updates on regional assessments

Eastern Mediterranean Sea

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

This is an update of the seafloor assessment of the Greek sea areas in the Eastern Mediterranean (Eastern Ionian, Aegean and Cretan Seas). It is based on estimates of sensitivity of benthic macroinfauna, otter trawl swept area ratios based on Vessel Monitoring by Satellite (VMS) fishing data and habitat maps, and follows the methods described in ICES (2022a). The PD and RBS (1-PD) indicators were used to assess the impact of trawling to the benthic ecosystem. Validation of the PD was assessed through testing of the indicator against a new set of benthic data from the HCMR MSFD 2023 monitoring programme. In addition, the new indicator PD_{sen} was compared annually for a 6-year period with the existing PD outputs for Greek waters (ICES, 2024). The threshold used in this assessment is arbitrarily set at 0.8.

Interpretation of the results

The predicted impact of bottom trawling on total biomass loss, as estimated by the population dynamic model (PD), was compared to actual biomass data collected from sampled sites during the Greek MSFD 2023 monitoring program. The analysis revealed no statistically significant differences between the observed and predicted longevity classes (Figure 1.1). It is worth noting that the observed data, although limited, were derived from areas with minimal or no fishing activity, making them comparable to the predicted sensitivity layer representing pristine conditions.

Additionally, when a range of SAR values was applied to both the sampled and modeled longevity distributions within the RBS model, no significant differences were observed (Figure 1.1). While validation is still in its early stages, there are plans to estimate various other ecological indicators used in the Water Framework Directive (WFD) and Marine Strategy Framework Directive (MSFD) — such as AZTI's Marine Biotic Index (AMBI), multivariate AMBI (M-AMBI), and the Biotic Index (BENTIX)—and compare these results with the Relative Benthic State indicator against a gradient of trawling pressure.

Furthermore, the comparison of the PD and PD_{sen} indicators showed that PD_{sen} was approximately 10 times more sensitive across all MSFD broad habitat types (Figure 1.2). However, in nearly all cases (99.8% of the area), the indicator remained above the threshold level of 0.8

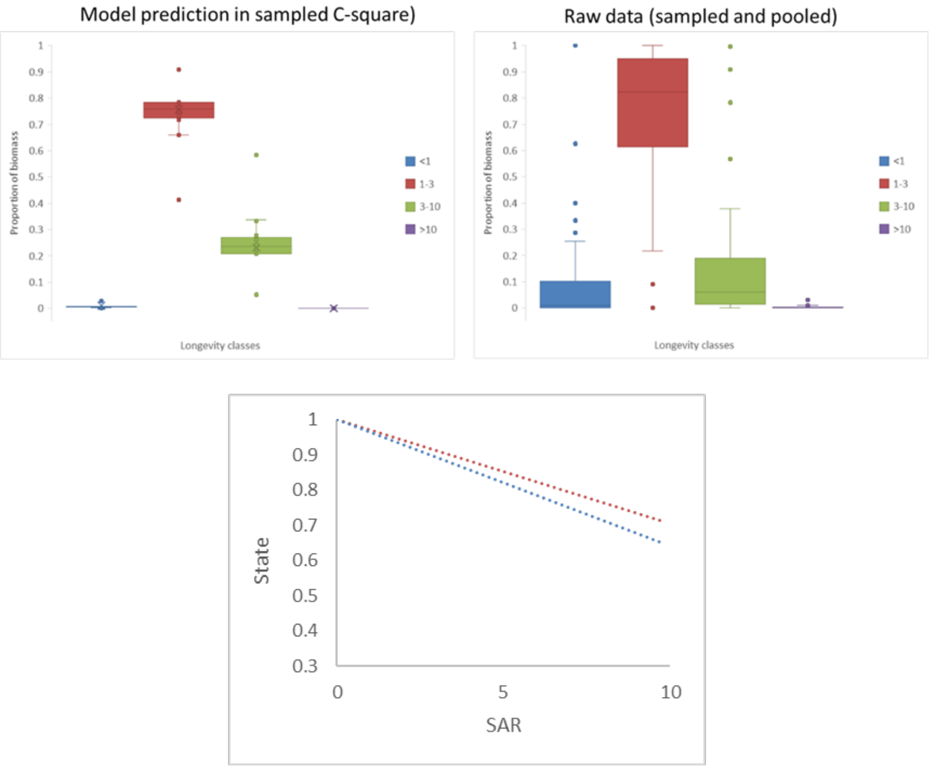


Figure 1.1. Boxplots of predicted biomass per longevity class for c-squares that overlaps with the sampling sites of the HCMR MSFD 2023 monitoring programme and state of the benthic ecosystem based on the observed versus the predicted sensitivity at different levels of SAR.

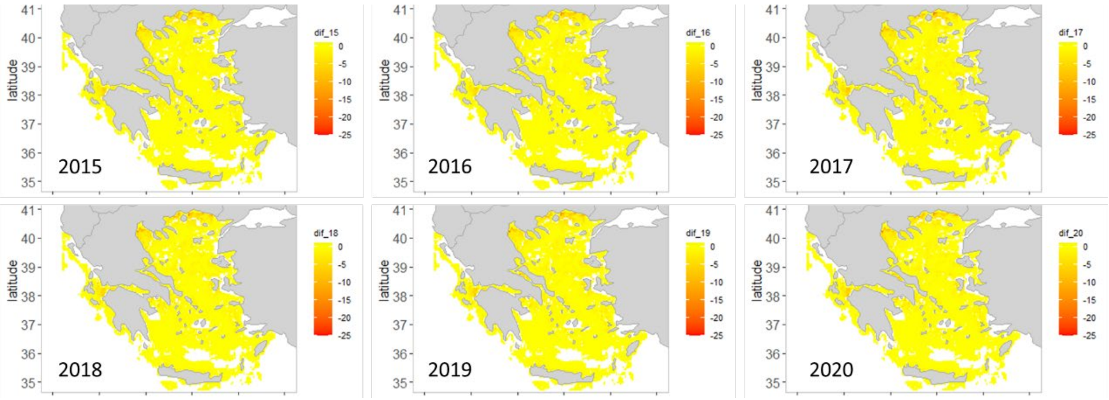


Figure 1.2. Comparison of the two indicators, PD and PD$_{sen}$ (percentage difference), for the Greek sea areas in the Eastern Mediterranean for the period 2015–2020. The indicators are explained in the technical guidelines for WGFBIT seafloor assessment (ICES 2021).

Update of the assessment of Adriatic and western Ionian Seas

On the basis of the 2023 WGFBIT report assessments for the Adriatic and Western Ionian Seas, management scenarios were simulated to evaluate the potential impact of management measures on both economic terms and changes in RBS at the MSFD broad habitat level.

A common baseline was defined for both scenarios, incorporating current management measures such as Natura 2000 sites, Fishing Restricted Areas (FRAs) (including 1000m, Lophelia reef, Jabuka/Pomo Pit, and Bari canyon), MPAs, Areas of Biological Conservation (ZTB), 3 NM permanent trawler closures, and the Adriatic Multiannual Management Plan (MAP) spatio-temporal closures (4 NM and 6 NM); (Figure 1.3). Additionally, new proposed closure areas (Figure 1.3) were implemented in the simulated scenarios: a new FRA expanding the trawling ban to 800–1000m, *Isidella elongata* VME, EFH of European hake (HKE), deep-water rose shrimp (DPS), red shrimp (ARS), longnose spurdog (*S. blainville*), and coldspots of RBS with values < 0.8.

Scenario 1 combined the baseline and proposed closures with the Adriatic MAP's fishing effort regime measures in GSA 17 and 18, aiming to reduce fishing effort to achieve F_{MSY} of European hake by 2026. Effort reduction was split among Adriatic fleets using the GFCM Recommendation (Rec. GFCM/43/2019/5) formula, resulting in 31%, 12.4%, and 7.1% reductions for Italian, Croatian, and Albanian trawlers, respectively. For the Western Ionian Sea (GSA 19), the scenario used the same target as the Adriatic MAP, aiming to reach F_{MSY} (0.21) of European hake by 2026, considering the current fishing mortality rate ($F_{current} = 0.33$).

Scenario 2 combined the baseline and previous closure areas with fishing effort measures based on a multi-species Pretty Good Yield (PGY) defined as the combination of fishing mortalities for individual stocks providing 95% of the yield in a single-species analysis (European hake and deep-water rose shrimp). A lower effort reduction of 11% was applied in the Adriatic Sea to attain the upper bound of deep-water rose shrimp Pretty Good Yield (PGY) range. In the Western Ionian Sea, the Pretty Good Yield scenario applied the same 11% reduction by 2026.

SAR values were estimated, for both Adriatic Sea and Western Ionian Sea, based on 2023 GFW AIS data, and then adjusted according to the effort reductions, and fishing activities at vessel level were statically redistributed from the closure areas to other areas explored by the same vessels, proportionally to their observed effort.

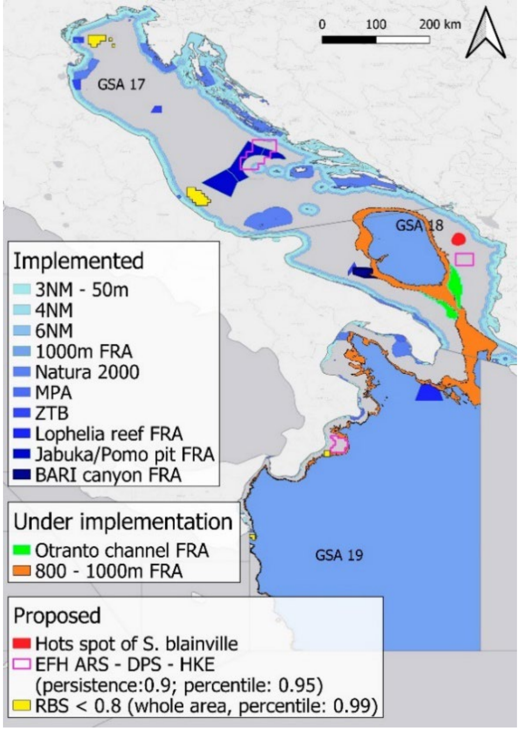


Figure 1.3. Map of the closure areas implemented, under implementation and proposed, located in the GSAs 17-18-19. FRA: Fishing Restricted Areas; MPA: Marine Protected Areas; ZTB: Biological Conservation Areas ("Zone di Tutela Biologica" in Italian); 3NM, 4NM, 6NM: Restricted width of coastal strips in Nautical Miles; Otranto channel FRA: VME of Isidella elongata; 800-1000m FRA: FRA moving the current fishing ban from depths of 1000 meters to 800 meters; Hot spot of S. blainville: hot spot of vulnerable bycatch species; EFH ARS – DPS – HKE: hot spot of EFH of commercial species' recruits (A. foliacea, P. longirostris, M. merluccius); RBS < 0.8: cold spot of Relative Benthic State (RBS).

The highest relative economic impact (-41.45%), expressed in terms of Gross Value Added (GVA), is expected on the fleet operating in the Western Ionian Sea (GSA 19); (Figure), particularly affecting vessels between 12–18 meters, where fleets have never experienced fishing effort regime measures like those in force in the Adriatic Sea. While less severe, the Adriatic Sea also experienced substantial GVA reductions in both GSAs 17 (-32.74%) and 18 (-30.63%). The lower impact on Albanian and Croatian fleets can be attributed to the smaller effort reductions applied to them compared to the Italian fleet. In Scenario 1, RBS closure areas displaced the most effort (4.70% of total GVA), followed by EFH (2.75%), with other closure areas inducing a smaller impact (1.22%).

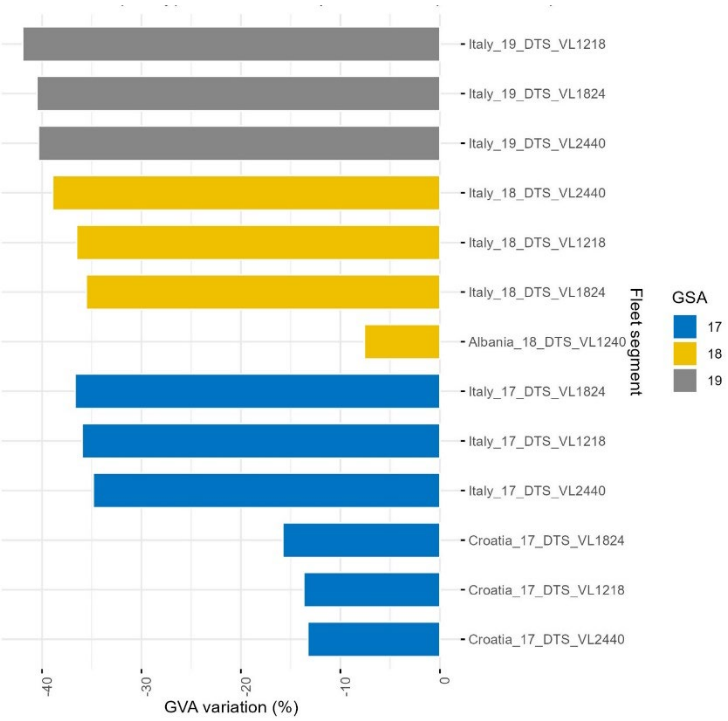


Figure 1.4. GVA impacted (in %) by the management measures defined in the scenario 1 at fleet segment level.

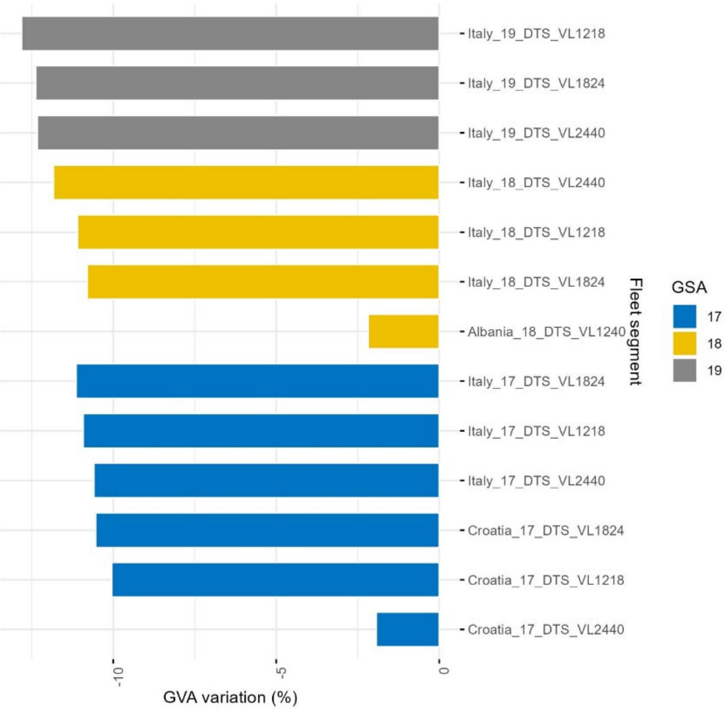


Figure 1.5. GVA impacted (in %) by the management measures defined in the scenario 2 at fleet segment level.

Scenario 2 results in a lower reduction in effort and, consequently, a lower decrease in Gross Value Added (GVA) compared to Scenario 1 (Figure 1.5), due to the less stringent effort reduction measures. At the fleet level, GVA reductions are largely comparable across fleet segments, with the exception of Albania and Croatia, where the reductions are less pronounced due to the lower imposed effort reductions. Furthermore, the displacement of effort is primarily attributed to closure areas with cold-spots of RBS (4.9% of total GVA), followed by EFH closure areas (2.44% of total GVA). The closure area encompassing the longnose spurdog hotspot contributes the least to effort displacement.

Comparing RBS estimates for both scenarios (Table 1) reveals that the combined approach of closures and fishing effort reduction to achieve Hake MSY generally improves the benthic state of nearly all Adriatic Sea habitats, with the exception of Offshore circalittoral sand in GSA 18. In the Western Ionian Sea, significant improvements are anticipated primarily in bathyal sediment habitats.

Conversely, Scenario 2 indicates that a less stringent fishing effort reduction may lead to less pronounced improvements in RBS, with significant gains limited to the circalittoral mud habitat of the Adriatic Sea.

In terms of surface area with RBS > 0.8 (Table 1.1), the lower effort reduction, coupled with effort displacement induced by the implementation of new proposed closure areas, likely contributes to a reduction in surface areas with RBS > 0.8 in certain habitats. This trend is particularly evident in the circalittoral sand of the Western Ionian Sea (GSA19).

The presented analysis allowed to effectively estimate the impact of the implementation of management measures on the fishing footprint, in terms of GVA loss, and on the fishing cumulative impact on benthic state, providing useful aggregated information at habitat level.

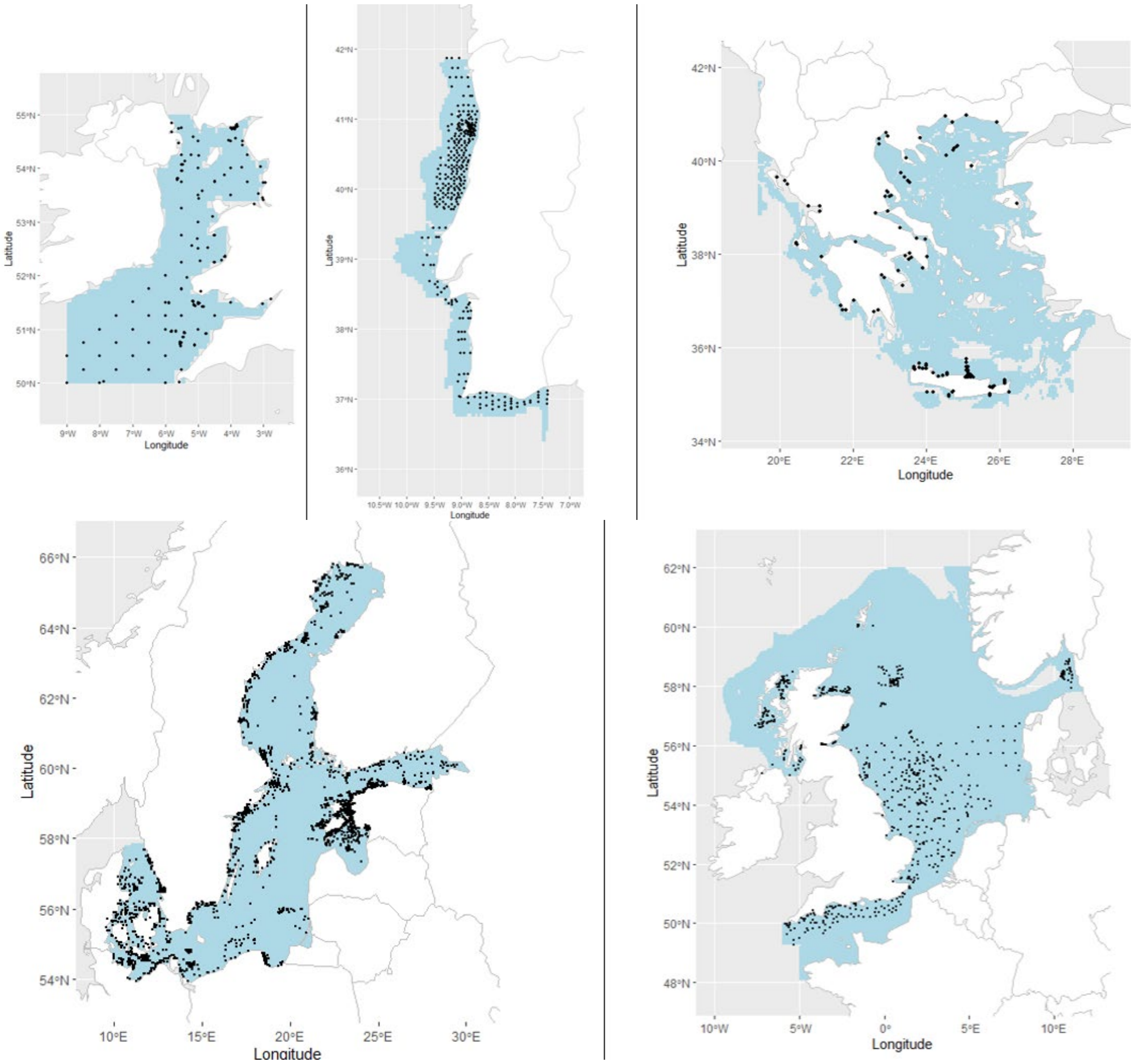
Table 1.1. Percentage of surface area with estimated RBS > 0.8 in both scenarios 1 and 2 in GSAs 17, 18, 19.

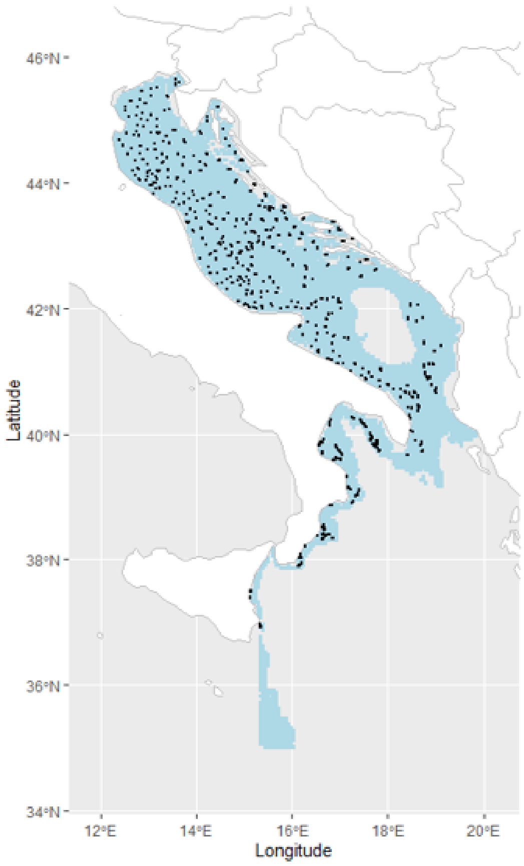
		Scenario 1			Scenario 2		
GSA	**MSFDhab**	**% RBS > 0.8 (baseline)**	**% RBS > 0.8 (scenario)**	**Percentage difference (%)**	**% RBS > 0.8 (baseline)**	**% RBS > 0.8 (scenario)**	**Percentage difference (%)**
17	**Circalittoral mud**	34.4	43.1	8.8%	34.4	37.9	3.5%
	Circalittoral sand	67.1	73.4	6.3%	67.1	69.2	2.1%
	Offshore circalittoral mud	44.7	57.6	12.9%	44.7	51.3	6.6%
	Offshore circalittoral sand	67.3	72.4	5.1%	67.3	66.4	-0.9%
	Bathyal sediments	81.5	87.1	5.6%	81.5	83.1	1.6%
18	**Circalittoral mud**	66.7	66.7	0.0%	66.7	66.1	-0.5%
	Circalittoral sand	94.6	96.8	2.2%	94.6	93.5	-1.1%
	Offshore circalittoral mud	51.2	55.8	4.5%	51.2	51.9	0.7%
	Offshore circalittoral sand	91.1	91.1	0.0%	91.1	91.1	0.0%
	Bathyal sediments	92.0	94.6	2.6%	92.0	92.9	1.0%
19	**Circalittoral mud**	100.0	100.0	0.0%	100.0	100.0	0.0%
	Circalittoral sand	86.1	87.5	1.4%	86.1	80.6	-5.6%
	Offshore circalittoral mud	81.0	84.1	3.2%	81.0	79.4	-1.6%
	Offshore circalittoral sand	80.0	86.7	6.7%	80.0	82.2	2.2%
	Bathyal sediments	89.6	94.0	4.4%	89.6	92.2	2.6%

Progress of the paper: ‘Assessment of bottom trawl impacts on the relative status of benthic communities of seabed sedimentary habitats in the NE Atlantic and Mediterranean Seas’

Preparation of a paper reporting on the outputs of the regional assessments has been taking place intersessionally. We now have coverage with impact assessments and swept-area ratio maps stretching from the northern Baltic via the Atlantic to the Mediterranean and the Black Sea.

The sensitivity maps are based on a very large number of benthic samples, as illustrated in Figure 1.6.

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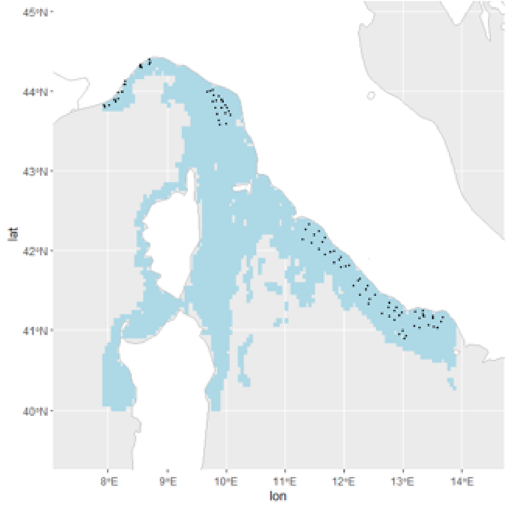
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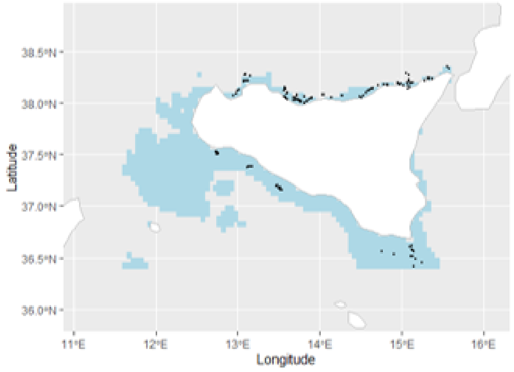
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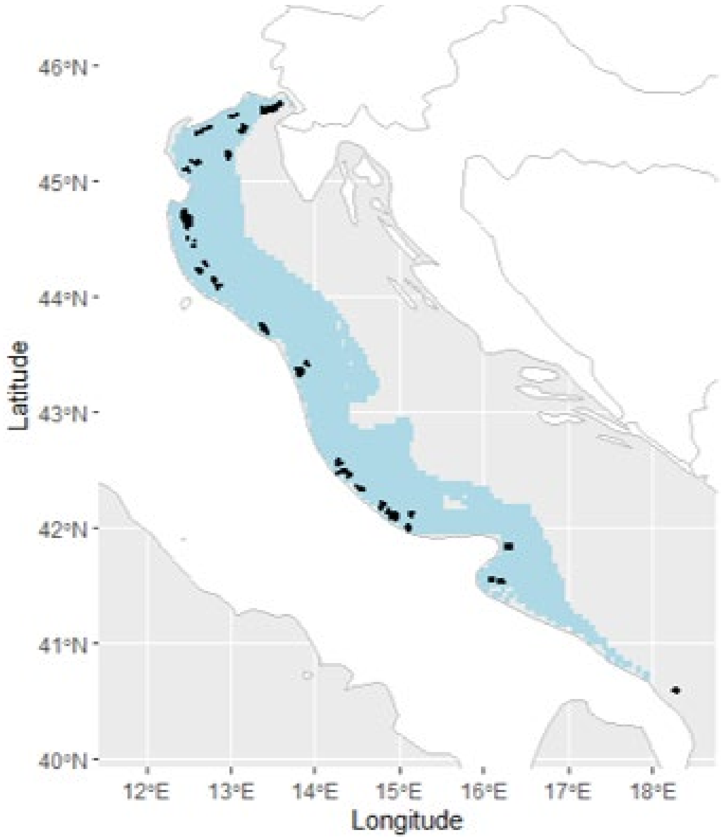
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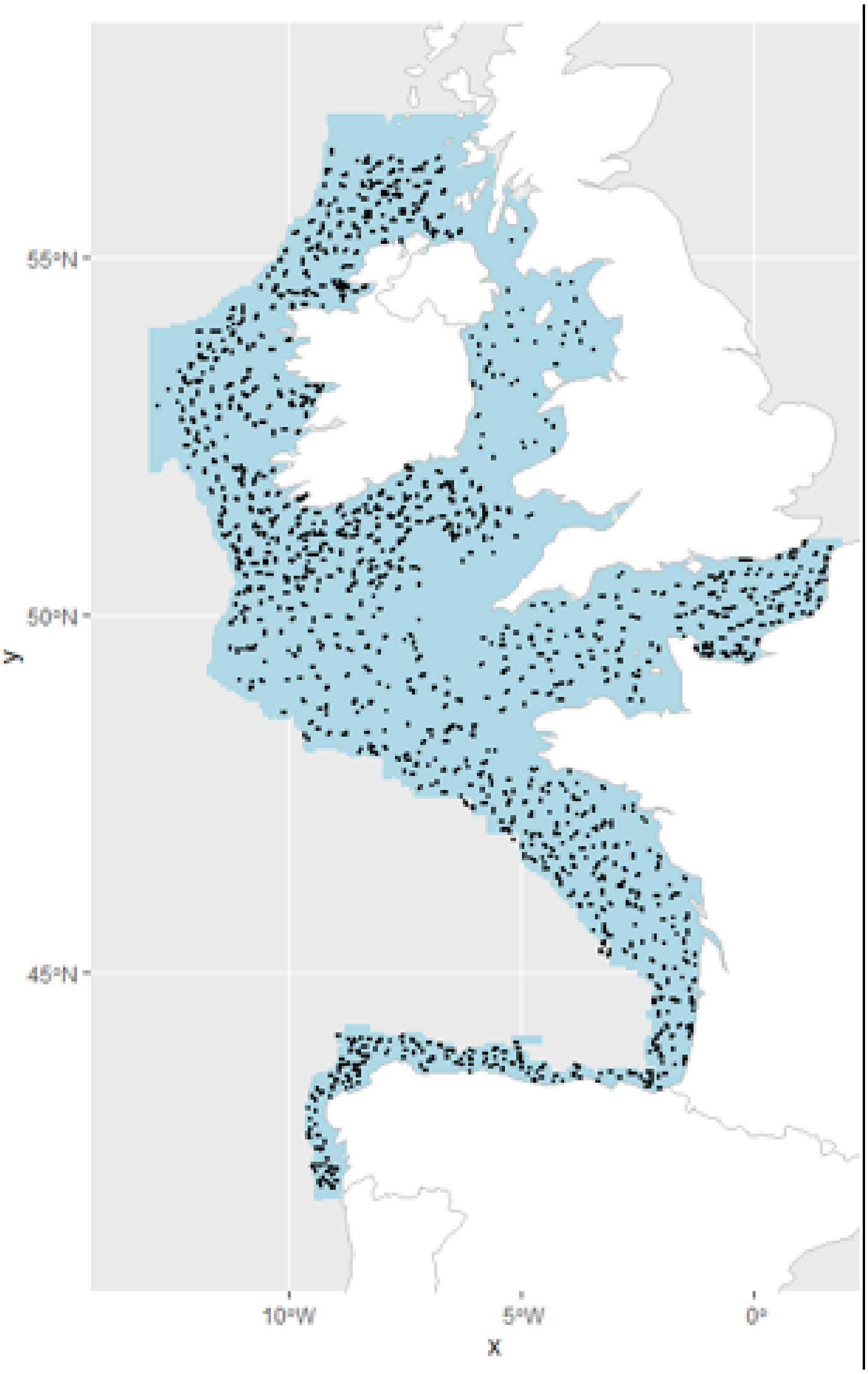
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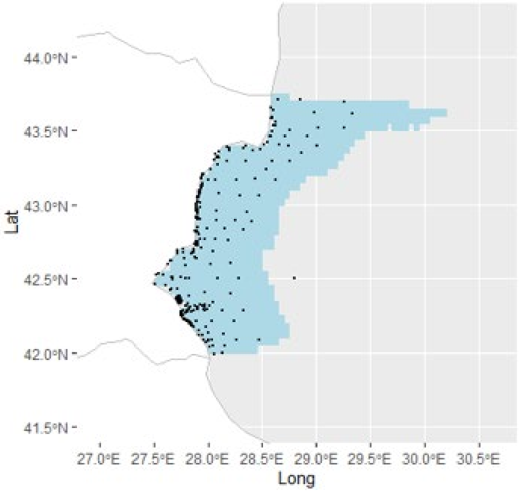
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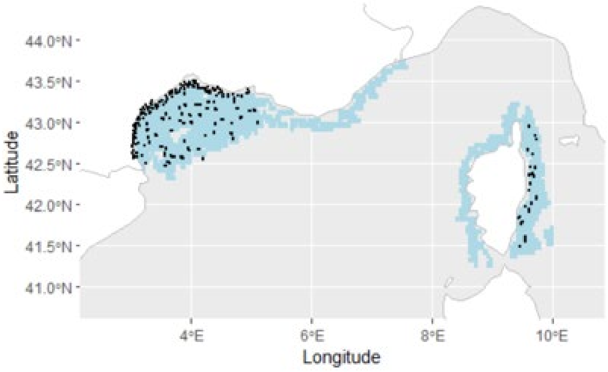
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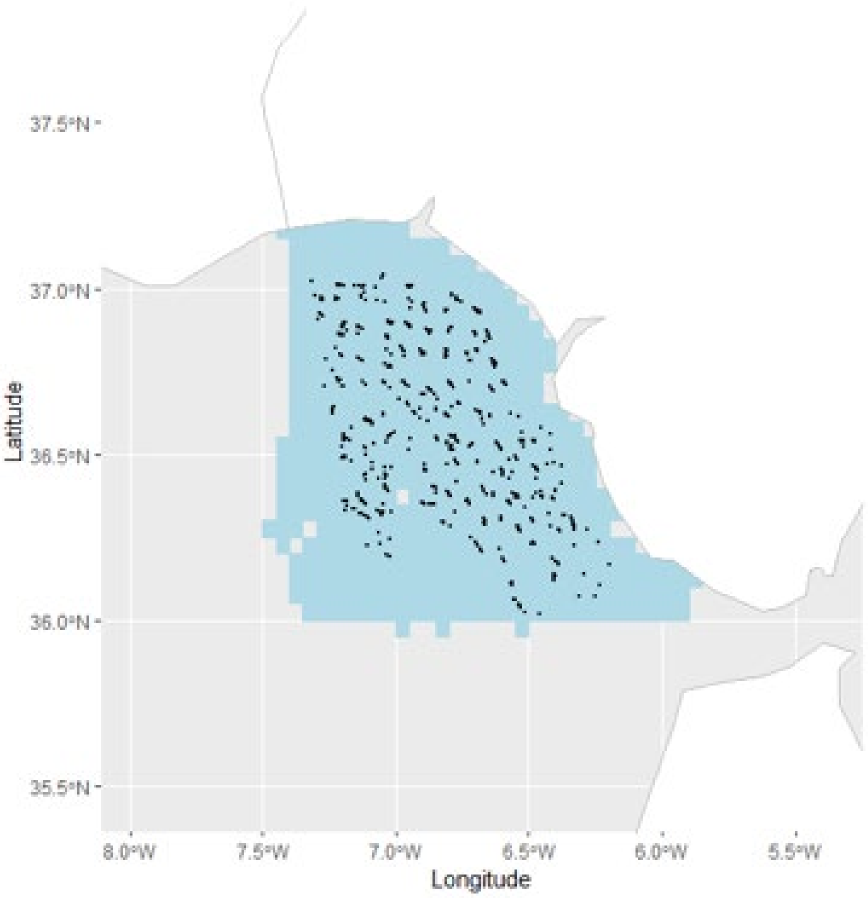
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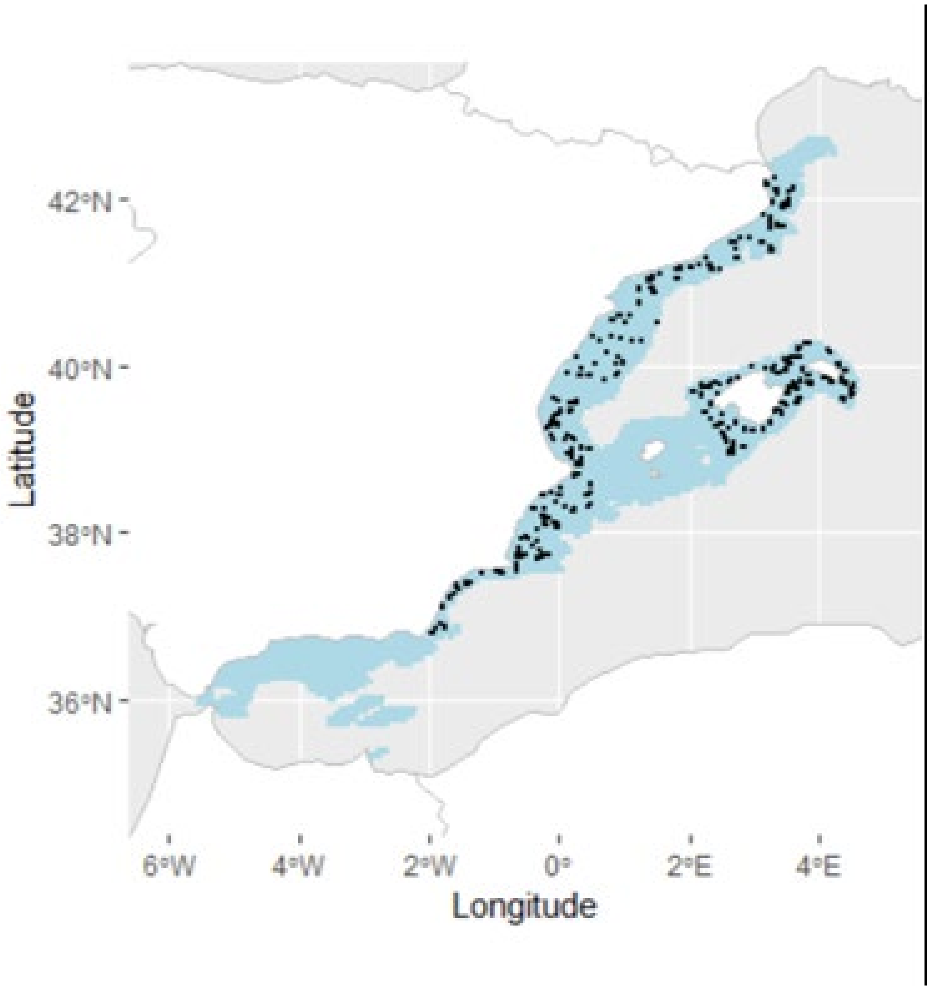


Figure 1.6. Maps showing the distribution of seabed samples that were used in the development of the sensitivity layers for each region.

The WG decided to standardise terminology in the manuscript with previously published papers, by reporting the state rather than the impact, and by using RBS rather than PD. RBS_{tot} = Relative Benthic State, whole community biomass relative to carrying capacity. RBS_{sen} = Relative Benthic State, 10% most long-lived biomass at no fishing. We will use 'broad habitat type' to describe the MSFD habitats. We will exclude reef, NA, none, 'mud and sand' from reporting.

There was some discussion on how to best present the results, with the main limitation being that it will not be possible to report on all MSFD habitats for each region in the main text (although it will be possible to include such tables in the SM). As a minimum, the WG decided that we need to present results by region, substrate type and depth zone, and separate for infauna and epifauna.

We still need to decide if and how report on sensitivity layers that bleed into adjacent regions.

The members now need to make sure that all SM tables are complete, and Daniel and Jan will draft the first complete draft of the manuscript in early 2025, for circulation past all contributors.

The manuscript will have to discuss the limitations of lacking inshore effort data, the effect of missing offshore effort data.

From discussions, it seemed not feasible to make the raw sample data available with the paper, but it should be possible to report the longevity distribution by station for all regions.

Thresholds

The ‘Range of natural variation’ (RNV) method estimates thresholds by calculating the total range of natural variation in an indicator using annual monitoring data from a least impacted condition and defining the lower 0.05 percentile of this range as the threshold (WKBENTH2, 2022). Thresholds were calculated using the RNV method for 33 annual monitoring time-series of benthic invertebrate biomass in least impacted conditions across sediment types, depth classes, and locations, and for 6 annual monitoring time-series of *Z. marina* shoot density from the UK. Least impacted conditions refer to areas that have not experienced manageable physical disturbance pressures, that could be determined through literature and sites such as Global Fishing Watch. Each dataset had a minimum of 10 years annual monitoring data to capture natural variability of biomass of the benthic invertebrate species.

The predicted distribution of thresholds for each system were calculated using an intercept only beta-regression model of n=33 invertebrate species RNV thresholds, and n=6 shoot density RNV thresholds, respectively. The modelled distribution of quality thresholds for *Z. marina* shoot density varied from 0.78 to 0.91, with a mean, and most frequent, threshold of 0.85 (Figure 1.7). For benthic invertebrate biomass species, the modelled distribution varied from 0.21 to 1.0, with an average threshold of 0.72 and the most frequent threshold of 0.76 (Figure 1.8). The distribution of seagrass thresholds demonstrates a smaller range than that of the benthic invertebrate thresholds, because there was less variability in the RNV thresholds across 6 seagrass monitoring sites (Figure 1.7). The benthic invertebrate datasets were higher in number and varied extensively across multiple environmental factors (i.e., depth, sediment type, species longevity). The left skewed distribution from density plots means that the average threshold value is lower than the most frequent threshold value (Figure 1.8). These quality thresholds represent the maximum negative change that this specific indicator can demonstrate from a relative starting value and still be considered within GES.

The threshold density plots can be used to understand the likelihood that an area/indicator is in GES based on where the indicator of biomass or density sits on the curve. For example, if a seagrass bed has a shoot density of 92% relative to the predetermined baseline value, we can be 100% certain that the bed is in GES (Figure 1.7). If a benthic invertebrate species has a total biomass of 72% of the relative baseline value, we can be 50% certain that it is in GES (Figure 1.8).

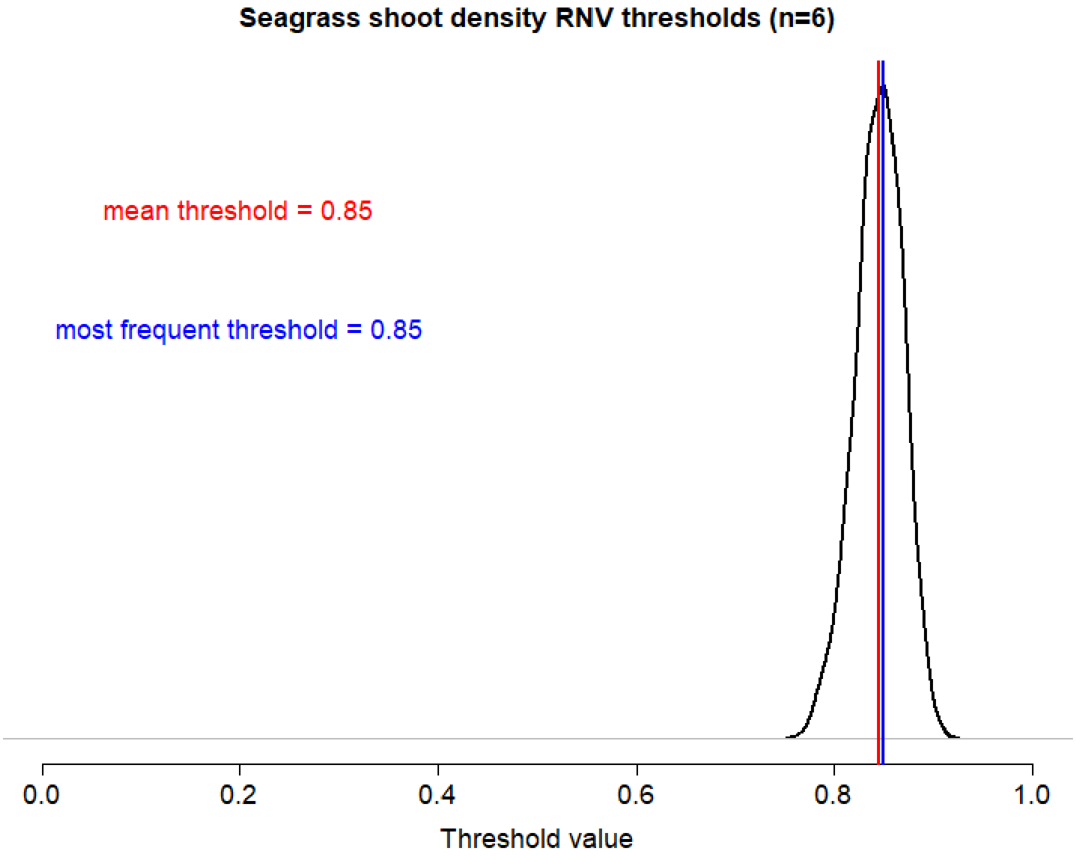


Figure. 1.7. Predicted distribution of thresholds for *Z. Marina* seagrass shoot density using thresholds calculated with Range of Natural Variation (RNV) method from six UK sites (Isles of Scilly and Skomer MCZ). A beta-regression model of shoot density thresholds was used to predict the probability distribution curve. The mean threshold is 85%, therefore if the shoot density of a *Z. marina* bed demonstrates 85% of its starting baseline value, there is a 50% probability it is in GES.

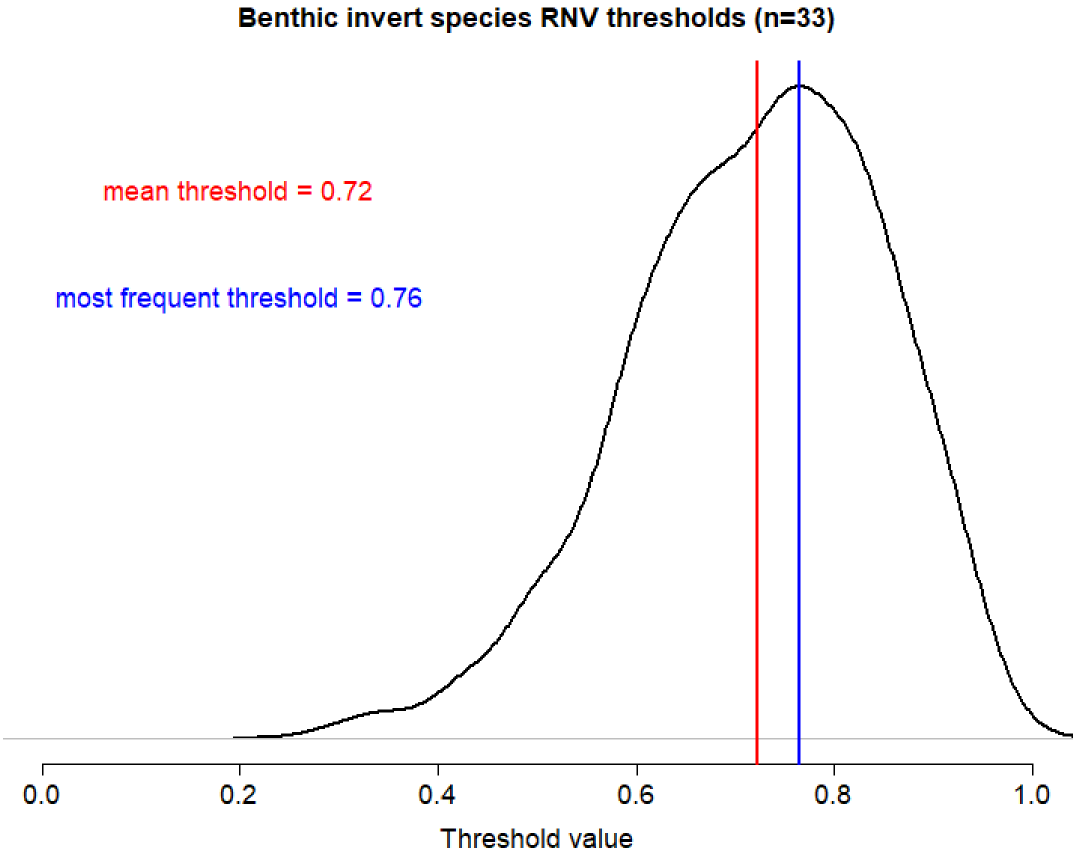


Figure 1.8. Predicted distribution of thresholds for benthic invertebrate species biomass using thresholds calculated with Range of Natural Variation (RNV) method from 33 sites with varying environmental characteristics (i.e., depth, sediment type, longevity of species). A beta-regression model of shoot density thresholds was used to predict the probability distribution curve. The mean threshold is 72%, therefore if the biomass/ indicator of a benthic species demonstrates 72% of its starting baseline value, there is a 50% probability it is in GES.

Cumulative curves of PDSens Epifauna in Greater North Sea region.

By assessing where a state indicator of benthic biomass sits on the threshold density plot, we can determine the likelihood that an area is in GES. The benthic RNV thresholds here were estimated using total benthic biomass, therefore PDSens was used as the state indicator as biomass informs these indicator values. Benthic state (PDSens) values for each c-square in the Greater North Sea were grouped by sediment type and depth class. The likelihood that a c-square is in GES was calculated by determining the proportion of the threshold distribution that was lower than the PDSens value for that c-sqaure. For example, if a c-square had a PDSens value of 0.72 we can determine there is a 50% probability that area is in GES based on where it sits on the threshold distribution plot (Figure 1.8). The probability that each c-square is in GES is plotted cumulatively for each sediment type (Figure 1.9) and depth class (Figure 1.10). These cumulative probability plots provide a clear delineation as to which areas can be considered 100% likely to be in GES, 75% likely etc. for each sediment type and depth class in the Greater North Sea. For example, 30% of the coarse sediment type in the Greater North Sea has 100% probability of being in GES, and ~20% of the sediment type has 75% probability of being in GES (Figure 1.9). By assessing the probability that an area is in GES we provide a useful tool for decision-makers to understand which areas we are more or less certain meet the GES threshold in order to inform management decisions and trade-offs moving forward.

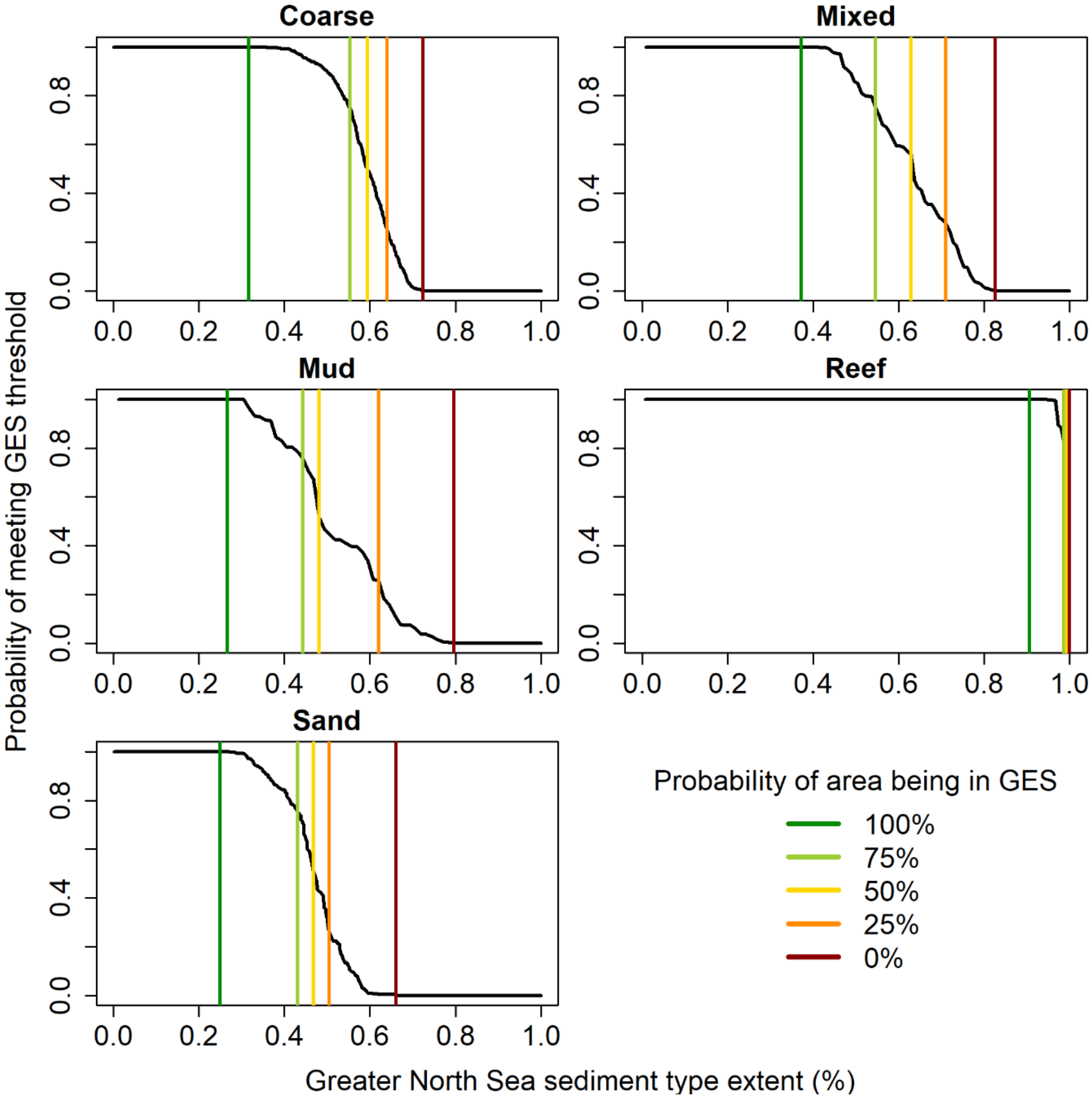


Figure 1.9. Probability of sediment types in the Greater North Sea region being in GES using PDSens indicator values from each c-square and the position of this state indicator value on the benthic biomass threshold distribution (Figure 1.7). For example, if a coarse sediment habitat type c-square had a PDSens value of 0.72, the probability of it being in GES would be 50% (0.5). Each coloured line delineates the total extent of the region that has a 100%-0% probability of being in GES. For example, 27% of the total extent of mud sediment type in the Greater North Sea region has 100% probability of being in GES, and 15% of the extent has at least 75% probability of being in GES.

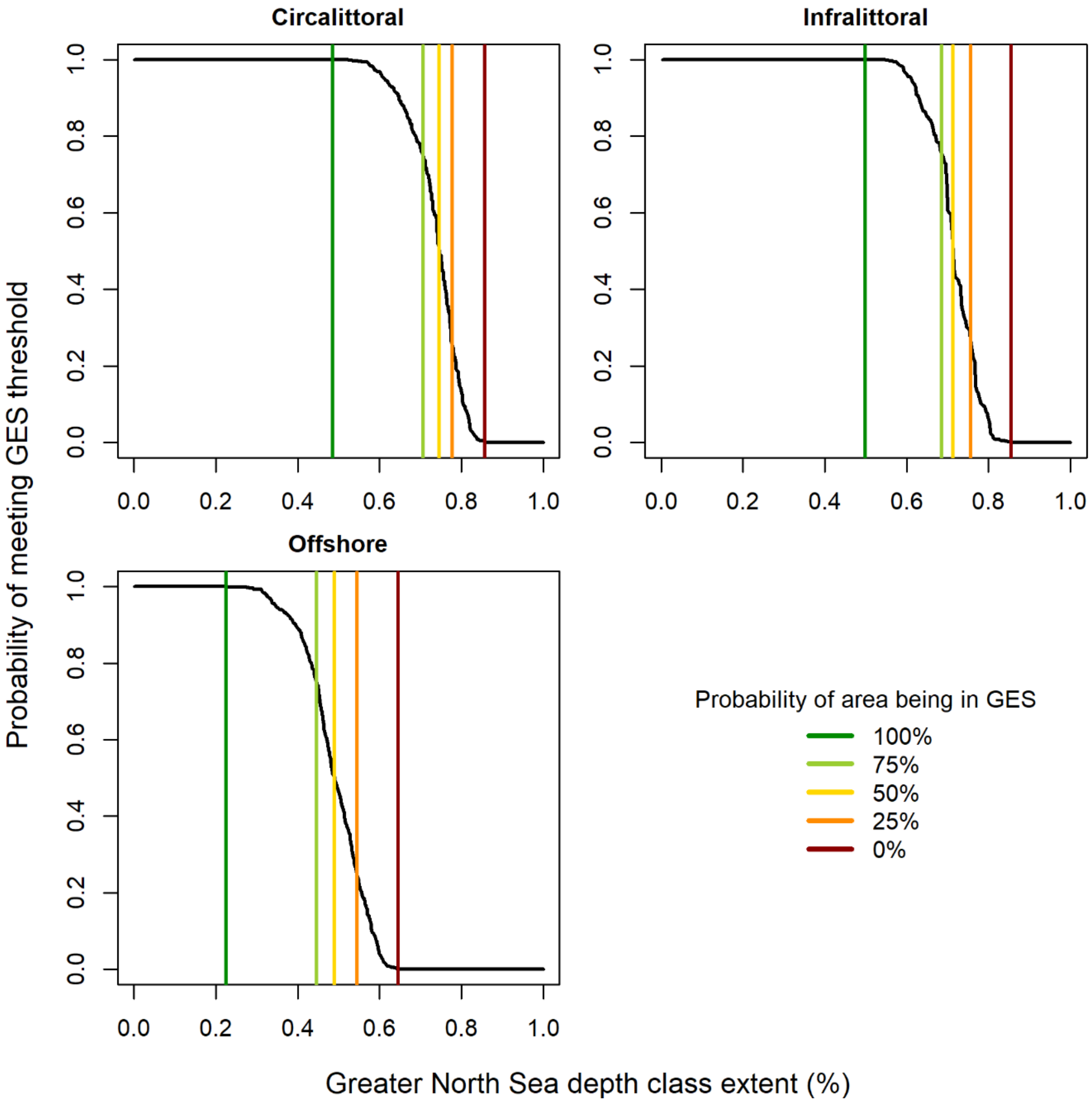


Figure 1.10. Probability of different depth classes in the Greater North Sea region being in GES using the same methods in Figure 1.9. Here we can determine that, for example, 57% of the total extent of the circalittoral area in the Greater North Sea region has 100% probability of being in GES, and 15% of this area has a 0% probability of being in GES.

2 Trade-offs

Priority ideas and roadmap for the three-years cycle

Background

The concept of **Core Fishing Grounds (CFGs)** is a practical tool in achieving ICES' mission to provide advice on the sustainable use of marine ecosystems, particularly by ensuring that high-value fishing areas are maintained while addressing environmental and economic considerations. CFGs refer to specific areas in marine ecosystems that are consistently and intensively used for fishing activities over time. The original idea of defining key fisheries areas from a spatial perspective was due to **Jennings & Lee (2012)**, and was later developed extensively within ICES, and in particular in the **Workshop on Trade-offs between the Impact of Fisheries on Seafloor Habitats and their Landings and Economic Performance (WKTRADE4)**. Core Fishing Grounds are characterized by the following attributes:

- **Spatial and Temporal Consistency**: these areas are regularly utilized for fishing across multiple years, demonstrating a predictable and persistent pattern of activity. They are often identified through analysing vessel monitoring system (VMS) data, logbooks, or other spatially explicit fishing activity records.
- **High Fishing Intensity**: CFGs are distinguished by a concentration of fishing efforts, indicating their importance to the fishing industry. This could include areas with high catch rates or economic value.
- **Ecological and Economic Importance**: CFGs often overlap with habitats that support key commercial species. Their stability and productivity make them critical for sustaining fisheries-dependent communities and economies.

Recognizing Core Fishing Grounds helps to reduce spatial conflicts, for instance, between fishing activities and offshore developments (e.g., wind farms). ICES highlights Core Fishing Grounds to inform sustainable fisheries management. By identifying and prioritizing these areas, managers can design spatial measures, such as marine protected areas (MPAs), or regulate fishing pressure to balance conservation and exploitation. In line with the principles of EBM, CFGs are considered within broader marine spatial planning efforts. Their identification ensures fisheries management aligns with ecological conservation objectives, protecting essential habitats while supporting sustainable use.

According to this rationale, the activities of this ToR will prioritize the progressive application of a Core Fishing Grounds analysis to all EU marine regions. This will require working simultaneously on two fronts: one **theoretical/methodological** and the other more **applied**. In the first case, the WGFBIT community will work to develop and explicitly define (even through a shared R workflow) a **core fishing ground analysis** for all regions (including the Mediterranean Sea, the Black Sea and the Atlantic region) building on the ICES trade-off advice. Develop an analysis that is applicable across all ICES ecoregions, as well as, using the best available information for specific regions. The aim is to have a standardized approach that can be adapted to the available data and applied in all the Ecoregions.

After a brief conceptual description of Core Fishing Ground Analysis, this section of the report presents some case studies, in the form of methodological/application boxes, representing as many recent experiences in the field of CFGs identification.

A **Core Fishing Grounds Analysis** aims to identify persistently and intensively used areas for fishing activities. Below are the basic steps typically followed in such an analysis:

Data Collection

- **Fishing Activity Data**: Gather spatially and temporally explicit fishing activity data, such as:
    - Vessel Monitoring Systems (VMS) data and/or Automatic Identification System (AIS) data. These sources of data provide information about the spatial distribution of fishing activities.
    - Logbook records. These data provide direct information about the gear type used, catch structure (landing weight) and, eventually, economic indicators such as landing value.
- **Environmental Data**: Include habitat and bathymetric data to contextualize fishing activity within ecological settings. Examples include depth strata and types of substrates.
- **Metadata**: Record vessel type, gear type, and targeted species, as these are critical for stratifying data. This source of information could allow us to refine the following stage of the analysis and, for instance, assess the association between CFGs and specific fleet segments or ports.

Data Processing

- **Filtering and Cleaning**:
    - Remove non-fishing signals (e.g., steaming points, errors, points on land).
    - Ensure accuracy in time stamps, coordinates, and gear usage information.
- **Effort Estimation**:
    - Calculate fishing effort metrics such as hours spent fishing, distance travelled, or the number of gear deployments.

Spatial Aggregation

- **Grid selection**:
    - Divide the study area into a grid (e.g., cquares cells of 0.05 ^{0} resolution) to aggregate fishing data spatially.
- **Effort Density Calculation**:
    - Sum different metrics such as fishing effort and landing weight for each cell to estimate related indicators.

Temporal Analysis

- **Persistence Analysis**:
    - Assess fishing activity across multiple years to identify areas with consistent use.
    - Define thresholds for persistence (e.g., percentage of years a cell shows significant fishing effort and/or landing weight or value).

Defining Core Fishing Grounds

- **Intensity Thresholds**:
    - Sort spatial units in decreasing order of importance and set thresholds for defining high-intensity fishing areas, often based on percentile values (e.g., top 90% of effort, top 90% of landings, or top 90% of landing value).
- **Core Area Delineation**:
    - Use statistical or clustering methods to delineate contiguous high-intensity areas. Here, it is possible to constrain the selection to contiguous spatial units or not.

Validation and Refinement

- **Stakeholder Input**:
    - Collaborate with fishers, managers, and researchers to validate identified CFGs and incorporate practical knowledge.
- **Ground-Truthing**:
    - Cross-check spatial data with direct observations or independent records to ensure accuracy.

Visualization and Reporting

- **Mapping**: Produce maps of CFGs with overlays of fishing effort, intensity, and environmental data.
- **Dissemination:** Develop appropriate and user-friendly platforms to share updated assessment of CFG distribution. Develop HTMLs (Markdown and/or Shiny) for each region for which trade-off outputs are available (following ICES trade-off advice) and develop a shiny with pressure and impact by metier.
- **Documentation**: Include detailed metadata, assumptions, and methods used in the analysis for transparency.

The most updated and advanced R workflow to perform Core Fishing Ground analysis is available on github at: https://github.com/ices-eg/WKTRADE3.

Following these steps, a CFG analysis provides a robust basis for identifying critical fishing areas, supporting sustainable exploitation while minimizing conflicts and conserving marine ecosystems.

Examples of Core Fishing Ground Analysis

Box 1 - Core Fishing Ground Analysis under the VMEs Regulation (2022/1614/EU). The Spanish Fleet Case Study

In this approach, the potential economic impacts of the regulations for Vulnerable Marine Ecosystems (VME) implemented under Regulation 2022/1614/EU, along with the various scenarios proposed by ICES in its latest recommendations (ICES, 2023), are analysed for the Spanish bottom fishing fleet. The analysis encompasses both mobile fishing gears (bottom otter trawls, OTB, and pair trawls, PTB) and static gears (set longlines, LLS, and gillnets, GNS). The findings aim to support decision-makers in achieving a balanced and effective approach that has negative socio-economic impacts on fishing communities while upholding the commitment to environmental sustainability.

The study specifically: (i) analyses the spatial distribution of fishing effort and gross landing revenues for each gear type; and (ii) identifies the "core fishing grounds" based on fishing effort and economic benefits. To achieve this, the fishing activity was calculated following the methodology established by ICES for VMS data analysis (Hintzen *et al.*, 2012) over the period 2016–2020, with a spatial resolution of 0.05° c-square. For bottom trawlers, fishing intensity (FI) was calculated as the swept area ratio (SAR). For static gears (LLS and GNS), FI was expressed as the total fishing time spent on gear retrieval in each cell per square kilometre (h/km^2), following the approach detailed by Fernández-Arcaya *et al.* (2024). Economic performance was assessed by integrating the value of the catches (in euros). Rather than relying on the STECF AES dataset, this was accomplished by directly linking each vessel to its catch records using sales notes. VMS data were merged with logbook records by vessel and date. First-sale prices for species caught by the Spanish fleet were incorporated into the dataset based on vessel, species, and date. When no match was found, the closest date within the preceding or subsequent days was used to ensure data accuracy.

Preliminary results from the project indicate that, regardless of the proposed management scenario, all bottom fishing gears are experiencing substantial economic losses. Among these, static bottom gears, particularly longlines (LLS), are the most significantly impacted by the proposed closures. The regulation directly affects critical core fishing grounds, resulting in a high proportion of eliminated landings and reduced fishing effort hours, severely affecting fleets that depend on these techniques (Figure 2.1). These economic impacts are projected to escalate under the new proposed closures, with northern Spain accounting for approximately 40% of the total closed fishing areas in most scenarios.

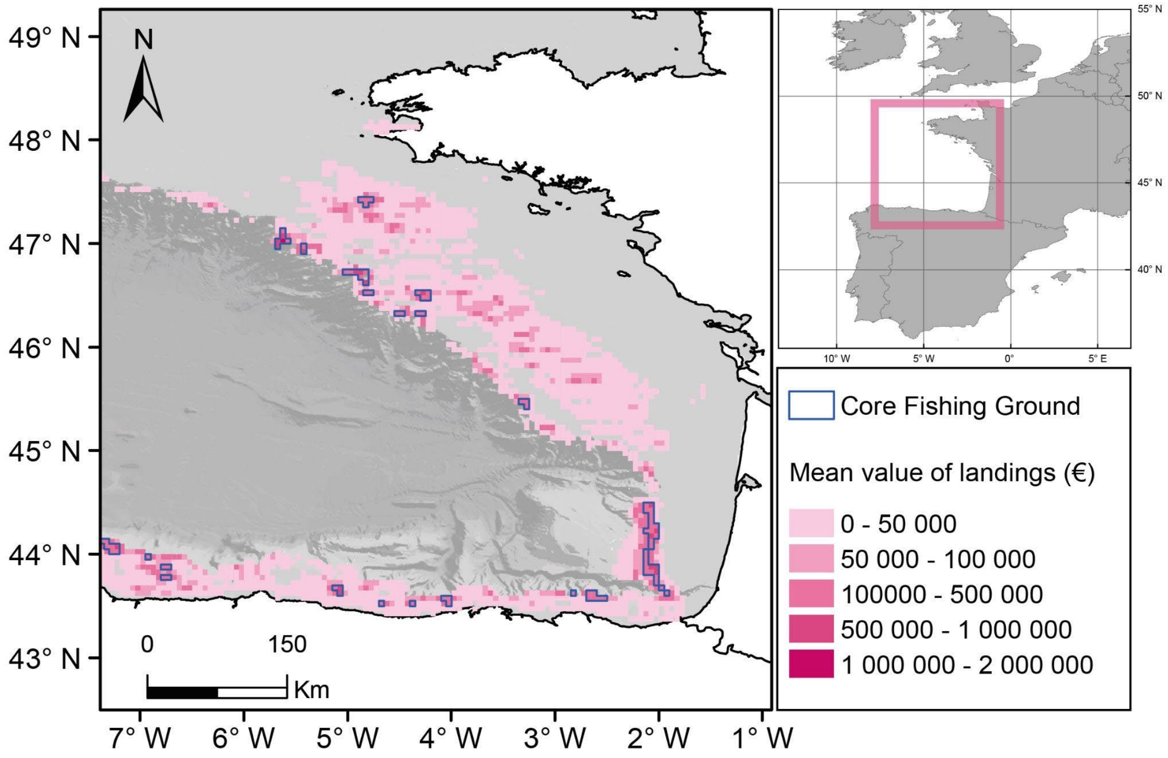


Figure 2.1. Distribution of landing values (€) and fishing grounds for GNS, based on combined data from 2016–2020 (average values). Fishing grounds are delineated using landings representing the top 90% of values, as defined by the methodology proposed by ICES (2021).

This study complements previous analyses by the STECF regarding socioeconomic impacts by providing spatially explicit mapping of the fishing effort for static gears using VMS data. Although the methodologies for quantifying static gears fishing have not yet reached the same level of acceptance as those for mobile bottom-contact gears (MBCG), the number of hours required to retrieve gear provides a reliable estimator for identifying core fishing grounds and habitat preferences for these techniques.

The research highlights that, although bottom-contact gears more frequently interact with VMEs, not all fishing practices cause significant ecological impacts. This underscores the need to better understand the effects of static fishing gears on VMEs. Further investigation into the socio-economic implications of deep-sea fishing using these gears is also essential, particularly focusing on more precise socio-economic indicators, such as values of net benefits and fleet resilience to changes. Addressing these knowledge gaps is imperative to developing management strategies that effectively balance the need to protect VMEs with safeguarding food security, employment, and the economic stability of local fishing communities.

These findings are part of an ongoing study currently being prepared (Fernandez-Arcaya, Plaza-Morlote, *et al.*, in preparation).

Box 2 - Core Fishing Ground Analysis performed in the ABIOMMED Project (DG Environment under grant agreement No 110661/2020/839620/SUB/ENV.C.2)

As part of the EU research project ABIOMMED (https://www.abiommed.eu/), this study evaluates the effects of various spatial-based bottom trawling management strategies and lessen their detrimental effects on the seabed while preserving fisheries productivity. Two distinct modelling methodologies were used in our investigation. The first one determined the optimal balance between protecting the seafloor and ensuring fishing operations remain financially viable. The second assessed how the implementation of various management strategies affected the displacement of fishing activities. Additionally, it evaluated how the economic situation changed due to the subsequent redistribution in the composition of catches. The work is focused on four case studies in different subregions of the Mediterranean Sea, using AIS, VMS, and Logbook data at the scale of individual vessels. Namely, we focused on four Mediterranean sectors defined within the Marine Strategy Framework Directive (MSFD): the Western sector, including the Sardinian Sea (GSA 11.1 and 11.2), the North Tyrrhenian Sea (GSA09) and the South Tyrrhenian Sea (GSA10); the Southern sector, including the Strait of Sicily (GSA 12-16), the Adriatic sector, including the Adriatic Sea (GSA17 and 18), and the Ionian sector, including the Eastern Ionian Sea (GSA19); (Figure 2.2). Three of these four case studies were related to Italian fleet activities, while only the Adriatic sector analysed Italian and Croatian fleets.

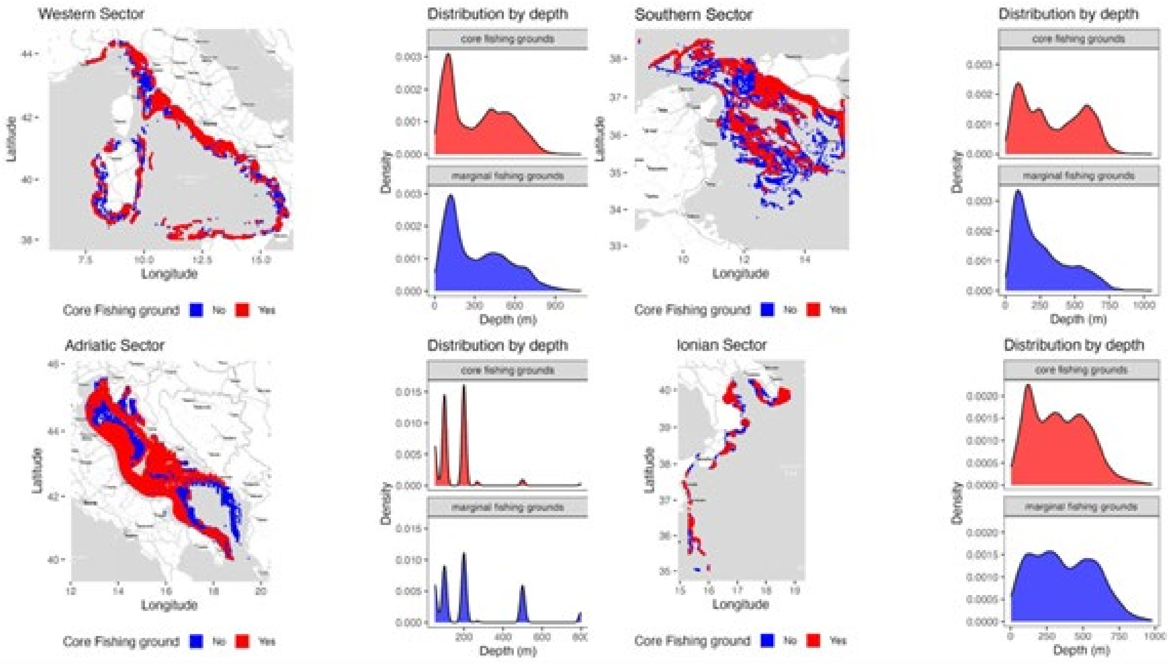


Figure 2.2. Map of Core fishing grounds for the four case studies together with their distribution with respect to the depth.

Using spatial economic variables, particularly profitability and Landing Value, allowed for identifying primary fishing grounds. The lowest region needed to maintain 90% of current revenues was identified as the core fishing grounds in each case study, using the criteria put forward by Ban and Vincent (2009). This is comparable to the Marxan approach used in conservation planning (e.g. Fabbrizzi *et al.*, 2023), which uses a simulated annealing process to find the least expensive solution to an objective function. Under a set of predetermined conservation aims, the Marxan optimization technique finds several near-optimal alternatives that promote conservation interests while reducing costs.

Figure 2.3 shows the areas identified as core fishing grounds for otter-trawling fleets. These areas largely overlap with the areas of high SAR values, since effort is concentrated in highly profitable areas that yield significant revenues. However, it is interesting to observe that, in the Western Mediterranean Sea, core grounds are more abundant along the coast and in the range of 400–600m. This dominance of depth grounds is even more evident in the Central Mediterranean Sea, where core grounds occur especially between 500 and 750 m, together with the range 50–250m. In the Adriatic Sea, two series of shallow grounds (between 50 and 200 m) can be observed, while the depth component is irrelevant. In the Ionian Sea, there is a more balanced situation in which only a relevant component emerges: the grounds between 100 and 200 m.

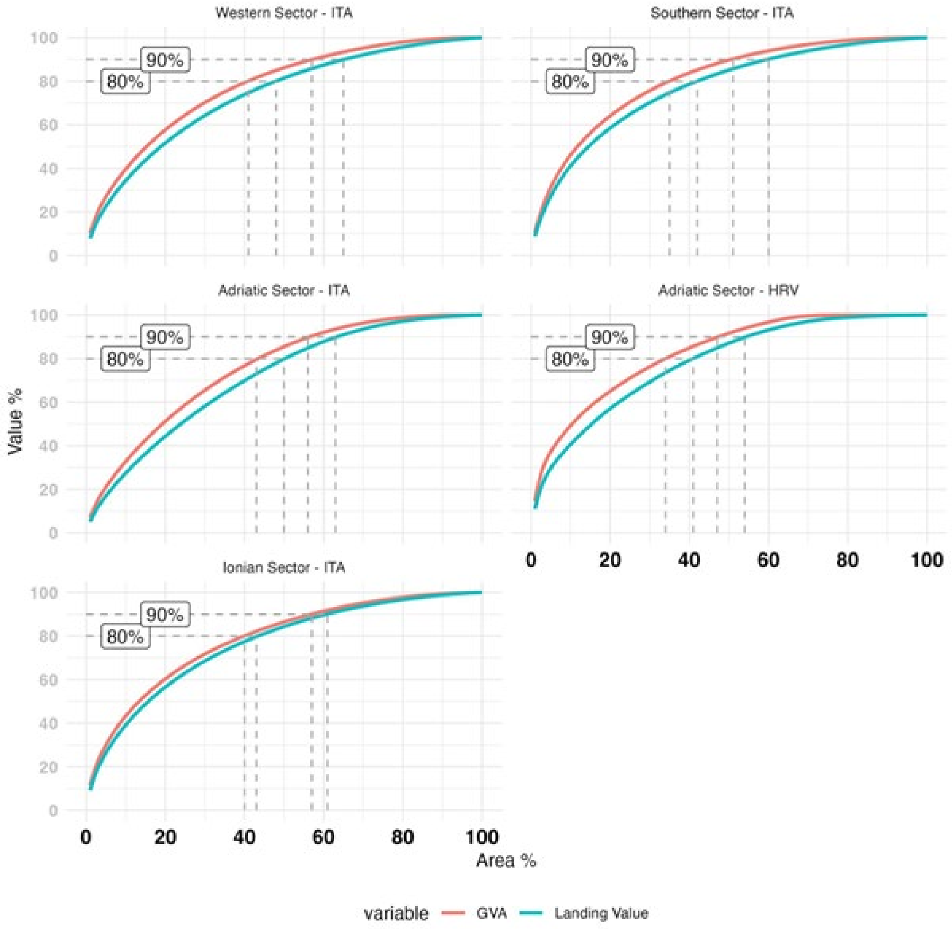


Figure 2.3. Rarefaction curves, for the economic indicators (GVA, LV and costs) and Swept Area, in which the trends by case study (colours) and country (line type) are represented.

The rarefaction curves in Figure 2.3 show a similar trend for all case studies. Their trend is steep since, as seen with the identification of core areas, fishing activities are concentrated in given areas. At the same time, the fact that the curves end horizontally indicates the presence of less fished areas whose subtraction to the available space would not result in significant loss in terms of landings. In the graphs, it can be seen that ~90% of GVA is related to 50–60% of the exploited cells and that reducing the total fished area by approximately 40% would only result in a decrease in the landings of roughly 10%. Slight differences can, however, be observed between case studies.

This box and the related Figures are part of a paper currently under review in the ICES Journal of Marine Science.

Present limitation and potential methodological development in the WGFBIT

This section discusses some aspects that currently limit the Core Fishing Ground analysis or should be appropriately developed to provide more realistic or more useful results for management purposes. In addition, guidelines that should be used to define the scenarios to be evaluated as part of the trade-off analysis are discussed.

Scenarios of Fishing Effort Removal and Displacement

The development of scenarios for removing and displacing fishing effort from specific areas, such as marine protected areas (MPAs), requires a multifaceted approach that integrates spatial optimisation and considers ecological, economic, and social dimensions. This section outlines potential methodologies, with reference to ICES trade-off advice, to optimise spatial planning while mitigating adverse effects on benthic habitats and marine ecosystems. The discussion is structured around key aspects influencing these scenarios.

Effect of the Topology

Topology plays a critical role in determining the outcomes of fishing effort removal and displacement. The spatial arrangement of protected areas, habitat connectivity, and the shape and size of grid cells influence the efficiency of closures. For instance:

Smaller, strategically placed grid closures may protect biodiversity hot spots without disproportionately displacing effort.

Larger closures might lead to broader ecological benefits but can induce higher displacement pressure on neighbouring areas, potentially leading to overfishing or habitat degradation elsewhere.

Advanced spatial models (Displace, Ecospace, SMART, Isis-Fish, etc.), can simulate and analyse these effects to identify optimal configurations that minimise unintended consequences.

Example from ABIOMMED project results
The potential effects of various spatial and/or temporal-based management scenarios were investigated by simulating and optimising the new fishing effort pattern of each vessel (in terms of number of cells exploited or closed to trawl fishing), starting from the result of the SMART model. Five different scenarios were considered for each sector: 1) permanent ban of bottom trawling in the existing GFCM Fisheries Restricted Areas (FRAs); 2) fishing ban within 6 nautical miles from the coast; 3) fishing ban at depths > 600 m; 4) >700 m; and 5) > 800 m. Scenario 1 is based upon the most recent GFCM information[1], while Scenarios 2 to 5 examine the extension of existing spatial restrictions further offshore (Scenario 2) and into deeper habitats (Scenarios 3–5). It is important to note that these last 3 management scenarios (Scenarios 3-5), are under evaluation in the framework of the activities carried out by the GFCM. With regard to scenario 1, it is important to specify that, for simplicity's sake, the entire area of each FRA was considered subject to permanent closure for trawling, without distinction between sub-areas. Currently, trawling bans are set at a distance of 3 nautical miles from the coast (or where depth is less than 50 m) and over 1000 m. If the limitations of the proposed scenarios were applied

to the investigated areas, and the fishing effort kept at the same present level, the interested vessels would need to consider costs, revenues, and economic sustainability of their fishing activity due to the reallocation of effort. For each scenario, 100 simulations were conducted, and the effects on fishery displacement patterns and relative landings were evaluated, including the value of profits (i.e. is assumed to be the best proxy for the economic performance of the fleet). Scenarios were conducted for areas up to 1000 m depth, beyond which trawling is prohibited in the Mediterranean.

Example from SEAWISE project: Application of Displace-like Models (Static Redistribution)

The SEAWISE framework, leveraging Displace-like models, offers a powerful tool for static redistribution simulations:

- **Static Redistribution Scenarios**: Models can predict the spatial reallocation of fishing effort under varying closure configurations, providing estimates of ecological and economic impacts.
- **Assessment of Trade-offs**: Scenarios can be refined to balance conservation objectives with socio-economic sustainability, incorporating ICES trade-off frameworks.

Displace-like models also facilitate:

- Evaluation of benthic state recovery trajectories.
- Testing of spatial management strategies under different governance contexts, such as Exclusive Economic Zones (EEZs) or metier-specific considerations.

Developing effective scenarios for the removal and displacement of fishing effort requires integrating diverse data sources, modelling tools, and stakeholder input. Emphasis should be placed on spatial optimization to ensure ecological benefits while mitigating socio-economic impacts. Through careful analysis of topology, MPA effects, fleet dynamics, VME protection, local knowledge, and advanced modelling, adaptive management strategies can be devised to sustainably balance conservation and fishing activities.

Core Fishing Grounds for Mixed Fisheries

Mixed fisheries simultaneously target multiple species using the same fishing gear in the same areas. Defining Core Fishing Grounds (CFGs) could also be necessary (but challenging) for mixed fisheries due to the complex dynamics and overlapping characteristics of these fisheries. For instance, considering that mixed fisheries often involve species with varying levels of vulnerability to overfishing, defining CFGs could allow managers to identify areas where target species are abundant and overlap with bycatch species, enabling measures to minimize the impact on sensitive populations. However, mixed fisheries often involve trade-offs between species management objectives. For example, reducing the effort to protect one species might impact the catch of another. CFGs can provide spatial clarity, helping managers design area-specific rules to optimize outcomes for multiple species and reduce stakeholder conflicts. In summary, by defining and incorporating CFGs into managing mixed fisheries, fisheries managers can address these fisheries' ecological, economic, and social complexities more effectively. This approach balances maximizing yield, conserving ecosystems, and supporting fishing communities.

High-resolution definition of Core Fishing Grounds

Defining Core Fishing Grounds (CFGs) at the port level or fleet level provides a tailored approach to fisheries management, reflecting the unique characteristics and operational scales of different fishing communities and fleets. This granularity could be important because ports often host fishing communities with distinct practices, traditions, and target species. CFGs defined at this level capture the specific areas most relevant to the local fishers operating from that port. Defining Core Fishing Grounds (CFGs) at the port level or fleet level could enable management to account for localized fishing pressures and dependencies, avoiding one-size-fits-all solutions.

Integration of fuel-related metrics

Currently, CFGs analysis is essentially based on SAR, Landings weight or Landings value estimated for each spatial unit. In reality, fishers work in a way that maximizes profits, and the fuel consumption associated with activity in fishing grounds more or less far from the coast is a very relevant aspect that cannot be ignored. Although in many cases it is reasonable to expect revenues (i.e., Landing Values) to be a reliable indicator, it would be worth exploring the possibility of conducting CFGs analysis based on more advanced economic indicators, such as Gross Value Added (GVA). In summary, the assessment of the economic values of different fishing grounds is still in its infancy and should be further developed to provide a realistic overview of the fisheries. Since FDI data do not provide spatial information about costs, aggregated information from the Annual Economic Report (AER) can be used to disaggregate some economic variables (e.g. Energy costs). Alternatives, such as spreading the costs over the cells, based on the effort allocated to them, flatly, seems too rough and unrealistic. Indeed, if costs (or other aggregate variables) are "spread" across the space based on effort alone, the results cannot be considered reliable because they probably underestimate the costs related to the exploitation of far fishing grounds (and, conversely, the costs related to the exploitation of fishing grounds close to the coasts are overestimated). This fact, combined with the different profitability of different métiers, prevent a realistic evaluation of the potential effects of different management strategies in terms of redistribution of effort among métiers and/or changes of fleets structure driven by medium and long-term economic performances. These observations have already emerged extensively in the review of activities carried out under WKTRADE3 and WKTRADE4, and it was recognised that modifications to the ICES VMS Data call could provide additional information to allow more in-depth analysis to be undertaken, such as requesting the landing harbour. At the same time, research activities funded by DG MARE are underway to develop spatial models of energy consumption distribution. In this regard, during WGFBIT 2024, the activities of the DecarbonyT project (https://decarbonyt.eu/) were presented. In particular, in the SubTask 1b "Operative tools for the analysis of the fuel consumption and carbon emissions by fleet/gear and area" of the project, two different approaches, based on the combination of different data sources, to reconstruct the spatial patterns of some variables (specifically energy consumption, understood as fuel, and the cost associated with it) and some performance indicators derived from the combination of these variables and others (effort, landings) already available within some data calls. In the first approach, spatial and temporal patterns of fishing effort and related catches and landings from the FDI are combined, at the level of individual fleet segments, with fuel consumption from the AER to carry out a top-down reconstruction of the spatial pattern of the Fuel Use Intesity (FUI - litres of fuel per ton of landed fish), Energy Use Intensity (EUI - litres of fuel per unit of effort), and Fuel Efficiency (FE - the ratio between fuel costs and revenue, expressed as a percentage); (Figure 2.4).

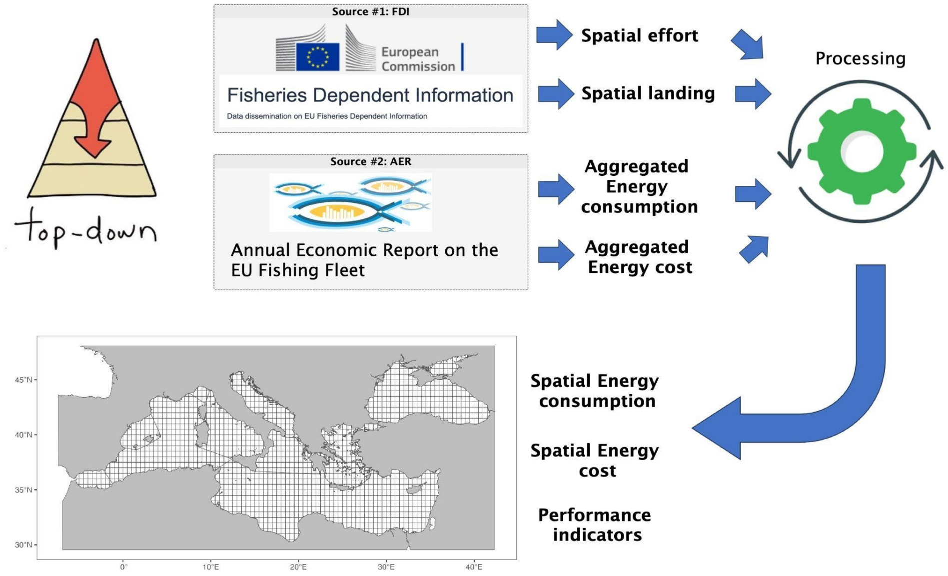


Figure 2.4. Representation of the main (top-down) approach adopted to reconstruct the spatial patterns of Energy consumption and Energy Cost, plus the Performance indicators, from FDI and AER data.

In the second approach, an application that models the fuel consumption of individual vessels (including steaming and fishing phases) to obtain a bottom-up estimation of the fuel consumption and carbon emission at the scale of the fleet segment was developed (Figure 2.6).

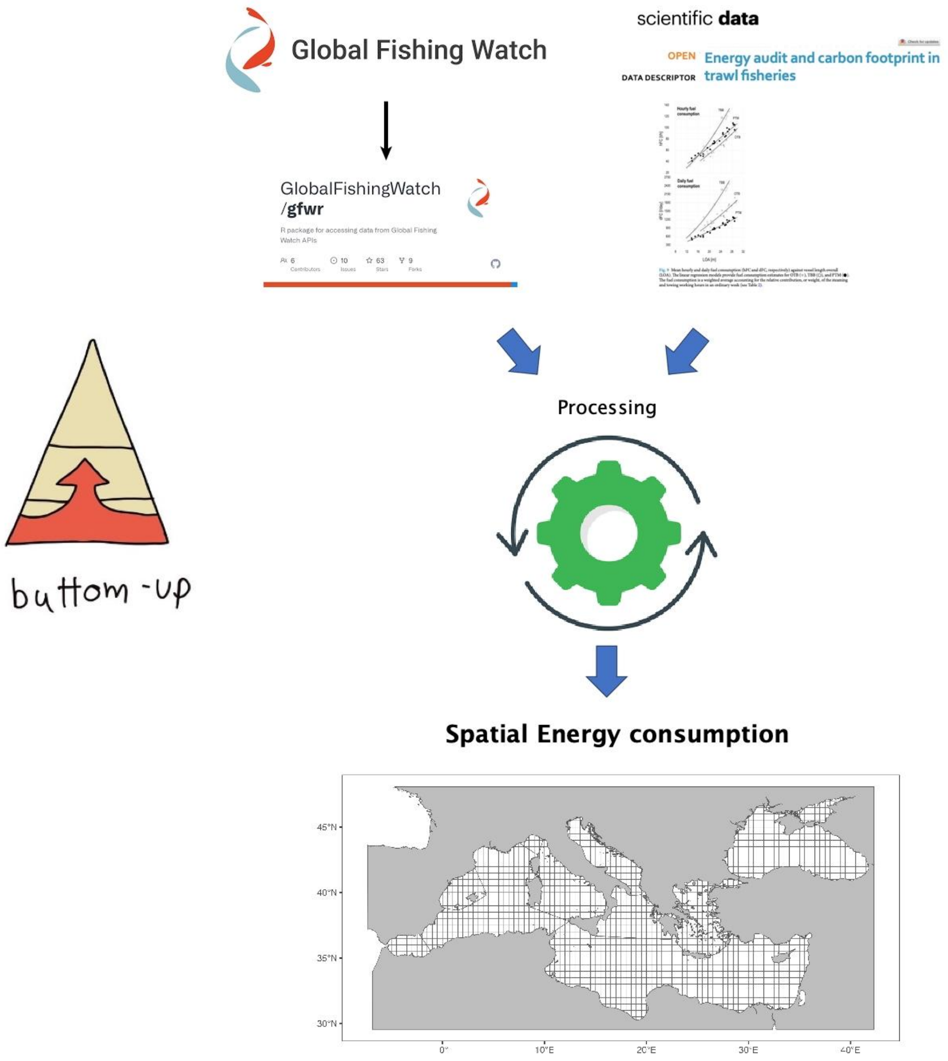


Figure 2.6. Representation of the alternative (bottom-up) approach adopted to reconstruct the spatial patterns of Energy consumpion from Global Fishing Watch data and the parameters in Sala *et al.*, 2022.

This bottom-up modelling approach was based on the Automatic Identification System (AIS) data made available by Global Fishing Watch (GFW - https://globalfishingwatch.org/), which were downloaded and used in conjunction with parameters published in. of parameters, such as those published in Sala *et al.* (2022).

Effect of the MPA (Attraction)

The "attraction" effect of MPAs refers to aggregating fish populations within protected zones due to reduced fishing pressure, potentially increasing fish biomass and spillover benefits. However, displaced fishing efforts may concentrate along MPA boundaries, intensifying pressure in adjacent areas. This edge effect can undermine broader conservation goals.

Scenario modelling must include:

- Spillover dynamics and boundary fishing behaviour.
- Design considerations to minimise adverse effects, such as buffer zones or rotational closures.

Displacement of fishing efforts is an important issue when considering MPAs or nursery/recovery areas; however, specific clarifications regarding coastal and offshore MPAs are necessary. Many stocks that are overexploited or at risk of overexploitation (according to STECF and GFCM) do not interact directly with coastal ecosystems during their life cycles and, therefore, do not interact directly with coastal MPAs. Nonetheless, analyses of connectivity and spillover dynamics are very important and well-known for significantly affecting species fitness through interactions with coastal stocks. Clarifying these points could help readers and assist us in planning our next steps more effectively. I would be happy to provide support on this if needed.

Effect of the Fleet Structure

Fleet heterogeneity, including vessel size, gear type, and fishing strategy, influences the impacts of displacement. Scenarios must account for:

1. Differential adaptability of fleets: Smaller vessels may struggle to relocate compared to larger, more mobile fleets.
2. Displacement pathways: Variations in where and how fleets relocate effort can alter benthic states and fishing mortality distribution.

Dynamic fleet behaviour models, such as agent-based simulations, can be employed to predict and optimise displacement outcomes.

Presence of Vulnerable Marine Ecosystems (VME) and Biodiversity Hot Spots

Protecting VMEs and biodiversity hot spots is a primary objective in spatial optimisation. Scenarios must integrate ecological data to:

- Prioritize areas with high conservation value.
- Assess the trade-offs between protecting VMEs and sustaining fishing activities.

ICES advice on benthic habitat sensitivity and recovery potential is essential for informed decision-making.

Information Provided by Local Knowledge

Incorporating local fishers' knowledge enhances scenario robustness by providing:

1. Insights into historical fishing patterns and habitat usage.
2. Context-specific data that might not be captured in scientific assessments.
3. Collaborative opportunities to gain stakeholder support.

Engagement strategies should be integrated into scenario development processes, ensuring equitable representation and the inclusion of traditional ecological knowledge.

Improve characterization of fishing gears and Incorporate new gear component assessments of impact to improve the realism of the scenarios

Apart from displacement scenarios, there is a need to improve the estimates for swept area and fishing impact, by refining the characterization of fishing gears. The approach currently considers 10 different fishing metiers: four otter trawls (OT_SPF, OT_CRU, OT_DMF, OT_MIX), three beam trawls (TBB_CRU, TBB_DMF, TBB_MOL), a dredge (DRB_MOL), and two demersal seines (SDN_DMF, SSC_DMF). All European MBCG-fisheries are categorized into one of these metiers, which may oversimplify our estimates of fishing intensity and impact (as vessel-length and gear-width relations and overall depletion estimates are metier specific (Eigaard *et al.*, 2017, Rijnsdorp *et al.*, 2020)). Applying the WGFBIT approach to an elaborated set of metier-groupings could improve the representability of the assessment for all different fisheries active. In addition, a new gear component approach in determining the swept area and fishing impact might refine the assessment even further. This approach, currently under review by ICES Journal of Marine Science, estimates the dimensions of seabed-contacting gear components individually. It establishes fishery specific relations between gear component dimensions and vessel lengths and uses them to determine component specific path widths. When combined with component-specific estimates of penetration depth, depletion rates can also be determined and applied to determine overall fishing impact while better accounting for actual fishing gear design. Moreover, the gear component approach allows for directly calculating mobilized sediment.

Potential effect of Displacement on Gas Emission and stored Organic Carbon

Future applications of the trade-off analysis may expand to service recommendations on identifying trade-offs between management measures and fisheries' climate impacts. Globally, government and industry focus are increasingly on GHG reductions and the protection/increase of our carbon stores in the coming years. Two areas to explore further would be 1) emissions to air from the fishing vessel (proportional to time spent at sea) and 2) the impact on stored organic carbon (OC) in marine sediments. Trade-off analysis on fisheries extent and emissions to air from vessel operations (KgCo2e (equivalent)). Combining the available data from FDI and methods for estimating fuel consumption in fisheries with relevant emission factors and indirect GHG scalers will estimate the total KgCO2e emitted from vessels. Once combined with displacement models, emissions data may provide insights into the impact management measures would have on fleet emissions (see Scherrer *et al.* 2024). For any emissions trade-off analysis to be possible, there needs to be better availability of primary GHG activity data or, if this is not possible, an analysis of the uncertainties associated with applying different methods for estimating fuel consumption in fisheries. The next step in an energy trade-off analysis would be to look at the Fuel Use Intensity (Fuel consumption/tonne of catch) OR GHG performance metrics (such as KgCO2e/kg Edible Weight of Catch). Calculating KgCO2e/kg Edible Weight requires knowledge of species groups within the catch per grid cell to apply edible protein content fractions. Once combined with displacement models, it may be possible to predict how the catch composition of vessels may change and, therefore, the GHG performance of boats. Finally, once the 'Effect of the MPA' work area has progressed and we have a greater understanding of potential stock increases from closing areas or spillover, naturally, you'd expect this to improve the fleet's energy efficiency, and this analysis would help determine appropriate management measures to implement.

With an increased understanding of the distribution and quality of OC stored in marine sediments, completing a trade-off analysis on fisheries extent and disturbance of sediment Organic Carbon stock could be helpful. Furthermore, once displacement models have matured, management scenarios could test the anticipated impact of fishing displacement on OC stores (Porz *et al.*, 2024). OC stock maps for the UK and the North Sea and resuspension models are now well-developed to support this trade-off analysis in determining the quantity of OC disturbed (Zhang *et al.*, 2024). Although not within the scope of this work, considering trade-offs through the climate change lens could also be beneficial in its application to other ICES WG, i.e., on nature restoration. For example, some blue carbon habitats will bring greater emission sequestration returns on investment.

Roadmap and recommendations

As a result of the discussion and sharing of the experiences described in the previous sections, WGFBIT has come up with several potential developments that are likely to be implemented in the next two years. At the same time, several recommendations were developed for the scientific community and management bodies involved in collecting and managing data used (also) within the WGFBIT community.

Table 2.1. Table presenting the WGFBIT assessment of the different products that can be potentially delivered during the 2024-2026 cycle of activities. Details are provided about the expected time to achieve them, the areas where these products can be obtained, and the issues limiting the immediate availability.

What (Product)	When (1 year? 2 year? more?) - Time required to deliver	Where (Areas where this product can be provided)	Main data sources	Why not now/what we still need
Core Fishing ground definition	Now	All	Atlantic: VMS-Logbook data Med: FDI	High-resolution & country-disaggregated FDI data
Spatially-explicit applications of models addressing the effect of closures including displacement	1 year (2026)	Where a VMS/Logbook data call is present Case study of westmed permanent and seasonal closure (with know pattern of effort reduction and displacement)	VMS/AIS/SAR Logbooks SDM Spatial Landings Spatial Costs Spatial GVA Monthly SAR values	Spatial Costs Possibility to use simple hypothesis of effort redistribution based on existing observations when no model exists
Scenario of gear modification	1 year (2026)	Where a VMS/Logbook data call is present	Case of OTB to OTT shift or OTT ban in Med spatial landings and effort per gear type (possibly by species) conversion factor in fishing footprint and catches between gears (possibly by species). See https://archimer.ifremer.fr/doc/00914/102619/ for an example of gear shift from OTB to OTT in West Med	conversion factor in fishing footprint and catches between gears (possibly by species).
Data visualization & Interactive Open-source platforms (Shiny)		html's are available;		Shiny version control?
Assessment of "MPA values" and/or VME distribution		All	Scientific Surveys Catches eDNA and other data sources Expert knowledge	

Table 2.2. Table presenting the WGFBIT assessment of the different products can be potentially delivered during the 2024-2026 cycle of activities. Details are provided about the scientific development, the available examples, and the expected implications.

Product description	Scientific development	Examples	Implications
Core Fishing ground definition (CFGD)		In the WKTRADE3, R scripts were developed to analyze the core fishing grounds based on ICES VMS/Logbook data In the WKTRADE4, R scripts were used to obtain CFGD for Atlantic and Med	When the resolution is too low (e.g. WKTRADE4), products cannot be used to develop spatial-based management measures
Spatially-explicit applications of models addressing the effect of closures including displacement	Implementing board-scale static models of fisheries displacement within the ICES' project for the EEA.	Scenarios displacing fishing activity relative to fishing effort and relative to LpUE. Projects: SEAwise	Case for comparability of static or dynamic outcome in displacement
Assessment of "FRA values" (especially trawling-restricted areas) and/or VME distribution **+ MPA where an effort regulation is applied**		Projects MAPAFISH (North Sea & Med) B-USEFUL (link)	
Scenario of gear modification	New approach to parameterize each (seabed-contacting) gear component individually to assess fishing intensity, impact & sediment mobilization. (DTU project; ppt Karin)	case study of 3 Danish OT fisheries (Nephrops, Cod, Plaice) DecarbonyT Project	Improved accuracy of impact assessments and integration of sediment mobilization quantification.

Final recommendations and next steps

The WGFBIT 2024 elaborated the following suggestions:

- The group agree that a spatial resolution of 0.05 degrees (c-squares 0.05) can be considered as "good" source of spatial information for fishery-related data (actual standard in the ICES context, but also recommended for the Mediterranean). 0.01 could be even better to adapt the model to the spatial definition of the different spatial structures (e.g. MPA, FRA, hot-spots). This aspect was already extensively discussed in other WGs (WGSFD)
- When the focus in on species characterized by seasonal exploitation and/or when the purpose of the analysis is to simulate temporal closures, data (effort, landings, catch) should be provided at a monthly scale.
- Standardize and disseminate updated information about the existing FRA and management layers in the form of Geospatial data (e.g. shapefiles). Further support already existing initiatives such as EMODNET, MedPAN, and other web repositories.

Trade-off Analysis

From the activities conducted in ToR A, a dataset was assembled, for the Atlantic and Mediterranean areas, with the structure represented in Table 2.3.

The dataset contains, for each csquare, information about:

- The Ecoregion (*https://www.emodnet-seabedhabitats.eu/access-data/download-data/?linkid=1*) and EEZ (*https://www.emodnet-seabedhabitats.eu/access-data/download-data/?linkid=1*) to which it belongs
- The area in Km^2
- The dominant habitat type, according to the classification (COM DEC 2017/848/EU) applied in the Marine Strategy Framework Directive (MSFD). The source for this layer is: *https://www.emodnet-seabedhabitats.eu/access-data/download-data/?linkid=1*
- The estimated value of the Population Dynamics (PD) indicator used in WGFBIT, which assess the decline in total biomass
- The sum of weight (in Kg), the sum of value (in Euros), and the sum of effort (in Fishing Days)

Table 2.3. Layout of the data frame used for the Trade-Off analysis.

Csquares	Ecoregion	EEZ	Area km^2	Depth	Dominant MSFD	PD	Sum Weight	Sum Value	Sum Effort
1602:352:487:3	Baltic Sea	Sweden	12.71	1.41	Circalittoral mud	1.00	0.00	0.00	0.00
1602:352:383:2	Baltic Sea	Sweden	12.74	0.48	Circalittoral mud or Circalittoral sand	1.00	0.00	0.00	0.00
1602:352:384:2	Baltic Sea	Sweden	12.74	0.24	Infralittoral mixed sediment	1.00	0.00	0.00	0.00
1602:352:487:1	Baltic Sea	Sweden	12.74	0.44	Infralittoral mixed sediment	1.00	0.00	0.00	0.00
1602:352:487:2	Baltic Sea	Sweden	12.74	0.83	Infralittoral mixed sediment	1.00	0.00	0.00	0.00
1602:352:488:1	Baltic Sea	Sweden	12.74	0.75	Infralittoral mixed sediment	1.00	0.00	0.00	0.00
1400:237:475:3	Western Mediterranean Sea	France	22.36	52.45	Circalittoral sand	1.00	4.05	0.00	27.45
1400:237:374:2	Western Mediterranean Sea	France	22.38	182.47	Upper bathyal sediment or Lower bathyal sediment	1.00	0.00	0.00	27.45
1400:237:475:1	Western Mediterranean Sea	France	22.38	246.91	Upper bathyal sediment or Lower bathyal sediment	1.00	4.05	0.00	27.45
1400:237:363:4	Western Mediterranean Sea	France	22.39	324.67	Upper bathyal sediment or Lower bathyal sediment	1.00	0.00	0.00	27.45
1400:237:364:3	Western Mediterranean Sea	France	22.39	603.29	Upper bathyal sediment or Lower bathyal sediment	1.00	0.00	0.00	27.45
1400:237:364:4	Western Mediterranean Sea	Monaco	22.39	643.39	Upper bathyal sediment or Lower bathyal sediment	1.00	0.00	0.00	27.45

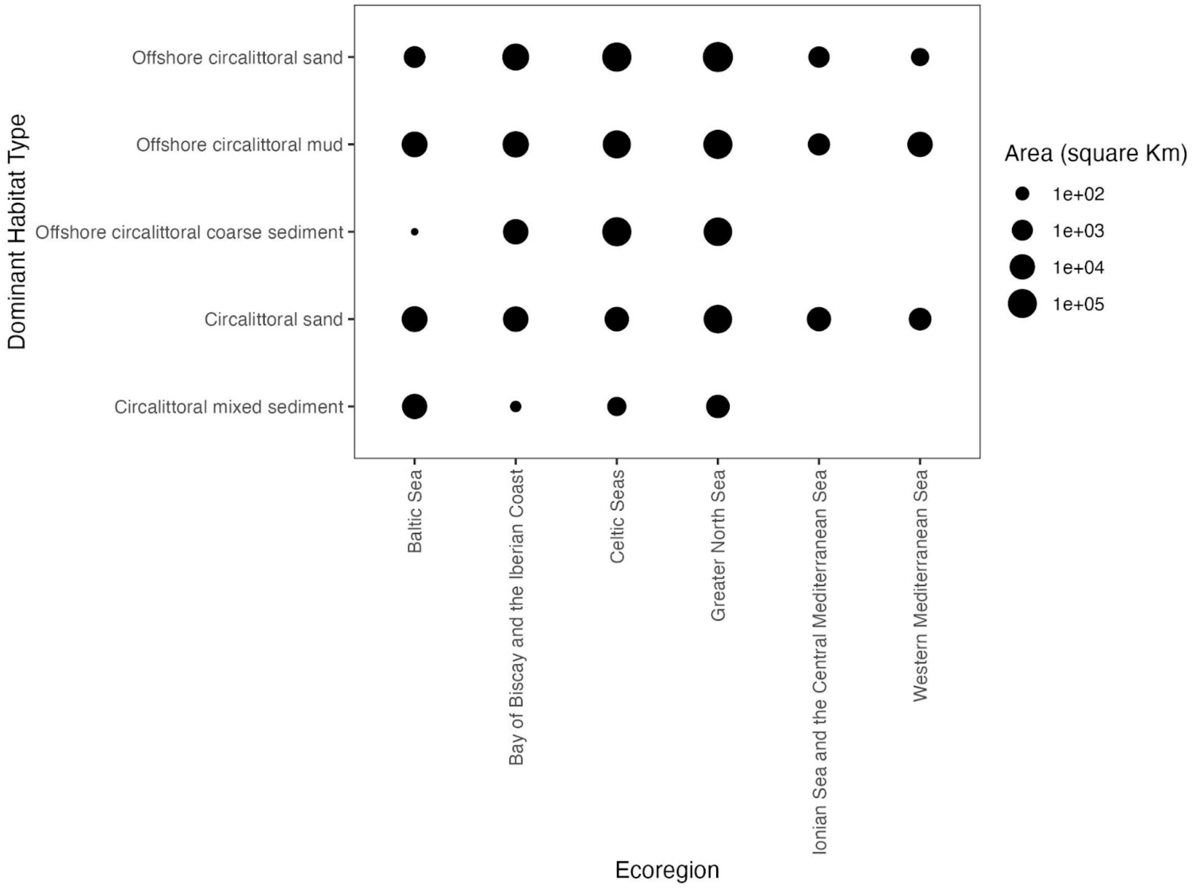


Figure 2.7. Coverage of the data with respect to Dominant habitat types and Ecoregions.

The main Habitat types are also scored in Figure 2.8.

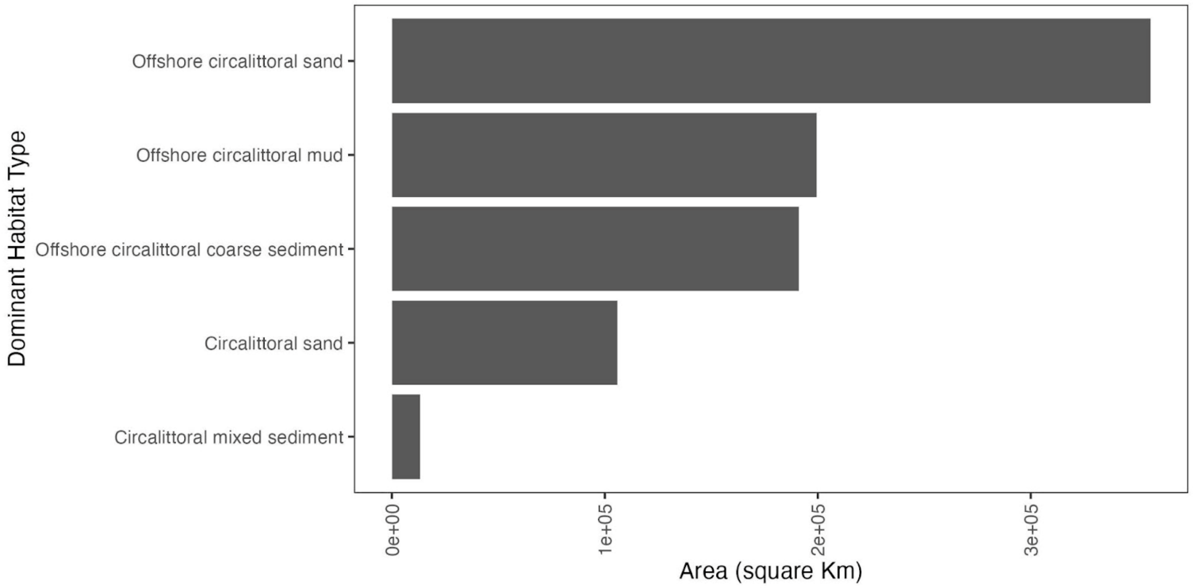


Figure 2.8. Barplot of the main habitat types by surface area in Km^{2}.

Using the PD index as an indicator of RBS, the proportion of cells exceeding a set of thresholds (0.55, 0.60, 0.65, 0.70, 0.75, 0.80, 0.85, 0.90, 0.95) defined as follows was assessed. The corresponding proportions of effort, weight and value were calculated in parallel.

Table 2.4. Layout of the table linking the threshold value (column "quality") to the corresponding values of proportion (over the total value by Habitat type and Ecoregion) of surface area, landing value, fishing effort and landing weight.

Habitat type	Ecoregion	quality	surface area	landing value	fishing effort	landing weight
Offshore circalittoral sand	Baltic Sea	0.95	0.67	0.77	0.76	0.77
Offshore circalittoral sand	Bay of Biscay and the Iberian Coast	0.95	0.16	0.96	0.96	0.97
Offshore circalittoral sand	Celtic Seas	0.95	0.38	0.88	0.90	0.87
Offshore circalittoral sand	Greater North Sea	0.95	0.50	0.90	0.91	0.89
Offshore circalittoral sand	Ionian Sea and the Central Mediterranean Sea	0.95	0.23	0.82	0.76	0.77
Offshore circalittoral sand	Western Mediterranean Sea	0.95	0.42	0.66	0.57	0.50

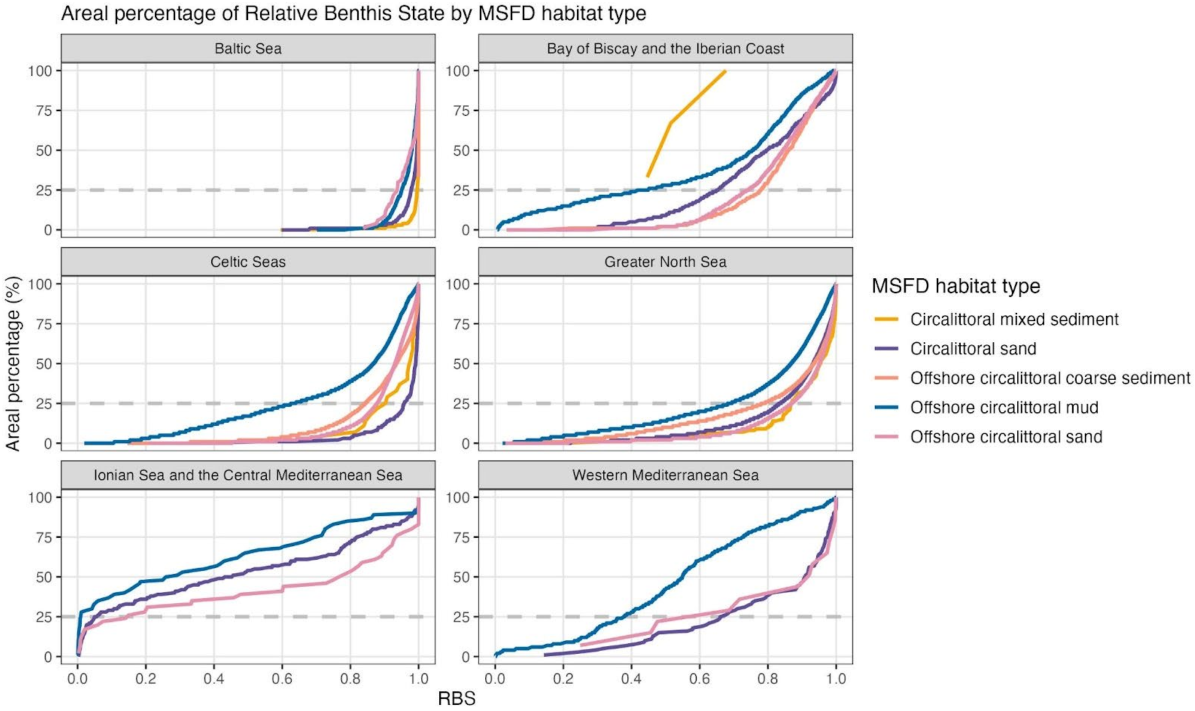


Figure 2.9. Scree plots of the % of area, by MSFD habitat type, with respect to the Relative Benthic Status (x-axis).

Then, in the following phase of this trade-off analysis, we explored the potential effects of selecting different values of the RBS to identify the GOOD status according to the purposes of the MSFD. In particular, we evaluated setting the RBS to a value between 0.55 and 0.95. The corresponding surface area above the quality threshold is scored, while the corresponding cumulative values are scored for fishing effort, landing weight, and landing value. The reference proportion of 75% is also visualized as a dashed line. In this way, in all combinations of habitat type and ecoregion considered, a decreasing trend can be described for the red line identifying the surface area. This is because as the minimum value of RBS that is considered (x-axis) increases, the proportion of the total area that meets this criterion decreases. In parallel, the lines for fishing effort, landing weight, and landing value show opposite trends.

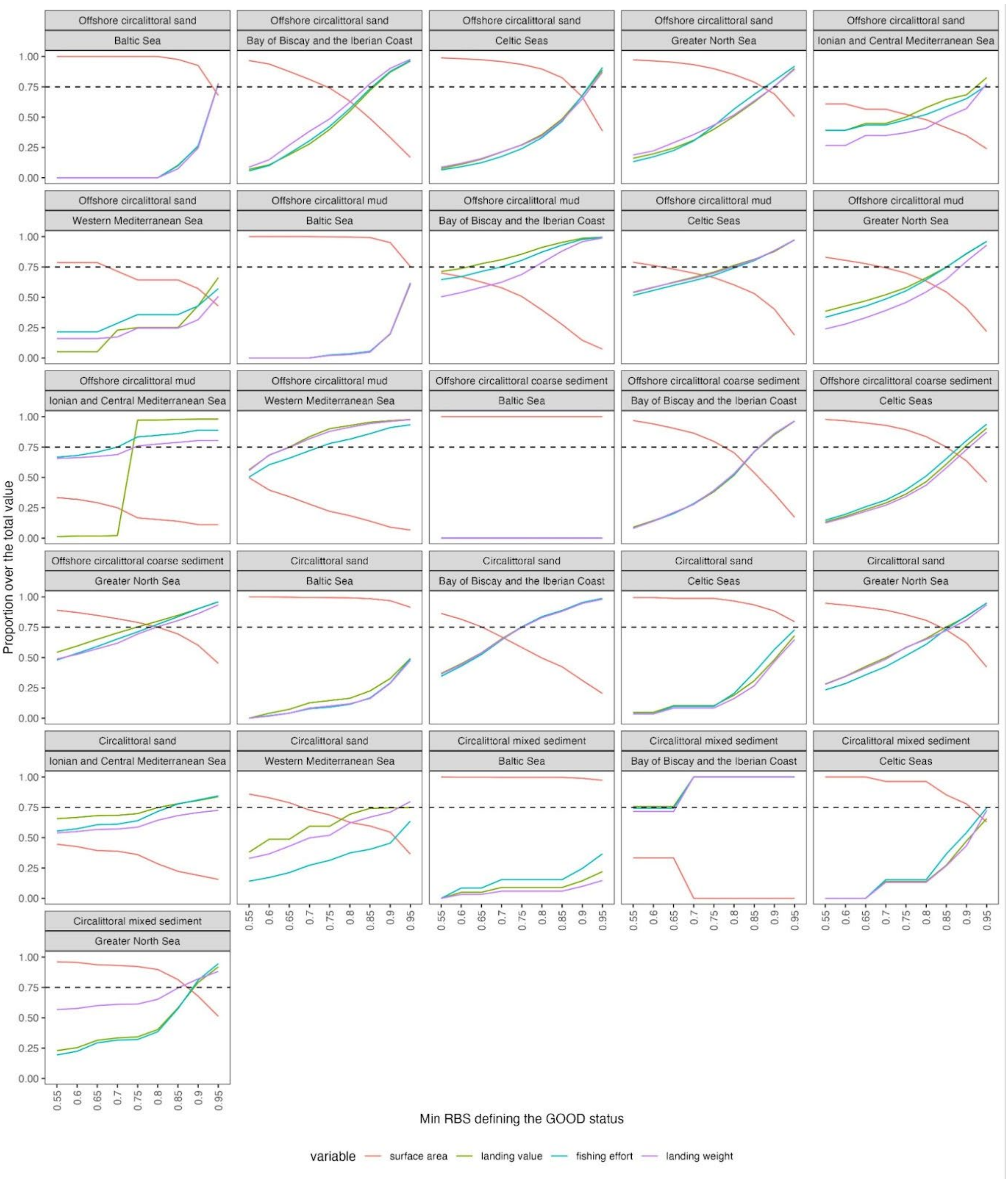


Figure 2.10. Scree plot representing the results of the trade-off analysis in which the potential effects of selecting different values of the RBS are used to assess the corresponding proportion of surface area, landing value, fishing effort and landing weight.

The trends of these indicators, in effect, being pegged to those of the surface area, grow because the larger the area is considered, the greater the proportion of total fishing activity (and thus of effort and all associated indicators). The relative position of the intersection point between the surface area curve and the indicator curve tells the main aspects of the case study considered.

For example, in the case of the Circalitteral sand habitat for the Greater North Sea, it is seen that about 75% of the surface area is associated with an RBS of 0.85 (and thus in good condition), and the corresponding fisheries accounted for about 75% of all fisheries-related parameters. In other cases, such as for the Offshore Circalittoral coarse sediment habitat in the Greater North Sea, this intersection corresponds to an RBS value between 0.75 and 0.8.

The D6C5 of the MSFD requests that the extent of the seafloor (in terms of surface area) not adversely affected (i.e. in good quality/condition) is above 75% of the total area by habitat type and ecoregion. Namely:

D6C5 Adverse effects on habitats– extent: the maximum proportion of a benthic broad habitat type in an assessment area that can be adversely affected is 25 % of its natural extent (≤ 25 %). This includes the proportion of the benthic broad habitat type that has been lost (D6C4).

Then, in the final phase of this trade-off analysis, the value of RBS = 0.8 was selected to identify the GOOD condition status and, for each Habitat type and Ecoregion, the percentage reduction of exploited area and of fishing effort to reach this target was estimated by habitat type and Ecoregion. These reduction percentals were calculated, from the data depicted in Figure 2.10, as the difference between the surface area already over the limit of RBS = 0.8 (if any) additional surface area to meet the target. For example, in the case of the Offshore Circalittora Mud in the Greater North Sea, only 64 percent of the starting area meets the criterion and, therefore, an additional 11 percent needs to be protected (by removing fishing activity within it), which, in turn, drags in 21 percent of the fishing effort and 18 percent of the landing value. The results of this trade-off analysis (Figure 2.11) shows that:

- In the Baltic Sea, fishing activities are concentrated in a very small portion of the available space and, therefore, for all habitat types, the reductions needed to reach the MSFD target would be small (< 10%) in terms of surface area, but very large (80–100%) in terms of effort;
- In the Bay of Biscay and the Iberian coast, some habitat types could reach the MSFD target with modest reductions (around 25% of the area) and effort (less than 35%), specifically Circalittoral Sand, Offshore Circalittoral Sand and Offshore Circalittoral Coarse Sediment. For the remaining two habitat types, however, reductions of nearly 100% in surface area and effort would be required;
- In the Celtic Seas and in the Greater North Sea, all habitat types could meet the MSFD target with surface area reductions within 25%, but in contrast, the corresponding effort reductions would vary between 10 and 80% depending on the habitat type;
- Reductions of nearly 100% in surface area and effort would be required in the case of the Ionian and Central Mediterranean Sea;
- In the Western Mediterranean Sea, two groups of habitat types, as observed in the Celtic Seas and in the Greater North Sea, characterize the pattern.

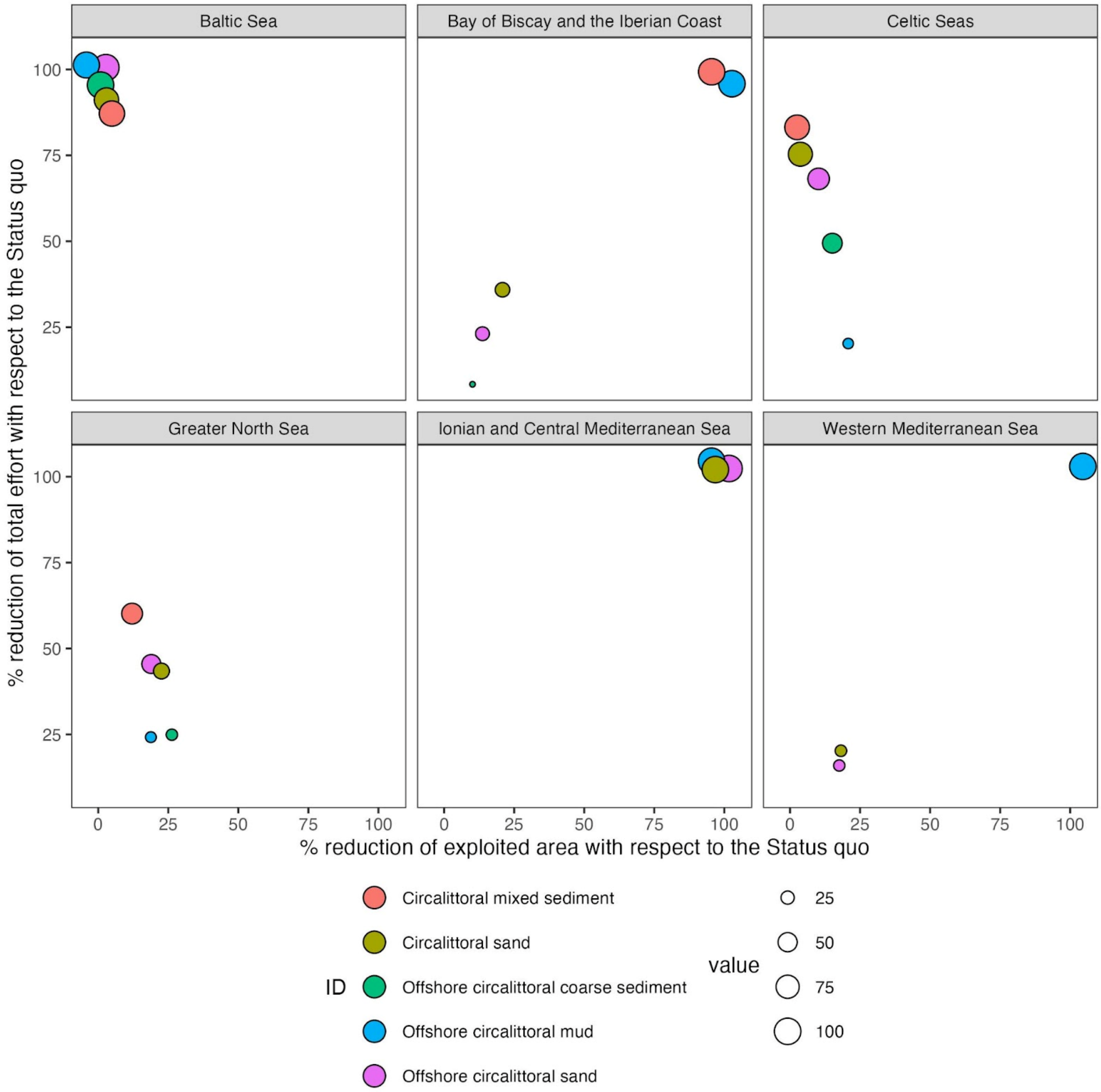


Figure 2.11. Scatterplot in which the % reduction of exploited area (x-axis) and the corresponding % reduction of the fishing effort to reach the target of RBS above 0.8 in the 75% of the surface area by habitat type are visualized for each Ecoregion. The % reduction of landing value is also represented as point size.

3 Knowledge exchange with other regional assessment methods

At the meeting there was some discussion on how to move ToR C, on knowledge exchange with other assessment approaches, forward. There was enthusiasm in the WG to compare different assessment methods and their outputs. The biggest advance in such comparisons was recently made was a paper by (Van Denderen *et al.*, 2024), but the difference there was that this compared indicator values calculated for stations from samples, while here we want to compare assessment methods that produce spatial maps of state. This is much harder to do because risk assessment methods that use the SAR layer as an input are likely to show strong correlations because the areas with no fishing and therefore no impact, will be identical. There are also issues with spatial autocorrelation. Comparisons may need to focus on identifying if similar areas are considered to be in a good state. Rather than comparing indicators, we could aim at comparing GES assessments after thresholds have been set, and see if those agree.

There was some suggestion that a way of testing methods was to identify if the maximum pressure level that is compatible with good state is similar for different indicators, but others disagreed because it cannot be expected that different indicators would require a similar pressure to achieve GES.

Some group members are or have been doing such comparison, and should be able to present these next year (JNCC, Jose and Sasa), and Gert may be able to present on the work that is being done through TGSeabed next year. A more comprehensive comparison is beyond the scope of what FBIT can take on, and may be more productively pursued through another or new WG/WK.

For now, it was decided that the role of FBIT for this ToR is to try to keep track and evaluate ongoing comparisons of assessment methods, rather than to lead the initiation of new comparisons.

Natural England

Reducing the impact from bottom-towed fishing gears to benthic habitats is generally accepted, but the conundrum of where, is of particular relevant in the prioritisation and trade-offs decisions for the marine sector. Benthic indicators can aid decision making by, for example, quantifying the status of benthic habitats after fishing (e.g. Relative Benthic Status (RBS)) or identifying areas of high risk to negative trawling impact (e.g. MarESA[1] approaches – such as Extent of Physical Disturbance to Benthic Habitats (BH3), Natural England's Spatial Seabed Sensitivity Tool (NESSST)). Whilst each indicator has its strengths, they can also have limitations in certain circumstances (e.g. in particular habitats) and thus identifying which indicators to use when, helps to provide the most accurate advice to UK inshore fisheries management.

Using the King Scallop fishery in English Channel as an example, we aim to apply and compare different benthic indicators in different management scenarios and assess their sensitivity to changes in management. We will evaluate the model outputs with a focus on the extent to which the indicators align, and what inference can be draw. We aim to conclude whether one, or a combination of indicators, can be used in the assessment of UK fisheries management and report to on UK Marine Strategy 'Good Environmental Status'.

4 Ecosystem functioning

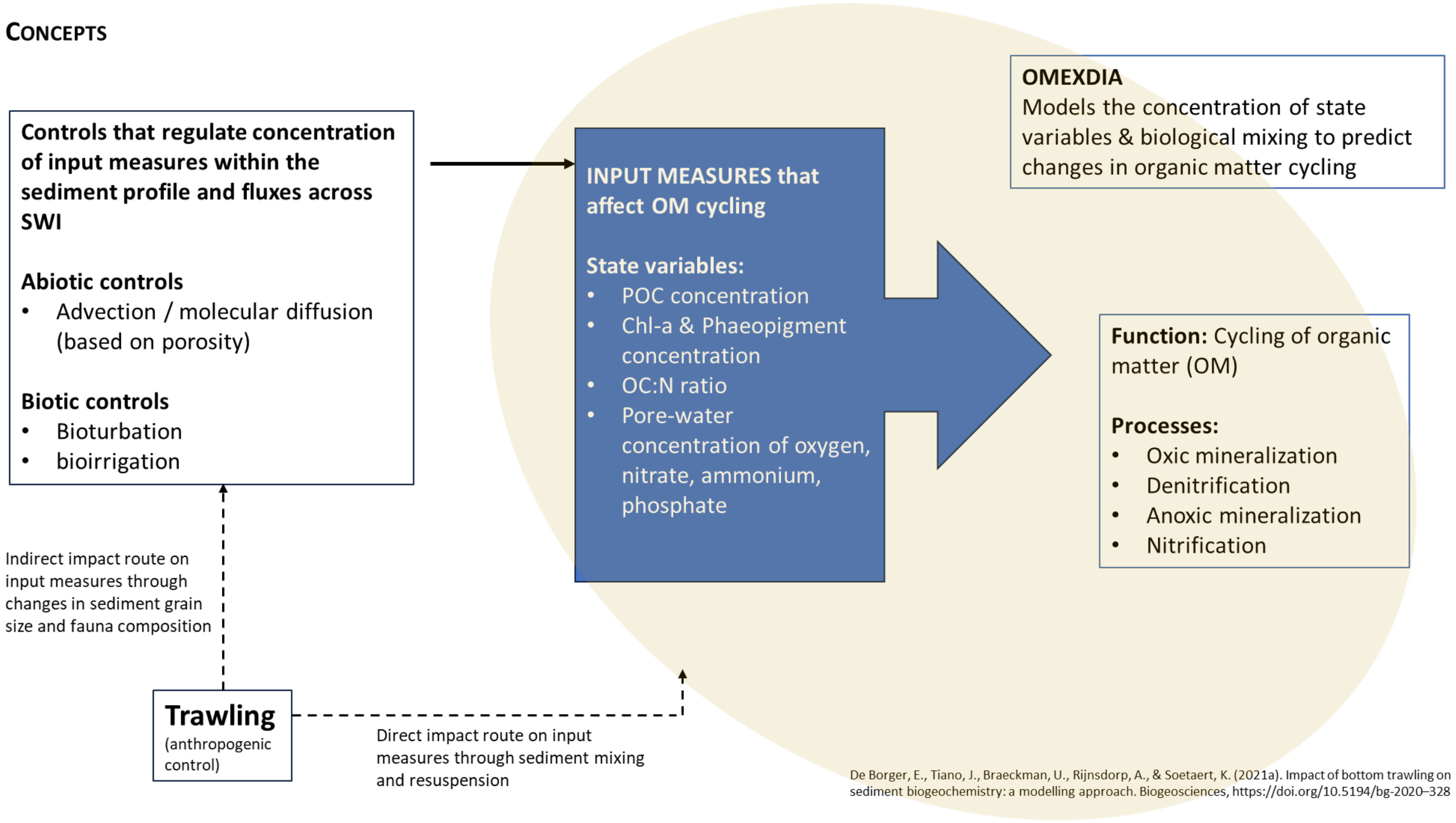
Mechanical disturbance from trawling impacts ecosystem functioning through changes in the physico-chemical compositions of the seabed as a result of sediment mixing and resuspension as well as through the mortality of the fauna present in and around the seabed. By depleting fauna and changing the species composition, bottom fishing can result in alterations in the functional effect traits (bioturbation, bioirrigation) of a community, which in turn may have broad implications for the overall ecosystem performance. The goal of ToR d is to develop further the WGFBIT seafloor assessment framework to predict changes in seabed habitat status in terms of ecosystem functioning.

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. Functional traits have often been advocated as proxies for predicting ecosystem functioning responses to anthropogenic perturbations.

In ToR d we:

1. Develop and test a data-driven mechanistic model that predicts changes in species composition due to trawling (following principles of PD model used in FBIT). The model, known as BFIAT, can estimate changes in biological processes such as bioturbation, bioirrigation and biodeposition of a community known to affect ecosystem functioning;
2. Examine empirical relationships between macrofauna descriptors (e.g. total biomass, bioturbation potential, bioirrigation potential, and species functional traits) and biogeochemical descriptors related to organic matter processing in the sediment and examine how this is influenced by trawling;
3. Link predicted changes in biological community from BFIAT to biogeochemical model such as OMEXDIA to estimate changes in the carbon processing and storing in the sediment due to sediment erosion, mixing or deposition as a result of trawling.

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

INPUT MEASURES that affect OM cycling

State variables:

- POC concentration
- Chl-a & Phaeopigment concentration
- OC:N ratio
- Pore-water concentration of oxygen, nitrate, ammonium, phosphate

OMEXDIA
Models the concentration of state variables & biological mixing to predict changes in organic matter cycling

Function: 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

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

BFIAT model: Predicting trawling effects on species community composition

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We present preliminary results of multiple case-studies using the BFIAT model (described in detail in ICES WGFBIT 2022 report) to predict trawling effects on species community composition and function. In brief, the model calculates the changes in benthic species density or biomass, using the logistic growth model parametrized using species-specific depletion rates based on the position of species in the sediment (surface, 0–5cm, 5–15cm, 15–30 cm, > 30cm) and gear-specific penetration depth (OT, BT, TD, S), and recovery rate specific for different life span (<1 yr, 1–3 yrs, 3–10 yrs, 10–20 yrs, >20yrs). These 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 following a period of fishing and cessation of trawling. 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 under construction and will be made publicly available in 2025.

Preliminary findings from BFIAT model for Greek waters

Data: Fished and unfished areas in the north of Heraklion city in Crete (south Aegean Sea) were selected for this analysis (Figure 4.1). The sampling stations are in an oligotrophic area in depths from 70 to 200 meters. We consider the benthic macrofaunal community composition, density and biomass of each station as the average of the different seasons and replicates.

Trait data required for the BFIAT model were sourced from several databases, including Beauchard *et al.* (2021, 2023), Clare *et al.* (2022), Queirós *et al.* (2013), Wrede *et al.* (2018). Fishing intensity, expressed as the maximum annual swept area ratio (SAR) for a 5-year period, was provided by the Hellenic Ministry of Mercantile Marine and Island Policy and was analyzed based on the methods and specifications further described in Maina *et al.* (2021) (and references therein).

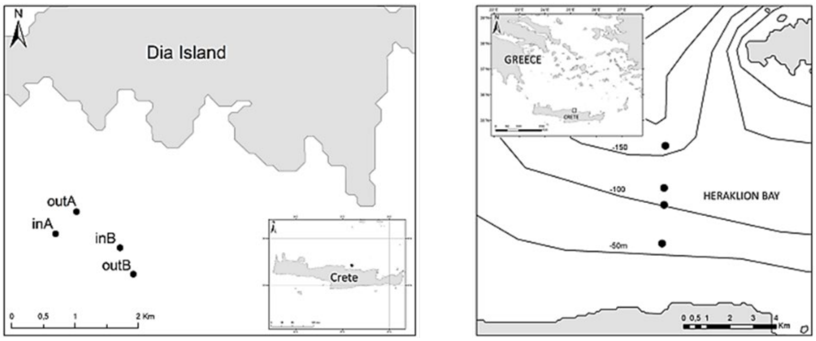

Figure 4.1. Sampling station locations in Greek waters used in the BFIAT model analysis.

Results and discussion

The model simulated a scenario where macrofaunal communities were subjected to 20 years of fishing, followed by a 20-year recovery period. Impacts were analyzed for stations in fished and unfished areas under a hypothetical fishing intensity of SAR=4. The analysis also assessed the effects of fishing on bioturbation potential. Results revealed that the station at 100 m depth experienced the most severe immediate impact, but deeper stations required longer recovery times than shallower stations (Figure 4.2, top). For undisturbed areas, shallower stations experienced greater impacts and required extended recovery periods (Figure 4.2, bottom).

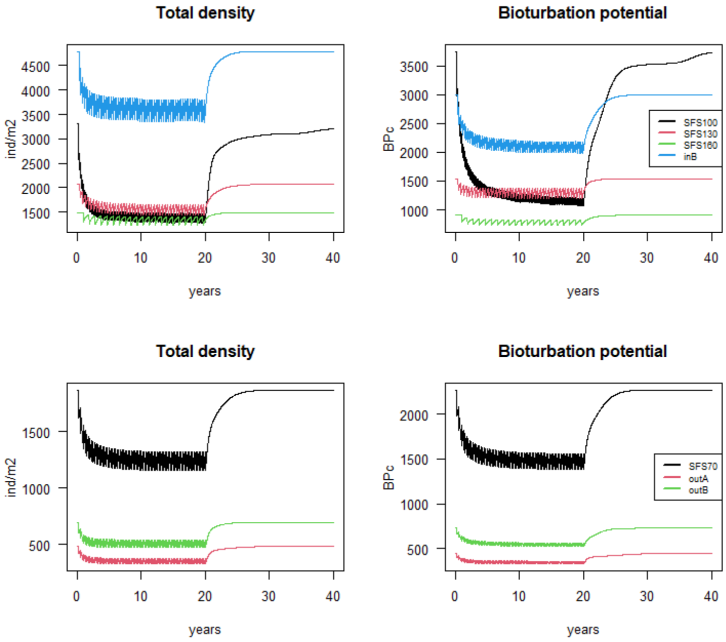

Figure 4.2. Changes in total density and bioturbation potential over time for stations exposed to 20 years of fishing followed by 20 years of recovery. Top: fished stations. Bottom: undisturbed stations with a hypothetical trawling intensity of SAR=4.

To visualize species-specific impacts, density was plotted as a function of carrying capacity for the 20 most dominant taxa (Figure 4.3). A 20% threshold of D/K (density/carrying capacity) was used to identify significant changes. Additionally, the eight species most vulnerable to trawling impacts were analyzed individually under the same 20-year fishing and recovery scenario (Figure 4.4).

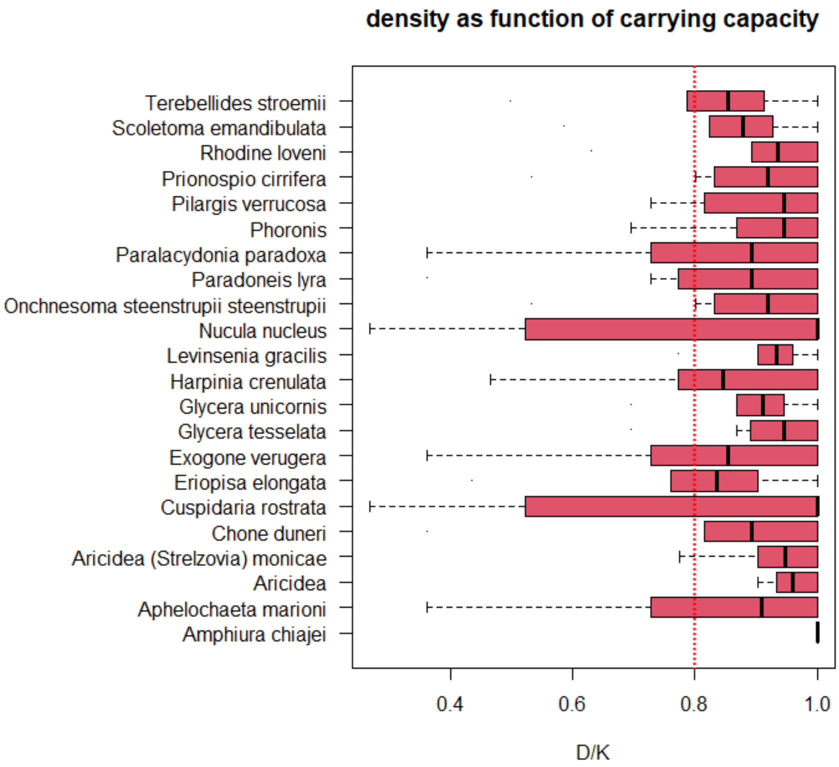

Figure 4.3. Density as a function of carrying capacity of the 20 most dominant species in the study area.

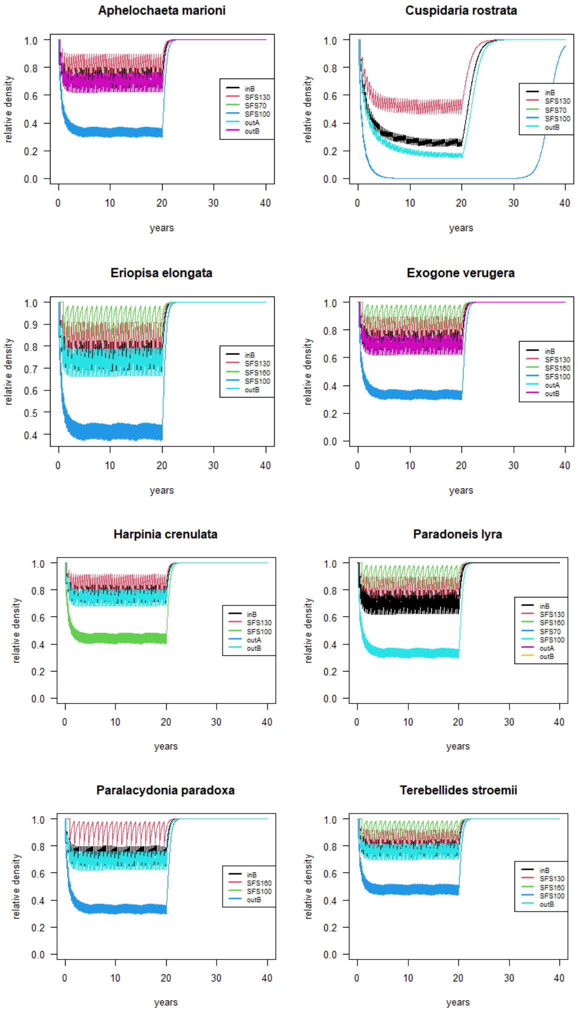

Figure 4.4. Relative density over time for species most susceptible to trawling impacts.

Preliminary findings from BFIAT model for Celtic Sea

Data

The dataset consisted of 51 stations from the Celtic Sea where macrofaunal communities were surveyed during March 2015 (Figure 4.5). The stations were from the same hydrographic unit but covered a range of sediment types (range of % silt: 1.7–86.6%), water depth (88–127 m) and fishing pressure (SAR = 0.25–15). Macrofauna samples were collected using a box core (0.08 m^2) and sieved through 1 mm. A detailed description can be found in Thompson *et al.* (2017).

Trait data required for the BFIAT model were sourced from Beauchard *et al.* (2021, 2023), and the values for community bioturbation potential and bioirrigation potential were calculated using the formulas provided in Queirós *et al.* (2013) and Wrede *et al.* (2018), respectively. Fishing intensity, expressed as the maximum annual swept area ratio (SAR) for a 5-year period, was obtained from ICES fishing pressure spatial layers (ICES 2022).

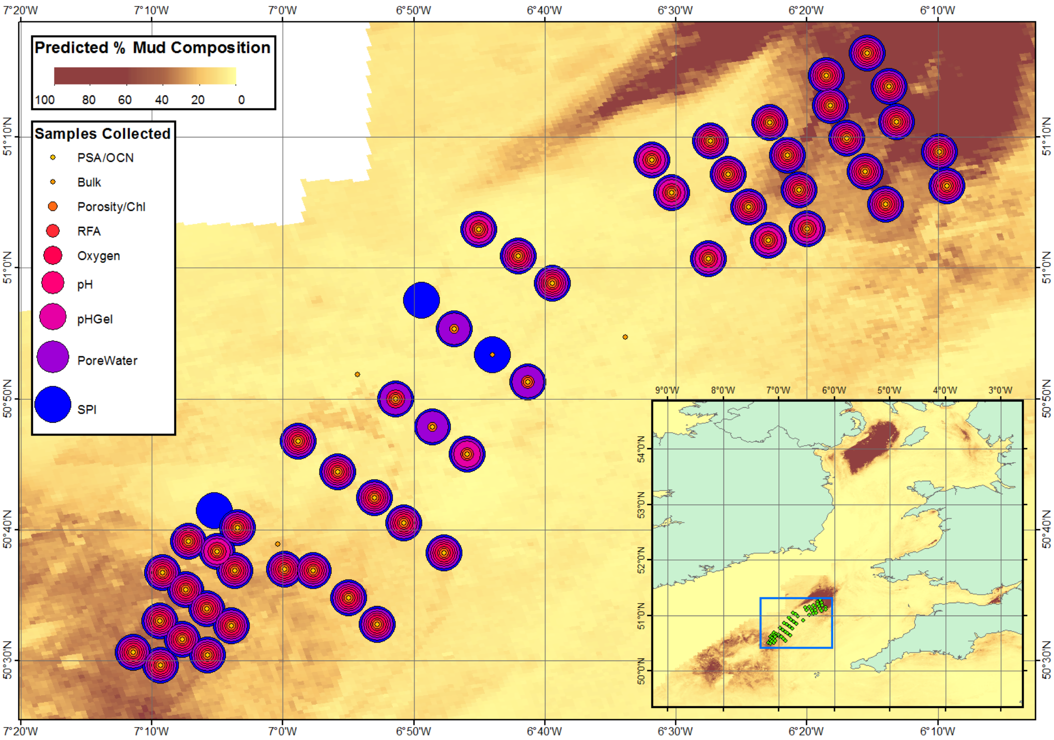

Figure 4.5. Location of the stations from which fauna data was used in the BFIAT model. Map courtesy of Ruth Parker, CEFAS.

Results and discussion

The model simulated a scenario where macrofaunal communities were subjected to 20 years of fishing frequency of 1/SAR, followed by a 20-year period of no trawling. Fishing impacts were analyzed on total community density, species community density and bioturbation potential. The community at the study sites was primarily dominated by a mixture of surface dwellers that occupy the first 5 cm of the sediment layer (*Abra nitida, Echinocyamus pusillus, Aricidea suecica, Ditrupa arietina, Amphictene auricoma*), organisms that occupy the first 15 cm of the sediment (*Galathowenia oculata, Magelona minuta, Mediomastus fragilis, Spiophanes kroyeri,* Nemertea, *Abyssonine hibernica*), and organisms that can burrow up to 30 cm deep in the sediment (*Ampharete falcata, Notomastus*).

Species-specific impact of trawling is shown for the 20 most dominant taxa, and is expressed as density as a function of carrying capacity (D/K) (Figure 4.6). Species occurring within the first 5 cm of the sediment such as *Mediomastus fragilis* and are long-lived such as *Amphiura filiformis*, Cariidae and *Nephtys hystricis* were impacted the most (i.e. D/K < 0.8).

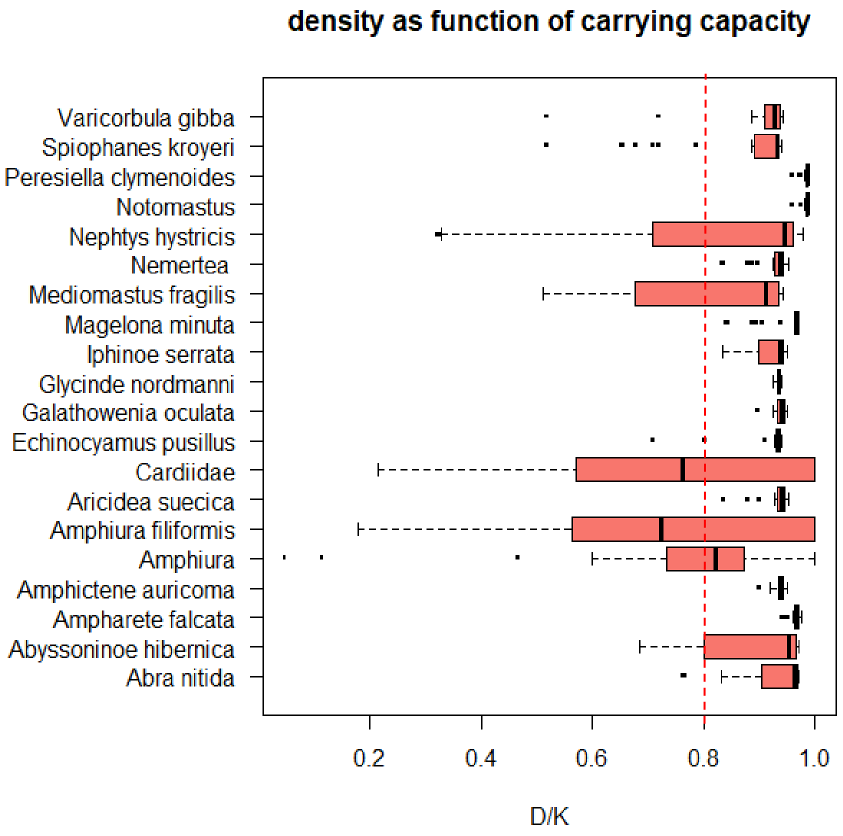

Figure 4.6. Density as a function of carrying capacity (D/K) of the 20 most dominant species in the study area. Box plots indicate the median, upper and lower quartile values of D/K from 51 stations. Low values of D/K indicate high impact on species density due to fishing.

Total community abundance and community bioturbation potential were least impacted (i.e. D/K > 0.8) at lightly fished areas (SAR < 1 yr^{-1}) (Figure 4.7). In general, community bioturbation potential was more impacted by fishing than community abundance as a higher number of stations were observed for D/K values between 0.2–0.6. Community bioturbation potential was also slower to recover compared to community abundance following cessation of fishing (Figure 4.7).

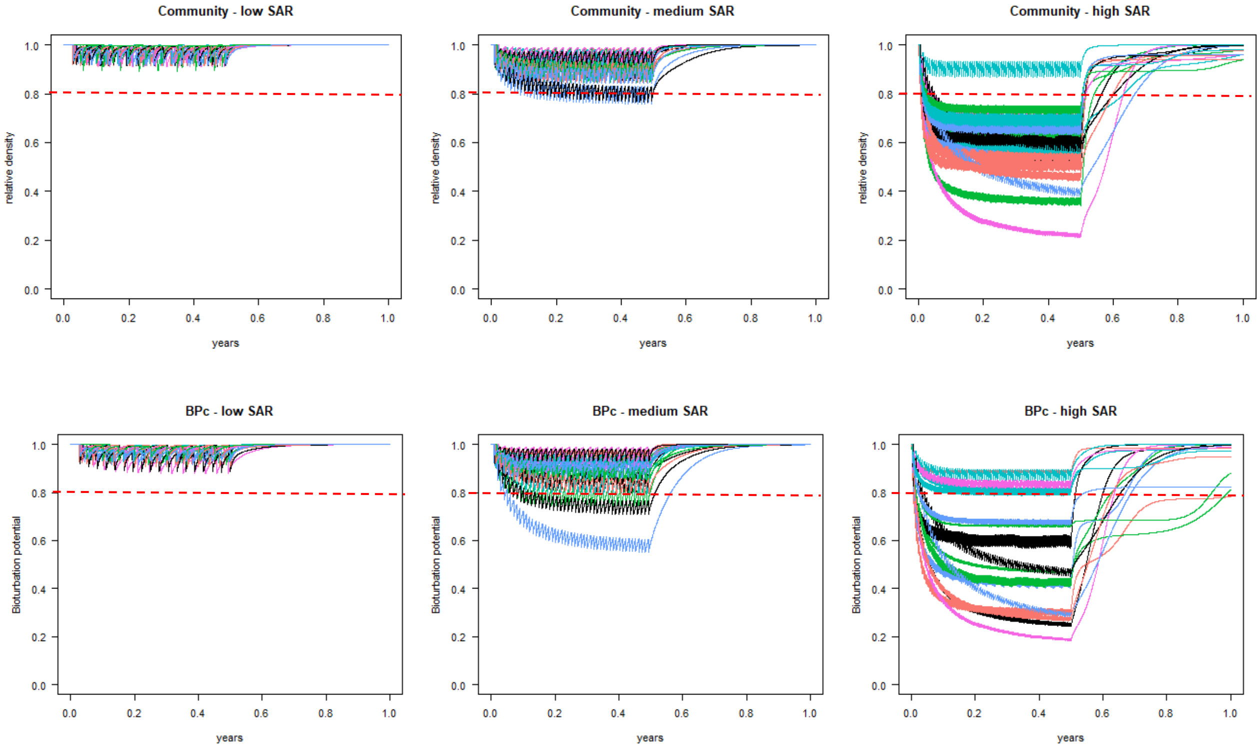

Figure 4.7 Trajectories of relative density (D/K) in terms of total community abundance (top panel) and community bioturbation potential, BP_C (lower panel) over time, as a result of 20 years of fishing disturbance followed by 20 years of no fishing. Each line represents a station (51 stations in total). Low SAR = 0.2–0.9 yr^{-1}, medium SAR = 1–2 yr^{-1}, high SAR = 3–15 yr^{-1}.

Preliminary findings from BFIAT model for Baltic Sea & Kattegat

Species and traits data were collated for two areas in Swedish waters, the southern Baltic Sea and Kattegat, and the BFIAT model run for each. For the Baltic, one of the most common species (*Macoma baltica*) could not be modelled, while for the Kattegat 13 common species could not be modelled (including the dominating species *Amphiura filiformis*). This was mainly due to the model causing unrealistically high mortality at higher trawling intensities for these taxa. The problem can be solved in the model by adjusting a parameter for “probability of escape” but this needs to be done in logical and systematic way across all the case studies in ToR D. This work is in progress.

Fauna – functioning relationships: empirical evidence

Evaluating community bioturbation potential (BPc) and biorrigation potential (IPc) as indicators of bottom trawling (in Swedish waters)

Clare Bradshaw (Stockholm University, Sweden), Mats Blomqvist (HaFok AB, Sweden), Mattias Sköld (SLU-Aqua, Sweden)

There is a need for both structural and functional indicators to assess trawling impacts and seabed status. Since it is difficult, time consuming and expensive to measure ecosystem function, using existing community structure data to estimate proxies of function, using a traits approach, has been suggested as a way forward. We calculated and assessed the functional indices community bioturbation potential (BPc) (Queiros *et al.* 2013) and community irrigation potential (IPc); (Wrede *et al.* 2018) which are proposed to be related to benthic biogeochemical cycling (ie. ecosystem function). We used existing benthic community data from four coastal areas around Sweden that experience bottom trawling but have highly contrasting environmental conditions. Trawling affected BPc and IPc in the Kattegat and Skagerrak, but not in the Bothnian Bay or Southern Baltic Sea, while environmental variables were important in all areas. For two sea areas, we measured bioturbation rates and bioirrigation rates and compared them with calculated BPc and IPc, respectively; there was a fairly good correlation between BPc and bioturbation but no correlation between IPc and bioirrigation. Although functional indicators are needed, BPc and IPc may not yet be fit-for-purpose, since they are highly sensitive to large individuals, total biomass, and small changes in the assigned trait modalities. Also, by integrating many different traits into one metric, they may obscure the importance of particular ecosystem functions.

Multiple case-study examination of fauna and biogeochemical data: data description

Ruth Parker (CEFAS), Amrei Grunder (Heriot Watt University), Karline Soetaert (NIOZ)

The biogeochemical metadata and datasets from across the group and case studies have been collated within the sharepoint. The data coverage and type were reviewed across the differing environmental settings and geographical areas to identify biogeochemical parameters with the highest overlap, enabling cross-regional assessments of changes associated with trawling. Additionally, the nature of the data— whether it represented bulk measurements (e.g., grabs or 0–5 cm and 5–10 cm intervals) or depth profile information—was examined. It was clear that depth profile information (including the shape, rate, and depth of changes) provides more detailed insights into the type and mode of trawling impacts compared to integrated sample data.

Given the available data with the most common parameters (UK, Sweden, NL, Greece) we will aim to explore trawling changes on measurements from sediment depths: 0–1cm, 0–2cm, 2–4cm or 2–5cm and 'deeper than'. This is designed to allow profile information and changes under trawling pressure to be explored. The 'deeper than' measure was decided on to allow inclusion of data where people have taken measurements at differing depths (e.g. 9–10cm, 12–13cm) but within a sediment biogeochemically which is consistent but should be below the biological mixing zone and hence most biogeochemically active layer (the suboxic and anoxic zones). The majority of data across all datasets pertains to the shallowest sampling levels, with data availability decreasing with depth (i.e., grab or surface sampling is more common than profiling). This pattern suggests a potential opportunity to refine sampling strategies to better enable cross-comparison of trawling impacts across different areas.

In the first instance, the multiple case-study assessment will focus on the following parameters:

Solid phase/particulate fraction

- Organic Carbon: (a bulk measurement of what OC is present), usually as % and is a longer time integrated measure of all particulate organic carbon present in the sediment. Many measurements did not have dry bulk density or porosity which prevents an organic carbon stock being calculated.
- OC:ON ratio: (a measure of OM source and degradation). Phytoplankton source material has a range of 6.6 (Redfield) and ON is lost preferentially as OC degrades. Terrestrial sources of OC from C3 nd C4 plants have C:N ratios of >20. However, mixes of OC sources can create blends of C:N levels which can provide challenges in interpretation across regions. Seasonality in fresh OC input can also make changes hard to interpret.
- Chlorophyll and phaeopigments: Both of these measures describe the amount and distribution (from profiles) of pigments within the seabed. These pools are an indication of the highly labile pools of carbon in the seabed. Chlorophyll levels inform on the amount of fresh OC from phytodetrital material (residence time <1 year) and phaeopigment is a degradation product of chlorophyll and operationally defined estimate of residual pigment labile carbon once chlorophyll is degraded (often post acidification via acetone). This has a longer residence time in the sediment (>1 yr) so may build up within the sediment. The ratio chla:phaeo is an indication of carbon source and degradation rates

Dissolved phase (porewater)

When organic matter is degraded by microbial processes inorganic nutrients bound into the organic matter matrix are released into the seabed pore-waters. These are in the forms ammonium, silicate and phosphate. They are measured in profiles but at often differing resolutions.

We will use this data as average concentrations for the depth bands (0–2cm, 2–4cm and ‘deeper than’) to align with the OC and pigment data where possible as a source for nutrient release.

If data from multiple depths or profiles are available we will calculate:

    - the slope of the upper part of the curve
    - total amounts (from the area(s) under the curve) across the depth ranges as listed above.

Optional extra, lower priority: where oxygen profiles have been measured Oxygen Penetration Depth (OPD) and O_2 fluxes (Diffusive Oxygen Uptake - DOU) will be calculated though discussions on methodologies and associated metrics are needed to ensure the acquisition of good data. The OPD is a good variable to differentiate between low or higher permeable sediments (diffusive or advection dominated) and hence the status from which trawling pressure may induce change.

Note

Other nitrogen species nitrate and nitrite (NO3, NO2 or NO3+NO2) are also processed within the seabed but have highly seasonal signals and also complex processing cycles from oxidation/reduction reactions within the seabed and also water column source which makes interpretation difficult. We are therefore not considering these parameters at this stage.

We will not use nutrient flux data as although it is useful for carbon breakdown assessments we have too few measurements across the case study datasets and they show a very high variability. Other seabed biogeochemical metrics which would be expected to form good indicators for trawling impacts such as aRPD (redox depth) or biological mixing depth from sediment profile imagery, carbon types (e.g. amino acids), oxygen profiles had too few measurements in common across the case studies to allow inclusion but in time additional datasets may allow the exploration of these variables with trawling impacts. Other biogeochemical and carbon parameters to include in future across the group members may be carbon reactivity measures, carbon stock and burial and other organic carbon source terms (stable isotopes) as per the blue carbon toolbox described in Graves *et al.* 2022.

Biological traits associated with key ecological functions

Clement Garcia (CEFAS), Clare Bradshaw (Stockholm University, Sweden), Pascal Laffrague (IFREMER), Marija Sciberras (Heriot-Watt University, UK), Amrei Grunder (Heriot-Watt University, UK), Olivier Beauchard (NIOZ)

The seabed supports a range of important biogeochemical functions which maintain and drive the health and productivity of shelf seas. Primarily, biogeochemical processes are driven by organic matter and oxygen input from the water column, temperature and sediment type. These processes are further mediated by the sediment movement and/or bio-irrigation activities of the biological assemblages inhabiting the sediments. Furthermore, the magnitude of change in these ecosystem properties following a perturbation is also modulated by the functional capability of the biota. This is why it is important to understand the specific contribution of the fauna to the different aspects of the biogeochemical cycles. The most promising avenue to-date to investigate the fauna-biogeochemistry relationships has been through trait-based approach whereby the species behaviour, ecology, life-history are classified in functional traits, ranked in terms of attributes depending on what they do and eventually integrated into a single index that is meant to quantify that activity. For example, the Bioturbation Potential index (BPi) and Bioirrigation Potential index (IPi) are both trait-based indices respectively quantifying sediment reworking and the exchange of dissolved substances between the porewater and overlaying seawater. Previous works have not been successful in finding clear and consistent correlation between these indices and various biogeochemical metrics. This is likely to be for two reasons: 1) The trait-based indices are merging faunal activities that may not be comparable with each other in the sense that a tube-builder and a biodiffuser are not two quantities of the same "bioturbation" gradient, they are two different biological activities with very different outcomes on the biogeochemistry, yet the BPc and IPc integrate them both in the same way; 2) biogeochemical metrics are measurements that are taken at different part of the carbon and nutrient cycles and are an integration of multiple processes from which they emerge of which the faunal mediation is only one of them.

A refined way of exploring the fauna-biogeochemistry relationships is to breakdown the organic matter cycle into a few key episodes containing clear processes and then specifically consider which individual faunal traits are likely to influence these processes in each of these episodes, including the direction and the magnitude of the anticipated influences. A helpful starting point is to use the conceptual model from Middelburg (2018) (Figure 4.8).

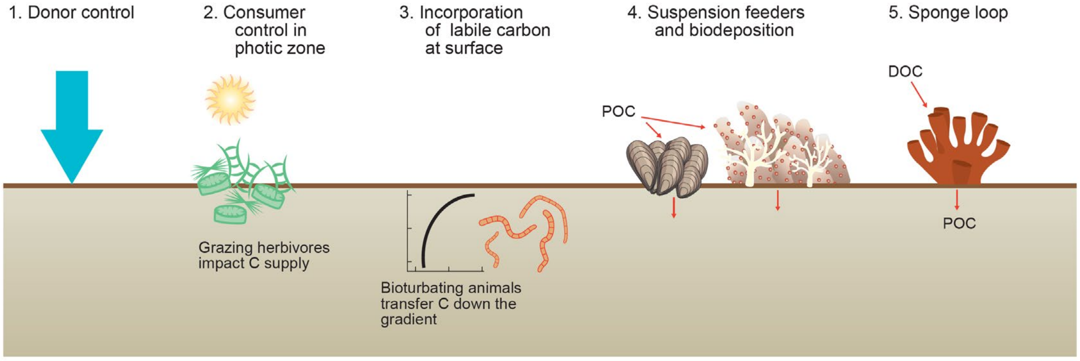

Figure 4.8. Schematic taken from Middelburg (2018) explaining the role of fauna in supplying organic matter to sediments. (1) The traditional view of organic matter settling passively from the water column (donor control). (2) Sediments in the photic zone are inhabited by benthic microalgae that produce new organic matter in situ and grazing animals can impact the growth of these primary producers. (3) Bioturbating animals transfer labile carbon from the sediment surface layer to deeper.

layers in the sediments. (Vertical axis is depth; horizontal axis is concentration.) (4) Suspension-feeding organisms enhance the transfer of suspended particulate matter from the water column to the sediments (biodeposition). (5) Sponge consume dissolved organic carbon and produce cellular debris that can be consumed by benthic organisms (i.e., the sponge loop).

As the organic matter is approaching the seabed from the higher layers of the water column, biogeochemical events can be divided into 3 main sections: biodeposition of the organic matter into the seabed, translocation of the organic matter within the seabed and actual bioturbation which is removing the most labile part of the organic matter and transferring the refractory part at depth for longer-term sequestration:

- During the biodeposition phase, any faunal activities likely to facilitate the transfer of organic matter onto the seabed will have a positive influence on the process. The lack of such activities means that only physical processes will drive that transfer. For example, faunal traits related to filter-feeding combined to surface deposition are likely to have a positive influence on biodeposition. It can be driven by bivalves that are living on the surface or have two siphons opening (inhale and exhale) at the surface whilst the body is buried at depth or by polychaetes living in a U-shaped tube with both opening at the surface of the seabed. Beyond the more traditional traits classification suggested above, processes such as filtering rate, respiration, assimilation and subsequent egestion would help measure the faunal contribution to the biodeposition process.
- Translocation of organic matter at depth can originate from both the water column or the surface of the seabed. Likewise, any faunal activities facilitating that burial will have a positive influence on the process, the absence of which will make translocation from physical forces depending on the sedimentation rate of the area. Filter-feeder or deposit-feeder will play a role in that process so long that they egest their faeces at depth (generally qualified as downward conveyor in the bioturbation conventional classification). Main actors would include tubicolous polychaetes which have an open-ended tube, gallery builder that collect their food at the seabed-end of their gallery. Again, novel ways of improving our understanding of that process would include filtering/deposit-feeding rates, assimilation and egestion rates but also tube characteristics (open-ended, blind), siphon size (for bivalves).

- Actual bioturbation at depth, specifically defined as faunally-created environments promoting a faster organic matter degradation that would not otherwise happen as fast (oxygen, redox, bacteria). The overall movement at depth of many animals will promote oxygenation at depth that would not otherwise be oxic; size and depth of biodiffusers activities, sub-surface deposit feeders downwards and upwards conveyors would be the conventional trait categories that would be expected to increase that process. Tubes and burrow types and shape will also be expected to change the oxic/redox layers; permeable tubes or galleries create a higher surface area continuously oxygenated by the animal movement within them and promote the existence of aerobic bacteria, and the efficient breaking of organic matter down at depth which would otherwise not occur. The way to measure this surface area was debated and reducing it to a single metric may be a sensible way to test the tube/gallery effects on organic matter breakdown. This metric could be computed using a combination of burrow depth, width, an indication of burrow complexity and size of the animal and would provide a measure of how much surface area could be available for bacterial growth and therefore how much faster could organic matter be processed.

It was generally agreed that, whilst we should mostly rely on existing traits classification and information to pursue investigations on how best to relate faunal activities to biogeochemical cycles, pursuing promising avenue of research would bear fruit in the medium-term. For example, progressively stepping away from categories to attempt to obtain continuous values for traits. Although this might not be possible for some trait categories (like bioturbation modes), it may however be possible to attempt a literature review for aspects related to metabolisms (feeding, assimilation, egestion), or tube/gallery surface area which, combined with categorical traits like bioturbation, types of tube etc would provide novel insights on the influence of faunal activity to biogeochemical processes.

Comparing biotic and physical effects of trawling on biogeochemical pathways

FBIT Seabed organic carbon modelling: Cefas overview

John Aldridge (CEFAS), Ruth Parker (CEFAS)

Background

Cefas are using three main modelling approaches in work connected with benthic carbon storage and potential trawling impacts. Three main strands of modelling work related to FBIT are being undertaken.

1D Seabed modelling using OMEXDIA: This is typically set up for a single location and includes a fully layered bed and describes benthic chemistry including carbon, nitrogen, and oxygen cycling. Within FBIT the aim is to understand in-bed processes and potential climate/trawling effects on carbon sequestration.

3D transport modelling using NEMO/SPM-IOW: This is set up for the European shelf with a ~7km grid and includes full shelf physics (NEMO) with sediment erosion/deposition (IOW SPM). The aim for FBIT related work is to model movement of refractory particulate carbon from terrestrial/marine sources to possible accumulation sites on/off the shelf and determine if trawling can affect these background processes due to disturbance and resuspension.

3D biogeochemical modelling using NEMO-ERSEM: This is set up for the European shelf with a ~7km grid and couples ERSEM to the NEMO physics model. ERSEM is comprehensive biogeochemical model that focuses on marine primary production and primarily ‘labile’ carbon (remineralised over timescales of days to months).

Outputs

1D Seabed modelling using OMEXDIA

Only the OMEXDIA carbon dynamics are being considered in these studies. Since in OMEXDIA there is no feedback to the carbon systemm it is possible to consider the carbon processes independently of the nutrient and oxygen components (‘CMEXDIA’ mode). The effect of trawling on seabed organic carbon has taken the form of sensitivity studies based around the OMEXDIA standard baseline parameters. Variation about these baselines were applied to investigate the effect on 10 cm carbon stocks and flux for carbon to deeper sediment layers.

As an example, sensitivity to the mixing (bioturbation) rate was investigated (Figure 4.9). This suggests that the 10 cm carbon stock will be relatively insensitive to changes in this parameter and that adjustments occur over multi decadal timescales. Carbon with ‘intermediate’ reactivity (~70 year decay timescales) shows the most sensitivity than more labile (14 year) or more refractory (550 year) carbon classes.

Further work is planned to look at the effect of:

- Fauna reduction (reduction of sediment reworking potential);
- Mechanical sediment mixing as a function of gear penetration depth;
- Erosion from sediment mobilization;
- Different type of carbon (i.e. decay rates).

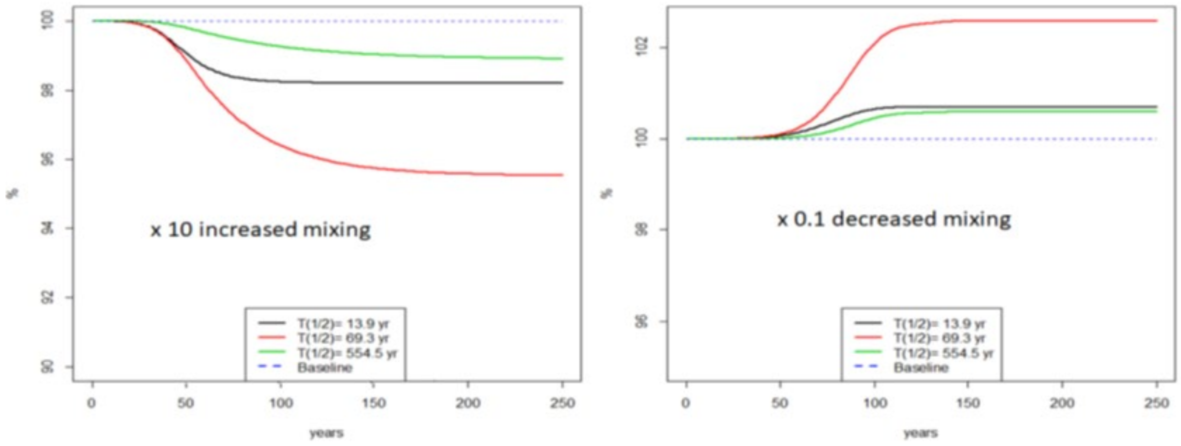

Figure 4.9. Dynamic response (%change from initial value) of 10cm seabed carbon stock to changes in mixing.

3D transport modelling using NEMO-SPM

Physical modelling of the chronic effects of trawling resuspension will be based on the NEMO-SPM modelling of long-term transport. Examples of outputs representing background processes of particulate organic carbon transport from terrestrial sources (rivers) show accumulation in known areas of fine sediment accumulation (Figure 4.10).

Fishing fleet activity supplemented by gear resuspension parameterisation of the main gear types (beam and otter trawls) will be used to impose a time and area integrated trawling resuspension flux. This will be used to assess the effect of trawling on background carbon accumulation rates. With assumptions of particle fall velocity, an assessment of possible carbon redistribution from trawling resuspension will be made. In addition, if observational results on the effect of resuspension on carbon breakdown are available, a spatially resolved estimate of the magnitude of excess carbon remineralization can be made.

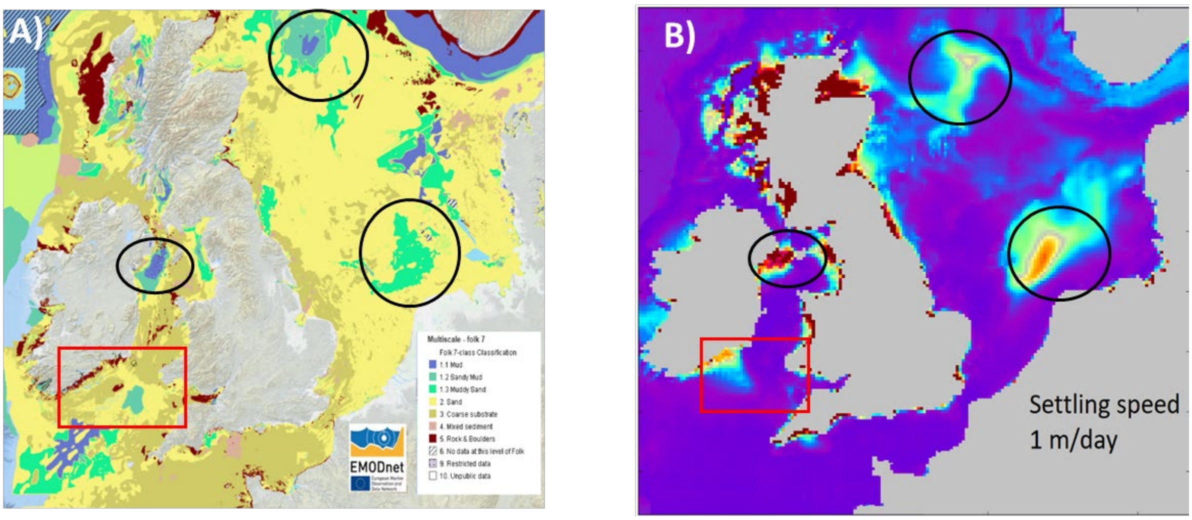

Figure 4.10. A) Observed seabed sediment distributions with muddy regions shown as green/blue. B) Modelled river sourced fine sediment accumulation over one year. Black circles indicate regions where accumulation coincides with known mud patches red box show where there is a difference with the model.

3D biogeochemical modelling using NEMO-ERSEM

Results from ERSEM modelling show that the observed organic carbon stock is one to two orders of magnitude larger than the modelled values (Figure 4.11). The model describes principally the labile active carbon relevant to biological processes acting on monthly annual timescales. We tentatively conclude that much of the observed stock is relatively old, unreactive carbon and that the relatively labile active carbon typically studied by biogeochemists only a rather small part of the observed carbon stock. The relatively unreactive nature of the observed profiles is supported by the near constant value with depth in contrast to the decrease with depth characteristic of more labile material as in the model derived profiles.

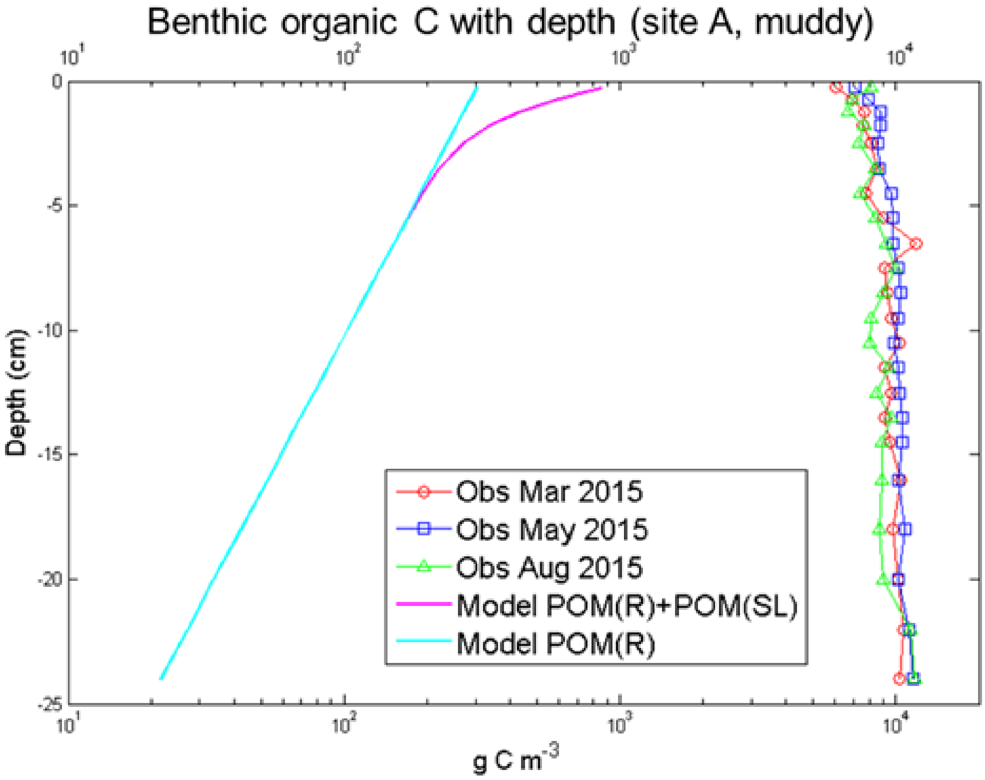

Figure 4.11. Modelled and observed organic carbon profiles.

Comparing biotic and physical effects of trawling on biogeochemical pathways

Justin C. Tiano (Wageningen Marine Research)

Background

One of the major challenges in linking bottom trawling impacts to biogeochemistry is reconciling the indirect effects on ecological functioning driven by benthic species with the direct physical disturbances caused by trawling gear. One approach is to estimate changes in a proxy representing faunal activity, which can then be incorporated into a biogeochemical model, such as OMEXDIA, to simulate both immediate impacts and longer-term recovery dynamics.

Bioturbation, a key faunal-mediated ecosystem process, strongly influences nutrient removal and transformation processes in marine sediments (Braeckman *et al.*, 2010). Understanding shifts in mineralization pathways due to bioturbation activity helps explain how the loss or alteration of benthic species affects sedimentary biogeochemical dynamics.

Emerging models like BFIAT, developed by WGFBIT, can estimate changes in bioturbation potential (BPc), a proxy for bioturbation activity. By quantifying reductions in BPc due to trawling disturbances, we can use BPc as an indicator of how trawling disrupts sedimentary bioturbation. De Borger *et al.* (2021) also modeled declines and subsequent recovery of bioturbation in OMEXDIA, combining these effects with sediment mixing caused by trawling. However, isolating the impact of reduced bioturbation and physical effects could provide deeper insights into the long-term biogeochemical changes induced by such disturbances.

This analysis aims to disentangle the physical and biological effects of trawling by separating reductions in bioturbation and physical trawl effects within OMEXDIA, examining how these changes influence biogeochemical processes in benthic ecosystems.

Methods

To conduct this analysis, the OMEXDIA biogeochemical model was applied to two North Sea locations: one sandy and one muddy. Biogeochemical data from previous studies were used to calibrate the model for each site (Table 4.1). The sandy site, an active coastal area off the southwest coast of the Netherlands, is high in benthic species (Figure 4.12; Tiano *et al.* 2022). The muddy site is located within the Frisian Front convergence zone, approximately 60 km off the Dutch coast (Tiano *et al.* 2019).

Estimates of mixing depth were derived from sediment profile imagery. The sandy site exhibits a high mineralization rate due to abundant tubeworms and associated invertebrates, while the muddy site, inhabited by burrowing mud shrimp, has higher bioturbation rates as determined by model parameterization.

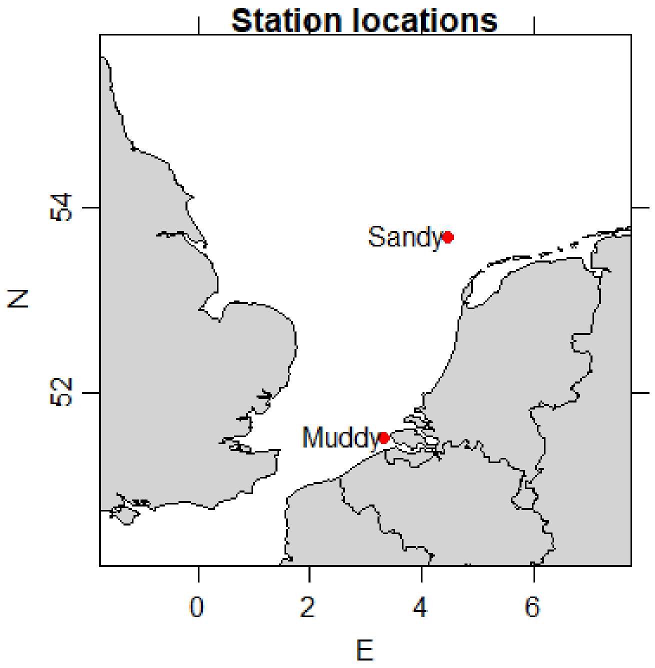

Figure 4.12. Map of represented stations.

Table 4.1. Selected parameters and literature associated with the sandy and muddy site used in the simulations.

Parameter	Sandy habitat	Muddy habitat	Units
Bioturbation depth	3.5 cm	10 cm	cm
Bioturbation rate	5.0×10^{-5}	8.0×10^{-4}	cm d^{-1}
Mineralization Rate	42.92	10.30	mmol C $m^{-2}d^{-1}$
Literature	Tiano *et al.*, (2022)	Tiano *et al.*, (2019)	

Each model underwent a 10-year ‘spin-up’ phase to approximate equilibrium states before the main simulations. Dynamic runs of one year tested changes in biogeochemistry following a 90% reduction in bioturbation, applied mid-year. Simulations used a constant carbon flux into the sediment to isolate the effects of bioturbation reduction. Descriptions of model parameters are provided in Table 4.2.

To simulate the physical effects of trawling, OMEXDIA was run with a combined erosion and mixing disturbance imposed mid-simulation, following methods similar to De Borger *et al.* (2021). However, unlike in De Borger *et al.* (2021), bioturbation rates were held constant before and after the disturbance to isolate the physical impacts of trawling from any changes in bioturbation. This approach allowed for a focused examination of sediment disruption without the confounding effects of altered faunal activity.

Table 4.2. Explanation of parameter names.

Parameter	Description
TotOxic	Total oxic mineralization
TotAnoxic	Total anoxic mineralization
TotDenit	Total denitrification
PartOxic	Proportion of oxic mineralization relative to total mineralization
PartAnoxic	Proportion of anoxic mineralization relative to total mineralization
PartDenit	Proportion of denitrification relative to total mineralization
PartPremoved	Proportion of phosphorus removed from the system
PartNremoved	Proportion of nitrogen removed from the system
Bioturbation	Faunal-mediated sediment mixing
NH3	Ammonia concentration in the sediment
ODU	"Oxygen Demand Unit" designated in OMEXDIA. It represents all reduced substances other than NH3 in the sediment. These substances act as electron donors and are oxidized, thus consuming it.
DIC	Dissolved inorganic carbon in the sediment
O2	Oxygen concentration in the sediment
NO3	Nitrate concentration in the sediment
TOC	Total organic carbon (note: TOC in OMEXDIA does not include refractory carbon)
TotMin	Total mineralization (oxic + anoxic + denitrification)

Results and Discussion

Reduced bioturbation

Reducing bioturbation by 90% at both the sandy and muddy sites resulted in a similar shift towards oxic mineralization (reduced anoxic processes) along with decreased rates of denitrification (Figures 4.13 and 4.15). Due to the much higher mineralization rate in the coastal sandy sediments, the sandy site exhibited a greater proportion of anoxic mineralization and a lower proportion of denitrification compared to the muddy site. This pattern is somewhat atypical in sand-to-mud biogeochemical comparisons, as muddy sediments generally retain lower oxygen concentrations; however, the high mineralization rate at the sandy site drives this dynamic.

At the muddy site, the proportion of phosphorus removed following bioturbation reduction intermittently exceeded 2.5, indicating that reduced sediment mixing led to a net influx of phosphorus as solutes from the overlying water were adsorbed into the sediment (Rios-Yunes *et al.*, 2023). The sandy site also showed a relative increase in phosphorus removal, though the change was minimal, starting from near-zero levels due to naturally low phosphorus removal in these sediments. After an initial sharp increase, both sites maintained slightly elevated phosphorus removal for the remainder of the simulation, while nitrogen removal trends approached zero in both habitats after bioturbation was reduced.

In both sites, reduced faunal activity led to declines in NH_3 and ODU concentrations, while muddy sediments showed an increase in DIC concentrations (Figures 4.14 and 4.16). Lower denitrification resulted in greater NO_3 retention in both sediment types. Additionally, reduced bioturbation led to higher oxygen levels in the sediment and an accumulation of TOC at the sediment surface, as decreased faunal activity limited organic matter transport to deeper layers (Figures 4.14 and 4.16). Additionally, reduced faunal-mediated transport of organic carbon to deeper sediment layers resulted in more concentrated organic carbon at the sediment surface.

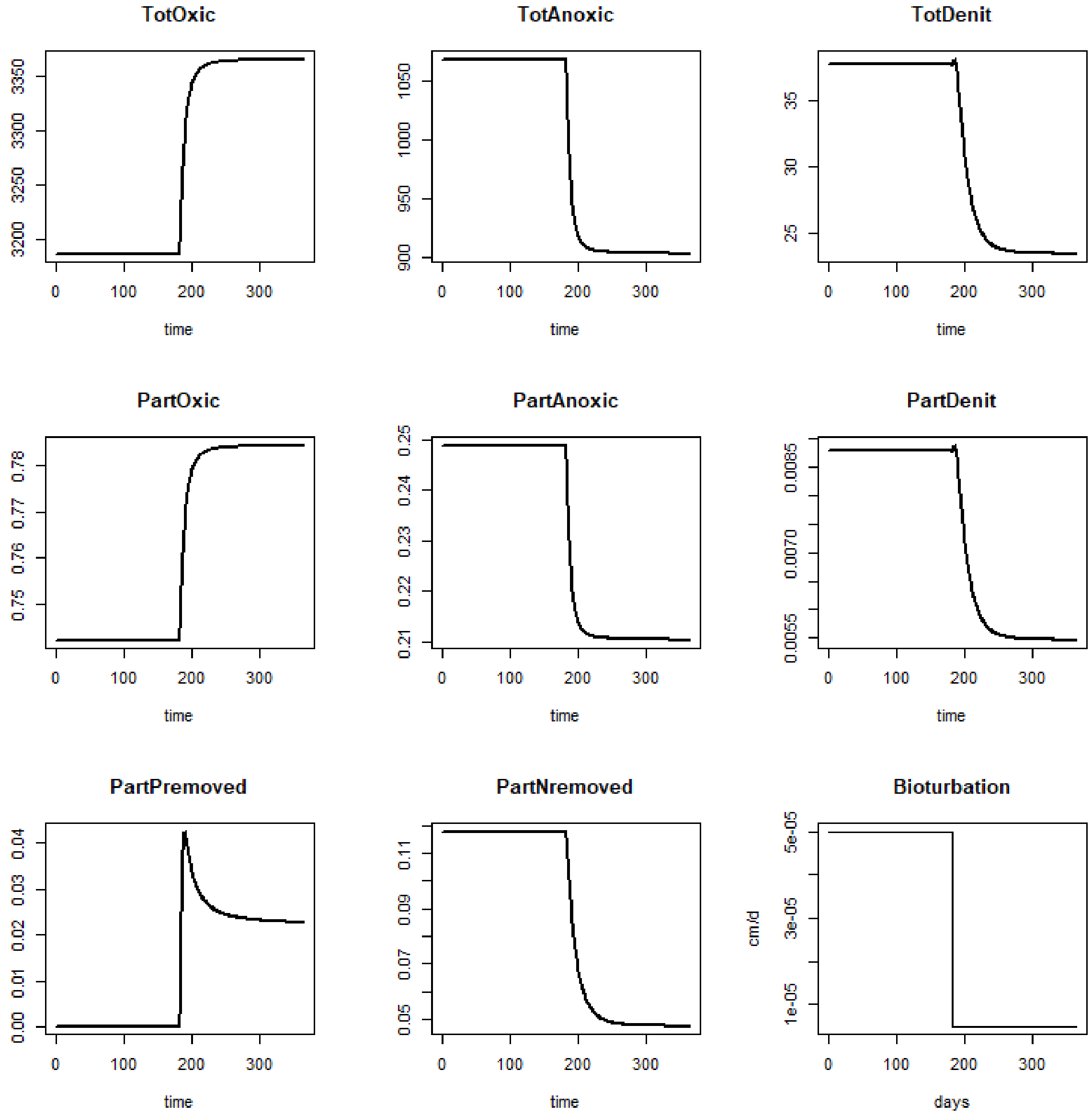

Figure 4.13. Sandy site mineralization pathways, nutrient removal functions and the change in bioturbation rate exhibited in the reduced bioturbation simulation (see table 2 for a description of parameters).

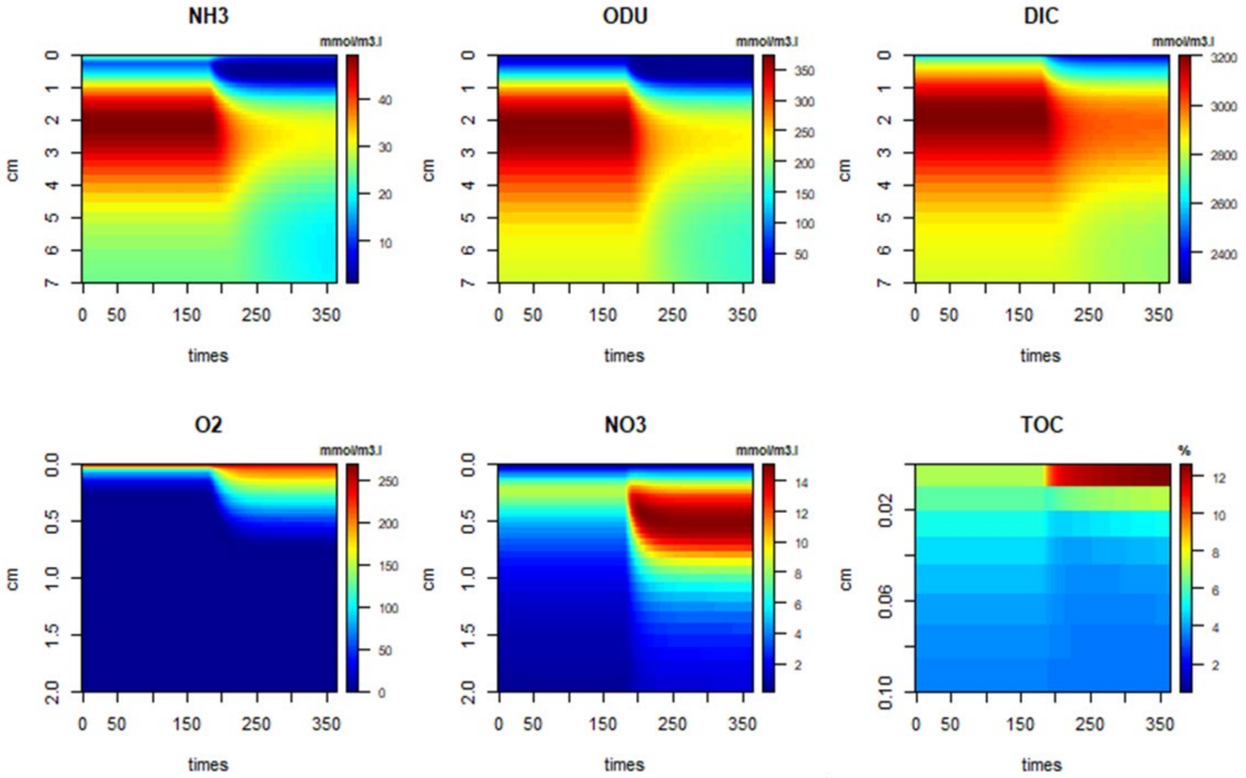

Figure 4.14. Sandy site solute (NH3, ODU, DIC, O2, NO3) and TOC concentrations in the sediment during the reduced bioturbation simulation (see table 2 for a description of parameters).

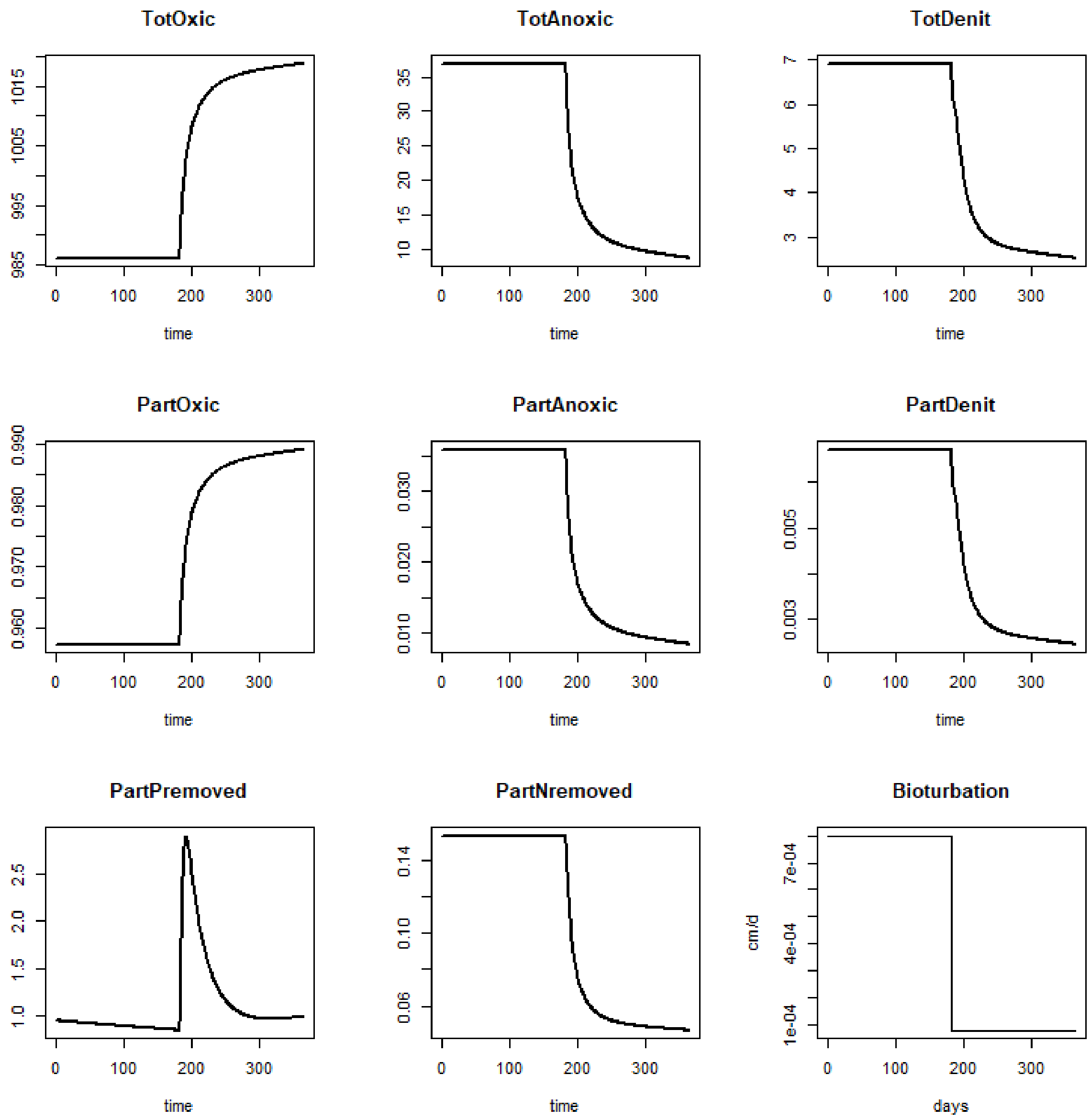

Figure 4.15. Muddy site mineralization pathways, nutrient removal functions and the change in bioturbation rate exhibited in the reduced bioturbation simulation (see table 2 for a description of parameters).

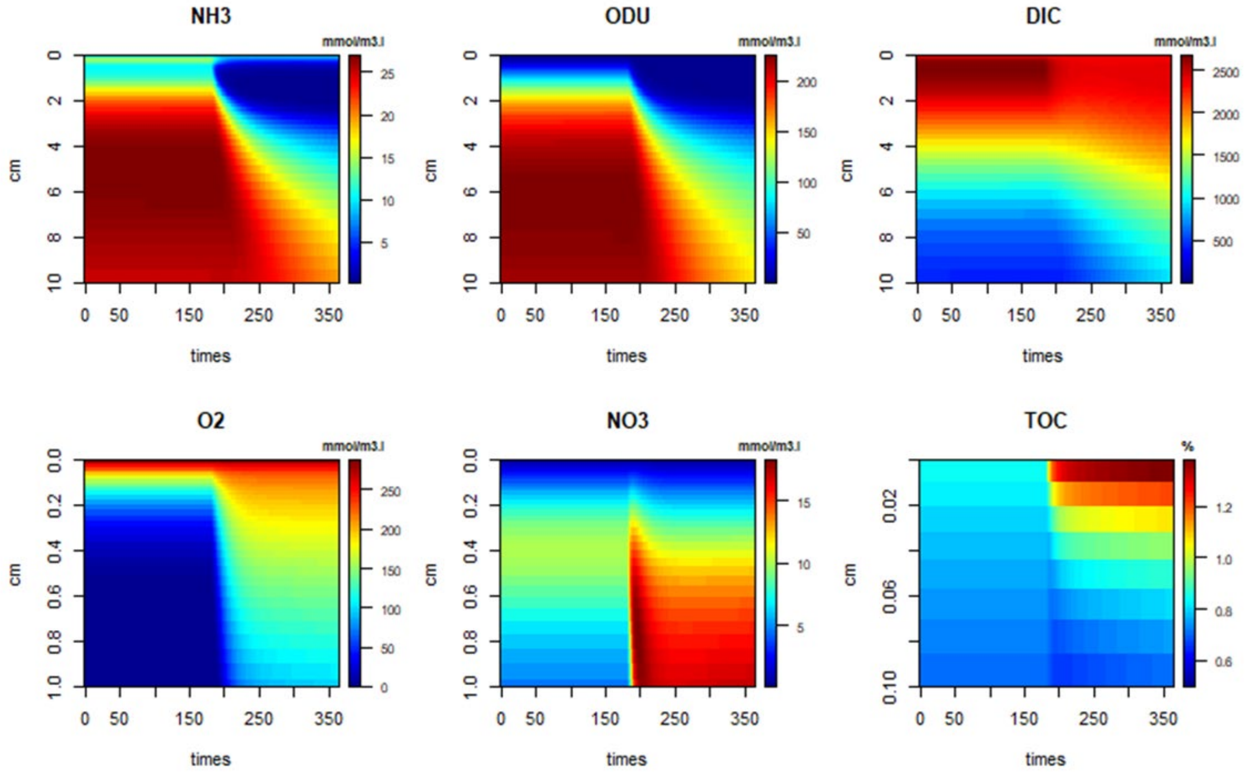

Figure 4.16. Muddy site solute (NH3, ODU, DIC, O2, NO3) and TOC concentrations in the sediment during the reduced bioturbation simulation (see table 2 for a description of parameters).

Physical effects

Given the significant role of bioturbation in natural biogeochemical processes, it's generally recommended not to fully exclude bioturbation in models that focus solely on physical trawling effects. Instead, maintaining a consistent bioturbation rate before and after disturbance allows for a more accurate assessment of trawling's direct physical impacts. Higher bioturbation rates have been shown to promote recovery of biogeochemical dynamics (De Borger *et al.*, 2021).

The key distinction between simulations with reduced bioturbation and those with physical trawling disturbances lies in the removal of total organic carbon caused by trawling, which leads to intermittent reductions across all mineralization pathways post-disturbance (Figure 4.17). In contrast, pure reductions in bioturbation do not impact total mineralization in OMEXDIA, which remains closely linked to a constant flux of total organic matter used in this analysis.

The sandy site trawling simulation led to an eventual increase in total denitrification in contrast with muddy sediments which featured a slight decrease in denitrification after recovering from an initial trawl-induced decline (Figures 4.17 and 4.19). Both sediment types showed an increase in oxic mineralization proportion, paired with a decrease in anoxic mineralization following trawling. Additionally, both habitats exhibited a transient spike in phosphorus removal proportion, briefly exceeding a value of 1, indicating phosphorus influx from the water column. This response, however, was an order of magnitude more pronounced in muddy sediments compared to sandy ones.

Similar to the bioturbation reduction simulations, trawling reduced NH3 and ODU concentrations (Figures 4.18 and 4.20). However, physical disturbance led to a post-trawling DIC increase in muddy sediments, while DIC decreased in the sandy site. Oxygen levels in the sediment also increased transiently following trawling, unlike the consistent increases in oxygen observed with reduced bioturbation. Additionally, elevated nitrates from reduced denitrification were present in the trawl simulations, though bioturbation reductions had a comparatively greater effect on nitrogen retention.

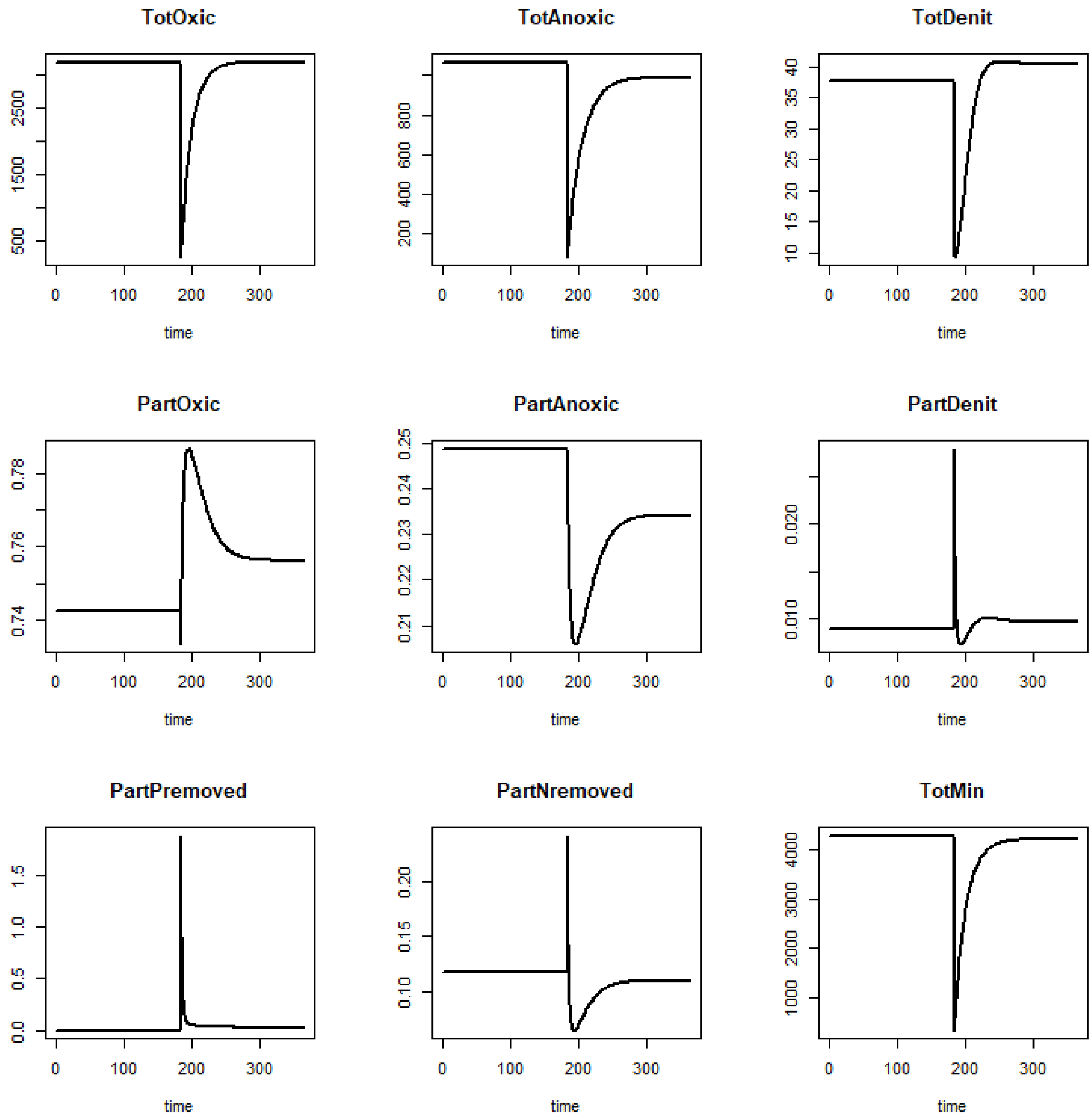

Figure 4.17. Sandy site mineralization pathways and nutrient removal functions exhibited in the physical trawling simulation (see table 2 for a description of parameters).

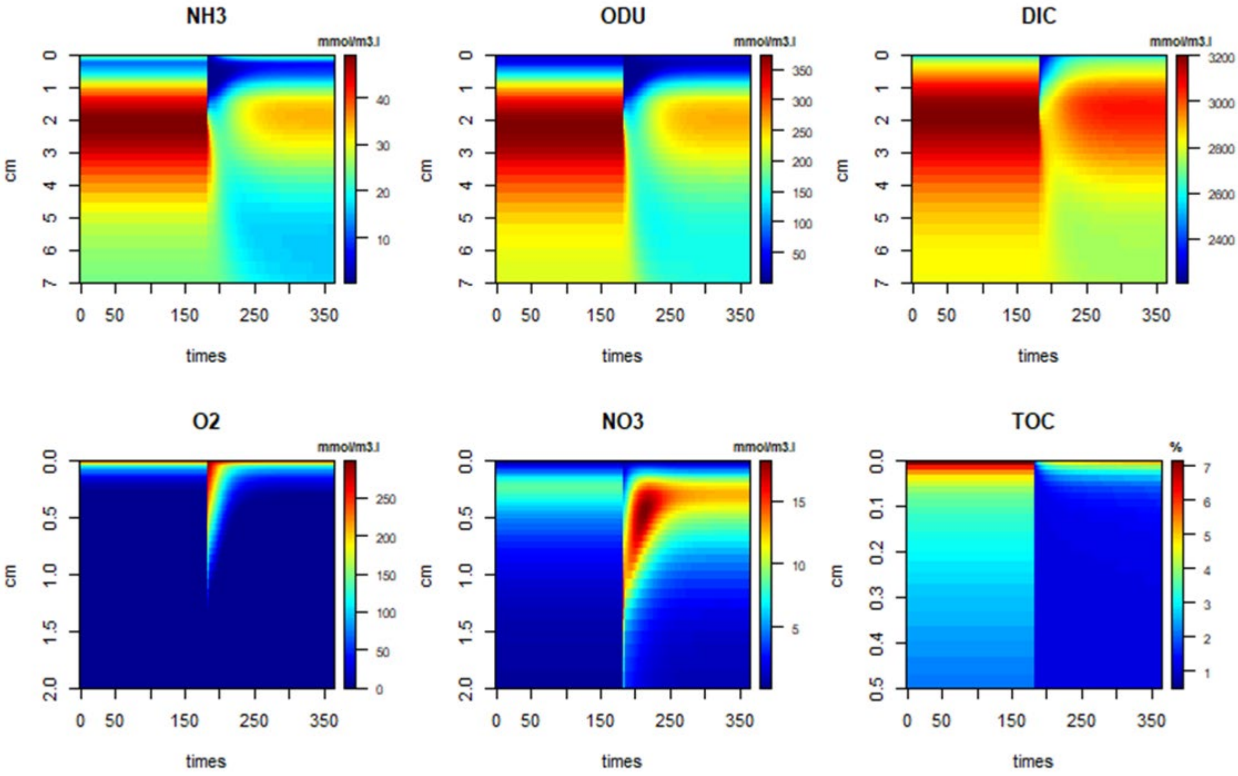

Figure 4.18. Sandy site solute (NH3, ODU, DIC, O2, NO3) and TOC concentrations in the sediment during the physical trawling simulation (see table 2 for a description of parameters).

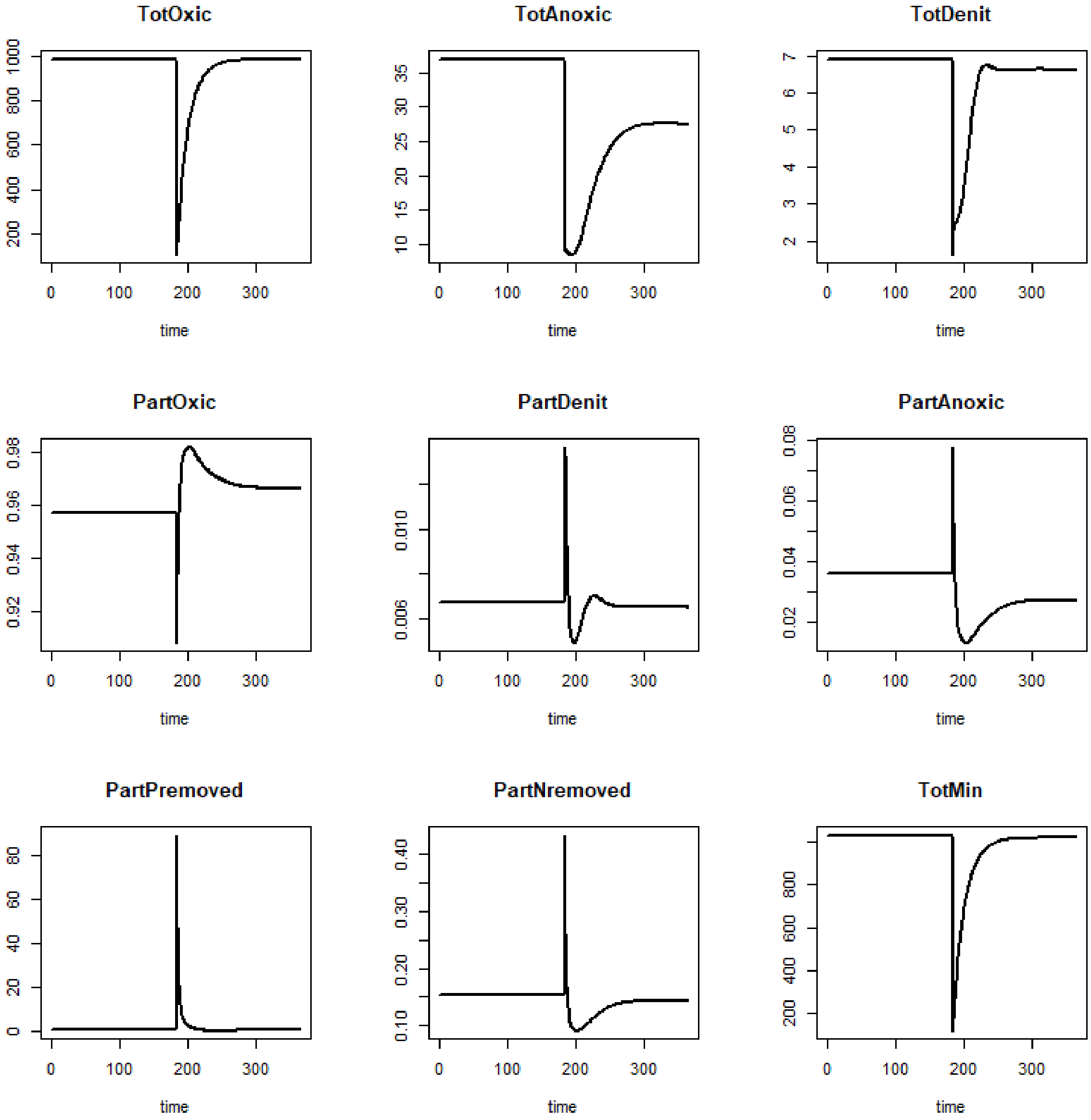

Figure 4.19. Muddy site mineralization pathways and nutrient removal functions exhibited in the physical trawling simulation (see table 2 for a description of parameters).

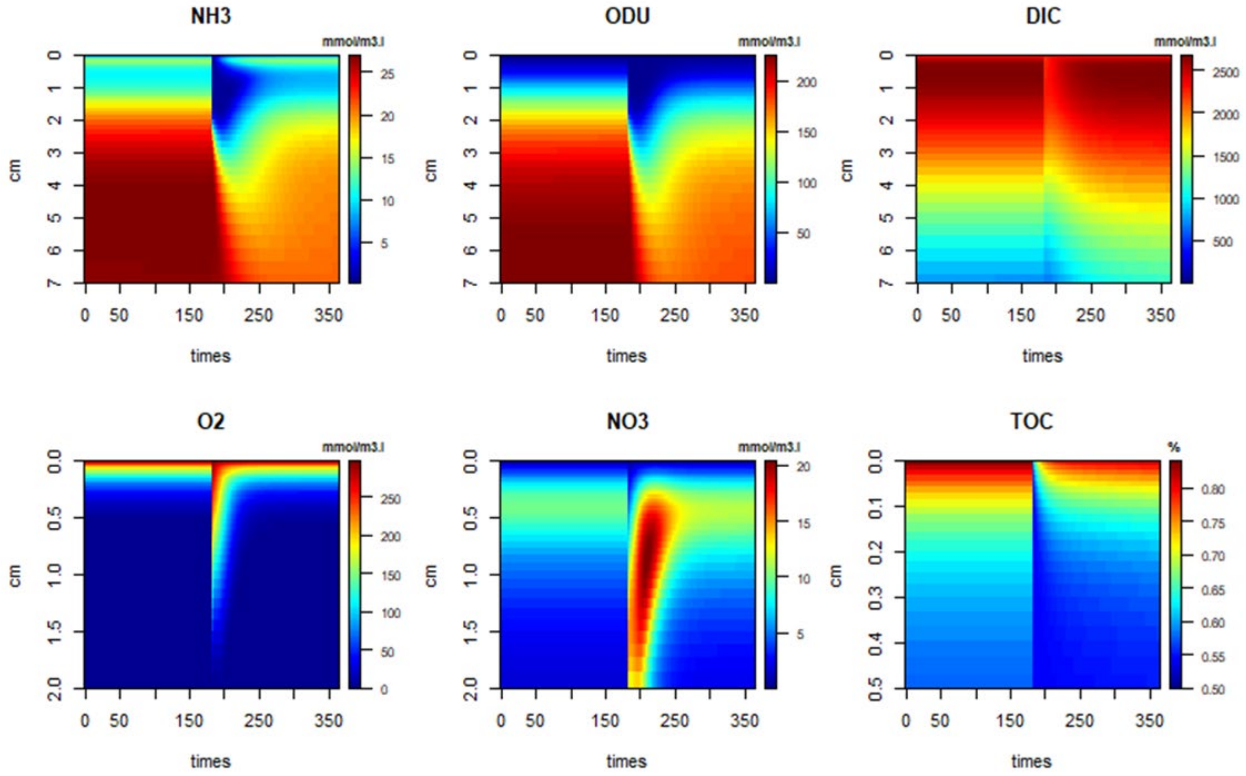

Figure 4.20. Muddy site solute (NH3, ODU, DIC, O2, NO3) and TOC concentrations in the sediment during the physical trawling simulation (see table 2 for a description of parameters).

Conclusion

The results suggest that the removal of benthos alone leads to a shift toward more oxic mineralization processes and reduced denitrification, causing nitrate accumulation within the sediment. While physical trawling causes changes to mineralization pathways, the largest changes are intermittent and the effect on denitrification and nitrate retention in the sediment is notably lower than when removing faunal-mediated sediment mixing. Longer-term reductions in the relative nutrient removal functions may incur more from the loss of fauna-driven processes while both physical and biotic mechanisms may change carbon sequestration capacity by either physically resuspending and transporting carbon to adjacent locations or reducing the fauna-driven downward transport of carbon, potentially diminishing the likelihood of carbon sequestration at greater depths.

Other related research

Sampling programmes in Italian waters

Maria Cristina Mangano (Stazione Zoologica di Napoli)

The ToR D developed frameworks and indicators will be applied and tested also on muddy/sandy habitats and on the related benthic communities of a Central Mediterranean area. Specifically, it will be possible to take advantage of both infaunal communities data and biogeochemical data collated during a one year EMFAF funded project (Project Rete 3 Golfi - 3G "Rete integrata per il monitoraggio e la produzione di un modello regionale di gestione delle risorse e degli ecosistemi marini nei Golfi di Castellammare, Patti e Catania" MISURA 1.40 - "Protezione e ripristino della biodiversità e degli ecosistemi marini e dei regimi di compensazione nell'ambito di attività di pesca sostenibili – lettere c) e i)" - PO FEAMP Sicilia 2014/2020 lead by scientists at the Lab, of Ecology, UNIPA and Sicily Marine Centre, SZN) with samples from across a gradient of trawling disturbance but also taking advantage of fishery restriction areas across the Sicilian continental shelf. It will allow examination of trawling induced longer-term change in carbon sequestration capacity as well as the provision of ecosystem services. The communities' responses to trawling across the proposed areas have been already investigate through the Relative Benthic Status (in ToR A).

Bottom trawling impacts on benthic microbial communities: summarizing findings from a regional studies in the North and Baltic Seas

Guido Bonthond (University Oldenburg, Germany), Laura Seidel (Stockholm University, Sweden) and Clare Bradshaw (Stockholm University, Sweden)

Importance of benthic microbial communities to ecosystem services

The seafloor is colonized by high densities of microbes, most of which are living tightly attached to grains of sediment (Probandt *et al.* 2018). These microbes respire oxygen to degrade detritus, but also consume sedimentary organic carbon through anaerobic metabolic processes (Jørgensen *et al.* 2022). As such, they impact the ecosystem functions of the seafloor, including degradation and sequestration of organic carbon in marine sediments and the removal of nitrates through denitrification. While the impacts of bottom trawling on benthic fauna and biogeochemistry have been studied (reviewed in Sciberras *et al.*, 2018; Tiano *et al.*, 2024), there is limited knowledge on the impact of bottom trawling on benthic microbial communities. While fauna influence benthic microbial communities through bioturbation and competition for oxygen (Deng *et al.*, 2020), the sediment biogeochemistry is partially regulated by microbial processes (Jørgensen *et al.*, 2022). Thus, benthic microbiota currently present a missing link to understand trawling impacts on ecosystem functioning. Further, microbial community properties such as diversity and biomass, and microbial traits such as respiration and denitrification may be potentially informative indicators for ecosystem functions.

We summarize findings from two recent case studies in the Baltic and North Sea, characterizing benthic microbiota along gradients of fishing pressure. Different approaches were used and different microbial properties were evaluated. We discuss the potential information that can be obtained from microbial communities, and how microbial ecological approaches may potentially inform ToR D and provide additional insights into trawling impacts on ecosystem functions.

A regional scale assessment in the North Sea

Bonthond *et al.* (2023) sampled surface sediments (the top cm) from 150 stations across the German North Sea, experiencing trawling pressures varying between 0 to 1.25 SAR y^{-1} (Figure 4.21). Using 16S rDNA metabarcoding, microbial communities were characterized and a spatial analysis was conducted to assess whether trawling effort can explain changes in benthic microbial properties, after accounting for effects of in sediment properties, temperature, total organic matter content and natural bottom disturbance (i.e., shear stress). Overall, sediment variables were found to be the most informative parameters explaining microbial community properties. However, several microbial properties also varied with bottom trawling intensity. Besides a trawling associated change in community composition, microbial genus diversity declined with increasing bottom trawling intensity (Figure 4.22A). By predicting microbial functions from the 16S rDNA amplicon data, the study also analyzed several functional indices. Based on these predictions, similar trawling associated trends were resolved for functional community composition and functional diversity (declining with trawling intensity as well, Figure 4.22B). The study also investigated how specific microbial energy metabolism groups were associated with bottom trawling intensity (Figure 4.22C). These results suggest that as trawling intensities increase, aerobic energy groups (i.e., aerobic respiration, nitrification) become relatively more abundant, whereas the relative abundance of several anaerobic groups decreases (i.e., denitrification, sulfate reduction).

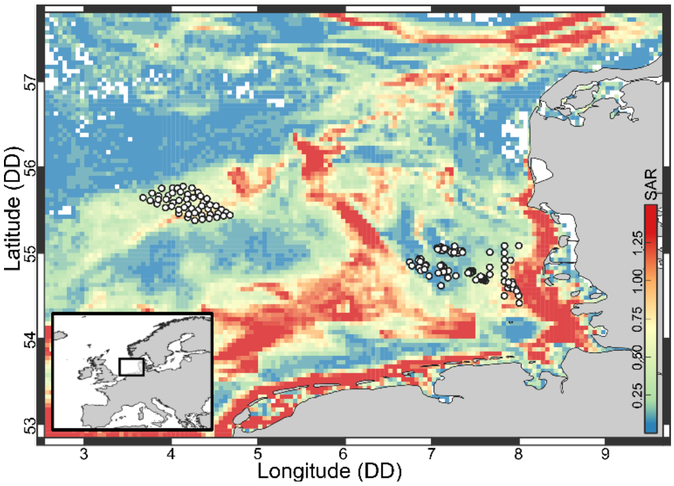

Figure 4.21. Geographic overview of the stations sampled in North Sea and with the bottom trawling intensity (in SAR y^{-1}). Figure adapted from Bonthond *et al.* (2023).

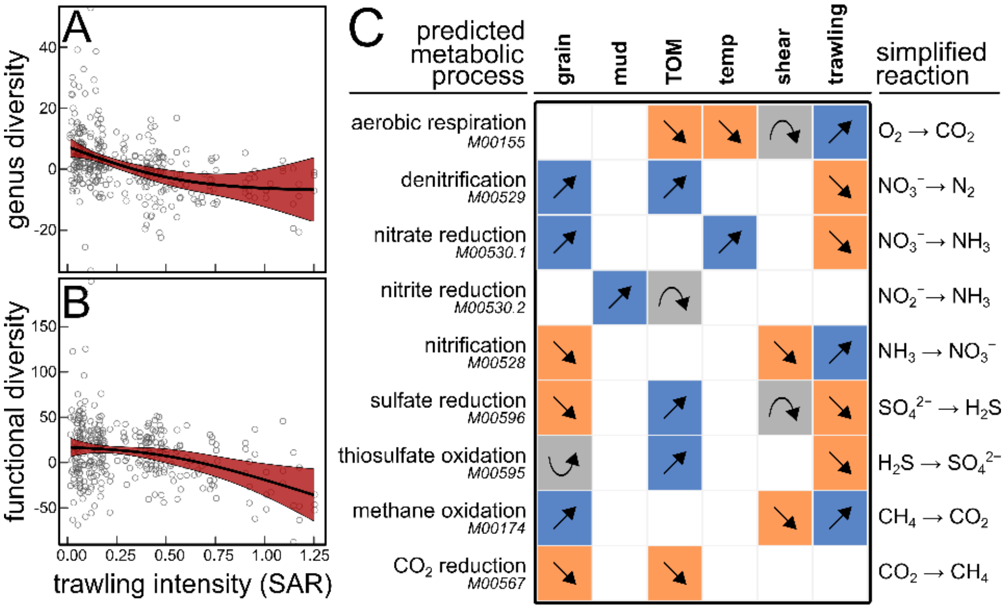

Figure 4.22 (A-B) Resolved trends estimated by generalized additive mixed models (GAMMs) in the North Sea associated with bottom trawling intensity (in SAR y^{-1}) after accounting for the effects of sediment properties, total organic matter (TOM), temperature and bottom shear stress. (A) prokaryote diversity at the genus level and (B) predicted functional prokaryote diversity. (C) Simplified trends from GAMMs fitted on predicted relative abundances of microbial energy metabolism. Effects of median grain size, mud content, TOM, temperature, bottom shear stress and bottom trawling are shown. Adapted from Bonthond *et al.* (2023).

Baltic Sea

Bradshaw *et al.* (2024) analyzed bacterial communities (16S rDNA) and surface sediment characteristics in the Southern Baltic Sea, at six stations with different sediment types and either high (SAR > 6 y^{-1}) or low (SAR <1 y^{-1}) fishing intensities. There was no effect of fishing intensity on microbial community composition, but environmental factors such as bottom water oxygen concentration and salinity, sediment organic matter content and porosity had a significant effect. Though not included in that paper, microbial alpha diversity was not affected by trawling (Bradshaw pers. comm.).

In contrast, several microbially-mediated processes (sediment carbon degradation rates, extracellular enzyme activities and PO_4 effluxes) were significantly higher at highly trawled sites, while sediment oxygen consumption and NO_2 + NO_3 effluxes were lower. Due to the relatively small number of samples, robust predictions of microbial functions from the 16S data, as in Bonthond *et al.* (2023), was not possible.

This study also found that ecosystem processes were strongly linked to the abundance of key bioturbators, including a deep burrowing priapulid worm. Bioturbation is known to affect bacterial activity, by increasing sediment oxygenation and the area of the sediment-water interface and by altering the amount and type of organic carbon in the sediments processes (Mermillod-Blondin and Rosenberg, 2006; Mermillod-Blondin, 2011; Aller and Cochran, 2019).

Discussion

The summarized studies used relatively comparable approaches (e.g., sampling the sediment surface, utilizing the same primers) and both analyzed the effect of trawling intensity on microbial community composition (as trawling intensity gradient in Bonthond *et al.* 2023 and low versus high trawling in Bradshaw *et al.* 2024). However, while Bonthond *et al.* (2023) detected a trawling effect on benthic microbial community composition in the North Sea, Bradshaw *et al.* (2024) did not find a this in the Baltic Sea. This discrepancy is currently difficult to explain and may be due to regional differences, use of different trawling gears, study sample size, or scale of the study, and demonstrates that more research is needed to better understand how benthic microbiota respond to bottom trawling, and how this mediates bottom trawling effects on ecosystem functions. A different study (Bruce *et al.*, 2022) in the North Atlantic analyzed prokaryote diversity between trawled and protected areas and found that diversity was lower outside at trawled stations, which is in agreement with Bonthond *et al.* (2023). No effect of trawling was seen on microbial diversity in Bradshaw *et al.* (2024), despite effects being seen on some biogeochemical processes. Many microbe groups have high metabolic plasticity (Arnosti, 2011) so that the same taxa can perform different functions in different environmental conditions. In addition, microbial studies based on 16S analysis are typically restricted to relative abundances, allowing comparisons of compositional differences between communities, but not the absolute differences, and are limited in their taxonomic resolution. Our ability to assess microbial functions on large scales is currently limited by our reliance on reference databases such as RefSeq, used with picrust2 in Bonthond *et al.* (2023), that predict functional abundances based on the 16S rRNA marker gene. Although easier and cheaper than full metagenome or transcriptome sequencing, there are limitations. For example, only known genomes and environments are represented in the database, which can bias the output predictions. For a full discussion see https://github.com/picrust/picrust2/wiki/Key-Limitations.

The observed trawling associated changes in predicted microbial metabolic groups are noteworthy (Figure 4.22C). Since microbes are metabolically superior to metazoans and are capable of degrading low-reactive organic carbon substrates (i.e., recalcitrant carbon), they may especially impact the degradation of detritus and potentially negatively impact the sequestration of organic carbon in the seafloor, one of the most important ecosystem services. The trawling associated relative increase in aerobic respiration may hint at enhanced microbial degradation of organic carbon in response to trawling While in Bradshaw *et al.* (2024) oxygen consumption decreased with high trawling, they observed that carbon degradation increased. Sediment oxygen consumption rates are driven by both faunal and microbial heterotrophs and could therefore mask changes in microbial aerobic respiration that can impact sedimentary organic carbon.

One of the microbial properties that neither case study quantified was microbial biomass. Previous research has indicated that microbial biomass increased in response to trawling in the Mediterranean Sea (Polymenakou *et al.*, 2005), with similar trends seen in deep waters on the West Iberian continental margin (Ramalho *et al.*, 2020). Changes in benthic microbial biomass likely affect the biogeochemistry and food web structure and are thus of importance for future studies benthic microbial ecology in the context of bottom trawling. In addition, microbial biomass may be relatively easy to integrate into the WGFBIT assessment method.

We suggest a discussion of these topics at a future ToR D meeting. For example:

- Are microbes already implicitly included in the current attempts in ToR D to link biogeochemical processes to macrofaunal community composition via traits related to bioturbation? Or does this leave out important parts of the microbial community?
- Do we need to include microbes or specific microbial processes explicitly? If so, can we scale microbial activity (rates of various processes) to bioturbation rates, for example through burrow surface area (as a substrate) and burrow depth (to include aspects of

redox conditions). Or should microbes be related more directly to gear penetration depth (relevant for redox conditions) and/or sediment type (since carbon type and amount are key drivers of microbial activity)?

- What is needed to link trawling-induced changes in faunal communities to the microbial processes impacting ecosystem functions (i.e., organic carbon degradation, denitrification). For example, how do changes in macrofaunal biomass or bioturbation behaviour affect these microbial processes? What can microbial studies consider/incorporate to optimally contribute in ToR D to link macrofaunal composition to sediment biogeochemistry.

These questions relate to a current discussion in ToR D about the biotic and physical effects of trawling on sediment biogeochemistry and whether these should (or can) be separated.

Presentation abstracts

Spatial scaling (0.05°, 0.01° & 0.001° resolution) of fishing pressure of MBCGs and environmental variables for RBS, hypoxia and trade-offs assessments in the Danish EEZ

Josefine Egekvist, Jeppe Olsen & Grete E. Dinesen (DTU Aqua)

The method for assessing RBS developed by ICES WGFBIT was tested in the Danish EEZ at the three different spatial resolutions, 0.05°, 0.01° and 0.001°, to evaluate spatial scale effects on the assessment results. Fishing pressure data (SAR) for mobile bottom-contacting gears was estimated for Danish vessels based on VMS, AIS and EM position data combined with logbook information including the métier specific gear information. Foreign vessels SAR estimates were based on VMS and AIS data and gear information from the fleet register. Modelling of SAR was based on positions interpolated to one-minute frequency, fishing hauls identified as lines, the métier specific gear width was added (Eigaard *et al.* 2016) to establish polygons of swept area. The swept areas were summed in polygons at the three spatial resolutions, per month to allow for a flexible 12-month period prior to benthic faunal sampling in May.

Data of depth and benthic Broad Habitat Types (EUSeaMap Sept 2023) and were prepared in the same spatial resolutions. The results showed that the area of dominant habitats was overestimated when using the 0.05° grid resolution, while the area of smaller habitats was underestimated. Oxygen data for the Danish EEZ were estimated using a NEMO4 model for 2014–2022. Oxygen data was estimated and used at 0.01º grid resolution. Benthic fauna mortalities reported by Vaquer-Sunyer & Duarte (2008) were used to establish oxygen conditions categorized according to risk of hypoxia effects on benthic fauna.

Benthic macrofaunal sample data from the Danish monitoring programme NOVANA (HAPS corer area of 0.0143 m^2) from the years 2014–2022 was used, with a total number of samples during this period of 14822. The macrofauna species were coded for maximum Longevity modality (l1 ratio, l1_3 ratio, l3_10 ratio, l10 ratio) and combined with their wet weight biomass ratio per sample to establish the longevity distribution from undisturbed sites (SAR < 0.01 y^{-1} and oxygen category 0 y^{-1} (zero) equal to no hypoxia).

The RBS in relation to fishing pressure were estimated at the three spatial resolutions. A resulting layer was created on the scales 0.05° and 0.01° by classifying the RBS into quality categories ≥0.8 (not impacted by fishery, equal to Good Environmental Status, GES), 0.6–0.8 (moderate impact by fishery, moderate subGES) <0.6 (high impact by fishery, poor subGES). To include the risk of hypoxia on benthic fauna, the oxygen categories categorized as high risk of impact by hypoxia were overlaid to the RBS results, and the combined area were estimated for each MSFD benthic

BHT. The results of this analysis showed that several habitats in the Baltic Sea are affected by hypoxia, whereas in the Greater North Sea some habitats are affected by fishing pressure. In the Kattegat, both fishing pressure and hypoxia affected several habitats. The consequences of using a lower spatial resolution is larger in the smallest habitats, they will often not appear if using the dominant habitat of the cell.

For the trade-off analysis, the core fishing grounds from the Danish fishery in the Danish EEZ has been estimated by métier. In the Jammer Bay area based on the 0.01° scale, where for each MSFD benthic BHT, cells were sorted from the highest to the lowest RBS value and landing values of landings were summarized cumulative, showing that for some habitats, fisheries are highly aggregated (i.e., concentrated in space), whereas for other habitats the fisheries are more evenly distributed. Also, the different fisheries showed different aggregation patterns. Three spatial fishing closure scenarios were illustrated, including 10%, 30% and 75% closure by habitat, and the corresponding values of landings and fisheries métiers that would be affected were estimated.

Estimating thresholds for good status using reference conditions from different marine ecosystems

Lorna McKellar

Thresholds for good status are required under marine legislation (i.e., MSFD, UKMS) to assess ecosystem condition, however there are currently limited thresholds in place to carry out these assessments, and it is not clear which methods should or can be used for different systems. Here, we apply two methods which quantify the natural variability of an indicator in a least impacted system and define the threshold as the maximum point at which an indicator can negatively deviate from a baseline before it's no longer considered to be in GES. Thresholds were calculated for pelagic, benthic, seagrass, and reef fish indicators, and the environmental characteristics of monitoring datasets were included to understand whether variance in thresholds across datasets could be explained for each system. Thresholds varied for each system, with the highest being seagrass shoot density, which had very little variation between sites, and the lowest being meroplankton abundance which demonstrated large variation in abundance across sites. Plankton abundance, tropical reef fish biomass, and benthic invertebrate biomass thresholds all demonstrated significant relationships with environmental characteristics. For example, benthic species biomass thresholds demonstrated a positive relationship with longevity and depth, such that thresholds were higher for deeper and long-lived species, as there were smaller fluctuations in the natural variability of these species. Overall, we demonstrate that both methods can be used to estimate consistent, straightforward, and robust quality thresholds for good status for different systems, and we can tailor thresholds based on the general relationships found here between the environmental characteristics and the natural variability of the system.

Evaluating community bioturbation potential (BPc) and bioirrigation potential (IPc) as indicators of bottom trawling impacts in Swedish waters

Clare Bradshaw

The Marine Strategy Framework Directive specifies that both benthic ecosystem structure and function should be considered when assessing seabed status. Species that are sensitive to disturbance, such as trawling, are not necessarily those that are the most important for ecosystem function. There is therefore a need for both structural and functional indicators. While structural indicators (such as biodiversity measures) have been used for decades, functional indicators are still being developed and assessed. Since it is difficult, time consuming and expensive to actually measure ecosystem function, making use of existing community structure data to estimate proxies of function, using a traits approach, has been suggested as a way forward.

In this study, we calculated and assessed the functional indices community bioturbation potential (BPc [1]) and community irrigation potential (IPc [2]); two indices based on biomass, abundance and effect traits of the benthic species present. Species' bioturbation and bioirrigation of sediments can be expected to play a large role in benthic biogeochemical cycling (ie. ecosystem function). We used existing benthic community data from four coastal areas around Sweden that experience bottom trawling but have highly contrasting environmental conditions.

Using multiple linear regressions, we assessed whether trawling and/or environmental variables best explained BPc and IPc in each area. Trawling affected functional indices in the Kattegat and Skagerrak, but not in the Bothnian Bay or Southern Baltic Sea, while environmental variables were important in all areas. We also calculated two structural indices (BQI and Margalef D) and found different results, suggesting that structural and functional indicators can complement each other in assessments. For two sea areas, we also compared calculated BPc and IPc with measured bioturbation rates and bioirrigation rates, respectively. BPc was fairly well correlated to bioturbation but we found no correlation between IPc and measured bioirrigation.

Although functional indicators are needed, BPc and IPc may not yet be fit-for-purpose, since they are highly sensitive to large individuals, total biomass, and small changes in the assigned trait modalities. Also, by integrating many different traits into one metric, they may obscure the importance of particular ecosystem functions. In addition, BPc and IPc were not always sensitive to trawling in our study. They also rely on extensive knowledge of species traits, however, they have the advantage that they can be calculated from existing data, such as from monitoring programmes.

[1] Queiros et al. (2013) doi:10.1002/ece3.769

[2] Wrede *et al.* (2018) doi:10.1016/j.ecolind.2018.04.026

Gear component approach to refine impact assessment of bottom trawling, and to quantify the amount of sediment mobilized

Karin van der Reijden

Increased awareness of bottom trawling impacts has led to a growing demand for assessments of its extent and associated effects. Consequently, multiple methods have been developed to assess the extent and impact of trawling-induced seafloor abrasion. These methods typically classify bottom trawls into broad groups (fisheries) and rely on whole-gear averages to assess their spatial distribution and seafloor impacts. However, such approaches ignore variations in gear design within fisheries and cannot capture changes related to gear innovations. Here, we present a gear component approach (GCA), which parameterizes each gear component with seabed contact individually (doors, clumps, sweeps and ground gear) per fishery, based on literature and industry-survey data. We demonstrate the GCAs ability to assess the extent and impact of three Danish otter trawl fisheries and compare our results with established whole-gear approaches (WGA). The GCA yielded different gear width and penetration depth estimates compared to the WGA-estimates. This resulted in lower predictions of the Relative Benthic State (RBS) indicator, implying higher fishing impacts of all three otter trawl fisheries compared to WGA approaches. This was most pronounced for the Nephrops fishery, where the RBS indicator was 23% lower. The GCA additionally allowed the quantification of sediment mobilized, with up to 3.2 kg per m2 swept by the Nephrops trawl. The GCA improved the fishing gear representativeness and the accuracy of impact assessments, supporting marine fisheries management towards sustainability. In addition, the wide applicability of the GCA facilitates the evaluation of innovative gear modifications aimed at reducing seabed abrasion.

Trawling Impacts in the Eastern Mediterranean, HCMR Regional Assessment Work: 2024 Smith C.J., Tsikopoulou, I., Papadopoulou K., Maina I., Kavadas S., Reizopoulou S.

Chris Smith *et al.*

Work based on the FBIT methodology, completed in the last year in Greece was presented. Within the SEAWISE project, a joint Greek and Italian analysis was completed with COISPA on the both macro- and epi-fauna based assessment for RBS in the northern Ionian Sea. Also, in SEAWISE, management scenarios were run for the Easter Ionian looking at potential impacts using both static and dynamic (DISPLACE) modelling from the impact of changes to fishing activity on RBS. Scenarios with RBS outputs were completed with respect to MPAs (complete no-trawling in protected areas), different depth-banded bans (<150 m, >800 m, >600 m) and closure of the least fished c-squares (10%). The methodology was also used to designate different areas of sensitive habitats (based on longevity) for more detailed socio-economic modelling within the project. The new indicator PDsens was compared annually for a 6-year period with the existing PD outputs for Greek waters. The new indicator was shown to be approximately 10 more times sensitive in all areas and habitats at a ‘threshold’ level of 0.8. Validation of the PD was assessed through testing of the indicator against a new set of benthic data from the HCMR MSFD 2023 monitoring programme. The distribution of longevity classes from the pooled data from 22 stations was compared to the base predicted sensitivity model with no statistical differences between the two distributions. Attempts were made to compare actual state (sampled data) and predicted state (modelled data) for the different SAR levels at the sampled stations. Since the sampled longevity data already “includes” the fishing impact, for the validation of RBS, we filtered the sampled data selecting the undisturbed or least fished (SAR<0.1) stations. Then, we impose a range of SAR values for both the sampled and the modelled longevity distribution in the RBS model and compare the resulting RBS. Further, more detailed, validation is being completed through comparison with other indicators as part of the GES4SEAS project, along with integrating PD and other indicators in the NEAT tool. The FBIT methodology will be used within the on-going MSFD 6-year cycle reporting. It is hoped in the next year to be able to make an area assessment based on epifaunal samples and to compare with the existing macrofauna based methodology, as well as to improve the resolution of the analysis from 0.05 to 0.01-degree c-squares.

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ABIOMMED – "SUPPORT COHERENT AND COORDINATED ASSESSMENT OF BIODIVERSITY AND MEASURES ACROSS MEDITERRANEAN FOR THE NEXT 6-YEAR CYCLE OF MSFD IMPLEMENTATION" is an EU research project funded under DG EN9/M6FD 2020. https://www.abiommed.eu/

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Annex 2: WGFBIT resolution

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

	MEETING DATES	VENUE	REPORTING DETAILS	COMMENTS (CHANGE IN CHAIR, ETC.)
Year 2024	18-22 November	Nantes, France		
Year 2025				
Year 2026			Final report by DATE to SCICOM	

ToR descriptors

ToR	Description	Background	Science Plan Codes	Duration	Expected Deliverables
a	**Regional assessments.** Apply and improve the seafloor assessment framework developed by WGFBIT to produce standardized sub- regional assessments of seabed state for the North, Celtic, Baltic, Arctic (Icelandic, Norwegian Barents sea), Mediterranean Seas and the Bay of Biscay and the Iberian Coast, in shallow waters (<200) and deep-sea areas (200-800m), and explore methods to set thresholds between good and degraded seabed state.	EU MSFD D6/D1 requires the assessment of the impact of physical disturbance on seabed habitats. Such methods are also needed by non-EU ICES countries. Seabed state assessments will be able to inform management decisions on how to achieve good environmental state at regional scales.	1.9, 2.1, 2.4, 6.3	3 years	Year 1: A draft Europe-wide set of regional assessments of the impact of towed bottom fisheries using standardized methodologies. Year 2 & Year 3: Further extension of the assessments into deeper waters for the regions where this is missing, and into regions where assessments have not been completed before.
b	**Trade-offs between benthic impacts and fisheries values and landings** Evaluate impacts of different management scenarios, including MPAs	DGENV activity and especially the implementation of the MSFD require the preliminary evaluation of different spatial scenarios which, in turn, should be based on the spatial assessment of both impacts and economic indicators (landing value, costs,	2.7, 5.4, 6.2, 6.4	3 years	Year 1: A series (not necessarily complete for all European seas) of state-of-the-art regional spatial assessments of the impact of towed bottom fisheries and of the related economic

		gross value added). The combined analysis of potential environmental benefits and related economic impacts on the fleets will allow to identify the best scenarios to achieve sustainability.			indicators (landing values, Gross Value Added, Costs). Year 2 & Year 3: Further extension of the assessments to all the European Seas. Consolidation and standardisation of methodologies for: 1) trade-off analysis; 2) estimation of possible consequences of spatial closures (displacement and its consequences on impacts and economic indicators) Research paper(s)
c	**Knowledge exchange with other regional assessment methods.** Keep informed about development of other methods for the regional assessment of bottom trawling impacts in a two-way knowledge exchange of the WGFBIT seafloor assessment framework with other assessment methods for benthic habitats under relevant EU directives (e.g. TGSeabed, NAFO).	The WGFBIT seafloor assessment framework (based on assessing the relative benthic state) is not the only way to assess benthic impacts from physical disturbance. Other methods are being developed in parallel. Therefore, alignment with other methods needs to be explored and compare the consistency of outputs.		3 years	
d	**Ecosystem functioning.** Examine the effect of trawling using funtional traits as proxies for predicting ecosystem functioning responses to fishing pressure. Develop methodology to predict changes in species composition following trawling to estimate changes in community known to affect ecosystem functioning.	EU MSFD D6 on seafloor integrity requires the assessment of the impact of physical disturbance on seabed habitats state and function.	1.3, 1.9, 2.3	3 years	Research paper(s)

Summary of the Work Plan

ToR a) REGIONAL ASSESSMENTS

EU MSFD D6/D1 requires the assessment of the impact of physical disturbance on seabed habitats. Such methods are also needed by non-EU ICES countries. Seabed state assessments will be able to inform management decisions on how to achieve good environmental state at regional scales.

We will apply and improve the seafloor assessment framework developed by WGFBIT to produce standardized (sub-) regional assessments of seabed state for the North, Celtic, Baltic, Arctic (Icelandic, Norwegian Barents sea), Mediterranean Seas and the Bay of Biscay and the Iberian Coast, in shallow waters (<200) and deep-sea areas (200-800m), and explore methods to set thresholds between good and degraded seabed state

ToR b) TRADE-OFFS BETWEEN BENTHIC IMPACTS AND FISHERIES VALUES AND LANDINGS

DGENV-MSFD set a series of targets in terms of seafloor protection. The achievement of these objectives must, however, in a *sensu*-FAO vision of sustainability, harmonise the reduction of environmental impacts with the safeguarding (as far as possible) of economic performance and the consequent social impacts.

To complete this route, therefore, it is essential to have high-resolution spatial assessments of both impacts and economic indicators (landing value, costs, gross value added). These assessments can then be used to identify the best scenarios as combination of spatial closures and other ancillary measures (e.g. effort reduction, improved selectivity, temporal ban, etc.).

At present, the Fishery-Dependent Information Data call represents the most comprehensive source of information for this kind of assessment, but its spatial resolution is too coarse and, consequently, there remains a need for linking of available VMS, STECF FDI and AER economic data to estimate landings and economic performance indicators of each fishery.

We will apply and improve the approaches developed by WKTRADE to consolidate the methodologies and information bases needed for a more homogeneous and complete coverage of European seas.

At the same time, we will explore different approaches to integrate the consequences of different protection scenarios in terms of effort re-distribution (displacement).

ToR c) KNOWLEDGE EXCHANGE WITH OTHER REGIONAL ASSESSMENT METHODS

The WGFBIT seafloor assessment framework (based on assessing the relative benthic state) is not the only way to assess benthic impacts from physical disturbance. Other methods are being developed in parallel. Therefore, alignment with other methods needs to be explored and compare the consistency of outputs. We will keep informed about development of other methods for the regional assessment of bottom trawling impacts in a two-way knowledge exchange of the WGFBIT seafloor assessment framework with other assessment methods for benthic habitats under relevant EU directives (e.g. TGSeabed, NAFO).

ToR d) ECOSYSTEM FUNCTIONING

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.

Year 1	A, B, C, D
Year 2	A, B, C, D
Year 3	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 some 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.