A SERIES OF TWO WORKSHOPS TO DEVELOP A SUITE OF MANAGEMENT OPTIONS TO REDUCE THE IMPACTS OF BOTTOM FISHING ON SEABED HABITATS AND UNDERTAKE ANALYSIS OF THE TRADE-OFFS BETWEEN OVERALL BENEFIT TO SEABED HABITATS AND LOSS OF FISHERIES REVENUE/CONTRIBUTION MARGIN FOR THESE OPTIONS (WKTRADE3)

VOLUME 3 | ISSUE 61

ICES SCIENTIFIC REPORTS

RAPPORTS
SCIENTIFIQUES DU CIEM

ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA
CIEM COUNSEIL INTERNATIONAL POUR L'EXPLORATION DE LA MER

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

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

ISSN number: 2618-1371 I

ICES Scientific Reports

Volume 3 | Issue 61

A SERIES OF TWO WORKSHOPS TO DEVELOP A SUITE OF MANAGEMENT OPTIONS TO REDUCE THE IMPACTS OF BOTTOM FISHING ON SEABED HABITATS AND UNDERTAKE ANALYSIS OF THE TRADE-OFFS BETWEEN OVERALL BENEFIT TO SEABED HABITATS AND LOSS OF FISHERIES REVENUE/CONTRIBUTION MARGIN FOR THESE OPTIONS (WKTRADE3)

Recommended format for purpose of citation:

ICES. 2021. A series of two Workshops to develop a suite of management options to reduce the impacts of bottom fishing on seabed habitats and undertake analysis of the trade-offs between overall benefit to seabed habitats and loss of fisheries revenue/contribution margin for these options (WKTRADE3). ICES Scientific Reports. 3:61. 100 pp. http://doi.org/10.17895/ices.pub.8206

Editors

Josefine Egekvist • Jan Geert Hiddink

Authors

Elena Balestri • Jörg Berkenhagen • Lancelot Blondeel • Philip Boulcott • Miquel Canals • David Connor • Kenny Coull • Lorenzo D'Andrea • Daniel van Denderen • Jochen Depestele • Valentina Doncheva • Josefine Egekvist • Emanuela Fanelli • Ulla Fernandez • Jan Geert Hiddink • Helen Holah • Jose Manuel Gonzalez Irusta • Stefanos Kavadas • Casper Kraan • Maria Cristina Mangano • Genoveva Gonzalez Mirelis • Eugene Nixon • Marina Panayotova • Silvia Paoletti • Nadia Papadopoulou • Raffaele Proietti • Marina Pulcini • Antonio Punzon • Marija Sciberras • Chris Smith • Katarzyna Stepanowska • Phil Rhodri Taylor • Valentina Todorova • Irini Tsikopoulou • Sebastiaan van de Velde • Ivelina Zlateva

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

Contents

i Executive summary

WKTRADE3 developed methods and data flows that allow the assessment of seabed abrasion, economic value, weight of landings and impact on the seabed of mobile bottom-contacting gears in European waters by MSFD broad habitat type and métier. This report provides regional-specific assessments of pressure and impact of bottom-contacting fishing gears on the seabed and of trade-offs between fisheries and seafloor habitat protection. We also present an analysis of spatial and temporal variation in core fishing grounds, and review and evaluate any potential consequences to the ecosystem that could arise, if greater areas of seabed are left undisturbed by bottom fishing. An attempt was made to disaggregate variable costs from the STECF Annual Economic Report out on VMS data. The assessment covers four MSFD (sub)regions, 22 sub-divisions and four countries from Mediterranean and Black Sea. It is spanning from Norway and Finland in the North to Bulgaria in the south. For all areas, the surface abrasion data were available for at least one year. For the Greater North Sea and Baltic Sea, it was possible to perform a complete analysis, while in the other regions data availability was more limited and it was not possible to assess the seabed impact. The impact of mobile bottom-contacting gears (MBCG) on seabed biota was assessed using two different methods and the percentage unfished c-squares was used as an indicator of fishing pressure. The average fishing intensity varies widely between habitat types and regions. Landings per swept area, and landings per unit impact also vary between métiers by an order of magnitude. Effort reductions resulted in different responses between the two impact indicators and the fishing pressure indicator. For PD, the reduction of effort resulted in proportional reductions between benthic impact and fisheries value. For the two other indicators, L1 and percentage area unfished, the relationship between the weight/value and the indicators was not linear, meaning that larger improvements in the indicators could be obtained at small decreases in fisheries landings. There are many other direct and indirect benefits to eco-system and ecosystem services that could result from a reduction in MBCG, but currently the methods and data are not available to quantify these at the required spatial scale. Collectively, ICES expert groups produce many valuable reports each year. Some of these are very long (up to 1000 pp.). As much of the target audience will not have time to read the whole of each document, it is *imperative* that reports start with a clear, succinct, and factual executive summary that presents the key issues addressed in the main report.

ii Expert group information

Expert group name	A series of two Workshops to develop a suite of management options to reduce the impacts of bottom fishing on seabed habitats and undertake analysis of the trade-offs between overall benefit to seabed habitats and loss of fisheries revenue/contribution margin for these options (WKTRADE3)
Expert group cycle	Annual
Year cycle started	2021
Reporting year in cycle	1/1
Chair(s)	Josefine Egekvist, Denmark
	Jan Geert Hiddink, UK
Meeting venue(s) and dates	6-9 April 2021, online, 30 participants

1 Introduction

Under ecosystem-based fisheries management, there is a need to inform managers about the interlinkages, and therefore possible trade-offs and synergies, between benthic impacts and the value (both economically and socially) of mobile bottom-contacting fisheries. Countries, the EU and Regional Sea Conventions are developing indicators of pressure and impact on benthic habitats, including from bottom-trawl fisheries. Such indicators are developed to support status assessments for the Marine Strategy Framework Directive (MSFD) and underpin the management needed to ensure that biodiversity, structure and function of benthic ecosystems are safeguarded, and fisheries production is sustained.

In 2016, the European Commission sent a request to ICES to deliver "advice on indicators of the pressure and impact of bottom-contacting fishing gear on the seabed, and of trade-offs in the catch and the value of landings". ICES advised on a set of indicators for assessing pressure and impact on the seabed from mobile bottom-contacting fishing. These indicators were selected based on their ability to describe impacts on a continuous scale that can be used in the evaluation of trade-off between the fisheries and their impacts on the seabed. ICES provided a demonstration advice product (ICES 2017) for the Greater North Sea ecoregion to illustrate possible future approaches to annual advice on this topic.

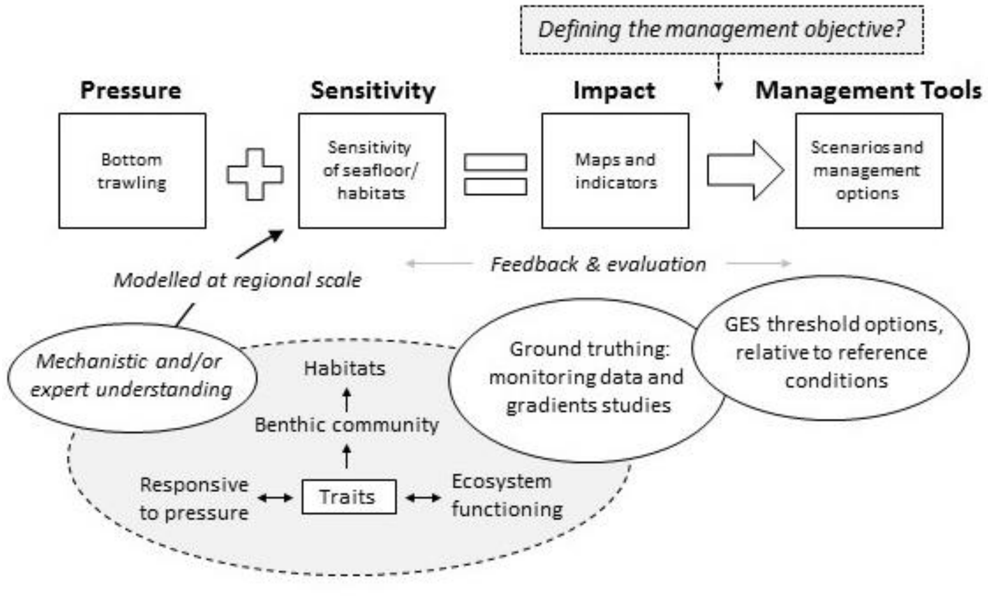


Figure 1. Conceptual diagram of the steps taken in developing management tools for assessing pressure and impact on the seafloor from bottom-contacting fishing (ICES 2017).

ICES has been asked by the European Commission in a new request for "advice on a set of management options to reduce the impact of mobile bottom contacting fishing gears on seafloor habitats, and for each option provide a trade-off analysis between fisheries and the seafloor". The purpose of this advice request is to provide a neutral analysis of potential costs or benefits to fisheries of achieving different levels of seafloor protection, based on the different management options identified. To address this request for advice, ICES experts developed a working document describing a workflow to be used by WKTRADE3 and ran a stakeholder and technical workshop (see Annex 2 for Terms of Reference).

1.1 Preparatory working document

A working document was prepared by a core group of ICES experts as preparation for the WKTRADE3 workshops (ICES 2021, annex 4). This document is based on ICES 2017 advice "EU request on indicators of the pressure and impact of bottom-contacting fishing gear on the seabed, and of trade-offs in the catch and the value of landings", and on further developments in the ICES Fisheries Benthic Impact and Trade-offs (FBIT) working group (ICES 2018). The working document includes a workflow that can be used to produce area specific trade-off assessment sheets with available data. The workflow includes proposals on key figures, tables and management options that can be produced in the trade-off analysis. The document provides proposals on these figures, tables and options using illustrations from the Greater North Sea.

1.2 Outcomes of the stakeholder workshop

ICES organised a stakeholder workshop on the evaluation of trade-offs between fisheries value and seafloor impacts of mobile bottom contact gears (ICES 2021). The aim of the workshop was to obtain inputs from stakeholders on 1) how to quantify fisheries value and seabed impacts, 2) what management options to evaluate to reduce the impact of mobile bottom-contacting gears on seabed habitats, and 3) how to present the trade-offs. Representatives of fisheries organisations, conservation NGOs and governmental managers and advisers discussed each of these topics. No attempts to reach consensus within and among groups were made, and a wide range of opinions was shared in the meeting. All groups mentioned the importance of maintaining ecosystem services, and the protection of sensitive habitats. Fisheries representatives emphasized the importance of maintaining flexibilities and livelihoods and part of the fisheries representatives expressed a preference for avoiding spatial management and prefer technical gear modifications instead, but the opinions vary in different areas. Conservation organisations expressed their opinion that spatial exclusions of all fishing with mobile bottom-contacting gears are priority management measures. All groups agreed that prioritising low fishing effort cells for exclusion of fishing was the best approach to minimize seabed impact while maximizing fisheries value. Freezing the trawling to a historic footprint was not a preferred management option for any of the groups. The participants generally preferred maps over figures as a means of presenting trade-offs.

In response to the feedback received at the stakeholder workshop, the following changes to the workflow were implemented:

- We explored a gear modification management option
- We removed the 'freezing the trawl footprint' option as a default from the outputs.
- We removed effort sequentially from the lowest effort cells as a default (rather than both from low and high)
- We added more tables and interactive maps to the outputs

1.3 Structure of the workshop and report

The technical workshop was conducted virtually over four consecutive days (April 6-9, 2021). The work was organized around plenary sessions and three breakout groups (agenda in Annex 3). The structure of this report follows the general structure of the workshop, complemented with information provided in the preparatory working document (ICES 2021, Annex 4).

The report begins with an analysis of spatial and temporal variation in fishing intensity appropriate to assess the footprint of mobile-bottom contacting fishing gears in a six-year management cycle (Chapter 2). This chapter includes an estimation of the proportion of 'core fishing grounds' and determines the spatial variation in 'core fishing grounds' over time.

Chapter 3 presents an estimate, where possible, of the revenue and contribution margin associated with the fishing activity per area by integrating fisheries economics data (e.g. STECF AER) with VMS/logbook data for all mobile-bottom contacting fishing gears and per gear grouping in (sub)regions.

The evaluation of trade-off between the fisheries and their impacts requires an assessment method to estimate mobile bottom-contacting fishing impact to the seabed. Chapter 4 describes the methodologies used to assess benthic impact and presents five pressure and two impact indicators that were used in the report.

Chapter 5 provides an overview of potential management options that can reduce the impact of mobile bottom-contacting fishing gears on seafloor habitats. This chapter includes different trade-off analyses between fisheries and benthic impact based on the management measures identified. This chapter is followed by a review of the wider benefits/consequences to the ecosystem of each management option (Chapter 6).

Regional-specific assessments of pressure and impact of bottom-contacting fishing gears on the seabed and of trade-offs in fisheries and seafloor habitats are presented in Chapter 7. Outputs of fishing footprint, benthic impact and the analysis of trade-offs (where available) are produced for the Greater North Sea, Celtic Seas and Bay of Biscay and the Iberian Coast subregion and the Baltic Sea region and for subdivisions in these seas. For different Mediterranean and Black Sea regions, part of the assessment is prepared with key data/knowledge gaps identified.

Finally, in Chapter 8, the main findings from WKTRADE3 are presented as input to the advice drafting group (ADGTRADE3) in response to the EU request to ICES.

1.4 References

ICES 2017. EU request on indicators of the pressure and impact of bottom-contacting fishing gear on the seabed, and of trade-offs in the catch and the value of landings. ICES Special Request Advice, eu.2017.13. 27 pp. https://doi.org/10.17895/ices.advice.5657.

ICES. 2018. Interim Report of the Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT), 12–16 November 2018, ICES Headquarters, Copenhagen, Denmark. ICES CM 2018/HAPISG:21. 74 pp.

ICES. 2021. A series of two Workshops to develop a suite of management options to reduce the impacts of bottom fishing on seabed habitats and undertake analysis of the trade-offs between overall benefit to seabed habitats and loss of fisheries revenue/contribution margin for these options (WKTRADE3). ICES Scientific Reports. 3:61. 65 pp. http://doi.org/10.17895/ices.pub.8206

2 Spatial and temporal analysis of core fishing ground

2.1 Vessel monitoring data: an introduction

The coupling of VMS (vessel monitoring systems) data with logbook data is currently the most practical and cost-effective method for describing the spatial dynamics of fishing activities, while in some regions the use of AIS data locally is tested. To describe the fishing footprint, we will express fishing intensity as swept-area ratios (SAR). The swept area for bottom and beam trawls is calculated as hours fished x average fishing speed x gear width. Hours fished and average fishing speed is available from the ICES VMS/log book data call, while the gear width is estimated based on relationships between average gear widths and average vessel length or engine power (kW), as stated in Eigaard *et al.* (2016) and using ICES expert input. The swept-area ratio is the sum of the swept area divided by the area of each grid cell. ICES has currently adopted a 0.05° × 0.05° grid, hereafter termed c-square. The c-square SAR value indicates the theoretical number of times the entire grid cell has been swept if effort was evenly distributed within the cell. For example, a SAR of 2 means that 100% of the c-square is fished 2 times per year, while a SAR of 0.5 means that 50% of the c-square is fished per year. Due to data availability, analyses of the fishing footprint do not account for sub-grid variation of fishing events within the c-square as described by Rijnsdorp *et al*. (1998) and Amoroso *et al*. (2018).

Data are available to describe temporal patterns in fishing activity from 2009 for vessels over 15m and from 2012 for vessels over 12m. To account for the increase in effort in the data set from 2012 as a result of the inclusion of 12-15m vessels we focus on the six year period 2013-2018.

In order to better understand the relationship between catch/value of landings and the levels of physical disturbance for MSFD purposes, all analyses consider mobile bottom-contacting fishing gears at a finer resolution gear grouping than used in the demonstration advice product (ICES 2017), on the basis that this is likely to be a more appropriate resolution for management purposes. To this end, 10 gear groupings (hereafter termed métiers) were examined together with the total intensity of all gears. The gear groupings follow Rijnsdorp *et al.* (2020) and the groupings available in the ICES VMS database (Table 2.1) based on the DCF métier on level 6 from the ICES VMS data call.

Table 2.1. Gear groupings used in the trade-off analysis. Some gear groupings are combined (note that regional-specific variation of important gear groupings may exist and may result in disaggregation of the combined groupings in specific areas). Depletion rates (the fraction of benthic fauna killed or removed in the trawl path by a single trawl pass) depend on the gear penetration depth of the different métiers (Rijnsdorp *et al.* 2020), see further chapter 4.

Métier	Main gear type	Target species assemblage group	Main target species	Depletion rate
DRB_MOL	Dredge	Molluscs	Scallops	0.200
OT_CRU[1]	Otter trawl	Crustaceans	*Nephrops*, *Pandalus*, mixed fish	0.100
OT_DMF	Otter trawl	Demersal fish	Cod or plaice	0.026
OT_MIX[2]	Otter trawl	Mixed fish	Mixed fish	0.074
OT_SPF	Otter trawl	Small pelagic fish	Sprat or sandeel	0.009
SDN_DMF	Danish seine	Demersal fish	Plaice, cod	0.009

Métier	Main gear type	Target species assemblage group	Main target species	Depletion rate
SSC_DMF	Flyshooter (seine)	Demersal fish	Cod, haddock, flatfish	0.016
TBB_CRU	Beam trawl	Crustaceans	Brown shrimp	0.060
TBB_DMF	Beam trawl	Demersal fish	Flatfish	0.140
TBB_MOL	Beam trawl	Molluscs	Whelk, snails and scallops	0.060

---

[1] including OT_MIX_CRU and OT_MIX_CRU_DMF

[2] including OT_MIX_DMF_BEN, OT_MIX_DMF_PEL

2.2 Data availability and limitations

Since the spatial variation of the fishing grounds is requested for a six-year management cycle the latest 6 years of data, covering 2013-2018 from the ICES VMS data call 2019 are used for the analysis (ICES WGSFD 2019). These data include effort, landings weight and landings value by c-square and métier. The analysis has been conducted for the following regions: Greater North Sea, Baltic Sea, Bay of Biscay and the Iberian Coast, Celtic Seas. Caveats in relation to the VMS data are listed in Chapter 7.

2.3 Core fishing ground analysis

The ToR defining the analysis is:

Conduct an analysis of spatial and temporal variation in fishing intensity appropriate to assess the footprint of mobile-bottom contacting fishing gears in a six-year management cycle. The analysis should include an estimation of the proportion of 'core fishing grounds' and should determine the spatial variation in 'core fishing grounds' over time

In the workshop, it was discussed that there are different methods and metrics that could potentially be used to assess the core fishing grounds. An optimization analysis has been explored using the prioritizr R package, and potentially clustering methods using the spatial cluster algorithms skater or DBscan could also be applied (D'Andrea *et al.* 2020). Figure 2.1 illustrates the variation in the core fishing areas by three different metrics: SAR, landings weight and landings value ranked from highest to lowest values by 10-percentile intervals for three métiers in the Greater North Sea: OT_DMF, OT_CRU and TBB_DMF.

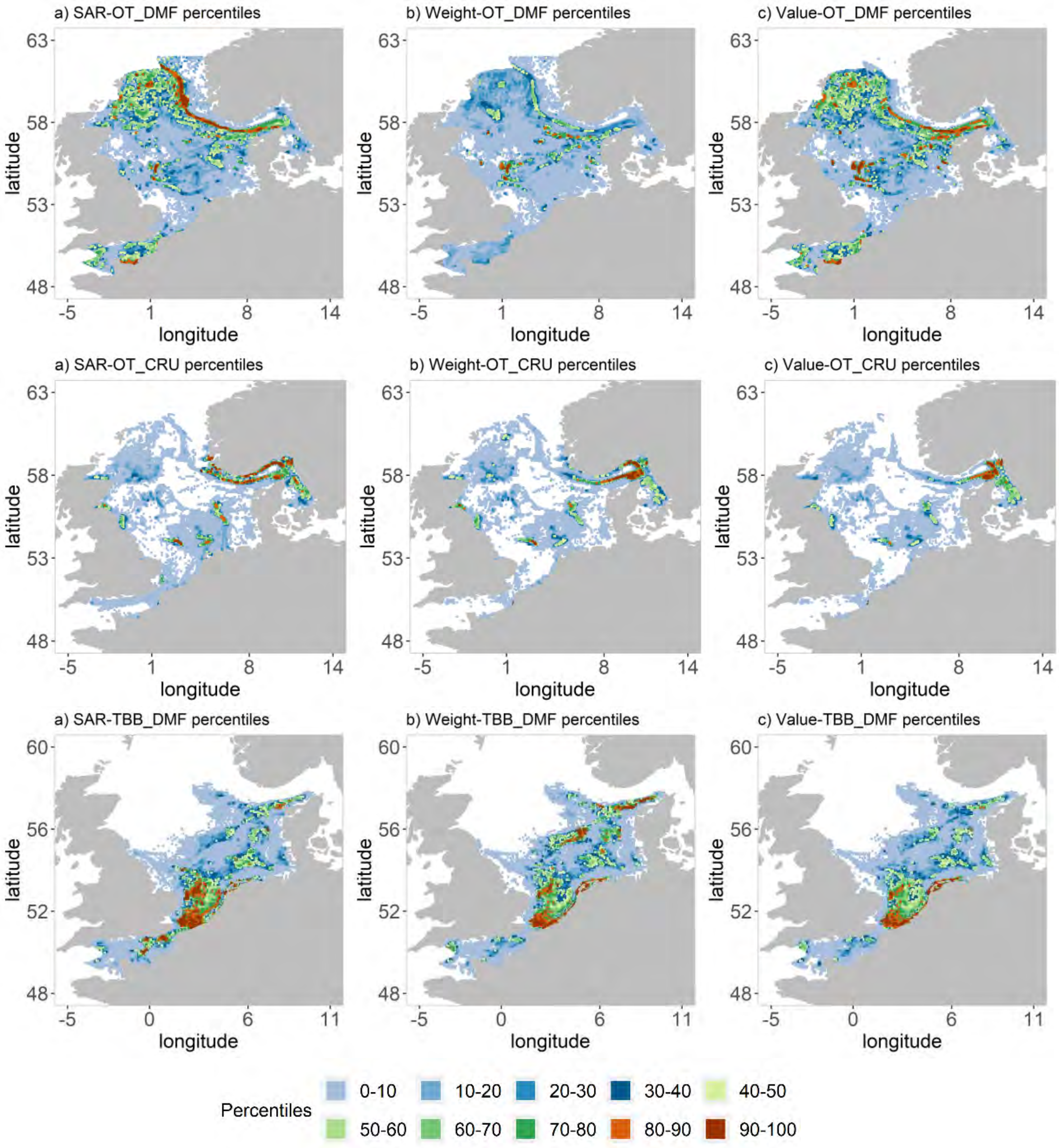


Figure 2.1: The area associated with each 10-percentile interval for métiers OT_DMF, OT_CRU and TBB_DMF using averages of SAR, landings weight (kg) and landings value (euro) for the period 2013-2018 for the Greater North Sea. The lightest blue c-squares represent the lowest 10% of total SAR (left column), weight of landings (middle column) or value of landings (right column). The brown c-squares represent the highest 10% of total SAR (left column), weight of landings (middle column) or value of landings (right column).

Table 2.2 show the percentage overlap between the core areas using the three metrics SAR, landings weight and landings value based on 90 percent highest values for the three métiers OT_DMF, TBB_DMF and OT_CRU for the Greater North Sea. Generally, the core area based on landings value has a large overlap with core areas based on weight and/or SAR. As highlighted by the colours in Table 2.2, some of the core areas based on weight or value for some métiers have limited overlap (e.g. only 48.9% of the SAR core c-squares are c-squares that are part of the weight core for OT_DMF). Looking at the landings map, this might be caused by some industrial fisheries for Norway pout and sandeel within the OT_DMF métiers as they typically catch a high weight of landings with low effort, and also low value per kg.

Table 2.2: Percentage overlap between core areas, based on the upper 90% threshold of the average SAR, value or weight of landings in the period 2013-2018 (see Figure 2.1)

Overlap	OT_DMF	TBB_DMF	OT_CRU
SAR core in weight core	48.9	87.3	78.8
Value core in weight core	49.8	94.8	98
Weight core in SAR core	89.2	89.4	93.1
Value core in SAR core	89.5	94.8	97.9
SAR core in value core	87.9	85.5	63.7
Weight core in value core	89.2	87.6	75.3

To illustrate spatial and temporal variation in the core fishing grounds three types of analysis have been conducted which are shown here and also output in the html output files. From the ICES VMS and Logbook Data (2013-2018), the total value of landings in euro are summed by year, c-square and métier. The c-squares are sorted by year, métier and descending value of landings and the rows with the 90% highest value of landings by métier and year are selected and defined as core fishing areas. The 90% was mentioned in the request from DG Environment to ICES, and since there was no argument for choosing another percentage for the analysis below the analysis of spatial and temporal variation in core fishing grounds was based on this, but could be changed to another percentage.

Results for (sub-)regions and subdivisions can be found in the output html files at https://github.com/ices-eg/WKTRADE3/tree/master/5%20-%20Output/Markdown_html, under the "Core fishing grounds" tab as figures 5, 6 and 7, but example figures are shown below for the Greater North Sea region. To analyse the spatial and temporal variability by métiers, the number of years c-squares are within the 90% highest value by métier have been counted and are illustrated on a bar-chart in figure 2.2 and on maps in figure 2.4. Figure 2.3 is showing the same as figure 2.2, but as percentage number of years c-squares are within the 90% highest value by métier. If the fishing with the 90% highest values within a métier occurs in the same c-square every year, the bars at the right in figures 2.2 and 2.3 will be high, meaning that the fishery with highest values took place in the same c-square every year during the period 2013-2018. If a c-square is only within the 90% highest value c-squares for a métier for one year, it will end up in the bar at the left, showing a larger spatial and temporal variation in the fishery by the métier. In the maps in figure 2.4, the c-squares that are often within the 90% highest value by metier, are coloured as red, orange or yellow, and can be defined as core fishing grounds.

The fisheries with otter trawl for small pelagic fish (OT_SPF) generally have a higher variation in space compared to fisheries with otter trawl for demersal fish (e.g. OT_DMF). The demersal seines (SDN_DMF, SSC_DMF) also have high spatial variation of where they catch their highest value of landings. The TBB_MOL fishery is a very small and local fishery (see figure 2.4) with variability between years.

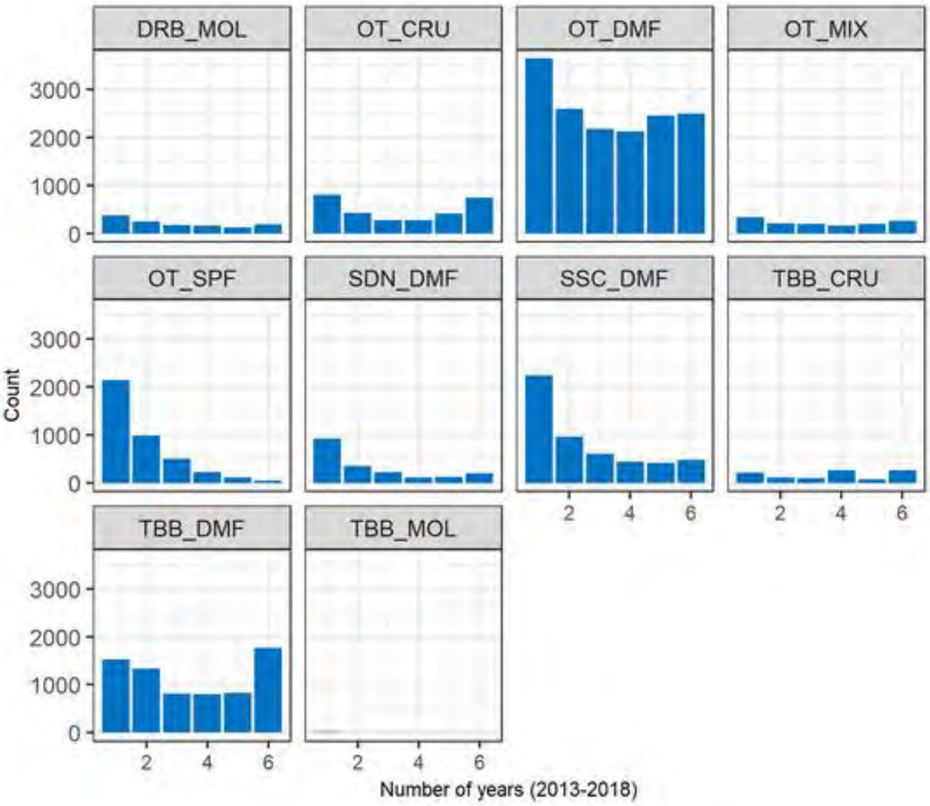


Figure 2.2: Number of years c-squares are within the upper 90% core fishing grounds (based on value) by métier during the period 2013-2018 in the Greater North Sea.

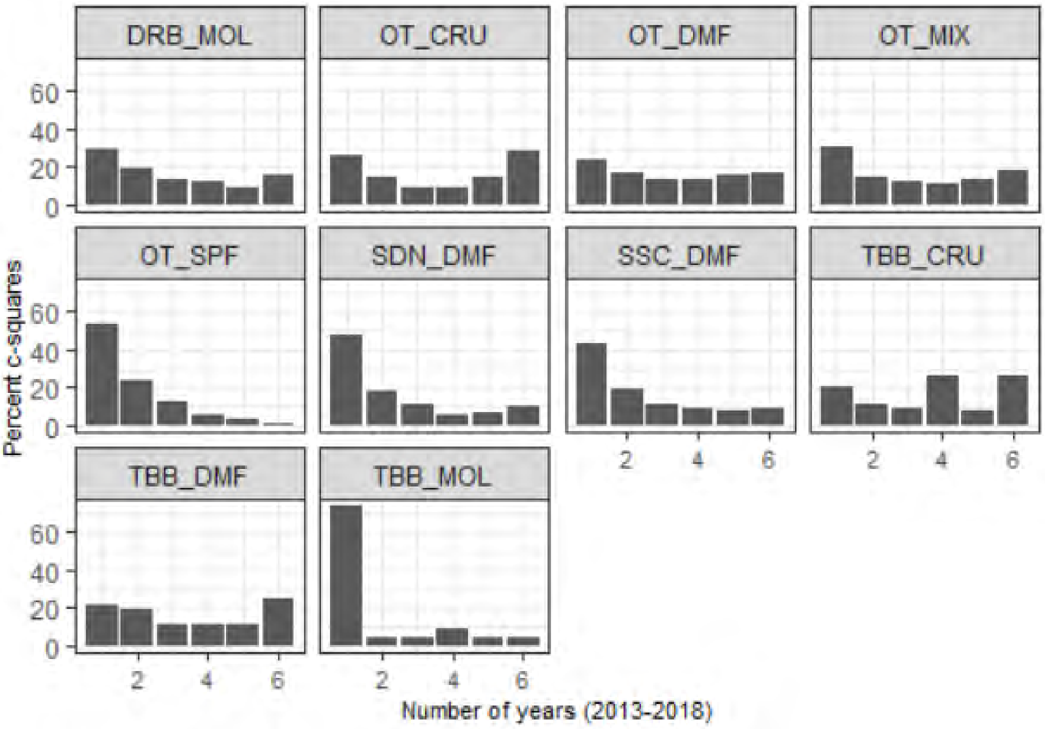
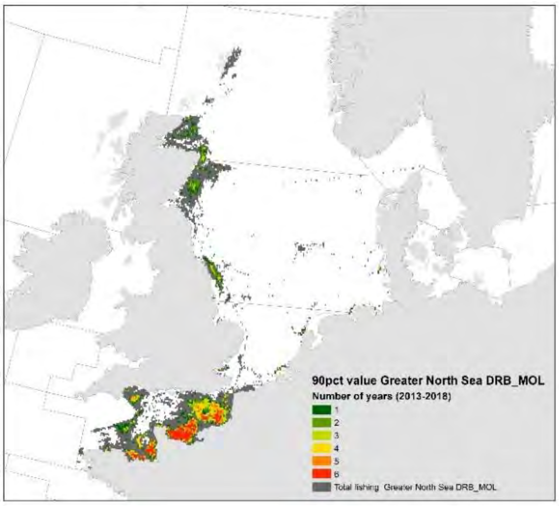
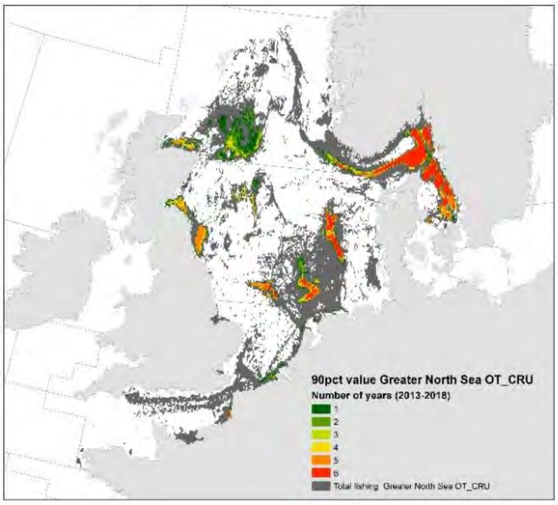
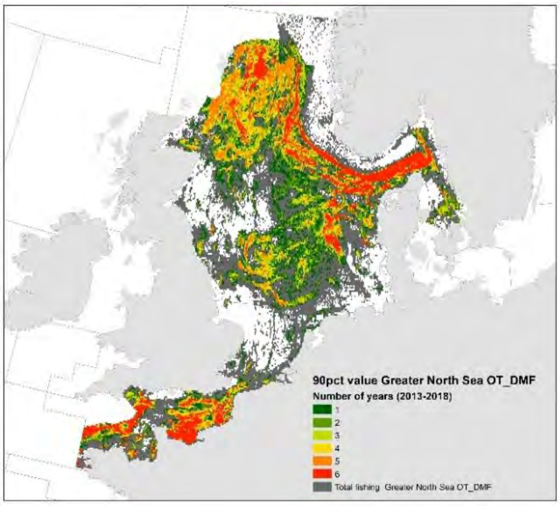
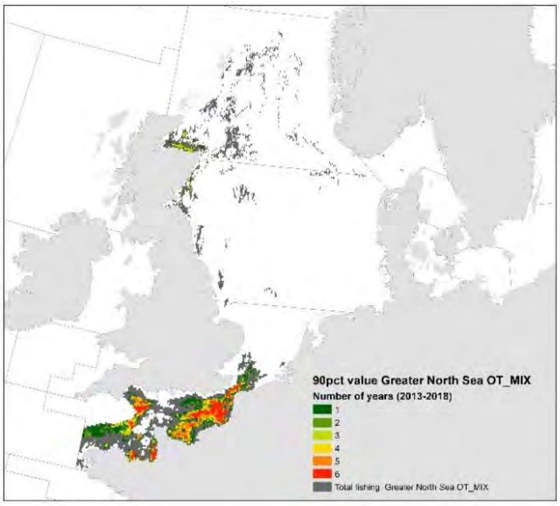


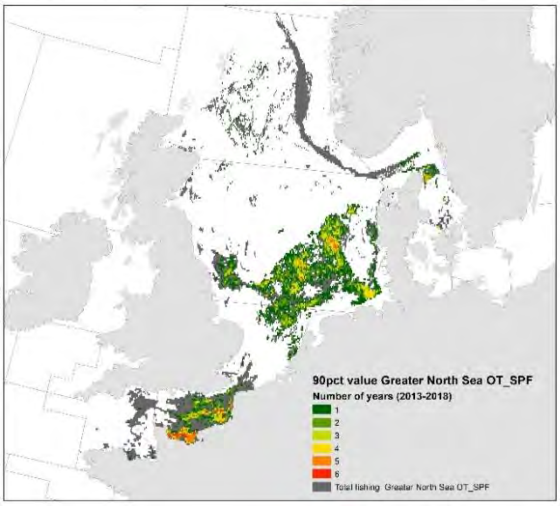
Figure 2.3: Number of years c-squares are within the upper 90% core fishing grounds (based on value) by métier during the period 2013-2018 in the Greater North Sea, shown as percent per year.

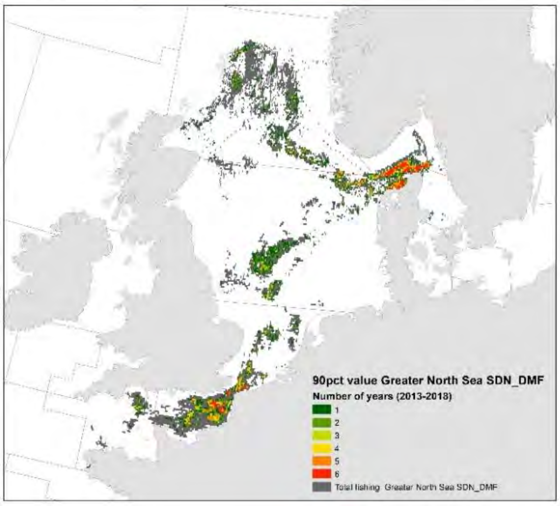

90pct value Greater North Sea DRB_MOL
Number of years (2013-2018)
1
2
3
4
5
6
Total fishing Greater North Sea DRB_MOL


90pct value Greater North Sea OT_CRU
Number of years (2013-2018)
1
2
3
4
5
6
Total fishing Greater North Sea OT_CRU


90pct value Greater North Sea OT_DMF
Number of years (2013-2018)
1
2
3
4
5
6
Total fishing Greater North Sea OT_DMF


90pct value Greater North Sea OT_MIX
Number of years (2013-2018)
1
2
3
4
5
6
Total fishing Greater North Sea OT_MIX


90pct value Greater North Sea OT_SPF
Number of years (2013-2018)
1
2
3
4
5
6
Total fishing Greater North Sea OT_SPF


90pct value Greater North Sea SDN_DMF
Number of years (2013-2018)
1
2
3
4
5
6
Total fishing Greater North Sea SDN_DMF

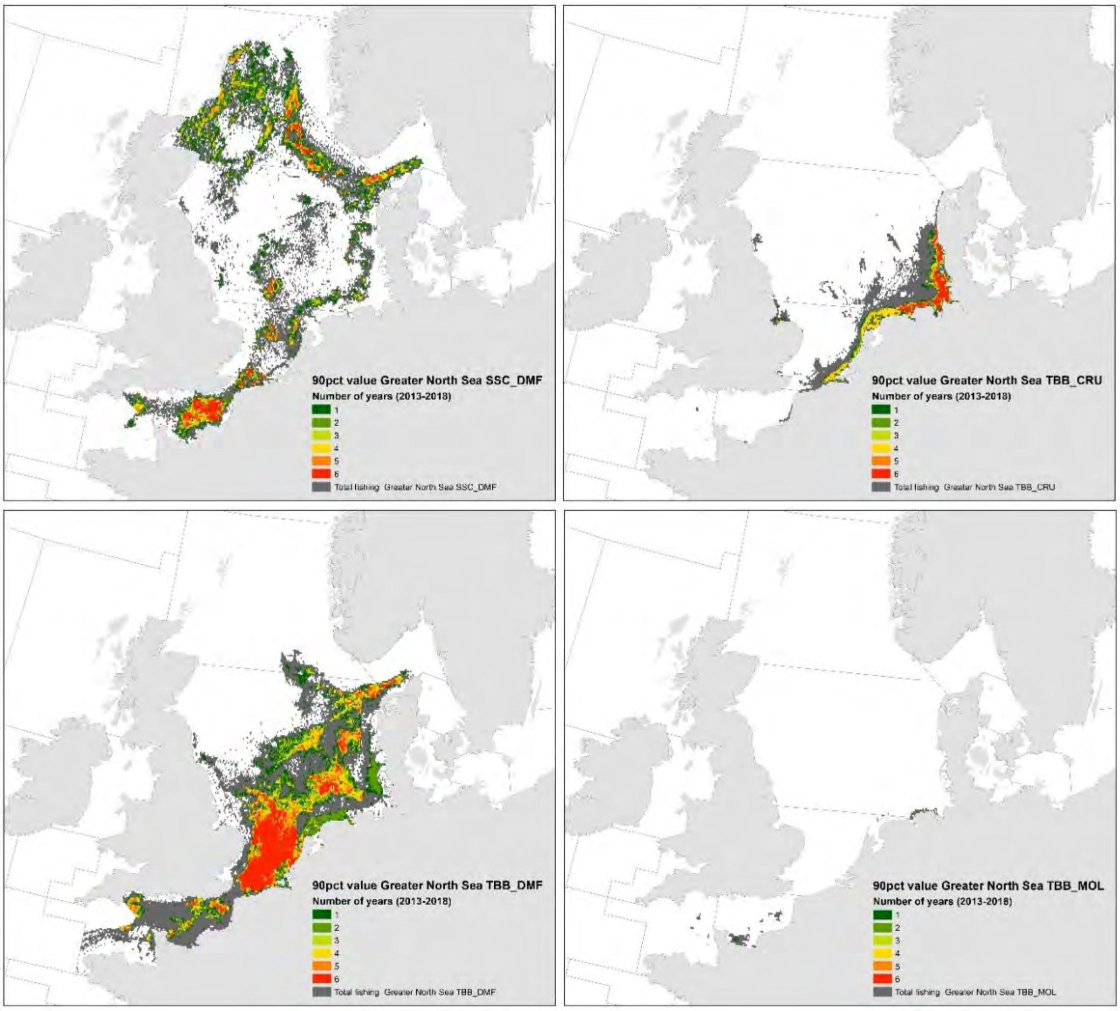


Figure 2.4: Maps of the Greater North Sea showing the number of years a c-square is within the 90% highest value within the period 2013-2018. The total extent of the fisheries by métier is shown in dark grey.

To analyse the spatial variation in the core fishing grounds between years, reference fishing grounds have been defined as c-squares within the 90% highest values for at least 2 years out of the 6 years for each métier.

Figure 2.5 show the percent area overlap between the reference fishing grounds and the 90% highest value c-squares per métier and year. As it is also seen in figure 2.3, the overlap is lower in the OT_SPF fishery for small pelagic fish as the fishery is moving in space from year to year. Again, it is noted that the TBB_MOL fishery is a small métier (see figure 2.4) where local annual variations are visible in figure 2.5.

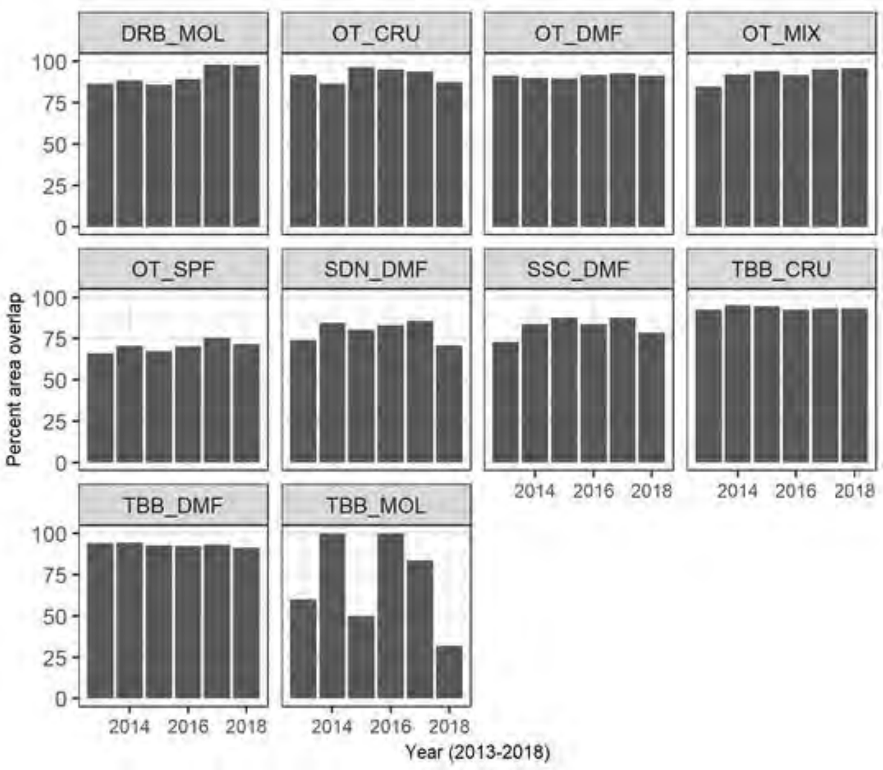


Figure 2.5: Percentage area overlap between the 90% highest value per year and the reference core fishing ground by métier during the period 2013-2018 in the Greater North Sea region.

The plots in figure 2.6 below illustrates the relationship between area fished in percent and the cumulated value of fisheries, sorted from the c-squares with highest value fisheries individually for each year. From the curves, the percent landings value can be read for a given percentage area fished, by métier. The curves are generally starting steeply, illustrating the concentration of the fisheries within fishing grounds and the curves are ending horizontally, illustrating concentration of the high value landings within the fisheries. Even though the curves are similar between years, it doesn't mean that the fishery occurs in the same c-squares, but is an indication of how spread out the landings are per year. The TBB_MOL métier curves are more spread than the other métiers, as this is a smaller métier (see figure 2.4), the curves are reflecting local variations.

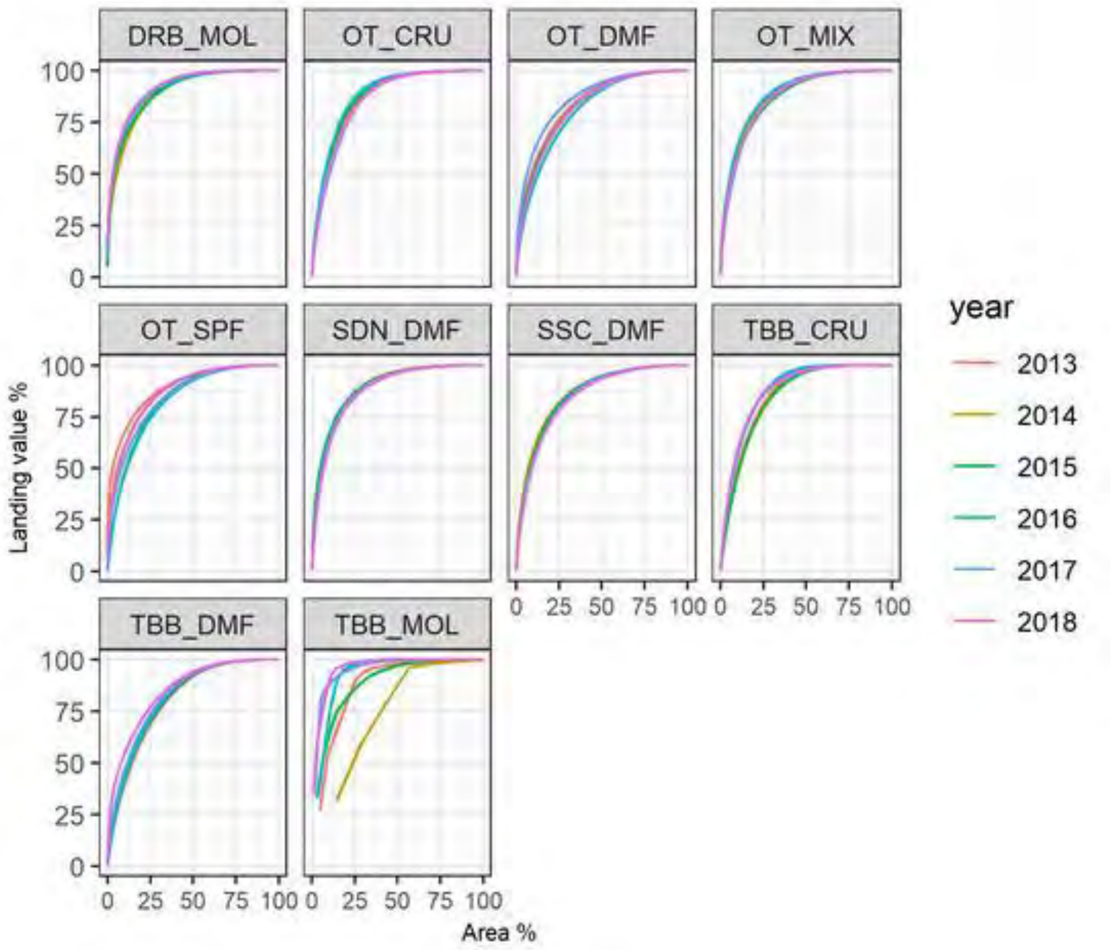


Figure 2.6: Percent area fished vs. landings value (euro) by métier, coloured by year for the period 2013-2018 in the Greater North Sea region.

2.4 Optimization approach

We tested an alternative definition for "core fishing area" with areal constraints. From this point of view a core fishing area is defined as the *minimum* area (the smallest possible configuration of c-squares) where a given proportion of the effort of each métier is guaranteed. This method is known as optimization, where a target is met for multiple spatial features (in this case, the effort distribution for various métiers), while another variable (in this case, area) is minimized. This can be implemented through Integer Linear Programming using the "prioritizr" package in R (Hanson *et al.* 2021). Furthermore, the algorithm can accept additional constraints to penalize overly fragmented solutions. We present an example of this analysis for the Greater North Sea region. Scripts for the optimization approach for the Greater North Sea are available on WKTRADE3 – github: optimization approach.

This approach is inspired by the seminal work by Ban and Vincent (2019), where they used a conservation planning software to efficiently allocate areas to different fisheries. They thus demonstrated that small reductions in fisheries, if strategically allocated, could result in large unfished areas and have the potential to achieve important conservation gains.

In this example, we defined the targets from the average surface abrasion by métier. We calculated this average using data for 2013-2018 in order to avoid confusion due to the change in vessel size policy. OT_MIX_CRU, OT_MIX_DMF_BEN, OT_MIX_DMF_PEL and TBB_MOL were excluded because none of them occurred in the area for these years. The solution for a target of 90% average surface abrasion and a moderate to strong penalty for fragmentation is shown in Figure 2.7. This is a different way of selecting the highest value c-squares than in figure 2.1, as fragmented c-squares can be avoided.

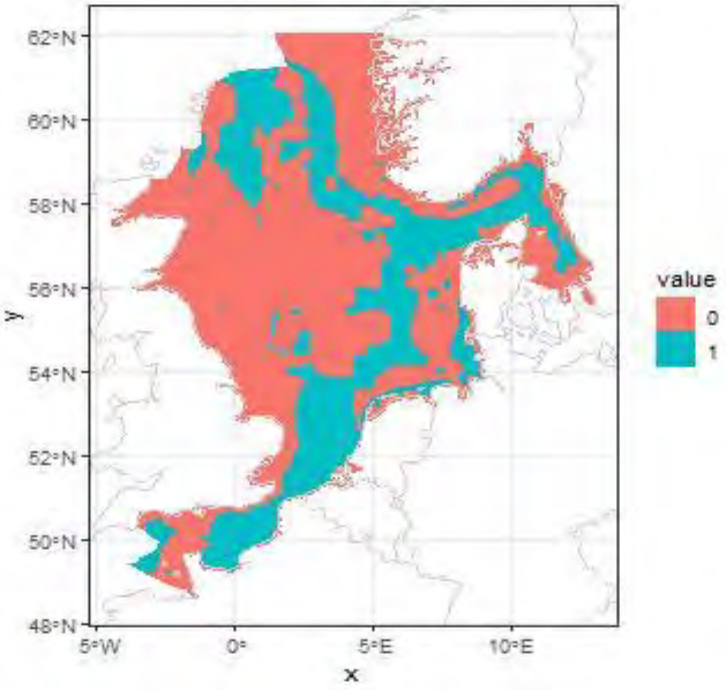


Figure 2.7: Result of running the optimization analysis on 2013-2018 with a target of 90% average surface abrasion and a moderate to strong penalty for fragmentation for the Greater North Sea. If the value is 1 (blue), the c-square is selected as a core area, if the value is 0 (red) it is not selected.

Figure 2.8 show a map resulting from an irreplaceability analysis made for the Greater North Sea based in 2013-2018 data. The c-squares marked as blue are the most important/irreplacable from the point of view of fishing, meaning that the areas have either exceptionally high catches, a wide range of different métiers operating in the same area or rare métiers/métier combinations. Cost is defined as area. The values represent the replacement costs, i.e. how costly (in area) it would be to replace each c-square, but still meet the fishing targets (90% of all metiers). Very costly c-squares (those with a value of 1) are those that contribute the most towards meeting fishing targets.

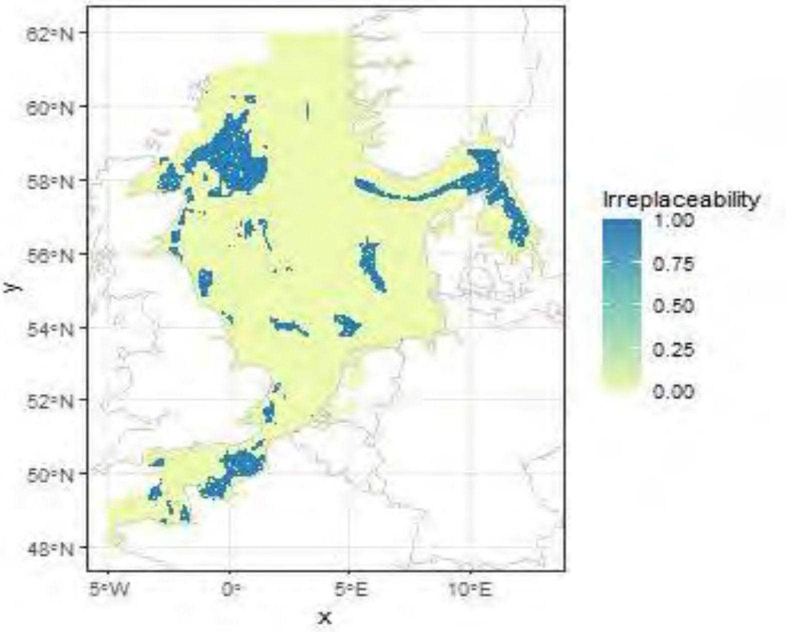


Figure 2.8: Map showing the result of an irreplaceability analysis for the Greater North Sea.

Progressive reduction of fishing effort

The same approach can be used to examine the pattern in ecological gain as effort is removed progressively by simply repeating the exercise above for the whole range of targets (95% - equivalent to a 5% reduction in effort, 90% - equivalent to a 10% reduction, etc.).

In figure 2.9 we have plotted the number of c-squares that would become "protected" for each target.

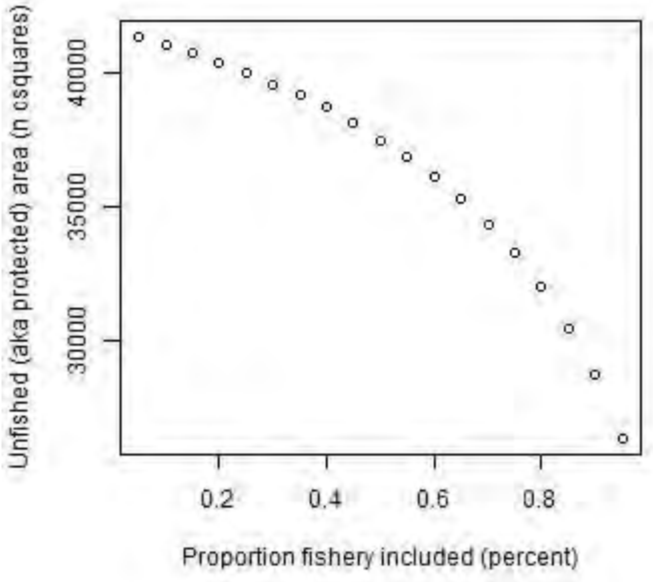


Figure 2.9: Result of running the optimization analysis in the Greater North Sea, where the x-axis show the percent fishing abrasion included (based on averages for 2013-2018) and the y-axis show c-squares that were fished at some point during the period, but could hypothetically be left unfished for each percent target (x-axis).

Future work

The optimization approach offers remarkable flexibility and warrants further exploration. Amongst the features that could prove useful is the option to define areas that are "unfishable" in order to avoid overestimating conservation gains. Equally, areas can be defined as "non-negotiable" fishing areas, for example the most irreplaceable ones. Incorporating this in the algorithm can result in increased trust from those using the results (e.g., the stakeholders).

Most importantly, the algorithm can also be used for the opposite problem, that is, an actual conservation planning problem, which is in fact what the algorithm was designed for. When used this way one can set targets for the proportion (extent) of biological features (e.g., habitat types) to be protected. The data collected under this data call offers the possibility to actually use the value and/or catch of all fisheries as the variable to be minimized (known as cost). This set up would return solutions where representativity targets are met for habitats at least cost to the fishing industry. This would allow calculating the baseline cost that the fishing industry would incur for a range of representativity targets for e.g. MSFD habitat types, optimized spatially.

2.5 Fishing in core fishing grounds vs. peripheral areas

The analysis above show that all métiers in all region appears to have core fishing grounds with relatively high yield and peripheral areas with relatively low yield. There are variation between years, but the general pattern is consistent across years. There is however some spatial variance from year to year, depending on the métier.

Our analysis shows that determining core fishing grounds is challenging as defining the core area based on landing value, SAR, or landing weight can lead to different outcomes. Although the amount of overlap is generally quite large, this is not the case for all métiers.

In addition, we here defined core areas as being c-squares included in the 90% highest value. This upper 90% limit is taken to provide a preliminary assessment of core areas, but more insight is needed in assessing what is the most appropriate percent to determine core areas or if, perhaps a continuous scale is better to show the complete spatial variation.

Moreover, by averaging across the 6 year assessment period, it is not possible to study seasonal fleet movements in response to migrating fish stocks, or to study small scale local fisheries. Such analysis would require higher temporal resolution and a more local focus.

When defining 'core' fishing grounds and capturing their spatial variability over time it is important to keep in mind the multitude of factors which influence fishers decisions on where to fish. These factors include but are not limited to: maximising the fishing opportunities from mixed fishery TACs, accessing stocks throughout their seasonal distributions, and facilitating voyage planning which optimises time and reduces operating costs taking account of any weather conditions. Fishers' decisions on where to fish can also be influenced by avoidance strategies. For example vessels will actively avoid dominant or abundant species when vessel quota is low, market value is low, or the biological characteristics of species are temporarily unfavourable (i.e. after spawning). Therefore the extent of core fishing grounds may include the spatial distributions of both target and non-target species.

Consideration should also be given to the role of "periphery" areas, or lower percentile core areas depending on the accepted threshold or extent. High levels of competition can arise for heavily fished grounds and in areas of gear conflict (e.g. if static gears have been set, trawling may be displaced). This may lead to displacement of some vessels away from priority areas or result in exploratory fishing to identify alternative grounds. Periphery areas may be more important to vessels or métiers that are more limited in terms of their suitability to particular ground types. Current approaches to defining core areas using the best available data do not incorporate the distributions of individual vessels or local fishing communities, and the analysis could be improved if home port or landing harbour was available in the VMS data. Each vessel could be operating as a separate business enterprise and may target a different species composition to other vessels within the métier. The preference of fisheries stakeholders (in some regions) is to maintain accessibility to peripheral grounds in order for fishers to keep their options open. One concern raised is that once areas are closed they are unlikely to become available again to the fishery. This limits fishers' ability to adapt to potential changes in species distributions occurring as a result of shifting environmental conditions (e.g. climate change). On the other hand, the cost of environmental damage from bottom trawling in peripheral areas can be high for limited economic gain.

2.6 Future work

The core fishing grounds can be further investigated, both in terms of the definition and the methodological approaches that can be tested, implemented and streamlined. The fishing grounds could be static areas, but also dynamic spatio-temporal entities, and additional measures could be explored in addition to the 90% threshold based on landings value used in this example.

The selection of areas based on c-squares in the spatial domain, according to a unidimensional statistical measure (the highest, or lowest or other 'direct' metrics) when connected to the spatial extent potentially yields a patchwork of large contiguous areas and then a gradual decrease and spreading of smaller zones up to the single cells, which could be complicated in relation to practical management. Other possibilities exists, such as optimization approaches or the skater or dbscan clustering algorithms, that explicitly considers the spatial topology of the system to be regionalized into more functionally and structurally similar regions (fishing grounds). The regionalization approach could also simplify the computational load for the distribution of the output through digital and interactive media.

The optimization approach could be explored further, with work on setting the targets and including information on un-fishable areas.

In conclusion, the definition of core fishing areas, including spatial and temporal variation and the value cut-off, need more consideration. Optimization techniques can be employed to define such areas for practical management purposes, taking account of irreplaceability, unfishable areas and areas occupied for other purposes such as wind farms etc.)

References

Amoroso, R., Pitcher, C.R., Rijnsdorp, A.D., McConnaughey, R.A., Parma, A.M., Suuronen, P., Eigaard, O.R., Bastardie, F., Hintzen, N.T., Althaus, F., Baird, S.J., Black, J., Buhl-Mortensen, L., Campbell, A., Catarino, R., Collie, J., Jr, J.H.C., Durholtz, D., Engstrom, N., Fairweather, T.P., Fock, H., Ford, R., Gálvez, P.A., Gerritsen, H., Góngora, M.E., González, J.A., Intelmann, S.S., Jenkins, C., Kaingeb, P., Kangas, M., Kathenab, J.N., Kavadas, S., Leslie, R.W., Lewis, S.G., Lundy, M., Makin, D., Martin, J., Mazor, T., Mirelis, G.G., Newman, S.J., Papadopoulou, N., Rochester, W., Russo, T., Sala, A., Semmens, J.M., Silva, C., Tsolos, A., Vanelslander, B., Wakefield, C.B., Wood, B.A., Hilborn, R., Kaiser, M.J. & Jennings, S. (2018) Bottom fishing footprints on the world's continental shelves. Proceedings of the National Academy of Sciences, 115, E10275-E10282.

Ban NC, Vincent ACJ (2009) Beyond Marine Reserves: Exploring the Approach of Selecting Areas where Fishing Is Permitted, Rather than Prohibited. PLoS ONE 4(7): e6258. https://doi.org/10.1371/journal.pone.0006258

D'Andrea, L., Parisi, A., Fiorentino, F., Garofalo, G., Gristina, M., Cataudella, S., Russo, T. (2020). SMARTR: An R package for spatial modelling of fisheries and scenario simulation of management stragies. Methods in Ecology and Evolution. Vol. 11, issue 7: 859-868

Eigaard O.R., Bastardie F., Breen M.l., Dinesen G.E., Lafargue P., Nielsen J.R., Nilson H., O'Neil F., Polet H., Reid D., Sala A., Sköld M., Smith C., Sørensen T.K., Tully O., Zengin M., Hintzen N.T., Rijnsdorp A.D. (2016). Estimating seafloor pressure from trawls and dredges based on gear design and dimensions. ICES J. Mar. Sci. 73(1): 27-43

Hanson JO, Schuster R, Morrell N, Strimas-Mackey M, Watts ME, Arcese P, Bennett J, Possingham HP (2021). prioritizr: Systematic Conservation Prioritization in R. R package version 7.0.1. Available at https://CRAN.R-project.org/package=prioritizr.

ICES 2017. EU request on indicators of the pressure and impact of bottom-contacting fishing gear on the seabed, and of trade-offs in the catch and the value of landings. ICES Special Request Advice, eu.2017.13. 27 pp. https://doi.org/10.17895/ices.advice.5657.

ICES. 2019. Working Group on Spatial Fisheries Data (WGSFD). ICES Scientific Reports. 1:52. 144 pp. http://doi.org/10.17895/ices.pub.5648

Rijnsdorp A.D., Buys A.M., Storbeck F. and Visser E.G. (1998). Micro-scale distribution of beam trawl effort in the southern North Sea between 1993 and 1996 in relation to the trawling frequency of the sea bed and the impact on benthic organisms. ICES J. Mar. Sci (55): 403-419

Rijnsdorp, A. D., Hiddink, J. G., van Denderen, P. D., Hintzen, N. T., Eigaard, O. R., Valanko, S., Bastardie, F., Bolam, S. G., Boulcott, P., Egekvist, J., Garcia, C., van Hoey, G., Jonsson, P., Laffargue, P., Nielsen, J. R., Piet, G. J., Sköld, M., & van Kooten, T. (2020). Different bottom trawl fisheries have a differential impact on the status of the North Sea seafloor habitats. *ICES Journal of Marine Science*, *77*(5), 1772-1786. [fsaa050]. https://doi.org/10.1093/icesjms/fsaa050

3 Economic analysis of fisheries

The term of reference is to "produce an estimate, where possible, of the revenue and contribution margin associated with the fishing activity per area by integrating fisheries economics data (e.g. STECF AER) with VMS/logbook data for all mobile-bottom contacting fishing gears and per gear grouping in (sub)regions".

The ICES VMS data call includes the revenue (landings value) from the fisheries. In 2017, the trade-off analysis and advice was based on the revenue of the fisheries. In the ICES WKTRADE2 workshop (ICES, 2019), it was advised to use the contribution margin, i.e. revenues minus variable costs, to assess the economic performance of fisheries a small spatial scale. The WKTRADE2 workshop explored different methods to assess the costs, both using mechanistic and disaggregation approaches. This WKTRADE3 analysis follows up on the disaggregation approach. In 2020, STECF FDI data (Fisheries Dependent Information) were published in a new format, including the DCF level 6 métier codes. This makes it possible to link the VMS data with FDI data, and to link the FDI data with AER data by fleet segment where the costs are reported by country EU-wide. Thus, FDI data on catch and effort are provided at a higher spatial resolution than AER data, thus allowing to characterise specific fisheries. If the variable costs can be distributed to specific fisheries, the contribution margin can be estimated for these fisheries. Further spatial specification might be achievable when implementing VMS data.

A disaggregation approach is used that combines three data sources

- **AER**: Data from EU STECF Annual Economic Reporting (AER) have been downloaded from https://stecf.jrc.ec.europa.eu/dd/fleet . Data are available for the years 2008-2019, in the sheet "data FS level", data on fleet capacity, effort and expenditure are available by country, year, fleet segment (fishing technique and vessel length group) and supra-region. The variable costs considered are energy costs (fuel), personnel costs, repair and maintenance costs and other variable costs. Within the AER data, the costs are disaggregated out on sub-regions proportional to effort (kW fishing days) by year, country, fleet segment and supra-region using the sheet "FS_effort by sub-region". The data are filtered to only include the sub-regions within the Greater North Sea, Baltic Sea and Celtic Seas where ICES VMS data are available for the analysis.

- **FDI**: Data from STECF FDI data call have been downloaded from https://stecf.jrc.ec.europa.eu/dd/fdi . File: FDI-effort-by-country.xlsx. FDI effort data are available by country, year, quarter, vessel length, fishing technique, gear type, mesh size range, target assemblage, métier, supra-region and sub-region. Member states can mark data values as confidential, and when data are published by member state, these data values have a C instead of the data value. Data are available for the years 2015-2019.

  In the AER, if there are too few vessels within a fleet segment (fishing technique+vessel length category), it can be clustered together with another fleet segment. In this analysis the national clustering schemes of fleet segments have been derived from the AER data and applied to the FDI data in order to get consistent groups of vessels (either segments or, where applicable, clusters). Then AER and FDI data could be joined by year, country, fishing technique, vessel length category and sub-region.

- **ICES VMS/Logbook data**: data from the ICES VMS data call are used with information on country, year, vessel length and DCF métier level 6 code. The vessel length ranges requested in the data call are <8, 8-10, 10-12, 12-15 and >=15. The vessel length categories requested in the AER and FDI data calls are 0-10, 10-12, 12-18, 18-24, 24-40 and >=40. This means that the vessel length categories do not overlap well, and for merging the two data sources, the vessel length categories are grouped into <12 and >=12. Data are available for the Greater North Sea, Baltic Sea and Celtic Seas for the years 2009-2018. This means that there is an overlap between the three data sources for the years 2015-2018. The VMS data are joined with the AER+FDI data by country, year, sub-region, vessel length and DCF métier level 6 code.

Figures below show examples from the 2018 data analysis.

Tables 3.1 and 3.2 show the percent match between the data sources. Mismatches between AER and FDI (table 3.1) data are caused by the fleet segmentation not matching within the sub-region. Mismatches between FDI and VMS data (table 3.2) can be caused by inconsistent métier codes between the datasets. In the case of Norway, VMS data are available, but Norway is not reporting for the EU AER and FDI data calls. In the case of Finland, all values in the FDI data call are marked as confidential.

Table 3.1: Percent match of kW Fishing Days between AER and FDI data for all gears in 2018 data.

Country	AER kWFD match %	FDI kWFD match %
BEL	100.0	100.0
DEU	100.0	73.9
DNK	80.8	98.1
ESP	98.0	99.0
EST	85.6	99.7
FIN	100.0	100.0
FRA	96.5	100.0
GBR	94.6	99.8
IRL	88.8	100.0
LTU	100.0	100.0
LVA	100.0	100.0
NLD	71.8	99.4
POL	86.9	100.0
SWE	95.3	99.9

Table 3.2: Percent match between FDI and VMS data for mobile bottom-contacting gears using 2018 data by kW Fishing Days in FDI data and by kW Fishing Hours in VMS data.

Country	FDI kWFD match %	VMS KWFH match %
BEL	100.0	97.2
DEU	96.8	99.3
DNK	99.4	96.9
ESP	87.9	99.6
FIN	100.0	100.0
FRA	48.1	15.9
GBR	96.7	92.5
IRL	100.0	99.7
LTU	100.0	99.9
LVA	100.0	100.0
NLD	68.1	95.5
NOR	NA	0.0
POL	87.4	100.0
SWE	99.9	100.0

The figure below shows the variable costs in the AER and disaggregated using FDI and VMS data. When the FDI and VMS columns are smaller than the AER column, it means that some of the costs were not assigned due to data mismatches.

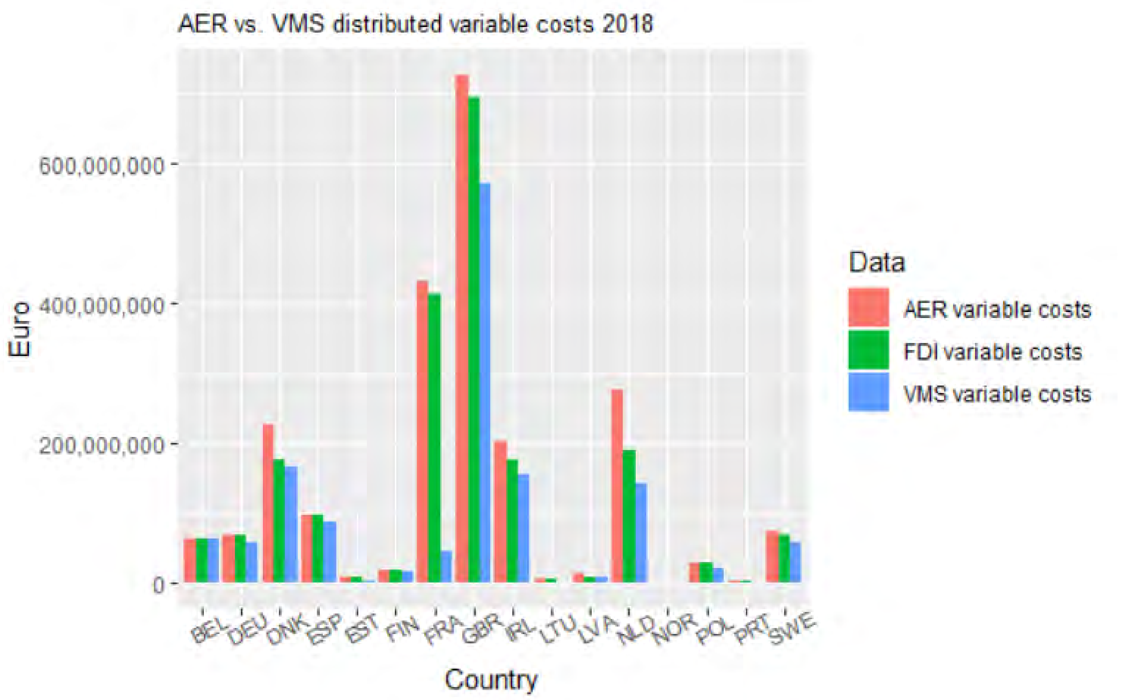


Figure 3.1: Variable costs in the AER and distributed in the FDI and VMS data, all gears.

The plot in figure 3.2 shows the total revenues and disaggregated variable costs in the AER data by fishing technique (the dominant gear group for a vessel during the year). In figure 3.3, the respective figures are displayed for the case when the variable costs are disaggregated based on VMS data (sums by métier codes).

It has to be borne in mind, though, that the variable costs which are indicated in figure 3.3 do not reflect cost structures by métier which apply to all fleet segments homogeneously. In fact, these values are average values for all fleet segments exerting the related métier, weighted by their share of the total effort.

The ratio of the two columns can illustrate the profitability within the dominant fishing technique group and, with caveat, between métiers.

The real cost structure by métier can only be estimated when cost information is available by métier. This should be further analysed, e.g. by collecting respective data (cost per métier per segment) or by using modelling techniques and a comprehensive set of individual vessel data.

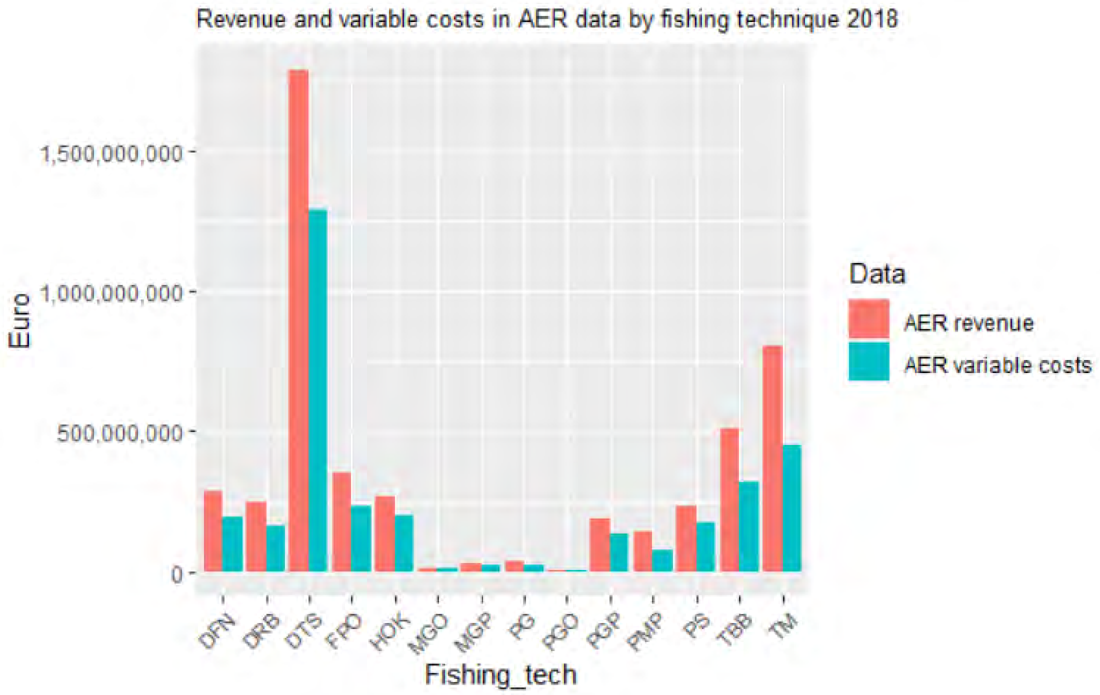


Figure 3.2: Revenue and variable costs in AER summed by fishing technique 2018

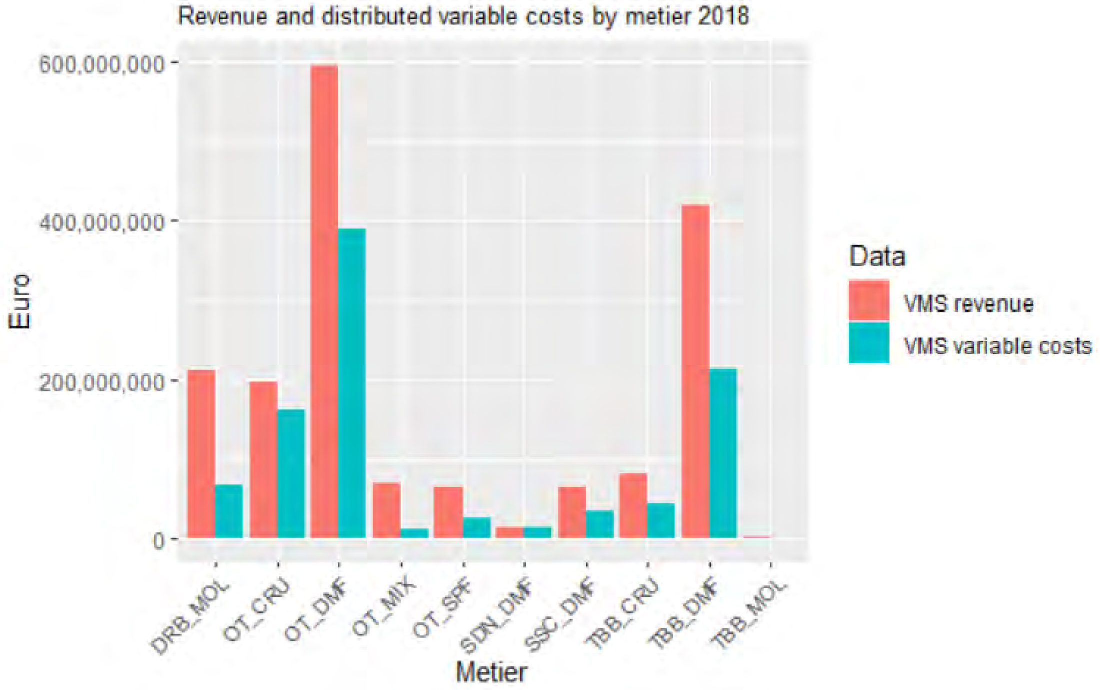


Figure 3.3: Total revenue from the ICES VMS data call and disaggregated variable costs summed by métier codes 2018

In figures 3.4, 3.5 and 3.6 revenues, effort in kW fishing hours and the disaggregated variable costs are shown for mobile bottom-contacting gears based on the ICES VMS data. If the effort is high, but variable costs are low (figure 3.5), this is most likely caused by the data mis-matches.

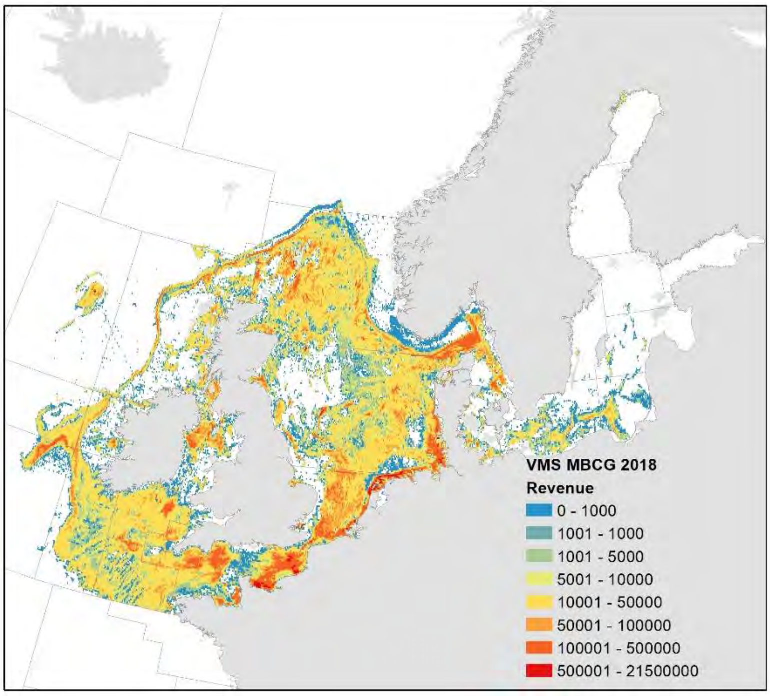


Figure 3.4: Map showing the ICES VMS total revenue of landings (euro per c-square) from mobile bottom-contacting gears 2018.

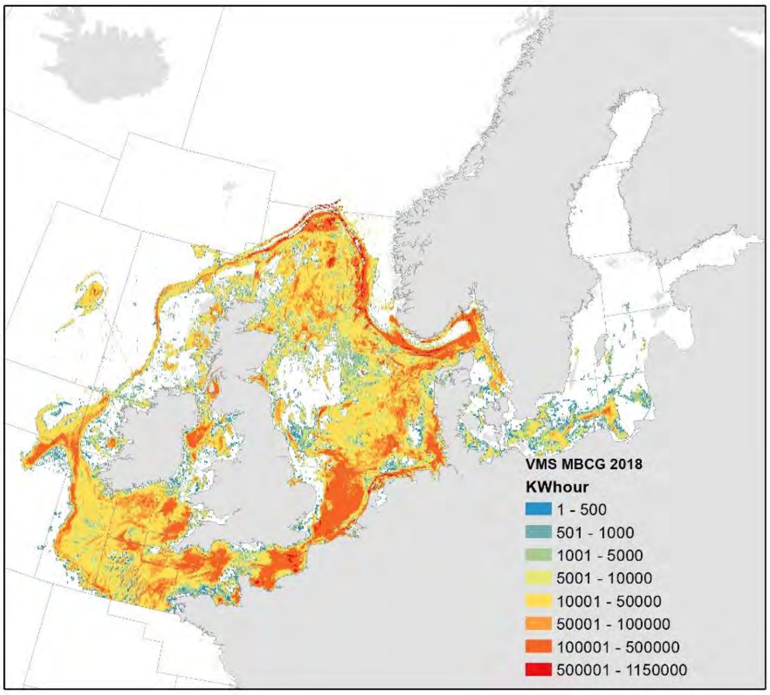


Figure 3.5: Map showing the ICES VMS kW hour effort per c-square for mobile bottom-contacting gears in 2018.

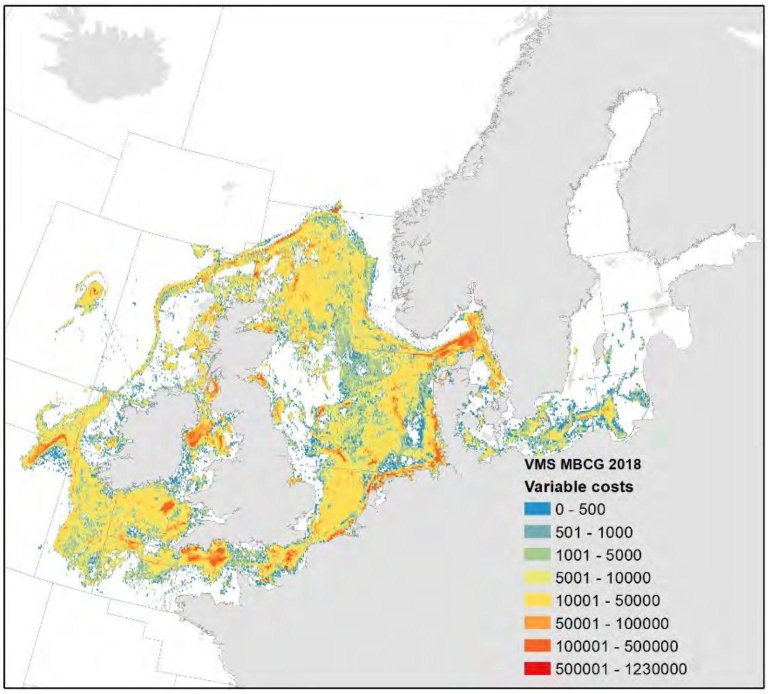


Figure 3.6: Map showing variable costs (euro per c-square) disaggregated proportionately to the fishing effort (kW fishing hours) 2018.

In figure 3.7 percentiles of revenue and contribution margin are illustrated after sorting the values from highest to lowest for the métier OT_DMF using 2018 data. Although there are local differences between the maps, the patterns are similar, which is probably a result of the disaggregation method, where the variable costs are disaggregated relative to effort. In reality, the fuel costs would vary with distance from harbour, and in future work, this might be included. The landing harbour by métier and country are available in the ICES RDB database, alternatively, if such analyses are needed, the landing harbour could be requested in the ICES VMS data call in the future. A simpler approach would be to include the distance from nearest coast in the disaggregation algorithm.

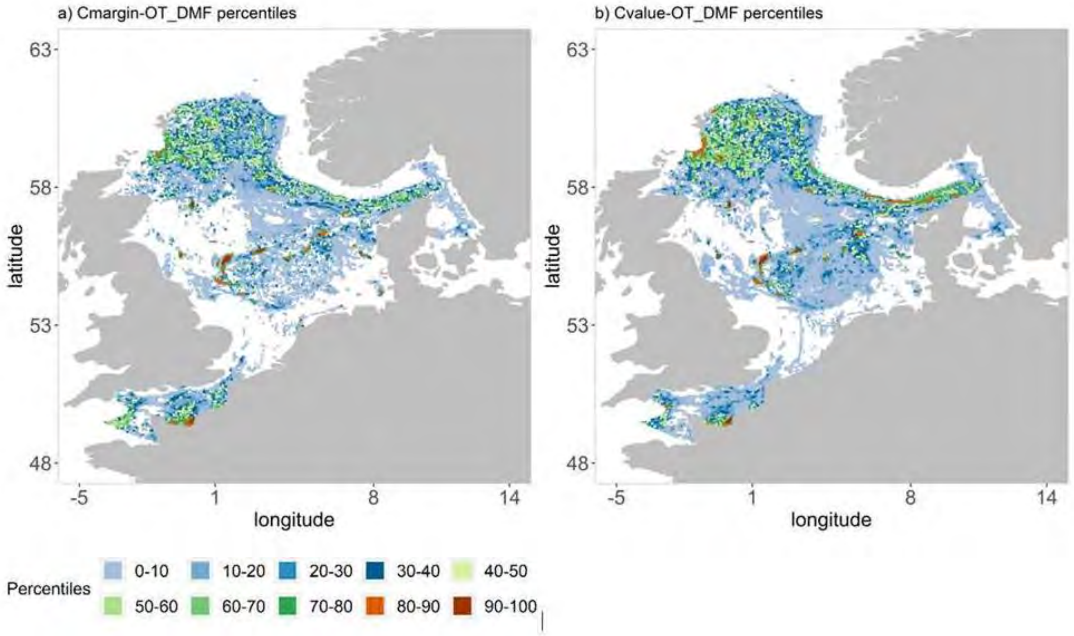


Figure 3.7: Percentiles of contribution margin (left panel) and revenue (right panel) for the métier OT_DMF in 2018.

3.1 Conclusions and the way forward

The variable costs can be estimated and assigned to spatial units using the disaggregation method and coupling the AER, FDI and VMS data. The AER data is reported on a very large spatial scale, and for some fleet segments fishing within a limited area, the disaggregation on the costs by fishing effort appears appropriate, while in other more diverse fleet segments fishing in a larger area, the disaggregation approach is more problematic, as the costs might vary e.g. with the distance from port. This is not yet included in the current analysis.

There are some data issues where the fleet segments and métier codes could be harmonized within the countries when answering the different data calls. Work is ongoing in the EU Regional Coordination Group (RCG) intersessional subgroup on Métier issues to harmonize the methodology for assigning the métier codes to transversal data using common script and reference lists. The new proposed harmonized métier codes are being implemented in the ICES RDBES test data call in 2021, and it is planned that they will be requested in the STECF FDI and ICES VMS data calls in 2022.

The variable costs are not spatially explicit, while the trade-off assessment does include the assessment of the consequences of spatial management. The lack of spatially explicit cost data prevents looking into the effects of spatial management on the cost structure. The value of adding cost data, however, lays in the comparison of the contribution margin on métier level. Figure 3.3 quite nicely illustrates that the contribution margin of OT_DMF in absolute value is higher than in the OT_CRU métier, meaning that the OT_DMF is more profitable. The effect of management measures on the fisheries requires the assessment of its effect on landings but also on the contribution margin.

Future work could include analysis of the cost structure in different fleet segments and their relation to the métiers and vessel length categories in the FDI/VMS data. In addition, the distance from major ports or coast could be included in the disaggregation algorithm using the ICES RBD data or including the landing port in the ICES VMS data call.

3.2 References

ICES 2017. EU request on indicators of the pressure and impact of bottom-contacting fishing gear on the seabed, and of trade-offs in the catch and the value of landings. ICES Special Request Advice, eu.2017.13. 27 pp. https://doi.org/10.17895/ices.advice.5657.

ICES. 2019. Workshop on Tradeoffs Scenarios between the Impact on Seafloor Habitats and Provisions of catch/value (WKTRADE2). ICES Scientific Reports. 1:63. 67 pp. http://doi.org/10.17895/ices.pub.5598

4 Fisheries pressure and benthic impact

4.1 Fishing pressure indicators

ICES (2017) advised on the use of five indicators and maps for the pressure from mobile bottom-contacting fishing gear: four annual indicators and one multiple year indicator, as shown in the table below. The indicators can be applied by (sub-)regional, subdivision sea, or broad habitat type within that sea, and assessed by total bottom-contacting fishery, a métier, or a combination of métiers (Figure 4.1). Three of these indicators rely on gridding of the considered area. ICES has currently adopted a 0.05° × 0.05° grid for this purpose.

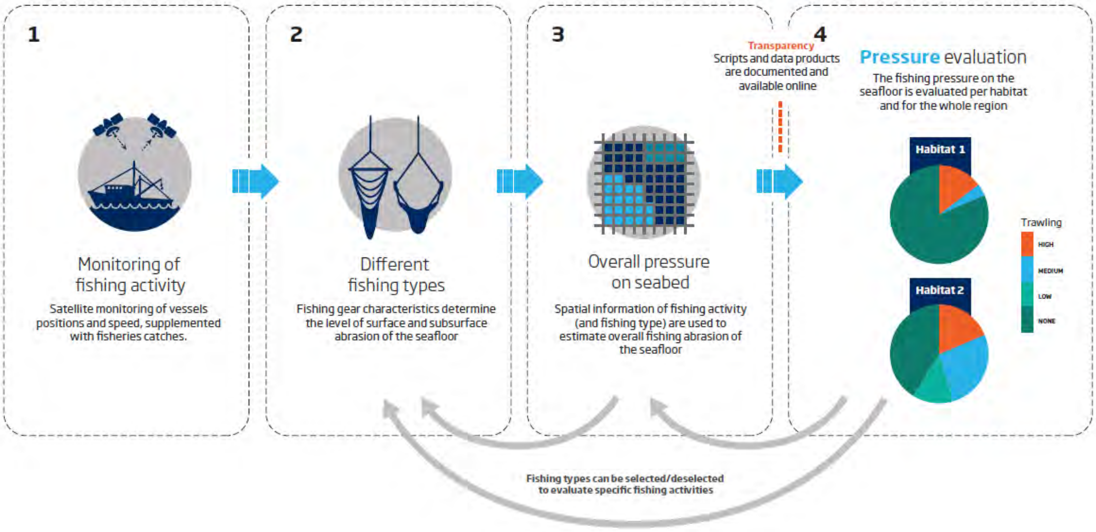


Figure 4.1 Translating different fishing types into a common measure of pressure (SAR) on the seafloor and its seafloor habitats.

WKTRADE3 adapted these five pressure indicators to be appropriate for a six-year management cycle of MSFD assessments. Therefore, assessment maps and indicator values produced are based on an average fishing intensity of the latest six-year (2013-2018) (Table 4.1). The use of an average stabilizes the fishing footprint and supports the calculation of impact indicators (which are based on equilibrium conditions). The 6-year average further corresponds to the recovery time of a high proportion of benthic organisms that are impacted by the trawl. The assessment product further shows year-to-year variations in the pressure (see Chapter 7).

Table 4.1. Pressure indicators that are applied by (sub-)regional, subdivision sea, or broadscale habitat type within that sea

Pressure indicators	Description
Intensity (I-1)	Average number of times the area is swept per year by MBCG. Estimated as the sum of swept area for all MBCG (averaged for the six-year cycle), divided by the total area.
Proportion of grid cells fished (I-2)	The number of c-squares fished at least once in the six-year cycle (irrespective of the swept area within the cell), divided by the total number of c-squares.
Proportion of area fished (I-3)	The sum of swept area across all c-squares based on the average for the six-year cycle, where swept area in a specific grid cell cannot be greater than the area of that grid cell, divided by the summed area of all c-squares.
Aggregation of fishing pressure (I-4)	The smallest proportion of c-squares in the area where 90% of the total swept area occurs.
Persistently unfished areas (I-5)	The number of c-squares persistently unfished in the six-year cycle (irrespective of the swept area within the cell), divided by the total number of c-squares.

4.2 Benthic impact assessment and indicators

The evaluation of trade-off between the fisheries and their impacts requires an assessment method to estimate mobile bottom-contacting fishing gears impact to the seabed. To assess impact of these gears, WKTRADE3 used two indicators of impact. Fishing impacts for these two indicators are determined for each c-square and summarized per MSFD habitat and gear grouping at the (sub-)regional and subdivision scale (Figure 4.2).

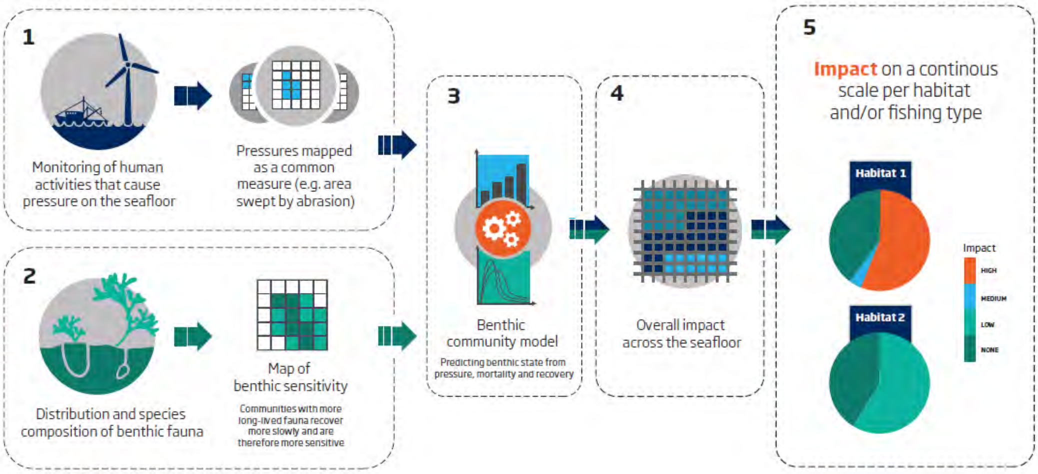


Figure 4.2 Evaluating seafloor impact and benthic habitats that are at greatest risk from human activities disturbing the seafloor.

The first indicator of impact estimates the amount of benthic biomass (relative to carrying capacity) which will not exist in the ecosystem if the current trawling intensity continues for a long time. This indicator is estimated using a population dynamic (PD) method (Pitcher *et al.*, 2017, ICES 2018, Hiddink *et al.*, 2019). The PD method uses explicit estimates of the removal of benthos by a single trawl event, and explicitly relates longevity to recovery rates. These parameters were estimated from all globally available trawl impact studies for infauna and epifauna (Hiddink *et al.* 2017, 2018). The PD method combines information on total benthic biomass (which is linked to the overall functioning of the ecosystem, see WGFBIT report 2018 section 3.2.1 on page 57) with the relative abundance of different longevity classes that in turn relates to the structure and biodiversity. For the calculation of PD-impact, the depletion of benthos by a single trawl event will differ between the different métiers based on the penetration depth of the métiers (Table 2.1, see further Hiddink *et al.* 2017, Rijnsdorp *et al.* 2020).

The PD method does not separately account for declines of rare, sensitive and fragile species that managers may want to protect (e.g. within MSFD Descriptor 1: biodiversity). Rare and sensitive species are potentially heavily affected by trawling even though total biomass, linked to the structure and function of a community, is less affected. To account for rare and sensitive species, WKTRADE3 includes a second benthic impact indicator, L1, which is more precautionary. This indicator assumes that a population is affected by trawling if animals are disturbed by trawls during their life span. Only species in the community with a longevity less than the average interval between two successive trawling events, based on the swept area ratio, will not be affected (Rijnsdorp *et al.* 2016, 2020).

For both indicators, sensitivity of the benthic community is estimated from the longevity of benthic fauna in the community, i.e. the more long-living organisms the higher their sensitivity. Predictions of longevity, and hence potential to be impacted, are available for the North and Baltic Sea, based on the present unfished reference condition of infauna and small epifauna, as collected by boxcore and grab samples (Rijnsdorp *et al.* 2018, van Denderen *et al.* 2019) (Figure 4.3). The unfished reference condition is based on the state of currently unfished ecosystems and locations, as quantified in the fishing impact studies underpinning the work by Hiddink *et al.* (2017). The unfished reference condition does not take account of the potentially different, but unknown and unquantified, historic state of the seabed before human activity started. It thus prioritizes areas that are at present sensitive to bottom trawl disturbance and directly benefit from protection.

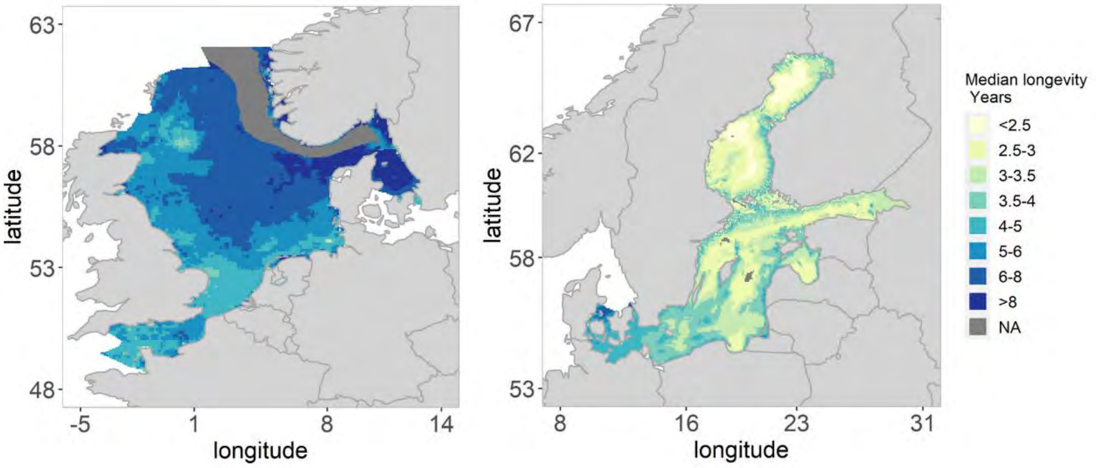


Figure 4.3 Predictions of the community longevity composition for the North and Baltic Sea, based on the present unfished reference condition of infauna and small epifauna, as collected by boxcore and grab samples (Rijnsdorp *et al.* 2018, van Denderen *et al.* 2019). For the Baltic Sea, the reference condition was derived for all sampling data in the absence of trawling and hypoxia (and anoxia) to estimate a reference state. The median longevity is estimate based on the modelled biomass distribution over the different longevities of benthic biota per grid cell.

WKTRADE3 does not consider the LL1-method as used in the demonstration product (ICES, 2017) (which is a different indicator than the L1 indicator that is presented in this report). The LL1 method is a statistical model that describes how the fraction of long-lived fauna changes with bottom trawling intensity and environmental variables. In effect, it is a multiple-regression model that interpolates between known data points. The method is therefore not mechanistic and more difficult to standardize across marine regions with varying data availability. Previous work has shown that the impact scores of the LL1-indicator are correlated in the North Sea with the indicators used in WKTRADE3 (Rijnsdorp *et al*, 2020; see all grid cells in Figure 3, métier -specific impact estimates in Figure 8). Nonetheless, the LL1-method does predict that impact is less strong in the southern parts of the North Sea due to interactive effects between trawling and natural disturbance. WKTRADE3 highlights that the development of methods to assess benthic impact are ongoing. The evaluation of trade-offs in this document is generic and can be done with other impact assessment methods, where available, when these methods describe impact on a continuous scale.

ICES (2017) advised the use of two annual impact indicators from mobile bottom-contacting fishing gear. These indicators can be applied by (sub-)regional/subdivision sea, or by broad habitat type within that sea and assessed by total bottom-contacting fishery, métier, or a combination of métiers. WKTRADE3 adapted these two impact indicators to be appropriate for a six-year management cycle of MSFD assessments (Table 4.2).

Table 4.2. Impact indicators that are applied by regional, subregional sea, or broad habitat type within that sea. These impact indicators are applied to both the PD and L1 indicators of estimating impacts.

Impact indicators	Description
Impact (I-6)	Average fishing impact across c-squares (averaged for the six-year cycle).
Proportion area with impact <0.2 (I-7)	The proportion of c-squares with an average impact below 0.2 (averaged for the six-year cycle)

4.3 References

ICES 2017. EU request on indicators of the pressure and impact of bottom-contacting fishing gear on the seabed, and of trade-offs in the catch and the value of landings. ICES Special Request Advice, eu.2017.13. 27 pp. https://doi.org/10.17895/ices.advice.5657.

ICES. 2018. Interim Report of the Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT), 12–16 November 2018, ICES Headquarters, Copenhagen, Denmark. ICES CM 2018/HAPISG:21. 74 pp.

Hiddink, J. G., Jennings, S., Sciberras, M., Szostek, C. L., Hughes, K. M., Ellis, N., Rijnsdorp, A. D. *et al*. 2017. Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance. Proceedings of the National Academy of Sciences of the United States of America, 114: 8301–8306. https://doi.org/10.1073/pnas.1618858114

Hiddink, J. G., Jennings, S., Sciberras, M., Bolam, S. G., Cambiè, G., McConnaughey, R. A., Mazor, T., *et al.* 2019 Assessing bottom-trawling impacts based on the longevity of benthic invertebrates. Journal of Applied Ecology, 56: 1075–1083. https://doi.org/10.1111/1365-2664.13278.

Pitcher, C. R., Ellis, N., Jennings, S., Hiddink, J. G., Mazor, T., Kaiser, M. J., Kangas, M. I., *et al.* 2017. Estimating the sustainability of towed fishing-gear impacts on seabed habitats: a simple quantitative risk assessment method applicable to data-limited fisheries. Methods in Ecology and Evolution, 8: 472–480. https://doi.org/10.1111/2041-210X.12705.

Rijnsdorp, A. D., Bolam, S. G., Garcia, C., Hiddink, J. G., Hintzen, N. T., van Denderen, D. P., and Van Kooten, T. 2018. Estimating sensitivity of seabed habitats to disturbance by bottom trawling based on the longevity of benthic fauna. Ecological Applications, 28: 1302–1312.

Rijnsdorp, A. D., Bastardie, F., Bolam, S. G., Buhl-Mortensen, L., Eigaard, O. R., Hamon, K. G., Hiddink, J. G. *et al*. 2016. Towards a framework for the quantitative assessment of trawling impact on the seabed and benthic ecosystem. ICES Journal of Marine Science, 73: i127–138.

Rijnsdorp AD, Hiddink JG, van Denderen PD, Hintzen NT, Eigaard OR, Valanko S, Bastardie F, Bolam SG, Boulcott P, Egekvist J, Garcia C. 2020. Different bottom trawl fisheries have a differential impact on the status of the North Sea seafloor habitats. ICES Journal of Marine Science. 77(5): 1772-86. https://doi.org/10.1093/icesjms/fsaa050

van Denderen, P.D., Bolam, S.G., Friedland, R., Hiddink, J.G., Noren, K., Rijnsdorp, A.D., Sköld, M., Törnroos, A., Virtanen, E.A. and Valanko, S., 2020. Evaluating impacts of bottom trawling and hypoxia on benthic communities at the local, habitat, and regional scale using a modelling approach. *ICES Journal of Marine Science*, *77*(1), pp.278-289.

5 Management options

5.1 Overview of management options

A list of potential management options to reduce the impact of mobile bottom-contacting fishing gears is shown in Table 5.1. This list of options was identified based on a recent review of McConnaughey *et al*. (2020) and through input from ICES experts and stakeholders in preparation of the WKTRADE3 workshop.

Table 5.1 Management options to reduce the impact of mobile bottom-contacting fishing gears (McConnaughey *et al*. 2020).

Measure/action	Objective
Technical measure	
Gear design and operations	Reduce impacts and maintain or increase catchability of target species
Gear switching	Use alternative gear with reduced impacts to catch target species
Effort control	
Reduction of effort	Reduce impacts by reducing fishing activity
Spatial control	
Prohibitions by gear type	Prohibit high-impact gears in a defined area
Freeze trawling footprint	Confine impacts to currently disturbed areas
Nearshore restriction and zoning	Reduce trawling in shallow sensitive habitats and minimize gear conflicts.
Prohibitions by small-scale habitat type	Protect small-scale sensitive habitat
Multipurpose habitat management	Broadly protect essential, representative and vulnerable habitats, i.e. MSFD broad habitat types
Impact quotas	
Invertebrate bycatch quotas	Reduce bycatch of benthic invertebrates
Habitat impact quotas	Habitat conservation to protect benthic biota

The different management options fall within one of four broad categories:

- Technical measures, aimed at lowering gear impact on the benthic ecosystem through changes in gear type and design
- Effort control measures, aimed at reducing benthic impact through a reduction in fishing effort
- Spatial control measures, aimed at protecting specific regions and/or habitats via spatial limitations that prohibit (some) métiers in defined areas

- Impact quota measures, aimed at reducing benthic impact through a change in the spatial (or temporal) distribution of fisheries that is based on a quota/credit system

Assessing the consequences of each of these management options on the fishing sector, target species for fisheries and the ecosystem and its benthic habitats is difficult in a trade-off analysis. Ultimately, it requires historical observations of such management actions and/or the development of coupled socio-economic and ecological models. These approaches should further consider indirect effects such as displacement of fishing effort, gear conflicts and potential changes in the productivity of target stocks and benthic ecosystems as a result of the management action (ICES 2019a). The wider socio-economic and ecosystem consequences of the management options are therefore not easily evaluated at the regional scale. An overview of the potential indirect effects of the management options is shown in Chapter 6.

We prioritized different management options for which we include a hypothetical trade-off analysis for the Greater North Sea in the next section. This trade-off analysis assesses the consequence of a management measure on 1) fisheries value and weight of landings and 2) the seafloor using two benthic impact indicators (PD and L1, see chapter 4) and one pressure indicator (% area/grid cells unfished). The effects of the different management measures are assessed against the current reference state of the Greater North Sea (see the regional assessment in Chapter 7 for further information on the reference state). All the management scenario evaluations are hypothetical simulations that illustrate the potential implications of a management option on the fisheries and benthic impact trade-off.

For some management options we did not include a trade-off analysis for reasons addressed here:

- Gear switching
- Gear switching behaviour may lower benthic impact when fisheries shift from high- to low-impact gears, e.g. *Nephrops* fishing with bottom trawl to pots. Such behaviour is difficult to implement in a regional assessment, as we need information on the possibilities of gear switching and on the benthic impact and fisheries revenue associated with the new gear. Gear switching behaviour was therefore not evaluated further.
- Nearshore restriction and zoning
- There is a desire by some stakeholders to protect nearshore areas, because of the importance of this zone for biodiversity, biomass and nursery areas, see also WKTRADE3 stakeholder report (ICES 2021). The current WKTRADE3 approach (chapter 4 and 7) is designed to evaluate the MSFD broad-scale habitat types and does not represent nearshore areas very well. The nearshore zone has a more complex/fine scale mosaic of habitat types and data for fishing activity, especially from smaller vessels <12m, is generally lacking. However, some nearshore habitats are subject to fishing and so the need to perform similar analyses will remain. A finer grid size would need to be applied also as the current c-squares are too coarse in relation to the complexity of habitat types.
- Prohibitions by (small-scale sensitive) habitat type (not MSFD habitat types)
- The finer resolution of such small-scale sensitive habitats, i.e. at EUNIS levels 4-6, would need better habitat maps and finer resolution of the fishing data (c-squares of 0.05 by 0.05 degrees are too coarse). Protection of MSFD broad habitat types will offer some protection of the finer types, but there will still be a need to evaluate whether more specific measures are needed for those habitats that have been most affected by pressures.
- Invertebrate bycatch quotas
- Not prioritized. Bycatch is not part of the current impact assessment (chapter 4 and 7) and we have no options to analyse trade-offs.
- Habitat impact quotas

- Not prioritized. Requires dynamic fisheries models which are not readily available across marine regions for regional assessments.

5.2 Management scenario evaluations for the Greater North Sea

Gear design and operations

Reducing benthic impacts through gear modifications is possible through, for example, less gear penetration into the seabed (Hiddink *et al*. 2017). Yet, no information is readily available to estimate how a gear penetration reduction, or any other technical measure that lowers benthic impact, affects catchability of the target species or the associated value at the regional scale. This change in catchability is likely gear- and target-species specific.

Therefore, the objective of this analysis is to hypothetically examine how reduction in gear penetration depth could change benthic impact at the sub-regional scale. An illustration of the trade-off analysis through the reduction in depletion rate is shown in Figure 5.1 The figure shows how the reduction in depletion rate changes benthic impact indicators and the percentage of unfished c-squares in water less than 200 m depth.

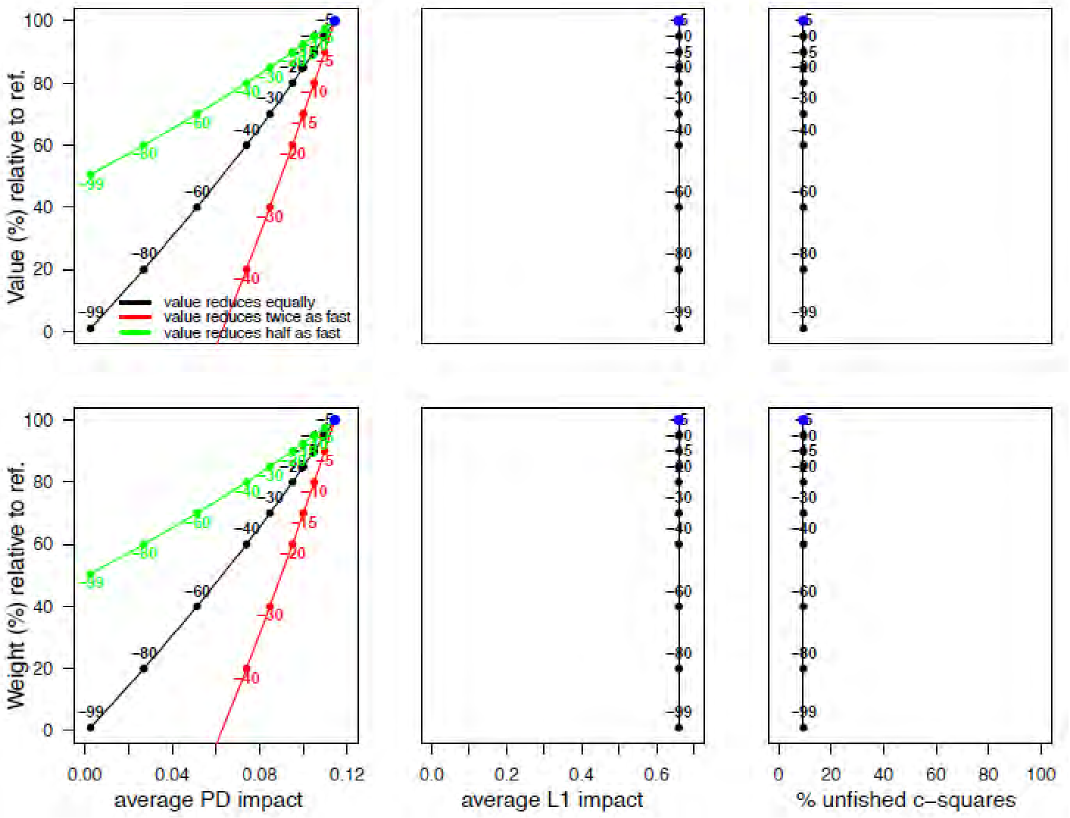


Figure 5.1. Example output of the trade-off between average impact/unfished C-squares and fisheries values/weight of catches in water less than 200 m depth after reducing the depletion rate (% noted next to the dot). The three lines in the average PD impact plot demonstrate differing assumptions of how reducing the depletion rates impacts value/weight; 1) value/weight reduces linearly (black), 2) value/weight reduces twice as fast (red), and 3) value/weight reduces half as fast (green). Blue dots show the current situation and are used as reference.

The reduction in depletion rate has a relatively large improvement in average PD impact although the effect on value/weight of fisheries landing is unknown. Figure 5.1 illustrates 3 hypothetical relationships between depletion rate and value/weight: 1) value/weight reduces linearly, 2) value/weight reduces twice as fast, and 3) value/weight reduces half as fast. The results show that the reduction in depletion rate has no effect on either the average L1 impact or the number of unfished c-squares. While in theory reducing the depletion rate could affect both the SAR values (through a resultant change in speed or gear width) and number of unfished c-squares (through changes in efficiency or displacement) this is difficult to parameterise and may not be unidirectional.

Gear modification was one of the preferred management options for the fisheries stakeholder group, although the regional representation was predominantly from the Greater North Sea. Soma *et al*. (2018) in a European stakeholder survey indicated that stakeholder perceptions differed between groups and between regions concerning different management measures, with for example restrictions in bottom contact being preferred in the Baltic, but spatial and marine ecosystem measure preferred in the Mediterranean.

The hypothetical simulation (Figure 5.1) was undertaken to reason about the implications of gear modifications on the fisheries and benthic impact trade-off. Moving from hypothetical simulation to quantitative assessment of gear modifications requires a substantial amount of data:

1. <u>Change in benthic impact through changes in depletion rate</u>
   A reduction in benthic impact can be achieved through a reduction in penetration depth. Eigaard *et al*. (2016) noted otter trawl impact reducing gear modifications could include the introduction of pelagic doors, buoyant sweeps, sweeps with discs/bobbins, raised footropes and dropper chains. The estimates of penetration depth and associated depletion rate for conventional gears are based on an elaborate meta-analysis (Hiddink *et al*, 2017). Estimating a reduction in depletion rate that is representative for the fleet is challenging, but can be approached through the estimation of the reduction of penetration depth of the conventional versus the modified gear.

2. <u>Change in benthic impact and fisheries landings/revenues through changes in Swept Area Ratio</u>
   SAR can directly be reduced by gear modifications, when the fishing speed is reduced (e.g. slower fishing speed of flatfish-directed pulse versus beam trawls) or when the width of the gear components that are in contact with the seabed is reduced (e.g. when otter boards can be operated off bottom), but SAR can also indirectly be affected by changes in fishing behaviour as a consequence of the gear modifications.
   When gear modifications alter the catch efficiency of the target species or when gear modifications are only applicable in certain fishing locations, then the locations being fished and the exerted effort in these locations may change. These changes in SAR (amount and location) affects both the benthic impact and the landings, revenues and contribution margin to the fisheries.
   For instance, replacing the conventional beam trawl by a sumwing-beam trawl is not possible for beam trawlers using chain mats, while it is feasible in tickler-chain beam trawl fisheries. The use of sumwings reduces the fuel cost and affects the contribution margin of tickler-chain beam trawls, but not those using chain mats. Another example is the fishing behaviour of Dutch demersal fishers that switched from conventional beam trawls to pulse trawls. The increased use of pulse trawls simultaneously displaced the SAR to the southern North Sea to increase the catches of sole. The changes in SAR, together with a reduced depletion rate of pulse trawls, reduced the benthic impact of pulse trawls (Rijnsdorp *et al*, 2020a).

Many gear modifications are assessed at the level of experimental trials. The assessment of the fisheries and benthic impact trade-off for gear modifications requires information from those experimental trials, including data on changes in depletion rate (or penetration depth, e.g. Depestele *et al*, 2018), in gear width and in fishing speeds. Gear modifications tend to focus on the components of the gear, e.g. semi-pelagic doors. The reduction in benthic impact of a gear component should be assessed in the light of its potential to reduce the total impact of the gear. Estimates from Eigaard *et al*. (2016) show that typical penetration of standard otter trawl parts in muddy seabeds (most penetrable sediment) range from 0 cm for sweeps and bridles, 2-5 cm for sweep chains, 15-35 cm for trawl doors and 0-10 cm for groundgears. Semi-pelagic doors, for instance, may have the potential to substantially reduce the seabed contact of the otter boards (Valdemarsen *et al*., 2007; Sistiaga *et al*., 2015; Rijnsdorp *et al*., 2017; ICES, 2019b), their overall contribution to a reduced depletion rate of otter boards, should be assessed in the light of the total gear width that is in contact with the seabed. Otter boards are the component of an otter trawl penetrating the deepest into the seabed, but they only comprise 1.1 – 2.8 % of the total width of an otter trawl (Eigaard *et al*, 2016) – however, this needs validation from gear and impact experts.

A study conducted in the western Mediterranean Sea showed that for trawls equipped with pelagic and light (<500 kg) semi pelagic bottom otter boards there was no noticeable resuspension of sediment despite contact with the sea floor. Data collected in mooring line deployments, slightly deeper than the maximum trawling depth ,showed a reduction in the intensity of erosion created by trawling gears (Palanques *et al*., 2018). After these positive results were reported these alternative otter boards were adopted throughout the full Palamós fleet.

When gear modifications have moved on from the experimental level to being fully operational at fleet level, the impact of the gear modifications on the dynamics of the SAR (amount and location) and the return to the fisheries (landings, revenues, contribution margin) should additionally be assessed (e.g. Rijnsdorp *et al*, 2020a) to deliver a complete assessment of the trade-off between fisheries and benthic impacts. This should also be incorporated into the workflow of the ICES data centre and the Working Group on Spatial Fisheries Data (WGSFD).

Gear modifications that intend to reduce benthic impacts may remain at the experimental level when only a reduction in benthic impact is achieved. The operationalisation of pulse trawls and sumwing beam trawls was for instance largely incentivized by an increased contribution margin through a reduction of fuel costs and increased catchability of sole in the case of pulse trawls. In contrast, gear modifications may pose additional constraints to their implementation. The use of semi-pelagic doors was shown to be technically feasible at experimental level, but its widespread use across otter trawl fleets is currently counteracted by its practicality.

Reductions in benthic impacts achieved through gear modifications could help to achieve benthic quality thresholds. Gear modifications could be used in combination with other management options to achieve agreed reductions in benthic impact or used to mitigate the additional impacts of spatial displacement from spatial closure management options into areas remaining open to the fishery. Further work could look at how technical measures could be balanced with spatial measures to reach the desired level of improvement. Reductions in benthic impact as a result of the two types of measures may not be equally feasible or achievable.

The workshop recommends that further development of technical measure management options would benefit from the input of gear specialists from the ICES Working Group on Fishing Technology and Fish Behaviour (WGFTFB) to better understand the appropriateness of assumptions made.

Effort reduction through spatial closure or removal of particular gears

We implemented different effort reduction through spatial control or removal of particular gear scenarios for exploration in the Greater North Sea. These are organised as a nested set of more and less detailed scenarios:

1. The progressive removal through spatial control of total MBCG fishing effort.
2. The prohibition of fishing effort of particular individual MBCG métiers.
3. Progressive removal through spatial control of all MBCG fishing effort for each MSFD broad habitat type.
4. The removal of effort through spatial control until the estimated pressure on each benthic habitat is reduced.

1. The progressive removal through spatial control of total MBCG fishing effort.

An illustration of the trade-off analysis through spatial control is shown in Figure 5.2 for two measures: 1) to close c-squares to fisheries, starting at the lowest effort c-squares, until 5 to 99% of effort has been removed (black lines), and 2) identical to 1, but where effort is removed starting from the highest effort c-squares (red lines). The analysis shows that reduction of effort starting at the lowest effort c-squares leads to more unfished c-squares, a lower average impact but also a larger decline of fisheries weight and value of catches. Importantly, a 5% decline in effort, starting at the lowest effort c-squares, results in a similar change in average impact and value/weight as a 20% decline of effort starting at the highest effort c-squares, whereas the first option leaves 40% of the North Sea c-squares persistently unfished.

The reduction of effort is done irrespective of MSFD habitat type and métier and will affect these in different ways. For example, measure 2 has a large effect on otter trawl fisheries on crustaceans (OT_CRU), which can reach high SAR intensity levels in c-squares (not shown). A more detailed analysis of MSFD habitat types and métiers is explored below.

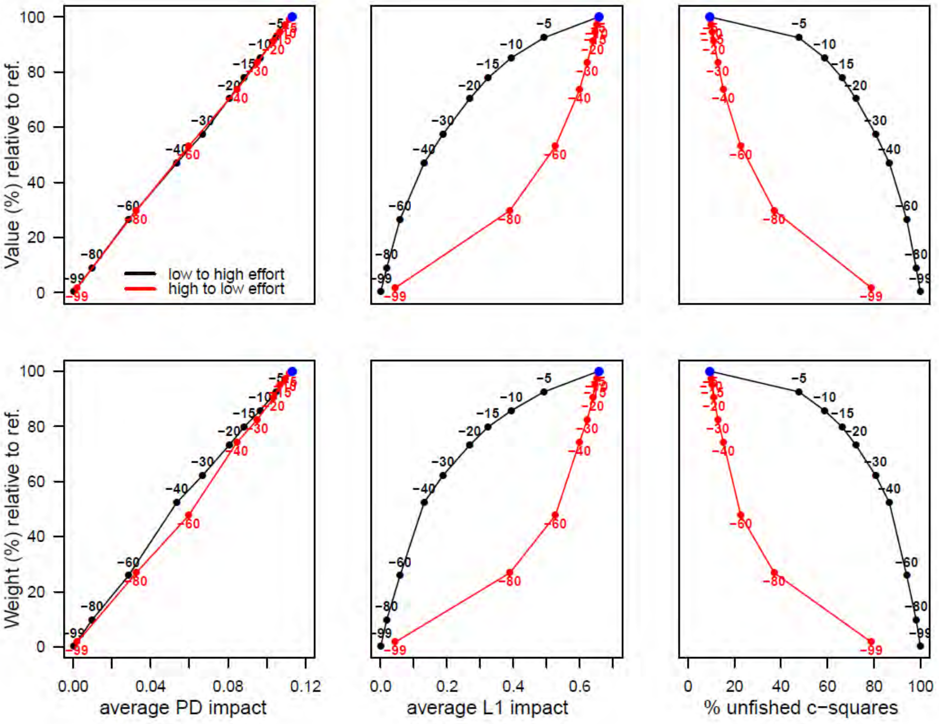


Figure 5.2. Example of the reduction in effort management option showing the trade-off between average impact (PD, L1) or unfished C-squares and fisheries values/weight of landings in water less than 200m depth. The analysis is based on the progressive removal of 5 to 99% of all MBCG fishing effort, starting from the least (black) or most (red) fished c-squares. Blue dots show the current situation and are used as reference.

2. The prohibition of fishing effort of particular individual MBCG métiers.

The objective is to examine how reductions in low/high-impact fishing gears change benthic impact at the sub-regional scale. An illustration of the trade-off analysis by gear type is shown in Figure 5.3. The figure shows how the total removal of one métier fleet segment changes benthic impact and the percentage of unfished c-squares in water less than 200m depth.

The results show that the removal of most gear types has a limited effect on total fisheries weight, except for the removal of OT_DMF, the gear that is used to capture around 60% of total weight of landings of all MBCG. The removal of métiers provides limited gains in the percentage of unfished C-squares, highlighting that most C-squares are fished by multiple métiers.

The removal of OT_CRU results in a relatively large improvement in average PD impact at a low decline in total fisheries weight and value. This is because OT_CRU has the highest impact relative to value and weight of landings and is associated with a high depletion rate (Rijnsdorp *et al.* 2020b).

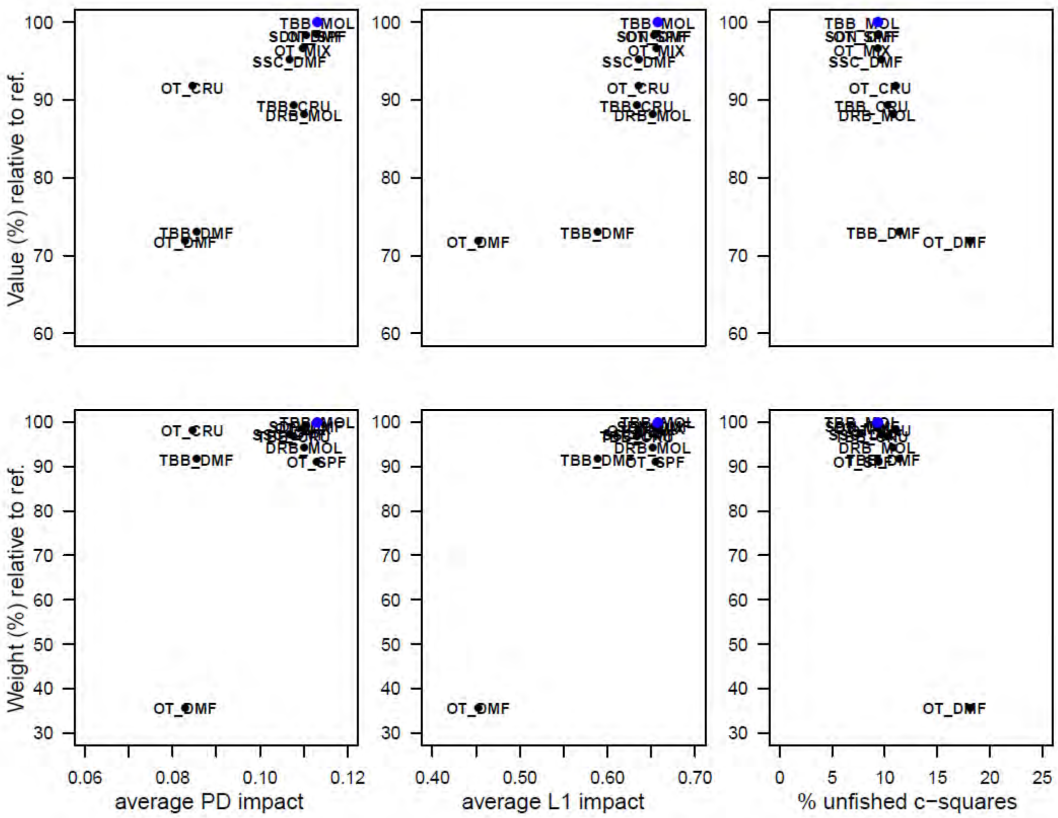


Figure 5.3. Example of the trade-off between average impact/unfished C-squares and fisheries values/weight of catches in water less than 200m depth after total removal of one métier (noted next to the dot). Blue dots show the current situation and are used as reference.

3. Progressive removal through spatial control of all MBCG fishing effort for each MSFD-broad habitat type.

The objective is to broadly protect essential, representative and vulnerable habitats, i.e. MSFD habitats. An illustration of the trade-off analysis to protect MSFD habitat types is shown in Figure 5.4 for the five most extensive MSFD habitat types that together cover 88% of the North Sea waters less than 200m depth. In all MSFD habitat types, a small reduction in effort leads to a large increase in unfished c-squares. This reduction is largest in circalittoral coarse sediment and offshore circalittoral coarse sediment where a 5% reduction in effort results in >50% unfished c-squares. Offshore circalittoral mud is the habitat that has the least unfished c-squares and the highest average impact in both impact indicators.

We included this option as a default for the regional assessment outputs in Chapter 7.

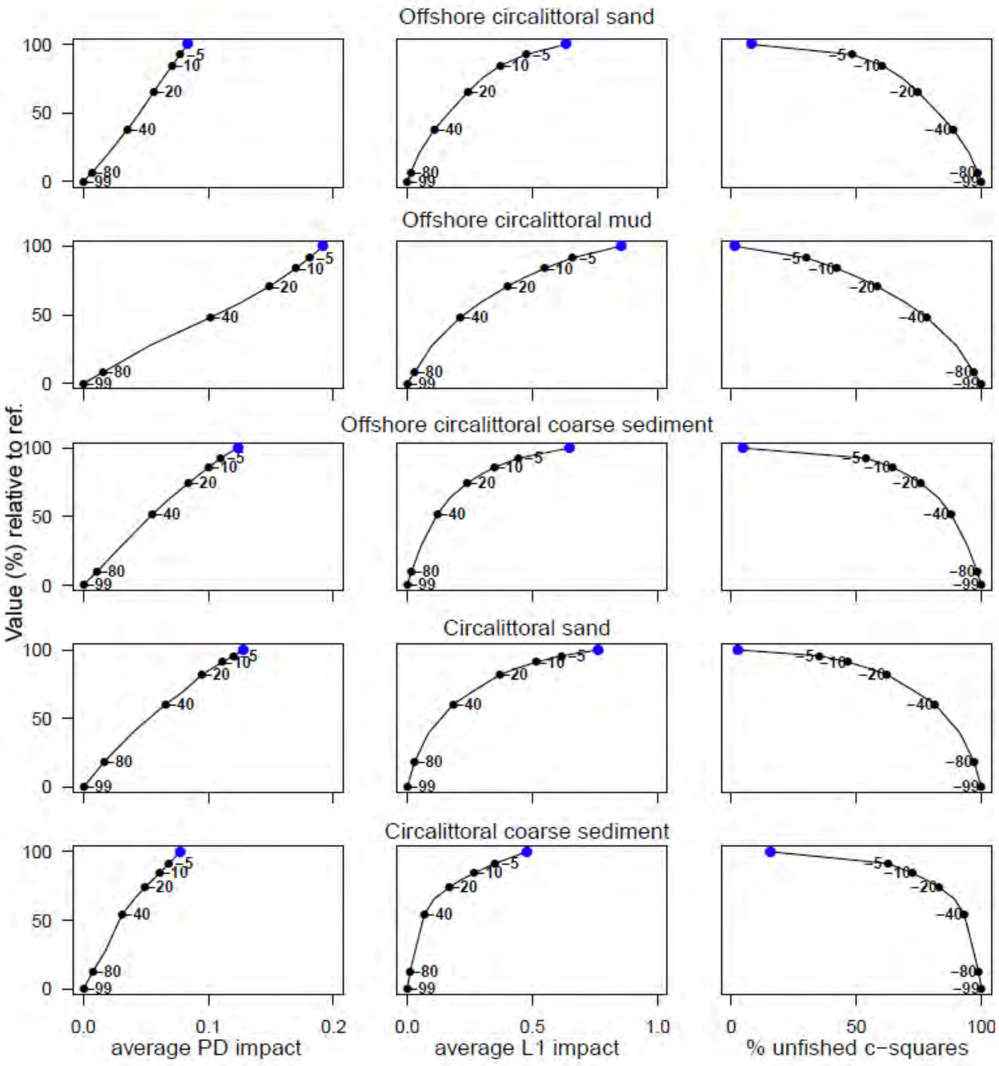


Figure 5.4. Example output of multi-purpose habitat management with reductions in effort for the five most extensive MSFD habitat types in the North Sea. Figures show the trade-off between average impact (PD, L1) or unfished C-squares and fisheries values of landings in water less than 200m depth. The analysis is based on the progressive removal of 5 to 99% of all MBCG fishing effort per habitat, starting from the least fished c-squares. Blue dots show the current situation and are used as reference.

4. <u>The removal of effort through spatial control until the estimated pressure in each benthic habitat is reduced.</u>

An illustration of the trade-off analysis to protect MSFD habitat types up to a certain threshold level is shown in Table 5.2. The table shows the consequences of protecting a certain fraction of each broad habitat type on fishing effort (as a % relative to the total swept area in each habitat type) sorted from low to high fished c-squares.

If the goal would be to protect, for example 30% of each MSFD habitat type by excluding fishing from the least fished c-squares (0.3 in table column header), some habitats will not need any management action as 30% of the area is already within unfished grid cells. For other habitat types, fishing effort will need to be reduced through spatial control. The reduction of effort needed to protect 30% of each MSFD habitat type is highest in offshore circalittoral mud (5.9%) and upper bathyal sediment (4.8%).

We included this option as a default for the regional assessment outputs in Chapter 7 and added an evaluation of the consequences of MSFD habitat protection on weight and value of fisheries landings.

Table 5.2. The consequences of protecting a certain fraction of each broad habitat type on fishing effort (as a % relative to the total swept area within the habitat) sorted from low to high fished c-squares.

MSFD broad habitat type	Extent of habitat 1000 km2	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Offshore circalittoral sand	242.72	0	<0.1	0.3	1.4	3.4	6.6	11.3	18.1	27.8	44.6
Offshore circalittoral mud	108.35	0.1	0.8	2.9	5.9	10	15.6	22.7	31.8	44.2	61.5
Offshore circalittoral coarse sediment	67.28	<0.1	<0.1	0.4	1.1	2.3	4.5	8.9	16.4	28	48.2
Circalittoral sand	68.39	<0.1	0.3	1.8	4.7	8.8	14.2	20.8	29.3	40.9	58.8
Upper bathyal sediment	70.27	0	<0.1	0.6	4.8	11	19.5	29.7	41.2	54.1	71.4
Circalittoral coarse sediment	27.16	0	0	<0.1	0.2	1.1	3.5	7.3	13.1	22.5	37.8
Infralittoral sand	12.36	0	0	0	<0.1	0.3	3.4	11.8	24.5	42.9	65.1
Offshore circalittoral mixed sediment	7.32	<0.1	<0.1	0.7	2.4	5.5	10.9	18.8	29.5	42.5	63.4
Circalittoral mud	5.84	0	<0.1	0.7	3.1	6.4	11.6	18.5	26.4	38	58.1
Unknown	7.88	0	0	0	0	0	<0.1	0.7	3.9	12.6	36.9
Offshore circalittoral rock and biogenic reef	4.08	0	0	0	0	<0.1	0.9	3.2	9.1	23.1	52.1
Circalittoral mixed sediment	4.88	0	0	<0.1	0.5	1.8	5.7	11.9	19.2	30.7	51.4
Infralittoral coarse sediment	2.68	0	<0.1	0.2	1.2	5	14.3	22.8	34.3	48.9	66.4
Upper bathyal rock and biogenic reef	1.81	0	0	0	0	0	0	0	0	2.2	19.7
Infralittoral mud	1.41	0	0	0	0	0	0	<0.1	0.7	11.5	37
Circalittoral rock and biogenic reef	2.17	0	0	0	0	0.2	1.5	3.9	10.6	21.8	42.4

MSFD broad habitat type	Extent of habitat 1000 km2	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Upper bathyal sediment or Upper bathyal rock and biogenic reef	1.43	0	0	0	0	0	0	0	0	0.1	18
Infralittoral rock and biogenic reef	1.04	0	0	0	0	0	<0.1	0.5	1.4	4.6	17.3
Infralittoral mixed sediment	1.24	0	0	0	0	0	0	0	1.3	5.3	16.8

Freeze trawling footprint

Freezing the trawling to a historic footprint was not a preferred management option for any of the stakeholder groups (ICES 2021). We therefore removed the 'freezing the trawl footprint' option as a default from the regional assessment outputs in Chapter 7. It is here shown for the Greater North Sea to illustrate how it was implemented in the preparatory working document ahead of the stakeholder workshop.

The objective is to confine impacts to previously disturbed areas. An illustration of the trade-off analysis through the freezing of the trawling footprint is shown in Figure 5.5 for two measures: 1) to freeze the trawling footprint to all fished c-squares (SAR > 0) per (sub-)region based on the reference period 2012-2014, and 2) to freeze the footprint to the core fishing grounds based on the reference period 2012-2014 (i.e. the c-squares with 90% highest average SAR values in water less than 200m depth).

The results show that freezing the trawling footprint has a limited effect on average impact and value/weight of fisheries landings, whereas the number of c-squares that are now persistently unfished is increased. Freezing the footprint to the core fishing grounds results in more unfished c-squares, lower impact and a larger decline of weight and value of catches.

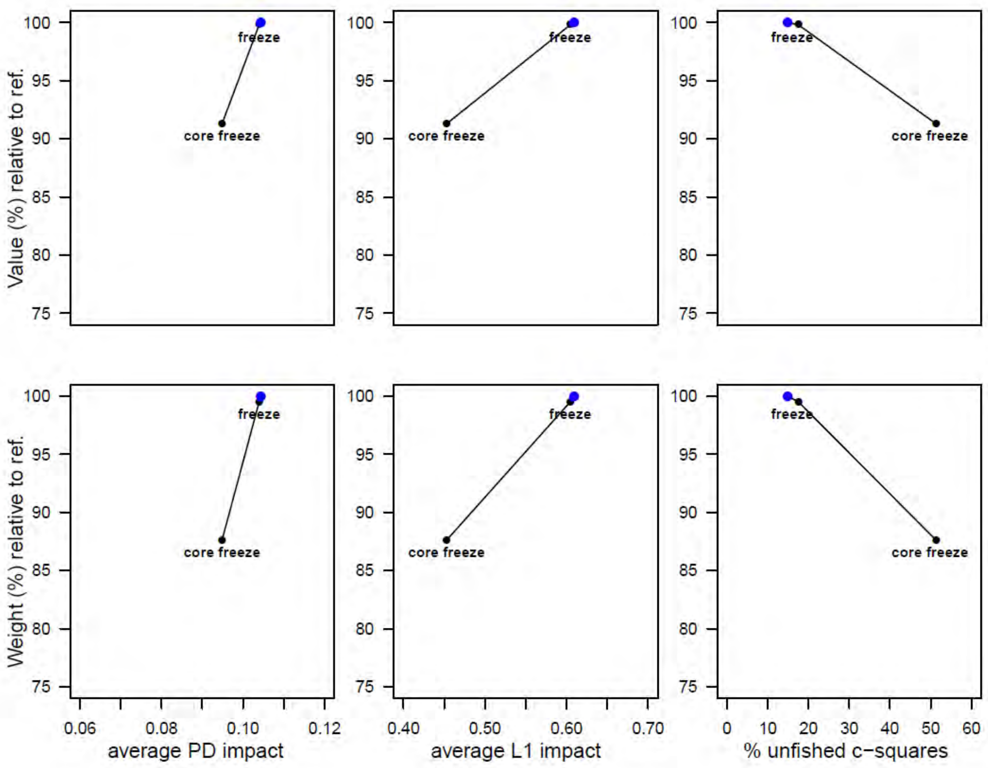


Figure 5.5. Example of the trade-off between average impact/unfished c-squares and fisheries values/weight of catches in water less than 200m depth under two different freezing the footprint measures (explained in the text). Blue dots show the current situation and are used as reference.

5.3 Limitations of the hypothetical management scenarios

Whilst we consider the approach taken here to be robust, it is limited in a number of specific ways, largely due to lack of data and information and does not attempt to include a quantification of the benefits accrued by various management scenarios when calculating the changes in fisheries value relative to reference (illustrated in 5.2-5.5 as the y-axis).

Importantly, when calculating changes in the *value relative to reference*, the approach taken attempts to quantify this change by summing the value of c-squares removed in the management scenario. This is considered a robust and reliable approach to calculating the immediate loss to the MBCG métier being considered in that assessment, but it is unlikely to be an accurate representation of true value change given the existence of benefits, including to that métier itself through greater protection of Essential Fish Habitats but extending also to the wider ecosystem and other métiers (see also Chapter 6). If overall fishing effort falls, variable costs (fuel and fishing time) would be reduced when fishers would spend less effort in peripheral areas, and when this drop in effort allows recovery of fish stocks in unfished areas, this could have benefits from spill-over effects into the fished areas.

This was considered and an option was developed to calculate a *net value relative to reference* which seeks to incorporate benefits into the workflow using a few additional lines of code to establish a more accurate reflection of real-world change. In simple terms this net change could be expressed as:

Net change = loss to MBCG métier + sum(gain through improved stock recruitment, gain to ecosystem, gain to other métier)

However, it was concluded that evidence was currently insufficient to allow an accurate estimate of any such gains without relying on assumptions which were untested. Therefore, the prior approach to using *value relative to reference* was retained, albeit with the noted limitation that this inherently assumes gains are 0.

Other limitations include issues relating to the distribution of value which is included in the information provided by c-squares. This is an amalgamation of VMS data and data from logbooks. As discussed in Chapter 2, this approach is well developed but it has the following key limitations:

i. It does not account for <12m fishing vessels
ii. It cannot account for sub-grid variation of fishing events within the c-square.
iii. There may be discrepancies between logbook and VMS in national data, e.g. catches reported in locations where no VMS records were detected.

Lastly, all the approaches presented in this Chapter did not evaluate displacement and are therefore likely to overestimate the benefits of the management scenarios for the PD and L1 impact indicators.

5.4 References

Depestele, J., K. Degrendele, M. Esmaeili, A. Ivanović, S. Kröger, F. G. O'Neill, R. Parker, H. Polet, M. Roche, L. R. Teal, B. Vanelslander., Rijnsdorp A. D. (2018). Comparison of mechanical disturbance in soft sediments due to tickler-chain SumWing trawl vs. electro-fitted PulseWing trawl. ICES J Mar Sci 76(1):312-329 doi:10.1093/icesjms/fsy124.

Eigaard O.R., Bastardie F., Breen M.l., Dinesen G.E., Lafargue P., Nielsen J.R., Nilson H., O'Neil F., Polet H., Reid D., Sala A., Sköld M., Smith C., Sørensen T.K., Tully O., Zengin M., Hintzen N.T., Rijnsdorp A.D. (2016). Estimating seafloor pressure from trawls and dredges based on gear design and dimensions. ICES J. Mar. Sci. 73(1): 27-43

ICES. 2019a. Workshop on Tradeoffs Scenarios between the Impact on Seafloor Habitats and Provisions of catch/value (WKTRADE2). ICES Scientific Reports. 1:63. 67 pp. http://doi.org/10.17895/ices.pub.5598

ICES. 2019b. Working Group on Fishing Technology and Fish Behaviour (WGFTFB). ICES Scientific Reports. 1:61. 363pp. http://doi.org/10.17895/ices.pub.5592

ICES 2021. WKTRADE3 stakeholder report (*in prep.*)

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

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

Sistiaga, M., Herrmann, B., Grimaldo, E., Larsen, R. B., Tatone, I., 2015. Effect of lifting the sweeps on bottom trawling catch efficiency: A study based on the Northeast arctic cod (Gadus morhua) trawl fishery. Fisheris Research, 167, 164-173. doi:10.1016/j.fishres.2015.01.015

Soma K, Nielsen JR, Papadopoulou N, Polet H, Zengin M, Smith CJ, Eigaard OR, Sala A, Bonanomi S, van den Burg SWK, Piet GJ, Buisman E, Gumus, A (2018) Stakeholder perceptions in fisheries management - Sectors with benthic impacts. Marine Policy, 92: 73-85.

Rijnsdorp, A. D., Eigaard, O. R., Kenny, A., Hiddink, J. G., Hamon, K., Piet, G. J., Sala, A., Nielsen, J. R., Polet,H., Laffargue, P., Zengin, M., & Gregersen, Ó. (2017). Assessing and mitigating of bottom trawling. Final BENTHIS project Report (Benthic Ecosystem Fisheries Impact Study).

Rijnsdorp, A. D., J. Depestele, O. R. Eigaard, N. T. Hintzen, A. Ivanovic, P. Molenaar, F. G. O'Neill, H. Polet, J. J. Poos., van Kooten, T. (2020a). Mitigating seafloor disturbance of bottom trawl fisheries for North Sea sole Solea solea by replacing mechanical with electrical stimulation. PLOS ONE 15(11):e0228528 doi:10.1371/journal.pone.0228528.

Rijnsdorp AD, Hiddink JG, van Denderen PD, Hintzen NT, Eigaard OR, Valanko S, Bastardie F, Bolam SG, Boulcott P, Egekvist J, Garcia C. (2020b). Different bottom trawl fisheries have a differential impact on the status of the North Sea seafloor habitats. ICES Journal of Marine Science. 77(5): 1772-86. https://doi.org/10.1093/icesjms/fsaa050

6 Indirect effects of management options

6.1 Identification of benefits of seafloor protection for the ecosystem

To address ToR b, the WK reviewed and evaluated for each management option any potential consequences to the ecosystem, including commercial fish stocks that could arise, if greater areas of seabed are left undisturbed by bottom fishing. Below we review those potential benefits. Table 6.1 summarises which benefits may be derived from which management options.

Trawling impacts are not homogeneous across benthic fauna but differs between species because differences on their biological and functional traits (Bremner *et al.* 2006, De Juan *et al.* 2007, De Juan & Demestre 2012, Bolam *et al.* 2014). Because of this, **K-strategist** (long-life species) **show larger decreases in abundance** than r-strategist (fast growing species) when exposed to trawling (Jones 1992). These sensitive species can reach values up to 90 % of reduction in relative abundance in areas exposed to high levels of trawling (González-Irusta *et al.* 2018). Trawling also reduces seabed complexity by removing or damaging epibenthic sessile fauna, including habitat forming species such as deep-sea sponges (Freese 2001, Clark *et al.* 2016, Pham *et al.* 2019, Morrison *et al.* 2020), cold-water coral reefs (Hall-Spencer *et al.* 2002, Clark *et al.* 2016, Ragnarsson *et al.* 2020), maërl (Hall-Spencer & Moore 2000, Bordehore *et al.* 2003, Steller *et al.* 2003) or alcyonaceans (Maynou & Cartes 2012, Cartes *et al.* 2013, Pierdomenico *et al.* 2018).There will also be more extensive areas, particularly of sediment plains, where such complex habitats do not form, but where habitat complexity has still been reduced by trawling by to removing and burying surface stones and shells that allow epibiota to settle and increase complexity. These species increase sea bed complexity and if they reach enough density, increase biodiversity (De la Torriente *et al.* 2018, Victorero *et al.* 2018, de la Torriente *et al.* 2020) by providing 3D structures that provide shelter for juveniles and small species as well as new ecological niches and feeding opportunities (Jones *et al.* 1994, Bruno & Kennedy 2000, Söffker *et al.* 2011, Linley *et al.* 2017). Furthermore, these habitat forming species can host cryptic species (Reveillaud *et al.*, Carreiro-Silva *et al.* 2017, Henry & Roberts 2020, Santín *et al.* 2020) which also are negatively affected by trawling directly and indirectly (by the loss of its habitat). Therefore, reducing trawling effort as well as the extent of trawling footprint it is expected that seabed habitats will be able to recover the relative abundance of fragile species, including habitat forming species. An increase in seabed complexity associated to the recovery of biogenic habitats is expected if greater areas of seabed are left undisturbed by bottom fishing, enhancing biodiversity recovery (including cryptic species) although the capacity of these habitats to fully recover as well as the time necessary to see these changes is unknown.

Seafloor protection increases resilience to stressors and climate change: One of the associated benefits from leaving the seafloor increasingly undisturbed is that it may enhance resilience to stressors and adaptation capacity to climate change (Sala and Giakoumi, 2017). Protected seafloors are not immune to climate change drivers, but the reduction of direct anthropogenic pressures enables richer communities with the genetic diversity needed to modify and adapt to shifting conditions maintaining ecosystem functionality (Roberts *et al.*, 2017). When fishery pressure is reduced in key-habitats and protection is maintained over time, increasing proportions of biodiversity are represented and likely continue to be represented under changing conditions (Davies *et al.*, 2017). The recovered portions of habitats serve as refugia for species and help population connectivity, reducing the chances of species distribution shifts and extirpation (Roberts *et al.*, 2017). Furthermore, replenished adult populations strengthen resilience and accelerate recovery from mass mortality events, like in Baja California where abalone populations lifted from fisheries pressure recovered twice as fast after an event of climate-driven hypoxia in 2009 (Micheli *et al*., 2012). Such reserves of individuals can also prevent fishery-exploited species to collapse following a catastrophic event, as shown in the predictions of Aalto *et al*. (2019). Moreover, higher density of predators prevents disease outbreaks and controls preys explosive growth (Roberts *et al*., 2017), possibly helping in controlling the expansion of non-indigenous species as in Noè *et al*. (2018) where higher predation rates on an invasive crab species were documented within protected areas. Increased biomasses may represent a carbon sink, an otherwise blue-carbon stock extracted by fisheries (Mariani *et al*., 2020). Nevertheless, marine protected areas are not immune to climate change, and its climate change should therefore be taken into account when locating areas to protect to maximize the climate resilience of these areas (Bates *et al*., 2019).

Reducing the pressure of bottom trawling on the seabed is expected to have beneficial effects for sediment ecosystem functioning from a geochemical point of view. The marine seafloor represents a globally significant **carbon** store; it is estimated that 0.3-1.0 Pg of organic carbon (OC) occur in the top 10 cm on the northwest European shelf alone (Legge *et al*., 2020). Field studies looking at the acute effect of trawling in muddy sand sediments found a decrease in Chlorophyll-a content of more than 40%, suggesting a loss of young organic carbon because of trawling (Tiano *et al*., 2019; Watling *et al*., 2001), which can translate in a decrease in OC content in the long term. Indeed, several field studies comparing trawled and untrawled sediment found that trawled sediments contained up to 30% less OC and even less young OC (Pusceddu *et al*., 2014; Hale *et al*., 2016; Paradis *et al*., 2019; Atkinson *et al*., 2011). This decrease in OC content agrees with modeling studies of trawling impacts on sediment geochemistry, although the predicted effect is much larger (a decrease of 90% in OC content for 5 trawling events per year; De Borger *et al*., 2020). Given that the average sediment accumulation rate in the coastal zone is ~0.2 cm yr^{-1}, and trawls generally penetrate the sediment 2-3 cm (Hiddink *et al*., 2017), 1 trawl every 10-15 years could be enough to have a permanent imprint on the seafloor (van de Velde *et al*., 2018), and the recovery time would be even longer in slow-accumulating deep-sea sediments (Paradis *et al*., 2021). Nevertheless, evidence indicates that the effect of trawling is variable, with some studies reporting no significant differences, or even increases in OC content in heavily trawled areas (Sciberras *et al*., 2016; Palanques *et al*., 2014; Sparks-McConkey and Watling, 2001; Bernard, 2021; Brown *et al*., 2005). In sandy sediments, no loss of OC was found but rather a vertical redistribution (Mayer *et al*., 1991). These discrepancies are likely to be attributed to factors such as sediment type and hydrodynamic conditions, which are known to influence the effect of trawling on sedimentary OC content. Evidence indicates that prohibiting trawling in certain areas might increase the OC content in those areas, but more research is needed to assess the magnitude of this effect on the carbon balance in coastal ecosystems. Nevertheless, recent research suggested that trawling could lead to high rates of CO_2 release from the sediment, and that sedimentary CO2 release by trawling could be a significant source of CO_2 to the atmosphere (Sala *et al*., 2021). However, the exact magnitude of these additional CO_2 emissions are unconstrained and would likely be spatially variable. Overall, the available evidence indicates that prohibiting trawling in certain areas might increase the OC content in those areas, but more research is needed to assess the magnitude of this effect on the carbon balance in coastal ecosystems.

Bottom trawling has been shown to **resuspend** the top few millimetres of sediment; depending on the gear and sediment type, in the range of 0.1-8 mm (Depestele *et al*., 2019; ONeill and Summerbell, 2011; Mengual *et al*., 2016; Durrieu de Madron *et al*., 2005). Sediment resuspended as a result of bottom fishing will have a variety of effects including the release of nutrients held in the sediment (Duplisea *et al*. 2001), exposure of anoxic layers, release of contaminants, increasing biological oxygen demand (Reimann and Hoffman 1991) and the smothering of feeding and respiratory organs. Although suspension feeders may benefit from enhanced levels of particulate organic matter (POM) as shown for scallops (*Placopecten magellanicus*, Pectinidae) on Georges Bank (Grant *et al*. 1997), elevated levels of suspended particulate matter has been shown to decrease the growth rates of juvenile king scallops (*Pecten maximus*, Pectinidae) (Szostek *et al*. 2013). Deposit-feeding benthos may be negatively affected by trawling due to a loss of surficial sediments and a reduction in the food quality (Mayer *et al*. 1991; Watling *et al*. 2001). Sediment resuspension by trawling, in particular its effect on POM, may thus have important trophodynamic consequences as it may affect the availability and quality of food for suspension feeding and deposit-feeding benthos. Furthermore, inducing sediment resuspension along upper continental slopes has been found to smooth the seafloor topography and create considerable down-slope sediment transport (Martín *et al*., 2014; Palanques *et al*., 2006; Puig *et al*., 2012). In the North-West Mediterranean Sea, sedimentation rates down-canyon have been found to increase 2-5 times following the expansion of trawling fleet operations in the area (Paradis *et al*., 2018). The impact of disturbance of the sediment structure by trawling, in particular in areas beyond the action of the wave base (i.e. mid-outer shelf and deeper), may last for decades, centuries or longer. For instance, a consolidated mud bottom, after trawling is transformed into a layer of reworked soft mud, which will not be adequate for sessile organism originally inhabiting on that substrate to fix and grow. The same could happen because of sedimentation by placing soft, water-rich fines on top of more consolidated substrata.

The seafloor has an important role in the global nitrogen cycle and is estimated to remove around half of the reactive nitrogen species through benthic denitrification (the transformation of NO_x^- and NH_4^+ into unreactive N_2) (Gruber, 2004). Field evidence from a shallow coastal system in Australia (water depth <10 m) suggest that trawling a sediment can result in up to a 50% reduction in net denitrification (Ferguson *et al*., 2020). A modeling study of North Sea sediments shows similar effects for fine grained and organic-matter-poor muddy sediments, but suggests that less frequent trawling events (1-2 times yr^{-1}) can increase benthic denitrification by ~10% and up to 50% in organic-matter-rich muddy sediments (De Borger *et al*., 2020). Less denitrification would lead to a higher nitrogen load in coastal waters, which could result in more eutrophication. Additionally, trawling has been found to release a nutrient pulses from the seabed, stimulating primary productivity in the water column (Dounas *et al*., 2007; Molen *et al*., 2013). Closing trawling grounds can thus be expected to reduce nutrient loadings on coastal waters.

<u>Expected biogeochemical benefits from proposed management options:</u>

- Improvements of gear (i.e. limiting the penetration of the seabed) could be beneficial for the biogeochemical ecosystem functioning of the seabed, although this would only be expected for the shallower coastal regions with a higher sediment accumulation rate and high natural sediment resuspension rates - not for slower accumulating bottoms.
- Effort restrictions benefits are expected to be similar as for gear improvements
- Spatial restrictions are expected to be the most effective for the biogeochemical functioning of the seabed
- Impact restrictions could be beneficial for the biogeochemical functioning of the seabed if these take into account the impact on the biogeochemical functioning in the first place.

The local removal of bottom trawling could results in **increases in the food abundance** for many species of benthivorous fish, and benthivorous and piscivorous seabirds. There are indications that bottom trawling reduces the food availability for commercial fish species, and that this results in a lower condition of some flatfish species (Collie *et al*., 2017), but at the same time fishing reduces competition over food by reducing the number of predators in the sea and this counteracts this effect (Hiddink *et al*., 2016). Sandeels form an important part of the diet of many seabirds, and bottom trawl fisheries that target sandeels can therefore reduce the breeding success of seabirds (Cury *et al*., 2011). The clams that benthivorous seaducks eat may also be reduced in abundance by beam trawling and other mobile gears, but good evidence of how this affects the ducks beyond the effect of hydraulic dredging is lacking (Camphuysen *et al.*, 2002).

Bottom fishing may impact the **productivity**, defined here as the rate of increase in the biomass of a population, of exploited fish and shellfish species that depend on these habitats for food and shelter (Auster and Langton 1999; Shucksmith *et al*. 2006). In the short term and over small spatial scales, trawling may increase potential prey available to predatory fish through increased carrion or displaced biota in the wake of towed bottom-fishing gear (Groenewold and Fonds 2000). However, chronic and frequent fishing has been shown to lead to wide-spread depletion of benthic invertebrate prey species (Hiddink *et al*. 2006; Hinz *et al*. 2009). Fish that occur within these prey-depleted patches for prolonged periods of time, particularly if their movement is limited or if they are specialist feeders, exhibit lower body condition relative to those in unfished or lightly fished areas (Dell *et al*. 2013; Hiddink *et al*. 2011; Johnson *et al*. 2015; Lloret *et al*. 2007). Ultimately, the response of fish condition and growth to bottom fishing depends on the interplay between reduced benthic prey abundance and reduced competition for benthic food as fish density declines (Hiddink *et al*. 2011, 2016). The ratio of the prey to consumer biomass will determine whether exploitation will result in an increase or a decrease in the food intake and condition of the predator. Flatfish may benefit from light trawling levels on sandy seabeds, while higher-intensity trawling on more sensitive habitats has a negative effect. Models suggest that reduction in the carrying capacity of habitats by bottom fishing could lead to lower equilibrium yield and a lower level of fishing mortality to obtain maximum yield (Collie *et al.*, 2017). Technical measures that aim to maintain catch performance (i.e. number of individuals in catch), effort control and habitat impact quota measures, will benefit fish productivity if these measures result in an increase in food availability.

Bottom fishing could also lead to increased mortality and therefore lower fish yield through alteration of the physical nature of seabed habitat and the removal of sessile epifauna, such as sponges, corals and hydroids, that provide refuges from predators and a substrate for juvenile settlement (Auster and Langton 1999; Auster *et al*. 1997). Furthermore, intense fishing can induce evolutionary responses in fish to reproduce at a smaller size, an adaptation that increases reproductive success and offsets the increased risk of mortality (Fenberg and Roy 2008; van Wijk *et al*. 2013). This size evolution negatively affects multiple desirable traits (e.g. larval viability, foraging behaviour), and reduces the yield and replenishment of exploited species. Spatial controls such as marine protected areas or closed areas to particular bottom towed gear have been shown to result in higher biomass (Sciberras *et al*. 2013), fecundity and egg production (i.e. reproductive potential) per unit area relative to fished areas (Beukers-Stewart *et al*. 2005; Diaz *et al*. 2011; Kaiser *et al*. 2007; Marshall *et al*. 2019). Increased recruitment from eggs and larvae exported from spatial closures is anticipated to produce benefits for exploited populations (in some instances more than spillover of adults), particularly for relatively sedentary and long-lived species such as scallops and lobsters. The bottom fishing has major adverse impacts on benthic habitats such as sandbanks, reefs and biogenic structures with their characteristic ecological communities and sensitive species, and some of these habitats are important as fish spawning and nursery habitats. The reduce impacts of bottom fishing on seabed habitat could result in an increased fish spawning area. Evidence for these effects is currently limited.

Direct benefits to fisheries of the reduction or removal of MBCGs may also occur. As this is not part of the ToR, we only cover it briefly here. When fishing effort is reduced, fish abundance will increase and the CPUE will go up in line with this, which is beneficial to the fishers that can continue fishing. In overfished ecosystems, where $F>F_{MSY}$, a reduction in effort may result in an increase in total yield (Amoroso *et al.*, 2018; McConnaughey *et al.*, 2020). Spill-over of juvenile and adult fish from closed areas to areas that remain open to fishing have also been recorded (Murawski *et al.*, 2005). Spatial management may also reduce gear conflicts between different métiers, and between static and mobile gears in particular (Blyth *et al.*, 2004). Technical modifications of fishing gears and spatial closures in areas where undesirable species occur (e.g. where no quota is available, or where species of conservation concern are abundant), can reduce the amount of bycatch of invertebrates and of undersized and non-target species (Uhlmann *et al.*, 2019). Finally, trawl fisheries may benefit from an improved perception of fishing by society when they engage with management measures to make trawl fishing more sustainable, although these benefits are likely to accrue slowly and diffusely.

Although there are many potential benefits, there may be trade-offs between these benefits. Bottom trawl management may not always positively affect all ecosystem components on which trawling has an impact, due to the food-web interactions between target and non-target species. The success of an MPA in achieving the underlying management objectives is a balance between the direct benefit (less mortality on fish and/or benthos) and the indirect food-web effects (e.g., less fish prey or more predation mortality) (Denderen *et al*. 2016).

Table 6.1. Assessment of which management measures of bottom trawling (broad categories from (McConnaughey *et al.*, 2020) are likely to lead to ecosystem benefits. The text above expands on the justifications.

Benefit	Technical measure	Effort control	Spatial control	Impact quotas
Biodiversity of large sessile fauna	Most sensitive fauna still affected even by low levels of effort by any gear	Most sensitive fauna still affected even by low levels of effort	Effective	Benefits likely if 'price' for high sensitive species is appropriate
Increased resilience	Effective	Effective	Effective	Effective
Biogeochemistry, resuspension	For BGC, only effective if top layer not disturbed because most BGC activity in the top layer. For resuspension, would be proportional to penetration depth	Likely effective in nearshore areas with high natural disturbance and high sediment deposition rates	Effective	Likely effective in nearshore areas with high natural disturbance and high sediment deposition rates. Or effective if quota given for BGC impacts.
More food for top predators	Effective	Effective	Effective	Effective
Increase in body size of fish, fecundity	Effective, but only through increased food availability	Effective	Effective	Effective, but only through increased food availability
Increased fish spawning area	Less effective is fishing still disturbs spawning behaviour	Effective if seasonal, but may be less effective is fishing still disturbs spawning behaviour	Effective, seasonal controls	If targeted at protecting spawning and nursery habitat

Of the benefits discussed above, only the direct benefits to fisheries of reducing effort in overexploited fisheries are currently understood well enough that they could be modelled at a regional scale for evaluating in management scenarios. Of the other benefits, the effects on sediment carbon, nutrients and resuspension are a field of study that is quickly developing and where we may be able to make predictions of the effect of bottom trawling on these benefits on regional scales within a few years if models and parameter estimates become more established.

6.2 References

Aalto, E. A., Micheli, F., Boch, C. A., Espinoza Montes, J. A., Woodson, C. B., & De Leo, G. A. (2019). Catastrophic Mortality, Allee Effects, and Marine Protected Areas. The American Naturalist, 000–000. doi:10.1086/701781

Amoroso, R., Pitcher, C.R., Rijnsdorp, A.D., McConnaughey, R.A., Parma, A.M., Suuronen, P., Eigaard, O.R., Bastardie, F., Hintzen, N.T., Althaus, F., Baird, S.J., Black, J., Buhl-Mortensen, L., Campbell, A., Catarino, R., Collie, J., Jr, J.H.C., Durholtz, D., Engstrom, N., Fairweather, T.P., Fock, H., Ford, R., Gálvez, P.A., Gerritsen, H., Góngora, M.E., González, J.A., Intelmann, S.S., Jenkins, C., Kaingeb, P., Kangas, M., Kathenab, J.N., Kavadas, S., Leslie, R.W., Lewis, S.G., Lundy, M., Makin, D., Martin, J., Mazor, T., Mirelis, G.G., Newman, S.J., Papadopoulou, N., Rochester, W., Russo, T., Sala, A., Semmens, J.M., Silva, C., Tsolos, A., Vanelslander, B., Wakefield, C.B., Wood, B.A., Hilborn, R., Kaiser, M.J. & Jennings, S. (2018) Bottom fishing footprints on the world's continental shelves. Proceedings of the National Academy of Sciences, 115, E10275-E10282.

Atkinson, L. J., J. G. Field, and L. Hutchings. 2011. Effects of demersal trawling along the west coast of southern Africa: multivariate analysis of benthic assemblages. Marine Ecology Progress Series 430, 241-255. doi: 10.3354/meps08956

Auster, P.J. and Langton, R.W. 1999. The effects of fishing on fish habitat. American Fisheries Society Symposium 22, 150–187

Auster, P.J., Malatesta, R.J. and Donaldson, C.L.S. 1997. Distributional responses to small-scale habitat variability by early juvenile silver hake, Merluccius bilinearis. Environmental Biology of Fishes 50, 195–200

Bates, A. E., Cooke, R. S. C., Duncan, M. I., Edgar, G. J., Bruno, J. F., Benedetti-Cecchi, L., … Stuart-Smith, R. D. (2019). Climate resilience in marine protected areas and the "Protection Paradox." Biological Conservation, 236, 305–314. doi:10.1016/j.biocon.2019.05.005

Bernard, G. 2021. Spatial distributions of surface sedimentary organics and sediment profile image characteristics in a high-energy temperate marine RiOMar: The West Gironde Mud Patch. Journal of Marine Science and Engineering 9:242.

Beukers-Stewart, B.D., Vause, B.J., Mosley, M.W.J., Rossetti, H.L., Brand, A.R. 2005. Benefits of closed area protection for a population of scallops. Marine Ecology Progress Series, 298: 189–204

Blyth, R.E., Kaiser, M.J., Edwards-Jones, G. & Hart, P.J.B. (2004) Implications of a zoned fishery management system for marine benthic communities. Journal of Applied Ecology, 41, 951-961.

Bolam SG, Coggan RC, Eggleton J, Diesing M, Stephens D (2014) Sensitivity of macrobenthic secondary production to trawling in the English sector of the Greater North Sea: A biological trait approach. J Sea Res

Bordehore C, Ramos-Espla AA, Riosmena-Rodriguez R (2003) Comparative study of two maerl beds with different otter trawling history, southeast Iberian Peninsula. Aquat Conserv Mar Freshw Ecosyst 13:S43–S54

Bremner J, Rogers SI, Frid CLJ (2006) Methods for describing ecological functioning of marine benthic assemblages using biological traits analysis (BTA). 6:609–622

Brown, E. J., B. Finney, M. Dommisse, and S. Hills. 2005. Effects of commercial otter trawling on the physical environment of the southeastern Bering Sea. Continental Shelf Research 25:1281-1301.

Bruno JF, Kennedy CW (2000) Patch-size dependent habitat modification and facilitation on New England cobble beaches by Spartina alterniflora. Oecologia 122:98–108

Camphuysen, C., Berrevoets, C., Cremers, H., Dekinga, A., Dekker, R., Ens, B., Van der Have, T., Kats, R., Kuiken, T. & Leopold, M. (2002) Mass mortality of common eiders (Somateria mollissima) in the Dutch Wadden Sea, winter 1999/2000: starvation in a commercially exploited wetland of international importance. Biological conservation, 106, 303-317.

Carreiro-Silva M, Ocaña O, Stanković D, Sampaio Í, Porteiro FM, Fabri M-C, Stefanni S (2017) Zoantharians (Hexacorallia: Zoantharia) Associated with Cold-Water Corals in the Azores Region: New Species and Associations in the Deep Sea. Front Mar Sci 4

Cartes J, LoIacono C, Mamouridis V, López-Pérez C, Rodríguez P (2013) Geomorphological, trophic and human influences on the bamboo coral Isidella elongata assemblages in the deep Mediterranean: To what extent does Isidella form habitat for fish and invertebrates? Deep Sea Res Part I Oceanogr Res Pap 76:52–65

Clark MR, Althaus F, Schlacher TA, Williams A, Bowden DA, Rowden AA (2016) The impacts of deep-sea fisheries on benthic communities: A review. ICES J Mar Sci

Collie, J., Hiddink, J.G., van Kooten, T., Rijnsdorp, A.D., Kaiser, M.J., Jennings, S. & Hilborn, R. (2017) Indirect effects of bottom fishing on the productivity of marine fish. Fish and Fisheries, 18, 619-637.

Cury, P.M., Boyd, I.L., Bonhommeau, S., Anker-Nilssen, T., Crawford, R.J., Furness, R.W., Mills, J.A., Murphy, E.J., Österblom, H. & Paleczny, M. (2011) Global seabird response to forage fish depletion—one-third for the birds. Science, 334, 1703-1706.

Davies, T. E., Maxwell, S. M., Kaschner, K., Garilao, C., & Ban, N. C. (2017). Large marine protected areas represent biodiversity now and under climate change. Scientific Reports, 7(1). doi:10.1038/s41598-017-08758-5

De Borger, E., Tiano, J., Braeckman, U., Rijnsdorp, A. and Soetaert, K.: Impact of bottom trawling on sediment biogeochemistry: a modelling approach, Biogeosciences Discuss., (September), 1–32, doi:10.5194/bg-2020-328, 2020.

Dell, Q., Griffiths, S.P., Tonks, M.L. et al. 2013. Effects of trawling on the diets of common demersal fish bycatch of a tropical prawn trawl fishery. Journal of Fish Biology 82, 907–926

Denderen, P.D., Rijnsdorp, A.D., and Kooten, T. 2016. Using marine reserves to manage impact of bottom trawl fisheries requires consideration of benthic food-web interactions. Ecol. Appl. 26: 2302–2310.

Depestele, J., Degrendele, K., Esmaeili, M., Ivanovic, A., Kröger, S., O'Neill, F. G., Parker, R., Polet, H., Roche, M., Teal, L. R., Vanelslander, B. and Rijnsdorp, A. D. 2019. Comparison of mechanical disturbance in soft sediments due to tickler-chain SumWing trawl vs. Electro-fitted PulseWing trawl, ICES J. Mar. Sci., 76(1), 312–329, doi:10.1093/icesjms/fsy124

Díaz, D., Mallol, S., Parma, A.M., Goñi, R. 2011. Decadal trend in lobster reproductive output from a temperate marine protected area. Marine Ecology Progress Series, 433: 149 – 157

Dounas, C., Davies, I., Triantafyllou, G., Koulouri, P., Petihakis, G., Arvanitidis, C., Sourlatzis, G. and Eleftheriou, A.: Large-scale impacts of bottom trawling on shelf primary productivity, Cont. Shelf Res., 27(November 2015), 2198–2210, doi:10.1016/j.csr.2007.05.006, 2007.

Duplisea, D., Jennings, S., Malcolm, S., Parker, R. and Sivyer, D. (2001) Modelling potential impacts of bottom trawl fisheries on soft sediment biogeochemistry in the North Sea. Geochemical Transactions 2, 112–117.

Durrieu de Madron, Ferre, B., Le Corre. G., Conan, P., Pujo-Pay, M., Buscail, R., Bodiot, O. 2005. Trawling-induced resuspension and dispersal of muddy sediments and dissolved elements in the Gulf of Lion (NW Mediterranean). Continental Shelf Research, 25: 2387-2409

Fenberg, P.B. and Roy, K. 2008. Ecological and evolutionary consequences of size-selective

Ferguson, A. J. P., Oakes, J. and Eyre, B. D.: Bottom trawling reduces benthic denitrification and has the potential to influence the global nitrogen cycle, Limnol. Oceanogr. Lett., 5(3), 237–245, doi:10.1002/lol2.10150, 2020.

Freese JL (2001) Trawl-induced damage to sponges observed from a research submersible. Mar Fish Rev 63:7–13

González-Irusta JM, la Torriente A De, Punzón A, Blanco M, Serrano A (2018) Determining and mapping species sensitivity to trawling impacts: the BEnthos Sensitivity Index to Trawling Operations (BESITO) (S Birchenough, Ed.). ICES J Mar Sci 75:1710–1721

Grant, J., Cranford, P. and Emerson, C. (1997) Sediment resuspension rates, organic matter quality and food utilization by sea scallops (Placopecten magellanicus) on Georges Bank. Journal of Marine Research 55, 965–994

Groenewold, S and Fonds, M. 2000. Effects on benthic scavengers of discards and damaged benthos produced by the beam-trawl fishery in the southern North Sea. ICES Journal of Marine Science 57, 1395-1406

Gruber, N.: The dynamics of the marine nitrogen cycle and its influence on atmospheric CO2 variation, in The ocean carbon cycle and climate, pp. 97–148, Springer, Dordrecht. [online] Available from: https://www.researchgate.net/profile/Nicolas_Gruber/publication/228868707_The_Dynamics_of_the_Marine_Nitrogen_Cycle_and_its_Influence_on_Atmospheric_CO2_Variations/links/0fcfd5127d7ba7a9af000000/The-Dynamics-of-the-Marine-Nitrogen-Cycle-and-its-Influence- (Accessed 2 February 2018), 2004.

Hale, R., Godbold, J.A., Sciberras, M., Dwight, J., Wood, C., Hiddink, J.G., Solan, M. 2016. Mediation of macronutrients and carbon by post-disturbance shelf sea communities. Biogeochemistry 135, 121–133 DOI 10.1007/s10533-017-0350-9

Hall-Spencer J, Allain V, Fosså JH (2002) Trawling damage to Northeast Atlantic ancient coral reefs. Proc R Soc B Biol Sci 269:507–511

Hall-Spencer JM, Moore PG (2000) Scallop dredging has profound, long-term impacts on maerl habitats. ICES J Mar Sci 57:1407–1415

Henry L, Roberts JM (2020) Marine Animal Forests (S Rossi, L Bramanti, A Gori, and C Orejas, Eds.). Springer International Publishing, Cham

Hiddink, J. G., Jennings, S., Sciberras, M., Szostek, C. L., Hughes, K. M., Ellis, N., Rijnsdorp, A. D., McConnaughey, R. A., Mazor, T., Hilborn, R., Collie, J. S., Pitcher, C. R., Amoroso, R. O., Parma, A. M., Suuronen, P. and Kaiser, M. J.: Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance, Proc. Natl. Acad. Sci. U. S. A., 114(31), 8301–8306, doi:10.1073/pnas.1618858114, 2017.

Hiddink, J.G., Jennings, S., Kaiser, M.J., Queir_os, A.M., Duplisea, D.E. and Piet, G.J. 2006. Cumulative impacts of seabed trawl disturbance on benthic biomass, production and species richness in different habitats. Canadian Journal of Fisheries and Aquatic Sciences 63, 721–736

Hiddink, J.G., Johnson, A.F., Kingham, R. and Hinz, H. 2011. Could our fisheries be more productive? Indirect negative effects of bottom trawl fisheries on fish condition. Journal of Applied Ecology 48, 1441–1449

Hiddink, J.G., Moranta, J., Balestrini, S. *et al*. 2016. Bottom trawling affects fish condition through changes in the ratio of prey availability to density of competitors. Journal of Applied Ecology 53, 1500–1510

Hiddink, J.G., Moranta, J., Balestrini, S., Sciberras, M., Cendrier, M., Bowyer, R., Kaiser, M., Sköld, M., Jonsson, P., Bastardie, F. & Hinz, H. (2016) Bottom trawling affects fish condition through changes in the ratio of prey availability to density of competitors. Journal of Applied Ecology, 53, 1500–1510.

Hinz, H., Prieto, V. and Kaiser, M.J. 2009. Trawl disturbance on benthic communities: chronic effects and experimental predictions. Ecological Applications 19, 761–773

Johnson, A.F., Gorelli, G., Jenkins, S.R., Hiddink, J.G. and Hinz, H. 2015. Effects of bottom trawling on fish foraging and feeding. Proceedings of the Royal Society B: Biological Sciences 282, 20142336

Jones CG, Lawton JH, Shachak M (1994) Organisms as Ecosystem Engineers. In: Ecosystem Management. Springer New York, New York, NY, p 130–147

Jones JB (1992) Environmental impact of trawling on the seabed: A review. New Zeal J Mar Freshw Res 26:59–67

Juan S De, Demestre M (2012) A Trawl Disturbance Indicator to quantify large scale fishing impact on benthic ecosystems. Ecol Indic

Juan S De, Thrush SF, Demestre M (2007) Functional changes as indicators of trawling disturbance on a benthic community located in a fishing ground (NW Mediterranean Sea). Mar Ecol Prog Ser 334:117–129

Kaiser, M.J., Blyth, R.E., Hart, P.J.B., Edwards-Jones, G. and Palmer, D. 2007. Evidence for greater reproductive output per unit area in areas protected from fishing. Canadian Journal of Fisheries and Aquatic Science, 64: 1 – 6

la Torriente A de, Aguilar R, González-Irusta JM, Blanco M, Serrano A (2020) Habitat forming species explain taxonomic and functional diversities in a Mediterranean seamount. Ecol Indic 118:106747

la Torriente A De, Serrano A, Fernández-Salas LM, García M, Aguilar R (2018) Identifying epibenthic habitats on the Seco de los Olivos Seamount: Species assemblages and environmental characteristics. Deep Res Part I Oceanogr Res Pap 135:9–22

Legge, O., Johnson, M., Hicks, N., Jickells, T., Diesing, M., Aldridge, J., Andrews, J., Artioli, Y., Bakker, D. C. E., Burrows, M. T., Carr, N., Cripps, G., Felgate, S. L., Fernand, L., Greenwood, N., Hartman, S., Kröger, S., Lessin, G., Mahaffey, C., Mayor, D. J., Parker, R., Queirós, A. M., Shutler, J. D., Silva, T., Stahl, H., Tinker, J., Underwood, G. J. C., Van Der Molen, J., Wakelin, S., Weston, K. and Williamson, P.: Carbon on the Northwest European Shelf: Contemporary Budget and Future Influences, Front. Mar. Sci., 7(March), doi:10.3389/fmars.2020.00143, 2020.

Linley TD, Lavaleye M, Maiorano P, Bergman M, Capezzuto F, Cousins NJ, D'Onghia G, Duineveld G, Shields MA, Sion L, Tursi A, Priede IG (2017) Effects of cold-water corals on fish diversity and density (European continental margin: Arctic, NE Atlantic and Mediterranean Sea): Data from three baited lander systems. Deep Sea Res Part II Top Stud Oceanogr 145:8–21

Lloret, J., Demestre, M. and S_anchez-Pardo, J. 2007. Lipid reserves of red mullet (Mullus barbatus) during pre-spawning in the northwestern Mediterranean. Scientia Marina 71, 269–277

Mariani, G., Cheung, W. W. L., Lyet, A., Sala, E., Mayorga, J., Velez, L., … Mouillot, D. (2020). Let more big fish sink: Fisheries prevent blue carbon sequestration—half in unprofitable areas. Science Advances, 6(44), eabb4848. doi:10.1126/sciadv.abb4848

Marshall, D.J., Gaines, S., Warner, R., Barneche, D.R., Bode, M. 2019. Underestimating the benefits of marine protected areas for the replenishment of fished populations. Front Ecol Environ 2019; 17(7): 407–413

Martín, J., Puig, P., Palanques, A. and Ribó, M.: Trawling-induced daily sediment resuspension in the flank of a Mediterranean submarine canyon, Deep. Res. Part II Top. Stud. Oceanogr., 104, 174–183, doi:10.1016/j.dsr2.2013.05.036, 2014.

Mayer, L. M., Schick, D. F., Findlay, R. H., & Rice, D. L. (1991). Effects of commercial dragging on sedimentary organic matter. Marine Environmental Research, 31(4), 249–261

Maynou F, Cartes JE (2012) Effects of trawling on fish and invertebrates from deep-sea coral facies of Isidella elongata in the western Mediterranean. J Mar Biol Assoc United Kingdom 92:1501–1507

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

Mengual, B., Le Hir, P., Cayocca, F. and Garlan, T.2019. Bottom trawling contribution to the spatio-temporal variability of sediment fluxes on the continental shelf of the Bay of Biscay (France), Mar. Geol., 414(May), 77–91, doi:10.1016/j.margeo.505 2019.05.009

Micheli, F., Saenz-Arroyo, A., Greenley, A., Vazquez, L., Espinoza Montes, J. A., Rossetto, M., & De Leo, G. A. (2012). Evidence That Marine Reserves Enhance Resilience to Climatic Impacts. PLoS ONE, 7(7), e40832. doi:10.1371/journal.pone.0040832

Molen, J. Van Der, Aldridge, J. N., Coughlan, C., Ruth, E., Stephens, D. and Ruardij, P.: Modelling marine ecosystem response to climate change and trawling in the North Sea, Biogeochemistry, 113, 213–236, doi:10.1007/s10533-012-9763-7, 2013.

Morrison KM, Meyer HK, Roberts EM, Rapp HT, Colaço A, Pham CK (2020) The First Cut Is the Deepest: Trawl Effects on a Deep-Sea Sponge Ground Are Pronounced Four Years on. Front Mar Sci 7

Murawski, S.A., Wigley, S.E., Fogarty, M.J., Rago, P.J. & Mountain, D.G. (2005) Effort distribution and catch patterns adjacent to temperate MPAs. ICES Journal of Marine Science, 62, 1150-1167.

Noè, S., Gianguzza, P., Di Trapani, F., Badalamenti, F., Vizzini, S., Fernández, T. V., & Bonaviri, C. (2018). Native predators control the population of an invasive crab in no-take marine protected areas. Aquatic Conservation: Marine and Freshwater Ecosystems. doi:10.1002/aqc.2921

O'Neill, F. G. and Summerbell, K. 2011. The mobilisation of sediment by demersal otter trawls, Mar. Pollut. Bull., 62(5), 1088 –1097, doi:10.1016/j.marpolbul.2011.01.038

Palanques, A., Martín, J., Puig, P., Guillén, J., Company, J. B. and Sardà, F.: Evidence of sediment gravity flows induced by trawling in the Palamós (Fonera) submarine canyon (northwestern Mediterranean), Deep. Res. Part I Oceanogr. Res. Pap., 53(2), 201–214, doi:10.1016/j.dsr.2005.10.003, 2006.

Palanques, A., Puig, P., Guillén, J., Demestre, M., & Martín, J. (2014). Effects of bottom trawling on the Ebro continental shelf sedimentary system (NW Mediterranean). Continental Shelf Research, 72, 83–98

Paradis, S., Goñi, M., Masqué, P., Durán, R., Arjona-Camas, M., Palanques, A. and Puig, P.: Persistence of Biogeochemical Alterations of Deep-Sea Sediments by Bottom Trawling, Geophys. Res. Lett., 48(2), 1–12, doi:10.1029/2020GL091279, 2021.

Paradis, S., Puig, P., Sanchez-Vidal, A., Masqué, P., Garcia-Orellana, J., Calafat, A. and Canals, M.: Spatial distribution of sedimentation-rate increases in Blanes Canyon caused by technification of bottom trawling fleet, Prog. Oceanogr., 169, 241–252, doi:10.1016/j.pocean.2018.07.001, 2018.

Paradis, S., Pusceddu, A., Masqué, P., Puig, P., Moccia, D., Russo, T., & Iacono, C. Lo. (2019). Organic matter contents and degradation in a highly trawled area during fresh particle inputs (Gulf of Castellammare, southwestern Mediterranean). Biogeosciences, 16(21), 4307–4320.

Pham CK, Murillo FJ, Lirette C, Maldonado M, Colaço A, Ottaviani D, Kenchington E (2019) Removal of deep-sea sponges by bottom trawling in the Flemish Cap area: conservation, ecology and economic assessment. Sci Rep 9:15843

Pierdomenico M, Russo T, Ambroso S, Gori A, Martorelli E, D'Andrea L, Gili J-M, Chiocci FL (2018) Effects of trawling activity on the bamboo-coral Isidella elongata and the sea pen Funiculina quadrangularis along the Gioia Canyon (Western Mediterranean, southern Tyrrhenian Sea). Prog Oceanogr 169:214–226

Puig, P., Canals, M., Company, J. B., Martín, J., Amblas, D., Lastras, G., Palanques, A. and Calafat, A. M.: Ploughing the deep sea floor, Nature, 489, 286–289, doi:10.1038/nature11410, 2012.

Pusceddu, A., Bianchelli, S., Martín, J., Puig, P., Palanques, A., Masqué, P., and Danovaro, R. (2014). Chronic and intensive bottom trawling impairs deep-sea biodiversity and ecosystem functioning. Proceedings of the National Academy of Sciences of the United States of America, 111(24): 8861– 8866

Ragnarsson SÁ, Burgos JM, Kutti T, Beld I Van Den, Egilsdóttir H, Arnaud-haond S, Grehan A (2020) Marine Animal Forests.

Reimann, B. and Hoffman, E. (1991) Ecological consequences of dredging and bottom trawling in the Limfjord, Denmark. Marine Ecology Progress Series 69, 171–178.

Reveillaud J, Maignien L, Eren A, … JH-TI, 2014 undefined Host-specificity among abundant and rare taxa in the sponge microbiome. nature.com

Roberts, C. M., O'Leary, B. C., McCauley, D. J., Cury, P. M., Duarte, C. M., Lubchenco, J., … Castilla, J. C. (2017). Marine reserves can mitigate and promote adaptation to climate change. Proceedings of the National Academy of Sciences, 114(24), 6167–6175. doi:10.1073/pnas.1701262114

Sala, E., & Giakoumi, S. (2017). No-take marine reserves are the most effective protected areas in the ocean. ICES Journal of Marine Science, 75(3), 1166–1168. doi:10.1093/icesjms/fsx059

Sala, E., Mayorga, J., Bradley, D. *et al*. Protecting the global ocean for biodiversity, food and climate. Nature (2021). https://doi.org/10.1038/s41586-021-03371-z

Santín A, Grinyó J, Uriz MJ, Gili JM, Puig P (2020) First deep-sea Hamigera (Demospongiae: Porifera) species associated with Cold-Water Corals (CWC) on antipodal latitudes of the world. Deep Res Part I Oceanogr Res Pap 164:103325

Sciberras, M., Jenkins, S.R., Mant, R., Kaiser, M.J., Hawkins, S.J., Pullin, A.S. 2015. Evaluating the relative conservation value of fully and partially protected marine areas. Fish and Fisheries 16: 58–77.

Sciberras, M., Parker, R., Powell, C., Robertson, C., Kröger, S., Bolam, S. and Geert Hiddink, J. (2016), Impacts of bottom fishing on the sediment infaunal community and biogeochemistry of cohesive and non-cohesive sediments. Limnol. Oceanogr., 61: 2076-2089. https://doi.org/10.1002/lno.10354

Shucksmith, R., Hinz, H., Bergmann, M. and Kaiser, M.J. 2006. Evaluation of habitat use by adult plaice (Pleuronectes platessa L.) using underwater video survey techniques. Journal of Sea Research 56, 317–328

Söffker M, Sloman KA, Hall-Spencer JM (2011) In situ observations of fish associated with coral reefs off Ireland. Deep Sea Res Part I Oceanogr Res Pap 58:818–825

Sparks-McConkey, P. J., and Watling, L. 2001. Effects on the ecological integrity of a soft-bottom habitat from a trawling disturbance. Hydrobiologia 456, 73-85. doi: 10.1023/A:1013071629591

Steller DL, Riosmena-Rodri´guez R, Rodri´guez R, Foster MS, Roberts CA (2003) Rhodolith bed diversity in the Gulf of California: the importance of rhodolith structure and consequences of disturbance. Wiley Online Libr 13

Szostek, C.L., Davies, A.J. and Hinz, H. (2013) Effects of elevated levels of suspended particulate matter and burial on juvenile king scallops Pecten maximus. Marine Ecology Progress Series 474, 155–165

Tiano, J. C., Witbaard, R., Bergman, M. J. N., Van Rijswijk, P., Tramper, A., Van Oevelen, D., Soetaert, K. and Degraer, S.: Acute impacts of bottom trawl gears on benthic metabolism and nutrient cycling, ICES J. Mar. Sci., 76(6), 1917–1930, doi:10.1093/icesjms/fsz060, 2019.

Uhlmann, S.S., Ulrich, C. & Kennelly, S.J. (2019) The European Landing Obligation. Reducing Discards in Complex, Multi-Species and Multi-Jurisdictional Fisheries.

van de Velde, S. J., Van Lancker, V., Hidalgo-Martinez, S., Berelson, W. M. and Meysman, F. J. R.: Anthropogenic disturbance keeps the coastal seafloor biogeochemistry in a transient state, Sci. Rep., 8(1), 1–10, doi:10.1038/s41598-018-23925-y, 2018.

van Wijk SJ, Taylor M, Creer S, *et al*. 2013. Experimental harvesting of fish populations drives genetically based shifts in body size and maturation. Front

Victorero L, Robert K, Robinson LF, Taylor ML, Huvenne VAI (2018) Species replacement dominates megabenthos beta diversity in a remote seamount setting. Sci Rep 8:1–11

Watling, L., Findlay, R. H., Mayer, L. M., & Schick, D. F. (2001). Impact of a scallop drag on the sediment chemistry , microbiota , and faunal assemblages of a shallow subtidal marine benthic community. Journal of Sea Research, 46, 309–324.

7 Overview of regional assessments

7.1 Regional assessments

We developed regional assessments of fishing pressure and impact for 4 different (sub-)regions (Figure 7.1) and 22 subdivisions (Figure 7.2) using quality-controlled VMS data from the ICES 2019 data call (ICES 2019a). Outputs were analysed in the workshop and main patterns described. The assessment outputs are available as an HTML-document (see further annex 4). The workflow of the regional assessment, with its respective scripts, is publicly available on an open source platform - WKTRADE3 github: https://github.com/ices-eg/WKTRADE3/tree/master.

Workshop participants further provided fishing footprint information for different EEZ regions in the Mediterranean and Black Sea. An overview of each of these is shown in Annex 5.

The assessments of fishing footprint and impact were developed to be appropriate for a six-year management cycle of MSFD assessments. The assessment period is linked to the latest available fishing data (2013-2018), rather than to the MSFD Article 8 assessment periods (which might run from 2011-2016 for reporting in 2018, 2017-2022 for reporting in 2024, although there is debate about which 6-year period should be used as it depends on data flows per descriptor). The assessment maps and indicator values produced are based on an average fishing intensity of the latest six-year (2013-2018). We used an average as it stabilizes the fishing footprint and supports the calculation of impact indicators (which are based on equilibrium conditions). The 6-year average further corresponds to the recovery time of a high proportion of benthic organisms that are impacted by the trawl. The assessment product further shows year-to-year variations in the pressure. This follows previous ICES advice highlighting that impact assessments for all physical disturbance pressures would benefit from taking variations in the pressure between years into account to get the most accurate estimate of impact (ICES 2019b). It may further allow managers to evaluate management options that were introduced part-way the six-year cycle. Lastly, year-to-year variation in the pressure was used to evaluate changes in core-fishing grounds over time.

All footprint and impact assessments on the seafloor used the seabed habitat assessments required by the GES Decision (EU) 2017/848, i.e. the MSFD broad habitat types, based on the EUNIS 2016 classification (Evans *et al.*, 2016) and provided by the EUSeaMap 2019 (https://www.emodnet-seabedhabitats.eu/about/euseamap-broad-scale-maps/). Since the MSFD habitat have a finer resolution than the 0.05° c-square VMS fisheries grid, we estimated the areal extent of each broad habitat type within each grid cell and we assumed a uniform distribution of fishing in the cell, i.e. all habitat types within a grid cell are fished with the same SAR.

The assessments had varying levels of data availability. The data sources used, and data gaps and limitations identified are highlighted in the next section for each (sub-)region where ICES VMS data were used. This section is followed with a description of data sources and processes used within the workflow of Mediterranean and Black Sea countries participating in the WKTRADE workshop.

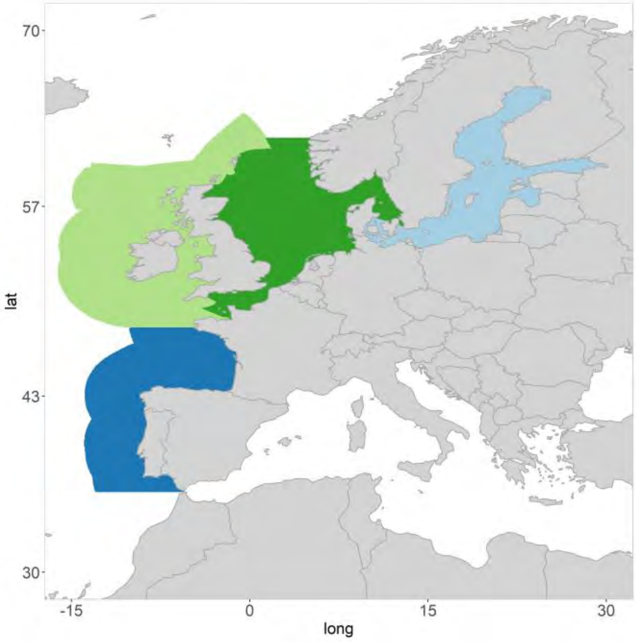


Figure 7.1. The four (sub-)regions: Bay of Biscay and the Iberian Coast, Celtic Seas, Greater North Sea and Baltic Sea.

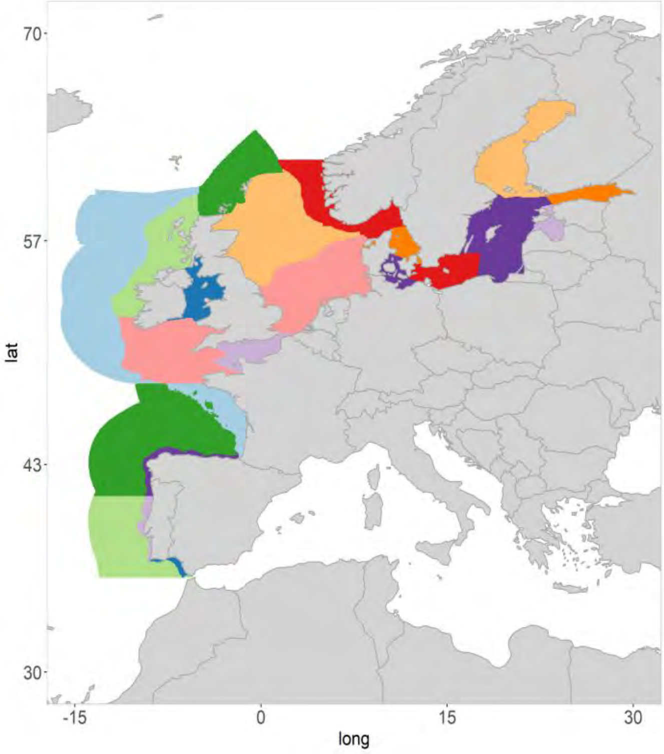


Figure 7.2. The 22 subdivisions used to produce the trade-off results; these are nested within (sub-)regions. These areas are illustrative of the biogeographically relevant subdivisions of MSFD subregions required by the GES Decision (EU) 2017/848. They are partly based on HELCOM sub-basins and OSPAR reporting level 2 areas. The subdivisions are a pragmatic proposal to produce the trade-off results at scales which are illustrative of the possible MSFD 'assessments'.

An overview of the areal extent and proportion of areal extent in three depth zones for each (sub-)region and subdivision is shown in Table 7.1. Most subdivisions are either associated with the <200m depth zone or the area deeper than 200m. Only "Northern area" in the Celtic Seas and "Norwegian Trench" in the Greater North Sea have large fractions in shallow and deeper depth zones.

Table 7.1. Overview of areal extent and proportion of areal extent in three depth zones for each (sub-)region (bold) and subdivision.

(sub-)region / subdivision	Areal extent (1000 km2)	Fraction < 200m depth	Fraction 200 - 800m depth	Fraction > 800m depth
Bay of Biscay and the Iberian Coast	781.885	0.19	0.06	0.75
Northern area deep	402.042	0	0.06	0.94
Bay of Biscay - shallow	83.478	1	0	0
Northern Iberian Coast	30.692	1	0	0
Southern area deep	229.759	0	0.08	0.92
Western Iberian Coast	18.896	1	0	0
Gulf of Cadiz	11.153	1	0	0
Celtic Seas	975.606	0.50	0.13	0.37
Northern area	107.278	0.50	0.18	0.32
Offshore deep	436.547	0.03	0.22	0.75
Centre area	146.127	0.98	0.02	0
Irish Sea	62.497	1	0	0
Southern area	221.514	0.97	0.03	0
Greater North Sea	690.644	0.90	0.10	0
Norwegian Trench	115.054	0.40	0.60	0
Northern North Sea	264.795	1	0	0
Kattegat	29.862	1	0	0
Southern North Sea	222.636	1	0	0
English Channel	58.296	1	0	0
Baltic Sea	388.605	0.99	0.01	0
Bothnian area	112.207	0.99	0.01	0
Gulf of Finland	34.377	1	0	0
Baltic Proper	146.552	0.99	0.01	0
Gulf of Riga	18.588	1	0	0
Western Baltic Sea	19.138	1	0	0
Arkona & Bornholm Basin	57.715	1	0	0

7.2 Data sources for regional assessments where ICES VMS data were used

According the ICES WGSFD report 2019 (ICES, 2019a), data were submitted in response to the ICES VMS data call by following countries: Belgium, Denmark, Estonia, France, Germany, Iceland, Ireland, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Sweden, United Kingdom. The data were quality checked, abnormalities reported back to the countries and either confirmed by the national data submitter or corrected and resubmitted. Data were not submitted by Faroe Islands, Greenland and Russia. The ICES VMS data call from 2020 was not approved because of logistic constraints, and the ICES VMS data from the 2021 data call were not available for the WKTRADE3 work as deadlines are after the WKTRADE3.

In the ICES WGSFD meeting 2019 participants were requested to describe how the value of landings were assigned. Methods varied retrieving the landings value from sales notes, using average prices by species. Iceland reported that the value of landings are not readily available and therefore not reported in response to the data call.

An overview of the data sources and spatial grid resolution used for the regional assessment is shown in Table 7.2 for each (sub-)region where ICES VMS data were used. Table 7.3 shows caveats and data limitations.

Table 7.2. Overview of data sources for regional assessments.

(sub-)Region	C-Square	Pressure (SAR)	Impact	Bathy/Habitat	Landings/Value
Greater North Sea	0.05 degree	SAR calculated based on ICES VMS/Logbook data call in 2019	PD2, L1	EMODnet EUSEAMAP 2019	From ICES VMS data call
Baltic Sea	0.05 degree	SAR calculated based on ICES VMS/Logbook data call in 2019	PD2, L1	EMODnet EUSEAMAP 2019	From ICES VMS data call
Celtic Seas	0.05 degree	SAR calculated based on ICES VMS/Logbook data call in 2019	Not available	EMODnet EUSEAMAP 2019	From ICES VMS data call
Bay of Biscay and the Iberian Coast	0.05 degree	SAR calculated based on ICES VMS/Logbook data call in 2019	Not available	EMODnet EUSEAMAP 2019	From ICES VMS data call

Table 7.3 Caveats and data limitations for (sub-)regions where ICES VMS data were used for the regional assessments

(sub-)region	Data	Caveat/data issues/limitations
All (sub-)regions	ICES VMS data	Only vessels larger than 12 m. Underestimation of the fishing pressure, especially in coastal areas.
All (sub-)regions	ICES VMS data	Ping rates. Varies up to 2 hours.
All (sub-)regions	ICES VMS data	Overestimation of the area fished. The method assumes that a c-square is equally affected by fishery, although the fishery can be aggregated within the c-square. Large size of c-squares in relation to resolution of habitat map reduces the accuracy of assessments of the spatial extent of bottom fishing per habitat type.
All (sub-)regions	ICES VMS data	Different ways of assigning value of landings (see WGSFD 2019 report)
All (sub-)regions	Habitat maps	Uncertainty associated with habitat mapping
Greater North Sea/Baltic Sea	Benthic sample data to predict longevity	Benthic community longevity prediction is only based on infauna and small epifauna data collected via cores and grabs Benthic community longevity prediction is based on spatial extrapolations using environmental data layers No longevity data available for the deeper parts of the Greater North Sea (> 200 m)
Greater North Sea	ICES VMS data	Peak in trawling intensity in 2016 and drop in 2017 are (most likely) data artefacts
Greater North Sea	ICES VMS data	Value of landings absent for one country in parts of Northern North Sea**
Baltic Sea	ICES VMS data	No fishing data is available from Russia
Celtic Seas/Bay of Biscay and the Iberian Coast	Benthic sample data to predict longevity	No longevity data available to estimate benthic impact
Celtic Seas/Bay of Biscay and the Iberian Coast	ICES VMS weight of landings data	Weight of landings data for OT_DMF is unrealistically high and based on erroneous inputs in the 2019 data call**. Analyses of weight are excluded from the regional assessment.
Bay of Biscay and the Iberian Coast	ICES VMS value/weight of landings data	Limited available and/or absent for the Iberian Coast in the 2019 VMS data call**. Analyses of weight/value are excluded from the regional assessment.
Celtic Seas	ICES VMS data	Drop in trawling intensity in 2017 in some habitats/regions is (most likely) a data artefact

**** note that this has been updated in the 2020/2021 ICES VMS data calls**

7.3 Towards harmonization in the Mediterranean and Black Sea – commonalities and differences

Table 7.4 lists the data sources and processes used within the workflow of Mediterranean and Black Sea countries participating in the WKTRADE workshop (Greece, Italy, Spain, Bulgaria; France and Romania offline). Information provided for each country includes the description of the grid size adopted (e.g. C-square size), calculation of swept area ratio (SAR), information related to impact assessment approach faunal element and how impacts are estimated, source of broad habitat type data, and source of landings and value data. The second part of the table (7.5) lists major limitations/issues described by the country participants. Following the tables there is a short explanation concerning the workflows for each country. Capabilities and status of the other Mediterranean EU Member States are not known (Malta, Slovenia, Croatia, Cyprus). However, there are other institutional frameworks, where these types of analyses are being actively discussed and coordination promoted (ICES WGFBIT, TG Seabed, DGEnv).

The overall view is that although approaches in the Mediterranean have lagged behind northern European waters, much progress has been made in recent years towards common standardized approaches particularly through initiatives from ICES and DG ENV, for example ICES WGFBIT, WKTRADE and TG Seabed, but also through targeted research projects (e.g. previously BENTHIS, currently MedRegion and the immanent ABIOMMED). There is still a lack of consistency in approaches between countries, including common points:

- Country specific or differences between definition of scale or size of grid for various parameters (SAR, impact, effort, landings, value),
- Methodology for assessing Swept Area and data available (VMS availability for all fleet sections, presence of non-national fleets in assessment area, AIS use),
- What faunal component or indices are addressed for impact assessment (macrofauna, megafauna, sampling method, type of index/indicator used),
- Background information on unimpacted habitats (trait and unimpacted biomass for all broad scale habitats),
- Reliability of habitat mapping (accuracy and resolution),
- Presence of large areas of deep waters (largely unfished and where fished, impact assessments/depletion rates are not verified/validated),
- Although official assessments for EU reporting are carried out nationally, high level assessments within countries may only be on an *ad hoc* basis and not formal (e.g. VMS reporting formal, but FBIT methodology on a localized or occasional basis).

A fuller list of points are specified by country in Table 7.5. The differences between the countries and areas indicate that it is likely that a harmonized regional assessment for Mediterranean EU waters will be complex to implement and that difficulties may also be found at sub-regional levels. A constant and closer coordination is therefore required within the regional sea, particularly between neighbouring countries sharing sub-regions.

Table 7.4. Workflow sources and methods within Mediterranean and Black Sea participants.

Country	C-Square	SAR	Impact	Bathy/Habitat	Landings/Value
Greece (Adriatic Sea; Ionian Sea and Central Mediterranean Sea; Aegean-Levantine Basin)	0.05 degree square (5 km)	Yes-FBIT compatible methodology (0.05 and 0.01 resolution) Preliminary 2011 (BENTHIS) Recent 2015-2018. Based on VMS, all trawl vessels included, one métier.	Macrofauna (grab samples): FBIT PD2 methodology and scripts. Updating the longevity models, not all habitats equally represented.	EMODnet (accuracy and resolution issues in habitats…)	STECF data available, but at 0.5x0.5 grid resolution.
Italy (Adriatic Sea, Western Mediterranean Sea, Ionian and Central Mediterranean Sea subregions)	1 km x 1 km	YES – Integration of VMS and AIS data for having high resolution data; analyses for WKTRADE3 based on 2012-2017. Under development analysis of AIS data with novel methodologies to obtain very high resolution to address pressure/impact on selected biogenic habitats	Different complementary sources: 1. Epi-megabenthos from experimental sites (samples from otter trawl sample); 2. Epi-megabenthos from trawl surveys (e.g. MEDITs, SOLEMON). Analysis based on biological traits including longevity under development	EMODnet EUSEAMAP 2019 (issues to be considered regarding accuracy on habitats mapping)	STECF data available, no current analysis ongoing but future assessments are foreseen under (e.g.) ABIOMMED Bioeconomic models already available for some areas, including methods to estimate displacement
France (Western Mediterranean Sea)	1’ x 1’ (~2x2 km)	Freely available (WGFBIT/OSPAR compatible method but not official data, only for research purpose) Data and methodology downloadable here Jac Cyrielle, Vaz Sandrine (2018). Abrasion superficielle des fonds par les arts trainants – Méditerranée (surface Swept Area Ratio). IFREMER. https://doi.org/10.12770/8bed2328-a0fa-4386-8a3e-d6d146cafe54	Epi-megabenthos from trawl surveys (e.g. MEDITS, NOURMED) and benthic video surveys. Analysis based on biological traits developed in research project (indicators and state analysis methodology developed and applied) Approach based on longevity under slow development within WGFBIT	EMODnet EUSEAMAP 2019 (issues to be considered regarding accuracy on habitats mapping) Non standardizes national or regional habitat maps in the coastal area (<40m)	STECF data available at GSA level LPUE at 3’x3’ grid resolution for French fleets only
Spain (Western Mediterranean Sea)	0.05 degree square (5 km)	Analyzed 2010-2012 & 2019. In progress (available soon) 2013-2020.	Macrofauna (IBTS and MEDITS Otter Trawl Surveys) and complementary MSFD specific surveys (beam trawl, box corer and	EMODnet EuSeaMap 2019 (issues to be considered regarding	STECF data available. Landings are available (0.05x0.05 grid)

Country	C-Square	SAR	Impact	Bathy/Habitat	Landings/Value
		Yes FBIT compatible methodology (0.05 and 0.01 resolution) Based on VMS, all trawl vessels included, all métiers.	photogrammetry sledges). SoS Indicator (BH1 OSPAR), BH2 (OSPAR) and BH3 (OSPAR). Approach based on longevity within WGFBIT being tested for the Cantabrian sea.	accuracy on habitats mapping)	Value available along 2021-22
Bulgaria (Black Sea)	0.5 km, 1 km, 2 km, 5 km	Yes. Pilot study in 2017. Technically executed in GIS through reconstruction of trawling lines from VMS data. All vessels and gears (OTM and TBB) aggregated. The finest grid with cell size 0.5 km selected for the assessment to increase the precision. Threshold established for low-high pressure at SAR>=0.2	Macrofauna (grab samples): M-AMBI(n) Interested to test PD2, Longevity models and other.	EMODnet EuSeaMap 2019	STECF-20-10 report provides figures on landings for the years 2015-2019 at 0.5x0.5 degree resolution. The data (GIS layers) are not available online.
Romania (Black Sea)	1 km, 5 km	NO. Some GIS spatial analysis were made based on partial VMS data (density of fishery vessels) only for research purpose. Work in progress depending of data availability.	Limited number of samples of macrofauna in the frame of national monitoring programme or other projects covering the areas potentially affected by fishery activities.	EMODnet EUSeaMap 2019 (issues to be considered regarding accuracy of habitats mapping)	Romania didn’t provide information for STECF-20-10 report Landings are available only as total values

Table 7.5. Major limitations/issues for developing the framework within the Mediterranean and Black Sea participants.

Country	Limitation/Issues
Greece	Preliminary analysis is at National, not yet sub-regional or MRU level; Other fleets in the areas (Italy and Turkey); Policy on unfished/unfishable squares, particularly deeper waters (largely unfished and where fished, impact assessments/depletion rates are not verified/validated; Considerable deep waters (+200 m) and lack of deep verified depletion rates; Accuracy and resolution of available modelled habitat maps.
Italy	Poor representation of some métiers in term of fishing pressure (Hydraulic dredging, Otter trawling for Vessels with LOA < 12-15m); Need to further refine integration of VMS to AIS data to ensure having the highest spatial resolution, needed in particular where the shelf is narrow (and it is possible to find many habitats (depending on depth) in few km’s from the shore; Poor local accuracy of biocenotic maps/EUSEMAP with associated uncertainties whose effects on the assessment needs to be addressed; Need to consolidate empirical relationships for fishing gear width to estimate SAR;

Country	Limitation/Issues
	Need to develop approaches tailored to Mediterranean biota and in particular deeper areas (below 200 m); Lack of unfished/undisturbed sites; Widespread chronic overfishing reducing contrast in mega-epifaunal data to represent adequately a range of fishing pressures; Management scenarios shall consider ongoing national and international (e.g. FRA) spatial fisheries management approaches since they will affect the range of options to reduce spatial footprint.
France	Underestimation of coastal and small scale fishery pressure (no VMS data available, no use of AIS); Need more detailed and updated definition of gear size for each fleet; No uncertainty assessment of SAR values (both in effort allocation algorithm and gear size definition effect); Large uncertainty of EUSEAMAP habitats nature and delineation (need to include more in situ biological data); Need to develop approaches tailored to Mediterranean biota and in particular in deeper areas (below 200 m); Lack of unfished/undisturbed sites in areas above 200m (no reference state); Widespread chronic overfishing reducing contrast in mega-epifaunal data to represent adequately a range of fishing pressures (spurious reference state, unknown resilience level of benthic communities); Management scenarios shall consider on-going national and international (e.g. FRA) spatial fisheries management approaches since they will affect the range of options to reduce spatial footprint.
Spain	Swept area available 2010-2012 & 2019; Problems with the swept area algorithm in areas near the coast and isolate areas; Other fleets in the areas (International and Small Scale Fisheries); Working at National Level (Demarcation Level); Large uncertainty of EUSEAMAP habitats nature and delineation (need to include more in situ biological data).
Bulgaria	Analysis done at the national level - Bulgarian Black Sea shelf delimited by 200 m depth.
Romania	Complete VMS and landings data are not available Limitations of EuSeaMap habitats and limited number of macrofauna samples in the areas potentially affected by fishing activities; Lack of a methodology for the Black Sea basin at least at EU Member State level in the region (Romania-Bulgaria)

Country Specific Descriptions

Greece

Greece under the MSFD has waters in several Mediterranean sub-regions: the Adriatic Sea; Ionian Sea and Central Mediterranean Sea; and the Aegean-Levantine Basin. The current preliminary assessment work in progress covers the entire Greek Sea as one unit. VMS data is processed for SAR using r-routines compatible with the ICES FBIT methodology and r-routines from the WKTRADE methodology. The data run has concerned average data over 2015-2018. Work is underway implementing the Benthic impact FBIT methodology (PD2 on macrofauna), initial results are available, but are being improved towards better and more representative coverage of habitats as more historical benthic data (grab stations) is collated to better represent the different MSFD broad habitat types. This will also help with better validation of the longevity model. The depletion rates used are those from the FBIT methods, but further work may need to be done to better represent more characteristic deeper Mediterranean waters (current FBIT depletion rates apply above 200 m depth, thus leaving out a large part of the fisheries areas). Broad habitat spatial data has been extracted from EMODnet, although available interpolated modelled data has some issues with accuracy and resolution in the Eastern Mediterranean. Landings and value data are extracted from the STECF FDI data base and are coarse (on a different grid scale from SAR). Current tables and outputs have been undertaken using the WKTRADE r-routines. Future work will lie in better matching scales, definition of borders and assessing at sub-regional levels, updating data and assessments. AIS data may also be explored as other fleets are fishing in the assessment area with no data available for analysis on their parameters, so at present the area assessment is based wholly on Greek activities and impacts.

Italy

In the context of MSFD, Italian waters are divided into three Mediterranean sub-regions: Western Mediterranean Sea, the Ionian Sea and Central Mediterranean Sea, and the Adriatic Sea. Italy is currently progressing in the testing of methods for assessing impact and defining GES in the context of fishing abrasion. The current assessment of the impact of fishing activity and other pressures on the sea-floor integrity is under development. Ongoing methodological setting regards both the definition of the assessment of fishing pressure/footprint and its impact. SAR estimates will benefit from enhanced empirical analysis of the relationships between technical features of fishing gear and associated swept area. Regarding fishing pressure, Italy is exploring two complementary approaches to estimate SAR: a) estimates based on VMS data from DCF integrated with AIS data at a 1 km * km scale. Results from this approach are shown in the current report; b) high-frequency AIS data (5 min.) is being used to reconstruct trawling tracks to allow generating high-resolution maps of fishing tracks. Specific maps are being used to investigating the interactions with biogenic habitats in areas where high-resolution maps are available. This approach is developed since the Italian definition of good environmental status (GES) for MSFD, states that no direct interactions of MBCG with biogenic habitats should be present. Specific national monitoring activities are in place on mega-epifauna, sampled by otter trawl on sites with contrasting fishing pressures. Species list are scored by specific functional life-history traits (including longevity). Also, data collected in the framework of DCF trawl surveys (e.g. MEDITs, SOLEMON) are used. Current studies are comparing alternative approaches, also considering those proposed in the context of WGFBIT and other applications developed in the Mediterranean context. In particular, methods to be applied in deeper habitats (<200m) seems to need more development. The trade-off between fisheries management options and benthic impact will be explored, among others, in the context of the DG-ENV funded ABIOMMED project.

France

In the context of MSFD, French waters are divided into four sub-regions including, in the Mediterranean, the Western Mediterranean Sea. France has researched indicators and methods for assessing impact and defining GES in the context of fishing abrasion and other pressures on the sea-floor integrity based either on community or sensitive biological traits composition. A framework to detect, model and quantify habitat specific impact thresholds was proposed for a data-rich situation. The current assessment of the impact of fishing activity is under development while the assessment of fishing footprint by the mean of SAR estimates is already developed based on VMS data only. Further work may be required to quantify the evaluated SAR uncertainty and SAR estimates accuracy will benefit from updated studies of fleet specific technical features of fishing gear. Methodological developments are on-going regarding the definition of the assessment framework of fishing impact possibly based on risk analysis and/or modelling approach for impact threshold detection. No specific monitoring activities are in place to monitor benthic fauna and available macrofauna from the Water Framework Directive (WFD) monitoring or mega-epifauna, sampled opportunistically by trawl surveys in the frame of CFP, will be used. Species list were scored by specific functional life-history traits (not including longevity at the moment). On-going participation to WGFBIT ensures that approaches proposed in that context may also be tested in the French Mediterranean waters. Further research is progressing towards the development of indicators including other biological compartment (meiofauna or foraminiferans) and the detection of historical reference states (fossil fauna) in deeper habitats (<200m). Specific risk analyses are being developed to investigate the interactions between VME and fishing pressure in deep sea areas to evaluate specific MFSD environmental objectives. The trade-off between fisheries management options and benthic impact was explored in the frame of research studies by the mean of spatial planning exercise (MARXAN based systematic conservation planning exercise). However, the lack of coordination between CFP and MFSD objectives has not prompted much further research in that field.

Spain

The MSFD Spanish reporting covers the assessment of five different Demarcations within two European marine regions; the North-east Atlantic Ocean and the Mediterranean Sea. In the Mediterranean, the current preliminary assessment is detailed covering the entire Spanish Western Mediterranean. Spain analysed VMS data from the year 2010. VMS and logbook data is collected by Ministry of Agriculture, Fisheries and Food and processed annually by Instituto Español de Oceanografía (IEO) using standard ICES R routines (i.e. VMStools) with some modifications. The assessment covered (Swept Area for Trawl Fisheries) the period 2010-2012 and 2019 and at the moment is working to have the overall data series analysed at the end of this year 2021 (2009-2020). Some technical issues on swept area algorithm in areas near the coast and isolated areas caused the delay in the analysing process. The assessment is done on 0.05°x0.05° C-square although, a finer scale could be used (0.01°x0.01°) in response to future subregional agreement. For the Mediterranean, the fishing effort for all trawlers was estimated in km2 and hours at sea and by three métiers (OTB_DEF; OTB_DWD; OTB_MDD). Additionally, Spain is working to improving the effort estimation for static gears, and data collection and fishing footprint for the small-scale fisheries. These fleets are relevant because some of their fishing grounds are located on Rocky Bottom Habitats, where habitat type 1170 from Habitat Directive are located. The distribution of the MSFD Broad Habitat in the region has been extracted from EMODnet. Landings data are available from 2010, but data these data are being improved.

In relation with measure the impact of fishing activities on seabed habitats, the Spanish approach, which will be common for all demarcations (North-east Atlantic Ocean and Mediterranean regions) and it will be based on the indicators developed in the frame of OSPAR benthic habitats expert group (OBHEG, see Elliott *et al.*, 2018). The ICES approach based on longevity is currently being tested for the northern coast of Spain within the WGFBIT, where IEO experts have participated since 2020. To apply these approaches Spain will use biological data of epibenthic abundance from its bottom trawl surveys (IBTS and MEDITS), two of them covering the Atlantic subregion Bay of Biscay and the Iberian Coast and coordinated by ICES (ICES, 2017) and the other covering the Mediterranean subregion and coordinated by MEDITS project (MEDITS, 2007). These surveys use a randomly stratified sampling design to survey the trawlable grounds of the Spanish seabed using otter trawls, providing information on abundance and distribution of all epibenthic fauna, including invertebrates. Furthermore, this information will be complemented with specific MSFD surveys, using other gears (such as box corers, beam trawls and photogrammetry sledges) to fill the gaps in the samples for special habitats and broad habitats not covered by these historical surveys. Last year (2020) two of these surveys were carried out for the first time in Canary Islands (Atlantic Ocean subregion) and Gulf of Cadiz (Bay of Biscay and the Iberian Coast) and another two are planned in 2021 in the northern coast of Spain and the Mediterranean region. Finally, to apply OSPAR indicators based on biological traits Spain experts are developing in collaboration with other partners a list of biological traits for epibenthic species for both Atlantic and Mediterranean regions.

The next steps will focus on improving the pressure indicators (calculated using WKTRADE r-routines) by accurately fish effort distribution and broad habitat distribution areas and conducting the analysis to include the economic values of the landings and trade-off analysis.

Bulgaria

A pilot study on the physical disturbance to the seabed from mobile bottom contacting fishing gear in the Bulgarian Black Sea shelf was carried out for 2017. All pressure and impact estimates were done for areas < 200 m depth as there is no aerobic macrofauna present or fisheries occurring in deeper Black Sea regions due to naturally anoxic conditions. Vessel Monitoring System data were analysed to reconstruct the trawling lines from fishing gear towed on/near the bottom. Only pings with fishing specifics speeds were extracted (1.6-3.6 kn). Start and end points of fishing operations were converted to lines, buffered with the average gear width and aggregated to generate the swept area in GIS. The pressure estimates were aggregated for all gear types and métiers. The physical disturbance intensity was estimated using the swept area ratio (SAR) calculated from reconstructed trawling lines, in grids with cell sizes 0.5x0.5 km, 1x1 km, 2x2 km and 5x5 km. Significant effect of the grid resolution on the assessment results was revealed: the spatial extent of physical disturbance was overestimated, while the intensity was underestimated as the cell size increased. The finest grid was used in the subsequent assessments.

Benthic habitats (macrofauna) status was assessed at 73 sampling locations (147 samples) using the multivariate marine biotic index M-AMBI(n). SAR was classified in two categories: “Low” – “High” pressure intensity corresponding to “Good” – “Not good” habitat status according to M-AMBI(n). ROC curve analysis on those classes derived an ecologically relevant low/high pressure threshold at SAR ≥ 0.2. Significant difference was demonstrated in the benthic habitats condition at low-high physical disturbance pressure. The established low-high pressure threshold (SAR ≥ 0.2) can be used to evaluate the habitats extent at risk to be adversely affected by physical disturbance from fisheries under GES criterion D6C3.

Areas with absent, low and high physical disturbance intensity were mapped and their extent was estimated. Overall, nearly 60% of the Bulgarian Black Sea shelf was trawled in 2017. Yet, only 12 % of the seafloor was subject of high physical disturbance (SAR ≥ 0.2) from fisheries.

EUSeaMap 2019 was used to evaluate the extent and proportion of MSFD benthic broad habitat types under physical disturbance from fisheries. The physical disturbance pressure was unevenly distributed across the habitat types: the most extensive disturbance occurred in circalittoral mud (82%), circalittoral mixed sediments (71%) and offshore circalittoral mixed sediments (61%). The respective proportion of intensive disturbance (SAR ≥ 0.2) was 21% for both circalittoral habitats and only 5% for the offshore circalittoral mixed sediments. The proportion of infralittoral sand physically disturbed was 31% and 12% were intensively disturbed. The latter estimates were probably low due to VMS non presence on small boats that operate in the shallow coastal area.

7.4 References

EU. 2017. Decision (EU) 2017/848 of the European Parliament and of the Council of 17 May 2017 laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment, and repealing Decision 2010/477/EU. 32 pp. http://data.europa.eu/eli/dec/2017/848/oj.

Elliott S.A.M., Guérin L., Pesch R., Schmitt P., Meakins B., Vina-Herbon C., González-Irusta J.M., de la Torriente A., Serrano A., 2018. Integrating benthic habitat indicators: Working towards an ecosystem approach, Marine Policy, 90, 88-94.

Evans, D., Aish, A., Boon, A., Condé, S., Connor, D., Gelabert, E. Michez, N., *et al*. 2016. Revising the marine section of the EUNIS Habitat classification – Report of a workshop held at the European Topic Centre on Biological Diversity, 12–13 May 2016. ETC/BD report to the EEA. https://www.eionet.europa.eu/etcs/etc-bd/products/etc-bd-reports.

ICES. 2017. Manual of the IBTS North Eastern Atlantic Surveys. Series of ICES Survey Protocols SISP, 15, 92.

ICES. 2019a. Working Group on Spatial Fisheries Data (WGSFD). ICES Scientific Reports. 1:52. 144 pp. http://doi.org/10.17895/ices.pub.5648

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

MEDITS, 2007. International bottom trawl survey in the Mediterranean (Medits). Instruction manual. Version 5. Ifremer, Nantes. 60 p.

8 Conclusions and recommendations

8.1 Conclusions

ICES has been requested to:

- Review and evaluate any potential consequences to the ecosystem, including commercial fish stocks, that could arise, if greater areas of seabed are left undisturbed by bottom fishing, for a range of management options.
- Conduct an analysis of spatial and temporal variation in fishing intensity appropriate to assess the footprint of mobile-bottom contacting fishing gears in a six-year management cycle. The analysis should include an estimation of the proportion of 'core fishing grounds' and should determine the spatial variation in 'core fishing grounds' over time.
- Produce an estimate, where possible, of the revenue and contribution margin associated with the fishing activity per area by integrating fisheries economics data (e.g. STECF AER) with VMS/logbook data for all mobile-bottom contacting fishing gears and per gear grouping in (sub)regions.
- Coordinate regional-specific assessments of pressure and impact of bottom-contacting fishing gears on the seabed and of trade-offs in fisheries and seafloor habitats

The WK developed methods and data flows that allows the assessment of seabed abrasion (derived from surface swept-area-ratio), economic value, weight of landings and impact on the seabed of mobile bottom-contacting gears in European waters. The assessment covers four (sub)regions, 22 sub-divisions and four countries from Mediterranean and Black Sea. It is spanning from Norway and Finland in the North to Bulgaria in the south (with a few gaps in the Mediterranean, where data from France, Slovenia, Croatia, Romania, Cyprus were not available). For all areas, the surface abrasion data were available for at least one year, but availability of weight, landings and longevity layers required to conduct the seabed impact and trade-off analyses were limited in some regions. For the Greater North Sea and Baltic Sea, it was possible to perform a complete analysis, while in the other regions data availability was more limited and it was not possible to assess the seabed impact.

Seabed abrasion, landings weight and value and their variation over time were quantified by MSFD broad habitat type and métier. The impact of mobile bottom-contacting gears (MBCG) on seabed biota was assessed using two different methods (PD and L1) and the percentage unfished c-squares was used as an indicator of fishing pressure. The area at fishable depths varies considerably between areas (i.e. (sub-)regions/subdivisions), and this means that the percentage of the area that is unfished and the average fishing intensity are not comparable between whole areas, but are comparable within MSFD broad habitat type and within depth bands.

The management scenario reduction of effort through spatial exclusion by habitat type was evaluated for all (sub-)regions and subdivisions. Bottom trawling impact and the percentage of unfished area were traded off against fisheries value independently of each other. Fishing impact on the seabed was evaluated in the management scenarios in the Baltic Sea and Greater North Sea, but not for the other areas.

Different methods to define core fishing grounds were explored to analyse the spatial and temporal variation for all combined MBCGs and 11 separate métiers. All métiers and all regions analysed exhibited core fishing grounds with high effort and landings and peripheral areas with less fishing activity. There is a spatial variation between métiers in the stability of the core areas of the six-year period assessed, which seems to depend on the species they are targeting. However, the balance between core and peripheral fishing areas is more consistent across the metiers.

The average fishing intensity varies widely between habitat types and regions. Landings per swept area, and landings per unit impact also vary between métiers by an order of magnitude. Effort reductions resulted in different responses between the two impact indicators and the fishing pressure indicator. For PD, the reduction of effort resulted in proportional reductions between benthic impact and fisheries value. For the two other indicators, L1 and percentage area unfished, the relationship between the weight/value and the indicators was not linear, meaning that larger improvements in the indicators could be obtained at small decreases in fisheries landings. The development of methods to assess benthic impact are still ongoing. The evaluation of trade-offs in this document is generic and can be done with other impact assessment methods, where available, when these methods describe impact on a continuous scale.

An analysis was done to disaggregate variable costs from the STECF annual economic reporting via the STECF FDI data and out on ICES VMS data to obtain the contribution margin.

There are many other direct and indirect benefits to ecosystem and ecosystem services that could result from a reduction in MBCG, but currently the methods and data are not available to quantify these at the required spatial scale.

8.2 Caveats

These results come with several important caveats. In many of the management scenarios we assumed a static distribution of fishing, and no effort redistribution. Where there is displacement of fishing in response to management, this would result in an overestimate of the benefits of management using the PD and the L1 indicators.

The fishing effort as recorded by VMS only includes vessels >12m and is therefore likely to underestimate fishing effort and benthic impacts in nearshore areas.

The analyses were limited by some mistakes in the data layers for weight and value that became evident during the workshop. Furthermore, the spatial resolution of the economic data does not match the c-square resolution of the fishing effort data for some countries, and different ways of assessing value of landings were used in different countries. This means that the outcomes for economic analysis are less consistent and less certain than for effort and weight analyses.

The resolution of the c-squares used in this analysis (1/20 of a degree) is limited by the VMS ping rate, but this size is large relative to the distribution and extent of some habitat types, and can result in fishing being recorded on habitats that unsuitable for fishing. The habitat maps themselves are also likely to be imprecise in many areas and this can contribute to incorrect attribution of fishing activity to habitats.

The AER data is reported on a very large spatial scale, and for some fleet segments fishing within a limited area, the disaggregation on the costs by fishing effort appears appropriate, while in other more diverse fleet segments fishing in a larger area, the disaggregation approach is more problematic, as the costs might vary e.g. with the distance from port. This is not yet included in the current analysis.

8.3 Recommendations for future work

In the Mediterranean and Black Sea, there is work to be done to standardize analyses to a common approach.

Future work on examining trade-offs in management scenarios should aim to model the effects of displacement. The approach presented in this report did not evaluate displacement and is therefore likely to overestimate the benefits of the management scenarios.

The definition of core fishing grounds could evaluate alternative approaches like optimization or spatial clustering methods and by using different thresholds and evaluating temporal stability of effort, catches and value.

Further work can be done to perform optimisation analyses that predict the spatial management scenarios that achieve the habitat protection objectives at the lowest cost to the fishery. This could also include other spatial information affecting the areas where fishing is possible, e.g. MPAs closed for fishing activities, areas for offshore wind farms and areas used for sand and gravel extraction.

Evaluating management scenarios on technical gear modifications requires further input on how the modification would affect depletion, weight and value of the catch.

It is necessary to strive towards harmonising codes for used for different métiers and fishing techniques between different data calls (VMS and FDI). Future work could include analysis of the cost structure in different fleet segments and their relation to the métiers and vessel length categories in the FDI/VMS data. In addition, the distance from major ports or coast could be included in the disaggregation algorithm.

An increase in VMS ping rates would allow carrying out analyses using smaller c-squares, which would increase the precision of impact estimates, increase the area percentage of the area that is unfished, improving the matching of fishing activity with habitats.

Future work could work towards the regional scale quantification of other benefits of the management of bottom trawl fisheries, such as the effect on sediment biogeochemistry and commercial fish stocks. If ecosystem benefits can be quantified at a regional scale, these should also be included in the trade-off assessment.

Annex 1: List of participants

Name	Institute	Country (of Institute)	Email
Casper Kraan	Thunen Institute	Germany	casper.kraan@thuenen.de
Chris Smith	HCMR	Greece	csmith@hcmr.gr
Daniel van Denderen	ICES	Denmark	daniel.vandenderen@ices.dk
David Connor	European Commission DGENV	Belgium	david.connor@ec.europa.eu
Elena Balestri	Scottish Fishermen's Federation	UK	e.balestri@sff.co.uk
Emanuela Fanelli	Polytechnic University of Marche	Italy	e.fanelli@univpm.it
Eugene Nixon	ICES	Denmark	eugene.nixon@ices.dk
Genoveva Gonzalez Mirelis	Institute of Marine Research	Norway	genoveva.gonzalez-mirelis@hi.no
Helen Holah	Marine Laboratory	UK	helen.holah@gov.scot
Jan Geert Hiddink *(chair)*	Bangor University	UK	ossc06@bangor.ac.uk
Jochen Depestele	ILVO	Belgium	jochen.depestele@ilvo.vlaanderen.be
Jörg Berkenhagen	Thuenen Institute	Germany	joerg.berkenhagen@thuenen.de
Jose Manuel Gonzalez Irusta	IEO	Spain	jmanuel.gonzalez@ieo.es
Josefine Egekvist (chair)	DTU	Denmark	jsv@aqua.dtu.dk
Katarzyna Stepanowska	West Pomeranian University of Technology	Poland	greyseal@o2.pl
Kenny Coull	Scottish White Fish Producers Association Limited	UK	kenny@swfpa.com
Lancelot Blondeel	ILVO	Belgium	lancelot.blondeel@ilvo.vlaanderen.be
Lorenzo D'Andrea		Italy	dandrea.lorenz@gmail.com
Maria Cristina Mangano	Sicily Marine Centre	Italy	mariacristina.mangano@gmail.com
Marija Sciberras	Marine Sustainability, Policy & Conservation Evidence The Lyell Centre, Heriot-Watt University	UK	M.Sciberras@hw.ac.uk
Marina Pulcini	ISPRA	Italy	marina.pulcini@isprambiente.it

Name	Institute	Country (of Institute)	Email
Miquel Canals	Universitat de Barcelona	Spain	miquelcanals@ub.edu
Nadia Papadopoulou	HCMR	Greece	nadiapap@hcmr.gr
Phil Rhodri Taylor	Opean Seas	UK	phil@openseas.org.uk
Philip Boulcott	Marine Scotland Science	UK	Philip.Boulcott@gov.scot
Raffaele Proietti	ISPRA	Italy	raffaele.proietti@isprambiente.it
Sebastiaan van de Velde	Royal Belgian Institute of Natural Sciences (RBINS)	Belgium	sebastiaan.van.de.velde@ulb.be
Silvia Paoletti	Royal Belgian Institute of Natural Sciences of Belgium	Belgium	spaoletti@naturalsciences.be
Ulla Fernandez	IEO	Spain	ulla.fernandez@ieo.es
Valentina Todorova	Institute of Oceanology, BAS	Bulgaria	vtodorova@io-bas.bg

Annex 2: Resolutions

A series of two Workshops to develop a suite of management options to reduce the impacts of bottom fishing on seabed habitats and undertake analysis of the trade-offs between overall benefit to seabed habitats and loss of fisheries revenue/contribution margin for these options (WKTRADE3)

2020/WK/HAPISG07 **WKTRADE3** responds to a special request from DG Environment. The two Workshops will be chaired by Josefine Egekvist*, Denmark; and Jan Geert Hiddink*, UK, and will be held in Copenhagen, Denmark, 4–5 March 2021 and 6–9 April 2021.

In preparation for the Workshops, a Core Group, consisting of the two Chairs of WKTRADE3, invited experts and members of the ACOM Leadership and the ICES Secretariat will be established. The Core Group will prepare a TRADE3 Working Document Draft 1, designed to describe the potential management options and the methodologies for undertaking the trade-off analysis. This Working Document will be built up incrementally to facilitate additions and modifications at each of the steps set out in the ToRs below.

TRADE3 Working Document Draft 1 will be based on the demonstration assessment contained in the 2017 ICES advice, *"EU request on indicators of the pressure and impact of bottom-contacting fishing gear on the seabed, and of trade-offs in the catch and the value of landings"* (sr.2017.13). It will receive input from WGFBIT, in particular on how the developing process described therein can be made operational. The document will be amended by the Core Group into TRADE3 Working Document Draft 2.

TRADE3 Working Document Draft 2, will be presented to the European Commission's (EC) Technical Subgroup on seabed habitats and sea-floor integrity (TGSeabed) for comment and input. Following this, TRADE3 Working Document Draft 3 will be prepared by the Core Group. The TRADE3 Working Document Draft 3 will be peer-reviewed to ensure the best available, credible science has been used and to confirm that the analysis provides a sound basis for the developing advisory product.

TRADE3 Working Document Draft 3 will be used as the input to the first of the TRADE3 Workshops, the Stakeholder Workshop scheduled for 4-5 March 2021.

ToRs for the March 2021 WKTRADE3 Stakeholder Workshop are:

a) Present TRADE3 Working Document Draft 3 to the workshop participants to inform them of the progress to date and the ICES process to finalise the TRADE3 Advice response to the EC.
b) Review the management options identified to reduce the impact of Mobile Bottom Contacting Gears on seabed habitats (e.g. are there options missing) and the criteria used for their prioritisation.
c) Input from the workshop participants on whether the proposed trade-off analyses in TRADE3 are informative and produce outputs that stakeholders need.

Participants for invitation to the Stakeholder Meeting will be selected in conjunction with DGEnv.

Following WKTRAD3 Stakeholder Workshop, the Core Group will update the working document to TRADE3 Working Document Draft 4. This will be used as input to the TRADE3 Technical Workshop, scheduled for 4 days during April 2021.

ToRs for the April 2021 WKTRADE3 Technical Workshop are:

a) Review TRADE3 Working Document Draft 4 to the workshop participants.
b) Review and evaluate for each management option identified in TRADE3 Working Document Draft 4 any potential consequences to the ecosystem, including commercial fish stocks that could arise, if greater areas of seabed are left undisturbed by bottom fishing.
c) Conduct an analysis of spatial and temporal variation in fishing intensity appropriate to assess the footprint of mobile-bottom contacting fishing gears in a six-year management cycle. The analysis should include an estimation of the proportion of 'core fishing grounds' and should determine the spatial variation in 'core fishing grounds' over time.
d) Produce an estimate, where possible, of the revenue and contribution margin associated with the fishing activity per area by integrating fisheries economics data (e.g. STECF AER) with VMS/logbook data for all mobile-bottom contacting fishing gears and per gear grouping in (sub)regions.
e) Produce regional-specific assessments of pressure and impact of bottom-contacting fishing gears on the seabed and of trade-offs in fisheries and seafloor habitats, based on available data and building on the 2017 demonstration advice *"EU request on indicators of the pressure and impact of bottom-contacting fishing gear on the seabed, and of trade-offs in the catch and the value of landings"* (sr.2017.13). The assessments will follow the methodology set out in the TRADE3 Working Document Draft 4. For data poor areas, only part of the assessment will be run, and key data/knowledge gaps will be identified. The assessments should include a trade-off analysis between fisheries and seafloor habitats, i.e. overall benefit to the seafloor, relative to loss in revenue/contribution margin, for prioritized management options identified in the TRADE3 Working Document Draft 4.

Experts from ICES WGs (WGSFD, WGFBIT, WGECON), as well as, other regional-specific experts will be encouraged to contribute to the Technical Workshop. Participants for invitation to the Technical Workshop will be selected by the Core Group.

In preparation for the workshop meeting, the Core Group will facilitate coordination and consolidation of work. The Core Group will also ensure that the workshop reports are finalized.

Supporting information

Priority	High, in response to a special request from DGENV on a set of management options to reduce the impact of mobile bottom contacting fishing gears on seafloor habitats, and to provide a trade-off analysis between fisheries and the seafloor. The advice will feed into ongoing efforts to provide guidance on the operational implementation of the MSFD.
Scientific justification	The demonstration assessment within the 2017 ICES advice (sr.2017.13) provided aggregate values for four types of bottom-contacting fishing gear groupings at the scale of the entire Greater North Sea region and in relation to the 2004 EUNIS habitat classification. In order to better understand the relationship between catch/value of landings and the levels of physical disturbance for MSFD purposes, this 'trade-off' analysis needs to consider the following two aspects: 1) Mobile bottom contacting fishing: at the level of fishing gear grouping, on the basis that this is likely to be a more appropriate resolution for management purposes. 2) Footprint/Impact on the seafloor: at the resolution of seabed habitat assessments required by the GES Decision (EU)

	2017/848 (i.e. the MSFD broad habitat types, based on the EUNIS 2016 classification, and subdivisions of an MSFD (sub)region). WKTRADE3 will review a suite of options to reduce impacts of mobile bottom contacting fishing gears on seabed habitats (ToR b in Stakeholder and Technical workshop). This review should include any wider benefits/consequences to the ecosystem, including commercial fish stocks that could arise, if greater areas of seabed are left undisturbed by bottom fishing. This should include an exploration of the empirical evidence of options presented in two recent publications (Collie et al 2017; McConnaughey *et al.* 2020). Potential consequences (positive and negative) to the wider ecosystem should be identified to provide some ecosystem perspective to the trade-off question. Based on the review, WKTRADE3 will produce a prioritized list of management options for trade-off analysis and include the criteria used to prioritize. WKTRADE3 will develop a methodology that explains how each option is implemented in the trade-off assessment. WKTRADE3 will provide analyses of spatial and temporal variation in fishing intensity, catch and landings in a way appropriate to assess the footprint of mobile-bottom contacting fishing gears in a six-year management cycle (Technical Workshop ToR c-i). The analyses should be done for all mobile-bottom contacting fishing gears together and per métier grouping, covering different MSFD (sub)regions (Greater North Sea, Baltic Sea, Celtic Seas, Bay of Biscay and Iberian Coast) and the subdivisions of these MSFD (sub)regions. The analysis should summarize the results for the entire assessment region and per MSFD broad habitat type within the region, based on the EUNIS 2016 classification. The analysis should include an estimation of the proportion of area fished that covers 90% of value/landings (i.e. core fishing grounds) for each métier and per MSFD (sub)region/subdivision and should determine the spatial variation in 'core fishing grounds' over time. The analysis of fishing footprint and core fishing grounds will be estimated for (sub)regions and per métier grouping where VMS and logbook data is available. WKTRADE3 will review available data that can be used to estimate the revenue and contribution margin associated with the fishing activity per area (Technical Workshop ToR c-ii). Revenue and contribution margin associated with fishing activity will be estimated for one region by integrating fisheries economics data (e.g. STECF AER) with VMS/logbook data for all mobile-bottom contacting fishing gears and per gear grouping. This analysis will also be done, where possible, for other (sub)-regions. Results will be incorporated in the trade-off assessment sheets, with recommendations on how to improve the dataflow. WKTRADE3 will produce a prioritized list of management options, and for each option provide a trade-off analysis between fisheries and seafloor habitats, i.e. overall benefit to the seafloor, relative to loss in revenue and contribution margin (Technical Workshop ToR c-iii).
Resource requirements	ICES secretariat and advice process.
Participants	Stakeholder Meeting with relevant stakeholders from DG-Environment, DG-Mare, NGO's, National Fisher Organizations and representatives from national agencies. Technical Workshop with researchers and RSCs investigators. If requests to attend exceed the meeting space available ICES reserves the right to refus

	participants. Choices will be based on the experts' relevant qualifications for the Workshop. Participants join the workshop at national expense.
Secretariat facilities	Data Centre, Secretariat support and meeting room
Financial	Covered by DGENV special request.
Linkages to advisory committees	Direct link to ACOM.
Linkages to other committee or groups	Links to WGFBIT, WGSFD, WGECON CSGMSFD and SCICOM.
Linkages to other organizations	Links to OSPAR and HELCOM.

Annex 3: Agenda

Tuesday 6/4

Note that all times in the agenda are CET

Plenary link: Click here to join the meeting

10.00 – 11.00	Welcome House rules, Terms of References, advice process *(Eugene Nixon)* Presentation round: Name, organization, interest in the topic Introductory presentations: • Background of the 2021 request *(David Connor)* • 2017 ICES advice to DGENV *(Josefine Egekvist)* • Preparation work for ToRs o Management options *(Jan Hiddink)* o Fishing grounds analysis *(Josefine Egekvist)* o Integrating economic data *(Josefine Egekvist)* o Trawl impact assessment *(Jan Hiddink)* • Outcomes from WKTRADE3 stakeholder meeting *(Jan Hiddink)*
11.00 – 11.15	*Break*
11.15 – 12.30	Introductory presentations continued
12.30 - 13.30	*Lunch break*
13.30 – 14.30	Html output files *(Daniel van Denderen)* Introduction to sub-group work *(Jan Hiddink and Josefine Egekvist)*
14.30 – 14.45	*Break*
14.45 – 16.00	Sub-group work: Subgroups A and B In subgroup B: Introduction to R-scripts at GitHub *(Daniel van Denderen)*

Wednesday 7/4

10.00 – 13.00	Sub-group work (*including breaks*): Subgroups A and B
13.00 – 14.00	Plenary: Status from sub-groups Presentation: "The ABIOMMED project and its support to a coordinated Mediterranean approach for the D6 assessment" *(Sasa Raicevich)* Presentation: "Assessing trawl impacts on benthic habitats in relation to MSFD implementation in Spain" *(José Manuel González-Irusta and Ulla Fernández)*
14.00– 16.00	Sub-group work (*including breaks*): Subgroups A and B In subgroup B: Presentation and discussion of economic data analysis

Thursday 8/4

10.00 – 13.00	Sub-group work (*including breaks*): Subgroups B and C
13.00 – 14.00	Plenary: Status from sub-groups Presentation: "Assessing the physical disturbance on the seabed from fisheries in the Bulgarian Black Sea area with reference to benthic habitats status" *(Valentina Todorova)*
14.00 – 16.00	Sub-group work (*including breaks*) Subgroups B and C

Friday 9/4

10.00 – 12.00	Sub-group work (*including breaks*) Subgroups B and C
12.00 – 13.00	*Lunch break*
13.00 – 16.00	Plenary: Report, conclusions

Subgroup A: Ecosystem consequences from management options. Click here to join the meeting

ToR b. Review and evaluate for each management option identified in TRADE3 Working Document Draft any potential consequences to the ecosystem, including commercial fish stocks that could arise, if greater areas of seabed are left undisturbed by bottom fishing.

Subgroup B: Technical subgroup: Fishing grounds analysis, fisheries economic data and assessment workflow. Click here to join the meeting

ToR c. Conduct an analysis of spatial and temporal variation in fishing intensity appropriate to assess the footprint of mobile-bottom contacting fishing gears in a six-year management cycle. The analysis should include an estimation of the proportion of 'core fishing grounds' and should determine the spatial variation in 'core fishing grounds' over time.

ToR d. Produce an estimate, where possible, of the revenue and contribution margin associated with the fishing activity per area by integrating fisheries economics data (e.g. STECF AER) with VMS/logbook data for all mobile-bottom contacting fishing gears and per gear grouping in (sub)regions.

ToR e. Coordinate regional-specific assessments of pressure and impact of bottom-contacting fishing gears on the seabed and of trade-offs in fisheries and seafloor habitats

Uncertainties, data caps and caveats

Suggestions for future work

Subgroup C: Write conclusions for the assessments. Click here to join the meeting

ToR e. Summarize findings across regions. What are the commonalities/differences?

Annex 4: Regional assessment using the ICES VMS data

We developed regional assessments of fishing pressure and impact for 4 different (sub-)regions and 22 subdivisions using quality-controlled VMS data from the ICES 2019 VMS data call. Outputs were analysed in the workshop and main patterns described.

The assessment outputs are available as an HTML-document (see below screenshot for the Celtic Seas) on WKTRADE3 github. The github includes the R-scripts used to run the assessments.

The HTML files can be downloaded from a zip-file, which can be found here: https://github.com/ices-eg/WKTRADE3/blob/master/5 - Output/Markdown html/Regional assessments of pressure and impact.zip

Celtic Seas

WKTRADE 3

Assessment sheet for Celtic Seas sub-region and for five subdivisions

The physical disturbance pressures from mobile bottom-contacting fishing gears varies spatially in the Celtic Sea sub-region, with 83% of the grid cells (I-2), and 53% of the surface area (I-3) <200m being fished on average per year for the period 2013-2018 (Table 1). Fishing is aggregated with 90% of the pressure occurring in 36% of grid cells (I-4). More intensive fishing occurs in the zone >200m depth in the Celtic Sea.

No longevity layer was available for the Celtic Sea region – declines in community biomass relating to impact cannot, therefore, be calculated for either the L1 or PD method.

Maps of spatial distribution of surface abrasion, economic value and weight of fisheries landings are shown in Figure 1. It is evident from the weight map that there is a mistake in the weights for the region, and weights are not presented in further analyses. The value layer also appears incomplete.

Screenshot of assessment sheet Celtic Seas sub-region.

Annex 5: Mediterranean and Black Sea regional assessments

Contents

Black Sea, Bulgarian shelf area

Authors: Valentina Todorova, Marina Panayotova, Valentina Doncheva, Ivelina Zlateva

Institute of Oceanology – Bulgarian Academy of Sciences

Summary

A pilot study on the physical disturbance to the seabed from mobile bottom contacting fishing gear in the Bulgarian Black Sea shelf was carried out for 2017. All pressure and impact estimates were done for areas < 200 m depth as there is no aerobic macrofauna present or fisheries occurring in deeper Black Sea regions due to naturally anoxic conditions. The pressure estimates were aggregated for all gear types and métiers.

The physical disturbance intensity was estimated using the swept area ratio (SAR) calculated from reconstructed trawling lines, in grids with cell sizes 0.5x0.5 km, 1x1 km, 2x2 km and 5x5 km. A significant effect of the grid resolution on the assessment results was evident: the spatial extent of physical disturbance was overestimated, while the intensity was underestimated as the cell size increased. The finest grid was used in the subsequent assessments.

Benthic habitats (macrofauna) status was assessed at 73 sampling locations (147 samples) using the multivariate marine biotic index M-AMBI(n). SAR was classified in two categories: "Low" – "High" pressure intensity corresponding to "Good" – "Not good" habitat status according to M-AMBI(n). ROC curve analysis on those classes derived an ecologically relevant low/high pressure threshold at SAR ≥ 0.2. Significant difference was demonstrated in the benthic habitats condition at low-high physical disturbance pressure. The established low-high pressure threshold (SAR ≥ 0.2) can be used to evaluate the habitats extent at risk to be adversely affected by physical disturbance from fisheries under GES criterion D2C3.

Areas with absent, low and high physical disturbance intensity were mapped and their extent was estimated. Overall, nearly 60 % of the Bulgarian Black Sea shelf was trawled in 2017. Yet, only 12 % of the seafloor was subject of high physical disturbance (SAR ≥0.2) from fisheries.

The physical disturbance pressure was unevenly distributed across MSFD benthic broad habitat types: the most extensive disturbance occurred in circalittoral mud (82 %), circalittoral mixed sediments (71 %) and offshore circalittoral mixed sediments (61%). The respective proportion of intensive disturbance (SAR ≥ 0.2) was 21% for both circalittoral habitats and only 5 % for the offshore circalittoral mixed sediments. The proportion of infralittoral sand physically disturbed was 31 % and 12 % were intensively disturbed. The latter estimates were probably underrated due to VMS not present on small boats that operate in the shallow coastal area.

Maps of the spatial extent, distribution and intensity of the physical disturbance from mobile bottom contacting gears are shown on Figure 1.

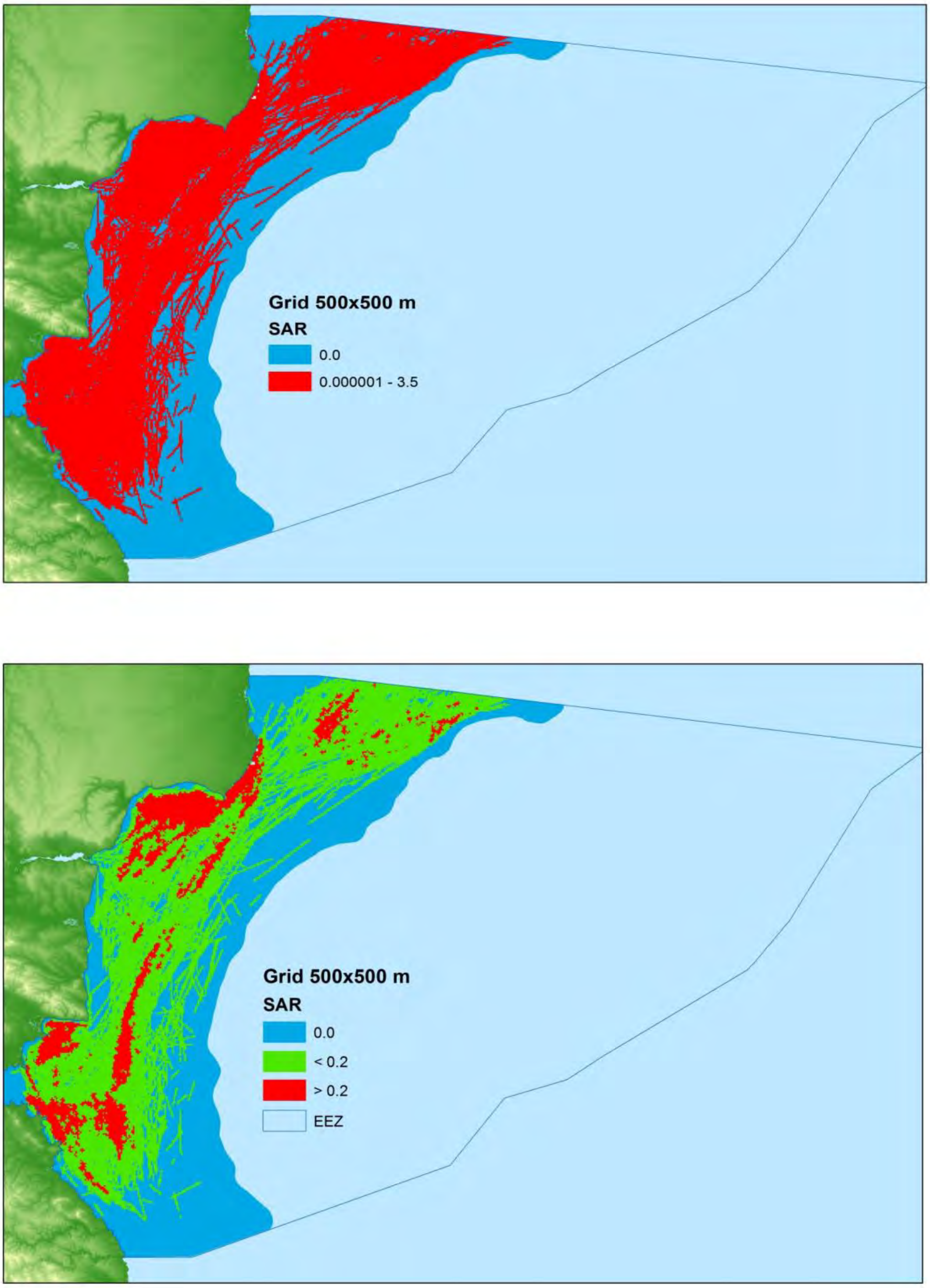


Figure 1. Spatial extent, intensity (assessed using Swept area ratio - SAR) and distribution of physical disturbance from mobile bottom contacting fishing gears on the Bulgarian Black Sea shelf in 2017.

Pressure

The distribution of physical disturbance intensity in the Bulgarian Black Sea in 2017 had a considerable spatial variation (Figure 1). While the overall fishing pressure occurred over 59 % of the shelf between 0-200 m depth, the areas of higher intensity (SAR ≥ 0.2) occupied only 12 % of the shelf and occurred either closer to the coast or in the circalittoral zone at depths typical of the main target species: 15-30 m for *Rapana venosa* and 50-70 m for *Sprattus sprattus*. Areas with lower intensity occurred offshore in the deeper parts of the Bulgarian shelf. There was no pressure observed beyond 100 m depth where hypoxic/anoxic conditions in the Black Sea prevent the distribution of fish stocks. Since the assessment area was aligned with the shelf boundary at 200 m, the proportion of intensively disturbed areas from the actual fishing grounds may be underestimated.

The proportion of area subject to fishing pressure varied between broad habitats types and was highest in the circalittoral mud (82%), circalittoral mixed sediments (71 %) and offshore circalittoral mixed sediments (61%) (Table 1). The respective proportion of intensive disturbance (SAR ≥ 0.2) was 21% for both circalittoral habitats and only 5 % for the offshore sediments. The proportion of infralittoral sand physically disturbed (overall 31 % and intensively 12 %) was probably underestimated due to absence of tracking devices on small boats.

The fishing footprint and intensity over time have not been evaluated yet but the fishing activities pattern was probably similar during the previous decade.

Table 1. Spatial extent and proportion of the broad habitat types subject of physical disturbance and high intensity disturbance, Bulgarian Black Sea shelf, 2017.

Habitat type	Total area	Trawled area		Intensively trawled area (SAR ≥ 0.2)	
	(km^2)	(km^2)	%	(km^2)	%
Circalittoral mud	4201.8	3466.1	82	876.3	21
Offshore circalittoral mixed sediment	2972.7	1812.4	61	162.2	5
Offshore circalittoral mud	3024.4	866.3	29	89.9	3
Circalittoral mixed sediment	853.3	603.4	71	181.4	21
Circalittoral coarse sediment	189.7	98.7	52	43.2	23
Circalittoral sand	108.1	64.3	59	29.1	27
Infralittoral sand	197.1	61.4	31	23.3	12
Infralittoral mixed sediment	55.3	31.4	57	3.8	7
Infralittoral coarse sediment	62.9	18.2	29	2.7	4
Offshore circalittoral sand	5.3	5.2	98	0.0	0
Infralittoral mud	9.5	2.4	25	0.0	0
Offshore circalittoral coarse sediment	4.5	0.0	0	0.0	0

Core fishing ground

The intensively fished areas could be qualified as the ‘core fishing grounds’. However, while some of these grounds contributed most of the landings, others were not as productive. Maps of the landings distribution at 0.5 x 0.5 degree resolution for the period 2015-2019 are available in STECF-20-10 Annex 4. Although areas with higher landings are made evident, the coarse resolution precludes from accurate delineation of the core fishing grounds. GIS layers are not provided with the report.

Fishing by métier

Not available.

Impact

The habitats condition was evaluated according to the status of zoobenthic communities using the multivariate marine biotic index M-AMBI(n). The data at 73 locations (147 sediment samples for macrozoobenthos) was obtained in October 2017. Habitat type specific thresholds for the constituent indices S, H′ and AMBI are established in the Bulgarian Black Sea. Common good status threshold is set at EQR M-AMBI(n) ≥ 0.68, which allows for comparison across habitat types.

ROC curve analysis was run on two classes of SAR: "Low" – "High" pressure intensity corresponding to "Good" – "Not good" habitats status according to M-AMBI(n). Thus an ecologically meaningful low/high pressure threshold of SAR ≥ 0.2 was derived in relation to the ecological status of benthic macrofauna.

The average EQR M-AMBI(n) was significantly different ($p=0.006$) at low/high SAR (t-test assuming unequal variances). Moreover, "good status" (mean EQR=0.81) was associated with low pressure (SAR < 0.2), while "not good" status (mean EQR=0.66) was estimated at high pressure (SAR ≥ 0.2).

The established low-high pressure threshold (SAR ≥ 0.2) can be used to evaluate the habitats extent at risk to be adversely affected by physical disturbance from fisheries under GES criterion D6C3.

Management scenarios

Not available.

Areas were identified where high fishing intensity was not coupled with high landings. These areas offer an opportunity to decrease/eliminate the fishing pressure and thus protect the habitats at small cost - small loss of value from fisheries.

Eastern Mediterranean, Greece

Authors: Nadia Papadopoulou, Irini Tsikopoulou, Chris Smith, Stefanos Kavadas

Preliminary analysis of otter trawl SAR, and landings (weight/value) by broad-scale habitat type in Greece

Summary

The physical disturbance pressure from mobile bottom-contacting fishing gears varies spatially in Greece and is strongly related to the bathymetry of the Aegean and Ionian Seas. There are spatial limits concerning depth and distance from shore (e.g. 1.5 mile from shore) for otter trawling including a minimum and maximum trawling depth of 50 and 1000 m respectively. However, in reality otter trawl fishing does not exceed 800 m depth. There are also numerous local fisheries temporal closures in addition to a compulsory 4.5 month seasonal closure over the entire area. There is also a 6 nm national territorial zone in the Aegean and a 12 nm territorial zone in part of the Ionian Sea. There is otter trawling in international waters under special permits for Greek vessels and by other fleets (e.g. Italian or Turkish vessels depending on subregion).

Maps of spatial distribution of intensity, and economic value and weight of fisheries landings are shown in Figures 1, 2 and 3. Economic value and weight of fisheries landings data are available at a coarser grid resolution (0.5 X 0.5 degree, in line with the Fisheries Dependent Information (FDI) data call, and use data use by STECF FDI EWG (available through JRC, https://stecf.jrc.ec.europa.eu/dd/fdi) than the rest pressure indicators (0.05X0.05 degree).

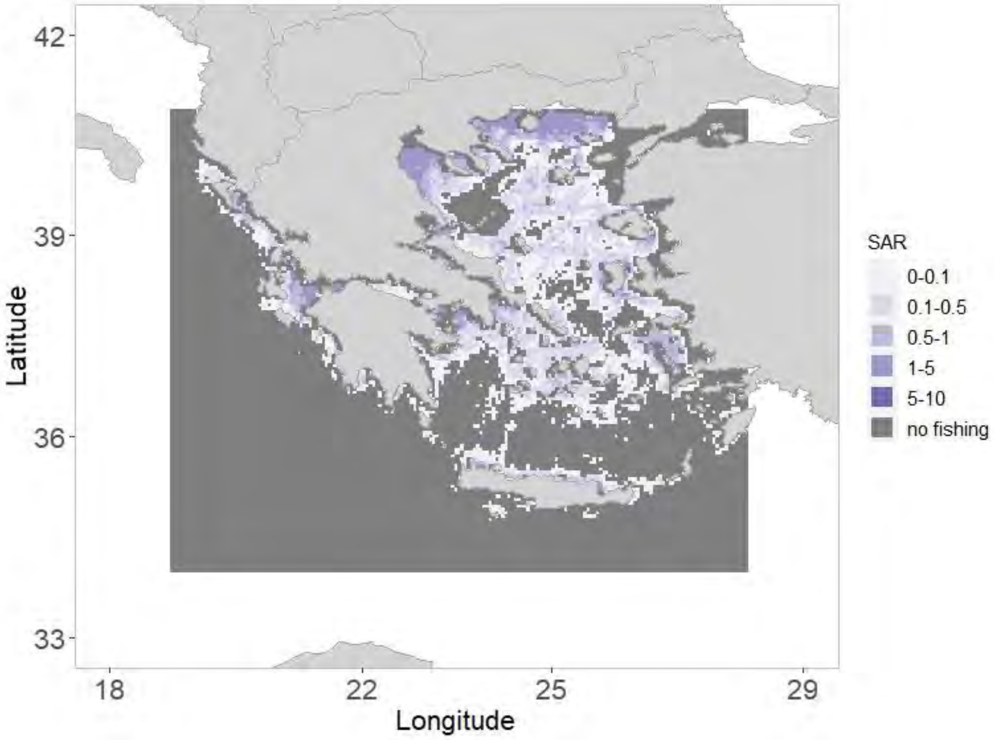


Figure 1. Distribution of average swept area ratio (SAR) per year for 2015-2018 from mobile bottom contacting gear (based on VMS data in the area from Greek vessels only).

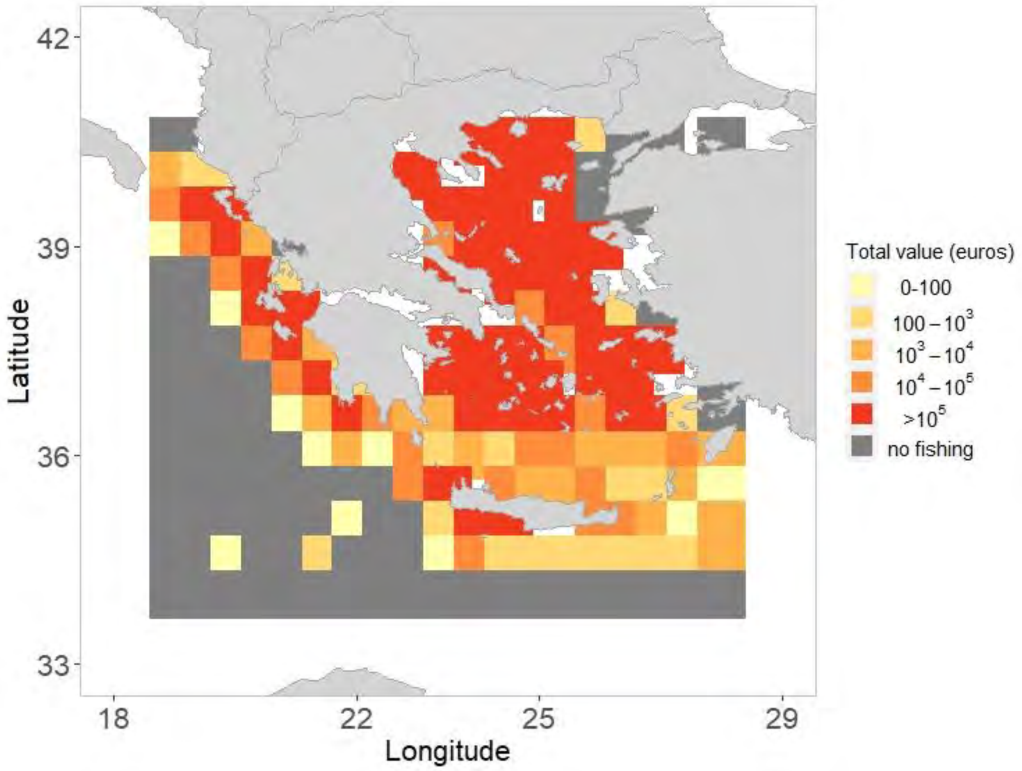


Figure 2. Distribution of average total value of landings per year for 2016-2019 from mobile bottom contacting gear (source of information: https://stecf.jrc.ec.europa.eu/dd/fdi) (based on VMS data in the area from Greek vessels only).

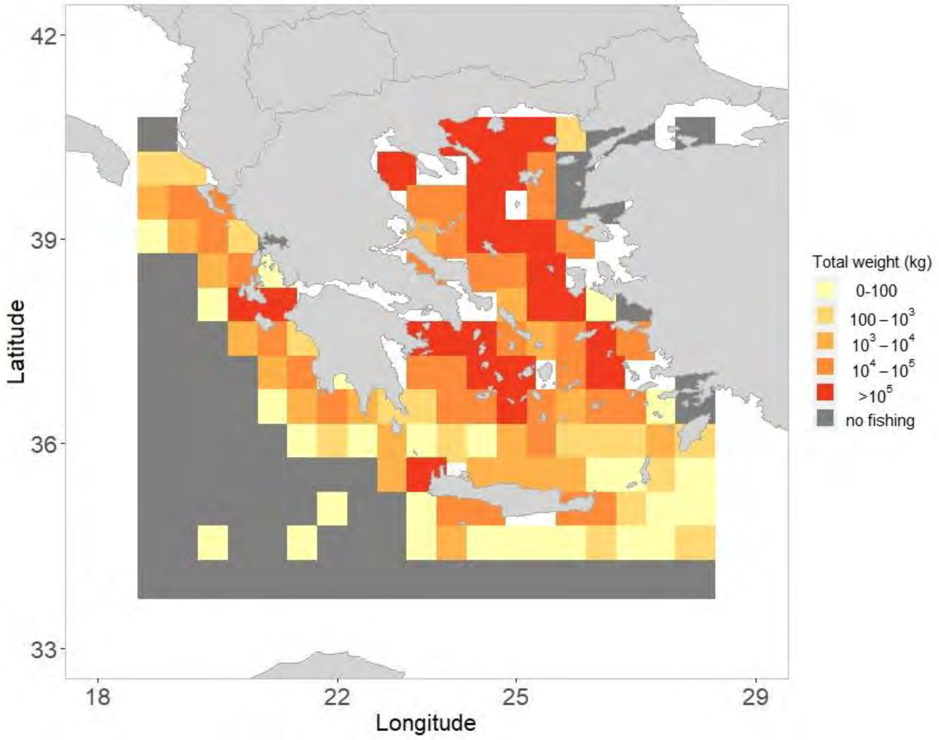


Figure 3. Distribution of average total weight of landings per year for 2016-2019 from mobile bottom contacting gear (source of information: https://stecf.jrc.ec.europa.eu/dd/fdi).

Pressure

The distribution of fishing intensity in Greece has a strong spatial variation (Figure 1). Areas of higher intensity occur in the northern Aegean Sea closer to the coastal zone, with a number hot spots in the Aegean and Ionian Seas. Areas with lower intensity occur in the southern part of the Aegean Sea which is deeper and less productive.

The proportion of area subject to fishing pressure differs between MSFD broad habitat types and is highest in offshore circalittoral mud (MSFD BHT/EUNIS level2 code: MD6, 81% of grid cells fished) and offshore circalittoral sand (MSFD BHT code: MD5, 68% of grid cells fished) (Table 1 and Figure 4 for MSFD BHT codes) followed by circalittoral mud (MSFD BHT codes: MC6, 62% of grid cells fished). Fishing intensity (SAR) is highest in the EMODnet combination habitat group 'circalittoral mud or offshore circalittoral mud' (MSFD BHT codes: MC6 & MD6, average intensity = 0.63 year-1) and circalittoral sand (MSFD BHT code: MC5, average intensity = 0.61 year-1) followed by offshore circalittoral sand (MSFD BHT code: MD5, 0.41 year-1). The smallest proportion of habitat with 90% of effort for the above mentioned 4 habitats varies between 37-42% (Table 1).

The highest weight and economic value of landings are recorded in the 'upper or lower bathyal sediment' habitat group (55500 tonnes and 39x106 euros, around 56% of total weight and 39% of total value) (Table 2). In this case in reality these figures relate to the upper bathyal sediment BHT (codes: ME3-ME6).

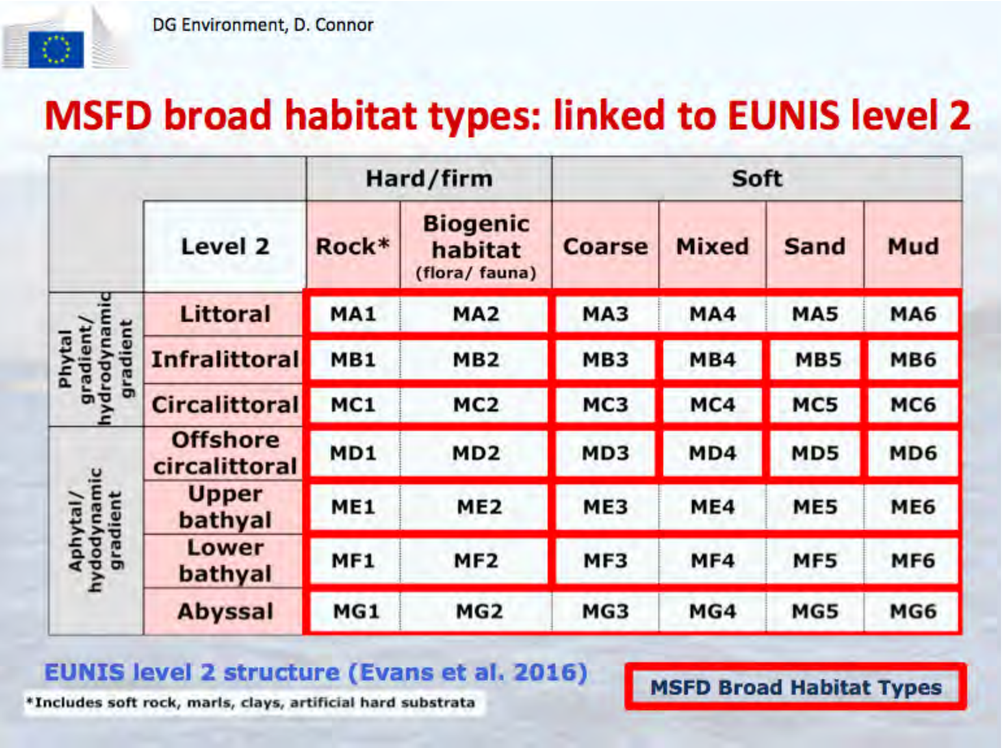
Table 1. Pressure indicators of mobile bottom-contacting gears at 0.05 x 0.05 degrees grid for Greece per MSFD broad-scale habitat type averaged for 2015-2018. Note: MSFD Broad habitat types are shown in order of extent of habitat not fishing intensity. The EMODnet habitat group 'Upper bathyal sediment or Lower bathyal sediment' includes large areas beyond legislated fishing depth limit (1000 m) and combining this with the lower bathyal unfished habitat results in low SAR and other metrics.

MSFD broad habitat type	Extent of habitat (1000 km^2)	Number of grid cells	Swept area 1000 km^2	Average fishing intensity (I-1) SAR by BHT	Prop. of area in fished grid cells (I-2)	Prop. of area fished per year (I-3)	Smallest prop. of area with 90% of fishing effort (I-4)
Upper bathyal sediment or Lower bathyal sediment	351.32	14128	10.4	0.03	0.18	0.03	0.08
Circalittoral sand	10.85	452	6.63	0.61	0.56	0.35	0.31
Circalittoral mud or Offshore circalittoral mud	9.21	388	5.86	0.63	0.44	0.38	0.32
Circalittoral mud	13.65	560	5.38	0.4	0.62	0.3	0.34
Offshore circalittoral mud	13.5	558	3.92	0.29	0.81	0.25	0.42
Offshore circalittoral sand	4.66	195	1.9	0.41	0.68	0.3	0.37
Unknown	19.01	781	1.67	0.09	0.26	0.08	0.14
Infralittoral mud	6.96	285	0.82	0.12	0.18	0.09	0.1
Infralittoral sand	6	248	0.36	0.06	0.15	0.05	0.08
Circalittoral coarse sediment	1.59	66	0.1	0.06	0.26	0.06	0.15

MSFD broad habitat type	Extent of habitat (1000 km²)	Number of grid cells	Swept area 1000 km²	Average fishing intensity (I-1) SAR by BHT	Prop. of area in fished grid cells (I-2)	Prop. of area fished per year (I-3)	Smallest prop. of area with 90% of fishing effort (I-4)
Circalittoral mixed sediment	0.6	25	0.05	0.08	0.28	0.08	0.12
Infralittoral rock and biogenic reef	0.41	17	0.04	0.09	0.18	0.07	-
Offshore circalittoral coarse sediment	0.27	11	0.02	0.08	0.18	0.08	-
Offshore circalittoral mixed sediment	0.34	14	0.01	0.04	0.14	0.04	-
Abyssal	7.59	302	0	0	0	0	-
Infralittoral coarse sediment	1.23	51	0	0	0.06	0	0.02
Infralittoral mixed sediment	0.17	7	0	0.01	0.14	0.01	-

Table 2. Total value and weight of landings of mobile bottom-contacting gears at 0.5 x 0.5 degrees grid for Greece per MSFD broad-scale habitat type averaged for 2016-2019

MSFD broad habitat type	Extent of habitat (1000 km²)	Number of grid cells	total weight of landings (1000 tonnes)	total value of landings (10^6 euros)
Upper bathyal sediment or Lower bathyal sediment	391.02	157	5.55	39.09
Unknown	17.07	7	0.46	3.86
Abyssal	12.59	5	0.00	0.01
Infralittoral mud	12.15	5	1.41	11.4
Offshore circalittoral mud	12.05	5	0.6	5.01
Circalittoral mud	9.7	4	0.54	4.17
Circalittoral sand	9.55	4	0.67	4.71
Infralittoral sand	4.84	2	0.05	0.41
Circalittoral mud or Offshore circalittoral mud	4.79	2	0.36	3.46
Offshore circalittoral coarse sediment	2.44	1	0	0
Circalittoral coarse sediment	2.39	1	0	0
Offshore circalittoral sand	2.35	1	0	0



DG Environment, D. Connor

MSFD broad habitat types: linked to EUNIS level 2

		Hard/firm		Soft			
	Level 2	Rock*	Biogenic habitat (flora/ fauna)	Coarse	Mixed	Sand	Mud
Phytal gradient/ hydrodynamic gradient	Littoral	MA1	MA2	MA3	MA4	MA5	MA6
	Infralittoral	MB1	MB2	MB3	MB4	MB5	MB6
	Circalittoral	MC1	MC2	MC3	MC4	MC5	MC6
Aphytal/ hydrodynamic gradient	Offshore circalittoral	MD1	MD2	MD3	MD4	MD5	MD6
	Upper bathyal	ME1	ME2	ME3	ME4	ME5	ME6
	Lower bathyal	MF1	MF2	MF3	MF4	MF5	MF6
	Abyssal	MG1	MG2	MG3	MG4	MG5	MG6

EUNIS level 2 structure (Evans et al. 2016)

*Includes soft rock, marls, clays, artificial hard substrata

MSFD Broad Habitat Types

Figure 4. MSFD Broad habitat types linked to EUNIS level 2 habitats.

Core fishing ground

No analysis of otter trawl fishing grounds has yet been attempted following the ICES routines (but studies are underway).

Fishing by métier

There is only one mobile bottom contact gear métier, the otter trawl (OTB mixed demersal) métier reported here. Although there is a distinct shelf and upper bathyal fishery.

Impact

A preliminary application of the PD model has been performed with more data collected aiming to increase coverage of BHT and depths, although this will also require the updating of the depletion rates for depths greater than 200 m (currently the limit of the ICES PD model application as there is no longevity prediction for deeper areas). A large part of the trawl effort and weight/value of landings is directed/originates from upper bathyal sedimentary habitats.

Management scenarios

There has been no elaboration of analysis of management scenarios, however previous experimental gear selectivity studies (e.g. BENTHIS project) have shown extremely limited potential of gear substitution (e.g. to replace otter trawl with pots/creels) and limited potential for technical alterations (e.g. substitute otter trawl boards with pelagic doors). In addition, concerning modifications using pelagic doors, reduced fuel costs have been indicated, but potential reduction in seabed penetration/physical impact has not been studied and there might not be a significant effect in benthos depletion rates, ameliorating impacts. Other gear modifications e.g. selectivity improvements, are needed for overexploited stocks as recent studies have concluded (e.g. EPI-LEXIS project). Spatial management measures are also highly relevant (e.g. exclusion of sensitive habitats, already implemented for certain habitats). Soma *et al*. (2018) reports on stakeholder preferences on measures mitigating benthic impacts in European seas including Greece.

Western Mediterranean Sea, Spain

Authors: Ulla Fernández Arcaya, José Manuel González Irusta, Antonio Punzon

Summary

The physical disturbance pressures from mobile bottom-contacting fishing gears varies spatially in the Spanish Western Mediterranean sub- region with 39% of the grid cells (I-2), and 22% of the surface area (I-3) being fished on average per year 2019 from 0-200m (Table 1). Note that most of proportions of unfished cells are located below 1000 depth, where bottom trawling is banned in the Mediterranean. These percentages will increase if we limited the computation only to areas available for trawling. Because of this, fishing is very aggregated with 90% of the pressure occurring in 17% of grid cells (I-4). The FI (I-1) decrease from 0-200m to 200-1000 m depth strata (0.35 to 0.19 respectively).

The ICES methods for computing impact are not available at the moment in the region and therefore, this part of the analysis has not been completed. Map of spatial distribution of fishing intensity is shown in Figure 1.

Table 1. Pressure indicators for 2019

Pressure indicators	Total area	0-200 m	200-1000m	>1000m
Intensity (I-1)	0.55	0.35	0.19	NA
Proportion of area in fished cells (I-2)	0.39	0.21	0.21	NA
Proportion of area fished per year (I-3)	0.22	0.14	0.1	NA
Smallest prop. of area in fished cells with 90% of fishing effort (I-4)	0.17	0.1	0.08	NA
Proportion of area in unfished cells (I-5)	0.61	0.79	0.79	NA

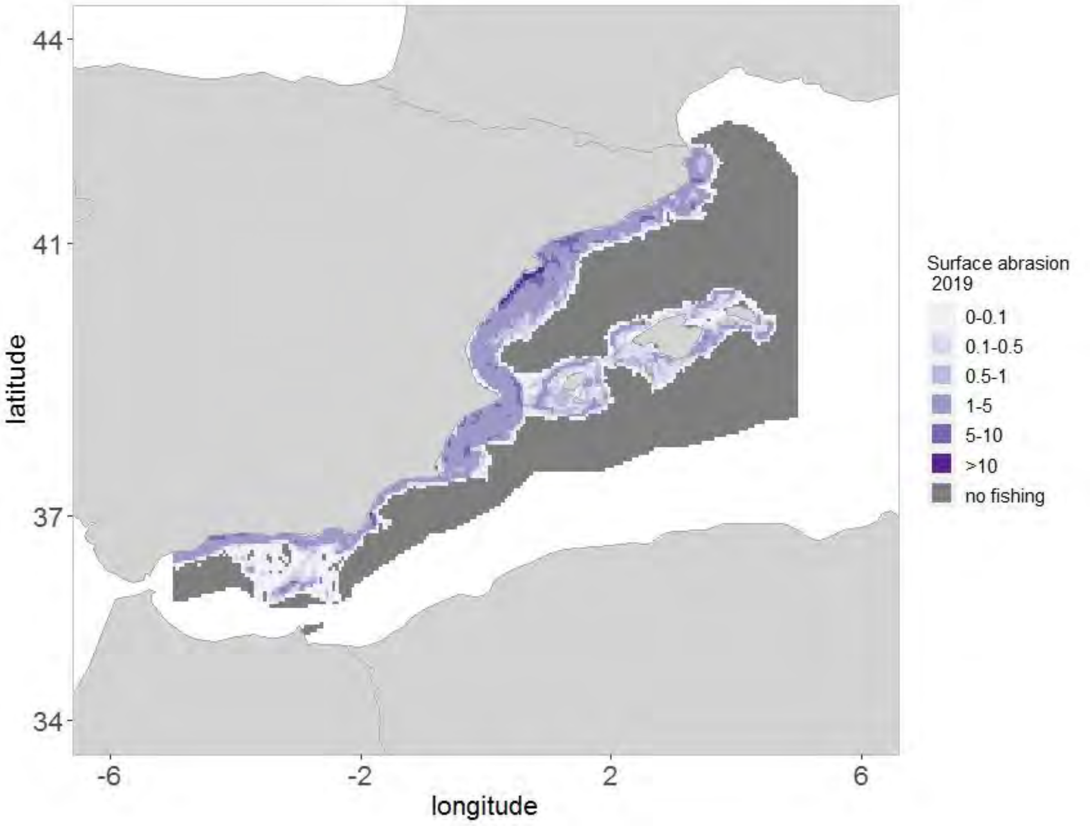


Figure 1. Distribution of average swept area ratio (SAR) for 2019 from mobile bottom contacting gear.

Pressure

The distribution of fishing intensity in the Western Mediterranean sub-region Sea in 2019 showed a spatial variation (Figure 1). Areas of higher intensity occur in the continental shelf, mostly concentrate in the Southern Balearic Sea, adjacent to the Ebro River Delta and Gulf of Valencia. Higher fishery intensity also occurs at deeper areas along the continental slope of Ibiza channel and at the slopes adjacent to submarine canyons in the western part of the Mediterranean. Areas with lower intensity occur in Balearic Island and Northern Alboran Sea.

The proportion of area subject to fishing pressure in 2019 differs between broad-scale habitats and is highest in Circalittoral mud (100% of grid cells fished) and Circalittoral coarse sediment (100% of grid cells fished) (Table 2). The fishing intensity is highest in the EMODnet combination habitat group of Circalittoral mud or Offshore circalittoral mud (average intensity = 4.28).

The temporal variations in the distribution of fishing intensity are not available at the moment in the region and therefore this part of the analysis has not been completed.

Table 2. Pressure indicators of mobile bottom-contacting gears at 0.05 x 0.05 degrees grid per MSFD broad-scale habitat type in 2019.

MSFD broad habitat type	Extent of habitat (1000 km2)	Number of grid cells	Swept area 1000 km2	Average fishing intensity (I-1)	Prop. of area in fished grid cells (I-2)	Prop. of area fished per year (I-3)	Smallest prop. of area with 90% of fishing effort (I-4)
Upper bathyal sediment or Lower bathyal sediment	138.03	5758	44.3	0.32	0.32	0.15	0.12
Abyssal	46.13	1917	0	0	0	0	NA
Circalittoral sand	12.13	507	18.57	1.53	0.98	0.71	0.56
Offshore circalittoral sand	7.52	316	9.64	1.28	0.97	0.68	0.59
Circalittoral mud or Offshore circalittoral mud	7.18	303	30.75	4.28	1	0.97	0.75
Upper bathyal rock and biogenic reef or Lower bathyal rock and biogenic reef	3.08	124	2.36	0.77	0.81	0.4	0.35
Offshore circalittoral mud	3.05	127	6.9	2.26	0.91	0.86	0.67
Circalittoral mud	2.88	121	8.62	3	1	0.97	0.77
Infralittoral sand	1.84	77	1.28	0.69	0.92	0.42	0.39
Infralittoral rock and biogenic reef	1.82	76	1.02	0.56	0.86	0.37	0.39
Circalittoral coarse sediment	1.29	54	1.11	0.86	1	0.55	0.61
Circalittoral rock and biogenic reef	1.1	46	1.83	1.66	0.98	0.67	0.52
Infralittoral coarse sediment	0.31	13	0.19	0.6	0.92	0.31	NA
Offshore circalittoral rock and biogenic reef	0.24	10	0.47	1.91	1	0.7	NA
Infralittoral mud	0.12	5	0	0	0.2	0	NA
Offshore circalittoral coarse sediment	0.12	5	0.09	0.77	1	0.56	NA
Na	0.02	1	0	0.17	1	0.17	NA
Circalittoral mixed sediment	0.02	1	0.01	0.43	1	0.43	NA

Core fishing ground/Fishing by métier

Not available

Impact/ Management scenarios

Not available

Mediterranean Sea, Italy

Authors: Sasa Raicevich, Marina Pulcini, Raffaele Proietti, Lorenzo D'Andrea

Summary

The distribution of effort by fishing gears (OTB only presented here) varies spatially in Italy and is strongly dependent on the bathymetry of its basins. In the Italian waters rules regarding minimum distance from the coast (3 nm) or depth (50 m) are enforced restricting trawling in the very shallow/coastal areas. In the Mediterranean, trawling is forbidden in waters deeper than 1000m. Spatiotemporal closures are also enforced in the coastal areas while some permanent closures to fishing have been recently established in some Fisheries Restricted Areas (FRAs). It is worth mentioning that in international waters fishing belonging to other countries could be present but not included in these data (e.g. Greek, Tunisian and Libyan, Spanish and French vessels) depending on the subregion.

Maps of the spatial distribution of intensity for OTB (average 2015-2019), are shown in Figures 1, 2, 3 and the respective data are summarized in tables 1, 2, 3.

Pressure

The distribution of fishing intensity in Italian waters (National Waters + Ecological Protection Zone) has a strong spatial pattern, mostly dependent on the bathymetry of its basins (Figures 1, 2, 3). Areas of highest fishing intensities (SAR > 10) occur relatively close to the coastal areas, in the central Western Mediterranean Sea (WMS; along the Italian western coast; Fig. 1), the Sicily channel (Ionian and Central Mediterranean Sea, ICMS; Fig. 2) and the Adriatic Sea (AS; eastern Italian coastline; Fig. 3). Indeed, in large part of Italian waters, the continental shelf is very narrow, and the limit of 1000m depth could be reached few nautical miles from the seashore, thus restricting the area that can be effectively exploited by mobile benthic contacting fishing gears.

Circalittoral mud, Offshore circalittoral Mud, and Circalittoral Mud or offshore Circalittoral Mud are the Broad Habitat Types (BHT) subject to the highest average fishing intensities from trawling in the three subregions, with an average intensity per year/cell of 3.38, 2.74 and 4.28 in WMS, ICMS and AS, respectively. Circalittoral sand and offshore circalittoral sand also show relatively high fishing pressure.

Core fishing ground

No analysis of otter trawl fishing grounds has yet been attempted following the ICES routines (but studies are underway). According to expert knowledge, the spatial distribution of the fishing grounds showing highest fishing pressures (as shown in Figures 1 2 3) were almost stable in the considered period.

Fishing by métier

Demersal otter trawling (OTB) fishing effort distribution and intensity (as indicators I-1, I-2, I-3) were estimated for the three subregions. Rapido trawls (TBB) and Hydraulic dredging (mainly acting in the Northern and Central Adriatic Sea) were not assessed in the current analyses.

Impact

No estimate was conducted in the current analyses.

Management scenarios

Not available

Italy: Western Mediterranean Sea subregion

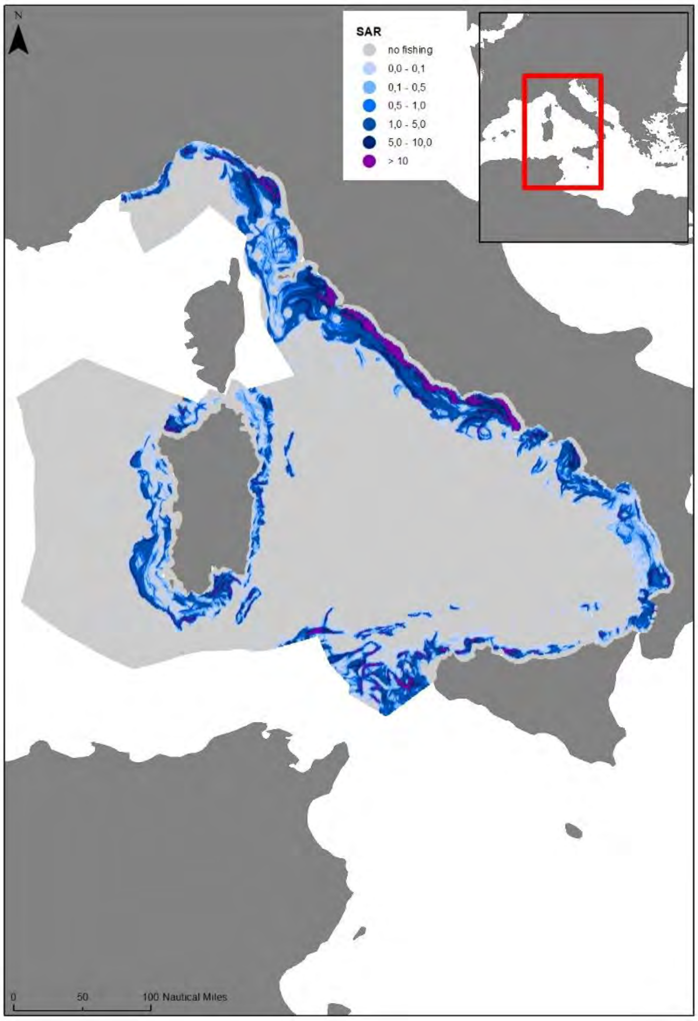


Figure 1. Distribution of average swept area ratio (SAR) per year for 2015-2019 from mobile bottom contacting gear (OTB) for Western Mediterranean Sea subregion (based on VMS data in the area from Italian vessels only). Grid cell size used is 1x1 km.

Table 1. Pressure indicators of mobile bottom-contacting gears (OTB) at 1 x 1 km grid for Western Mediterranean Sea subregion per MSFD broad-scale habitat type averaged for 2015-2019. Note: MSFD Broad habitat types are shown in order of extent of habitat not fishing intensity. The EMODnet habitat group 'Upper bathyal sediment or Lower bathyal sediment' includes large areas beyond legislated fishing depth limit (1000 m) and combining this with the lower bathyal unfished habitat results in underestimates in SAR and other metrics.

MSFD broad habitat type	Extent of habitat (1000 km^2)	Swept area 1000 (km^2)	Average fishing intensity (I-1)	Prop. of area in fished grid cells (I-2)	Prop. of area fished per year (I-3)
Upper bathyal sediment or Lower bathyal sediment	154.91	71.39	0.46	0.28	0.15
Circalittoral mud or Offshore circalittoral mud	9.92	29.53	2.98	0.95	0.72
Circalittoral sand	9.06	14.58	1.61	0.73	0.38
Offshore circalittoral mud	5.97	12.93	2.16	0.92	0.57
Circalittoral mud	2.41	8.13	3.38	0.83	0.49
Offshore circalittoral sand	3.20	3.51	1.10	0.82	0.36
Infralittoral sand	2.18	0.83	0.38	0.22	0.09
Circalittoral coarse sediment	1.56	0.72	0.46	0.61	0.25
Circalittoral rock and biogenic reef	0.68	0.39	0.58	0.68	0.24
Infralittoral coarse sediment	0.47	0.36	0.77	0.34	0.17
Infralittoral rock and biogenic reef	2.89	0.24	0.08	0.16	0.04
Infralittoral mud	0.30	0.09	0.32	0.43	0.16
Offshore circalittoral rock and biogenic reef	0.07	0.04	0.52	0.84	0.33
Upper bathyal rock and biogenic reef or Lower bathyal rock and biogenic reef	0.03	0.04	1.48	0.96	0.71
Offshore circalittoral mixed sediment	0.04	0.01	0.15	0.58	0.13
Offshore circalittoral coarse sediment	0.02	0.01	0.62	0.81	0.26
Abyssal	87.82	0.00	0.00	0.00	0.00
Circalittoral mixed sediment	0.05	0.00	0.05	0.67	0.05
Infralittoral mixed sediment	0.002	0.00	0.00	0.00	0.00
Unknown	0.08				

Italy: Ionian and Central Mediterranean Sea subregion

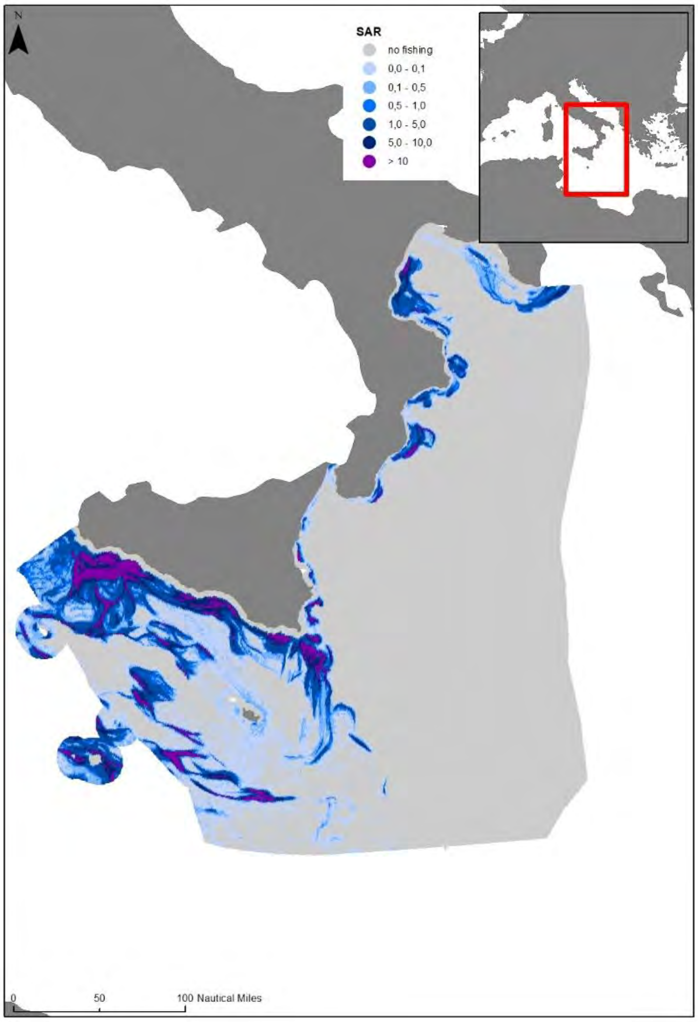


Figure 2. Distribution of average swept area ratio (SAR) per year for 2015-2019 from mobile bottom contacting gear (OTB) for the Ionian and Central Mediterranean Sea subregion (based on VMS data in the area from Italian vessels only).

Table 2. Pressure indicators of mobile bottom-contacting gears (OTB) at 1 x 1 km grid for the Ionian and Central Mediterranean Sea subregion per MSFD broad-scale habitat type averaged for 2015-2019. Note: MSFD Broad habitat types are shown in order of extent of habitat not fishing intensity. The EMODnet habitat group 'Upper bathyal sediment or Lower bathyal sediment' includes large areas beyond legislated fishing depth limit (1000 m) and combining this with the lower bathyal unfished habitat results in underestimates in SAR and other metrics

MSFD broad habitat type	Extent of habitat (1000 km^2)	Swept area 1000 (km^2)	Average fishing intensity (I-1)	Prop. of area in fished grid cells (I-2)	Prop. of area fished per year (I-3)
Upper bathyal sediment or Lower bathyal sediment	149.78	56.61	0.38	0.22	0.09
Circalittoral sand	9.34	23.37	2.50	0.84	0.55
Offshore circalittoral mud	4.14	11.32	2.74	0.87	0.53
Offshore circalittoral sand	3.19	7.50	2.35	0.82	0.48
Circalittoral mud	1.79	3.89	2.18	0.90	0.62
Infralittoral sand	1.64	0.75	0.46	0.17	0.11
Offshore circalittoral mixed sediment	1.70	0.30	0.18	0.69	0.13
Infralittoral mud	0.13	0.15	1.21	0.90	0.47
Circalittoral mixed sediment	2.61	0.14	0.06	0.37	0.04
Upper bathyal rock and biogenic reef or Lower bathyal rock and biogenic reef	1.08	0.12	0.11	0.13	0.04
Circalittoral rock and biogenic reef	0.74	0.07	0.09	0.37	0.06
Infralittoral rock and biogenic reef	0.74	0.06	0.08	0.16	0.05
Offshore circalittoral rock and biogenic reef	0.53	0.03	0.06	0.56	0.05
Abyssal	11.44	0.00	0.00	0.00	0.00
Circalittoral mud or Offshore circalittoral mud	0.04	0.00	0.07	0.80	0.07
Circalittoral coarse sediment	0.01	0.00	0.02	0.38	0.02
Infralittoral coarse sediment	0.01	0.00	0.01	0.23	0.01
Infralittoral mixed sediment	0.01	0.00	0.00	0.00	0.00
Offshore circalittoral coarse sediment	0.004	0.00	0.00	0.25	0.00
Unknown	0.43				

Italy: Adriatic Sea subregion

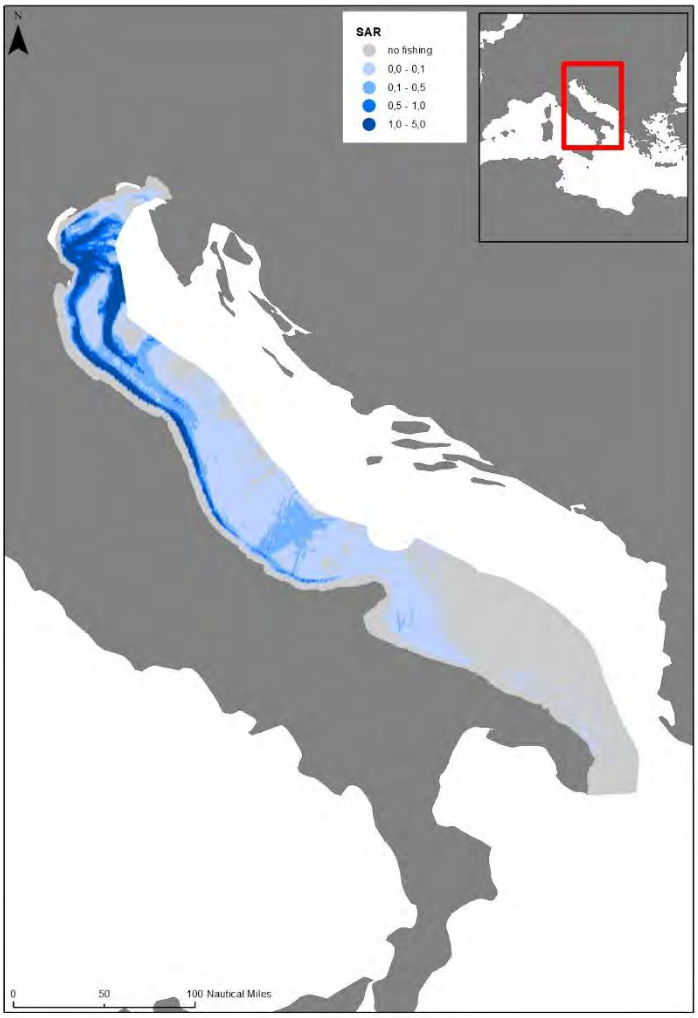


Figure 3. Distribution of average swept area ratio (SAR) per year for 2015-2019 from mobile bottom contacting gear (OTB) for the Adriatic Sea subregion (based on VMS data in the area from Italian vessels only).

Table 3. Pressure indicators of mobile bottom contacting gear (OTB) at 1 x 1 km grid for the Adriatic Sea subregion per MSFD broad-scale habitat type averaged for 2015-2019. Note: MSFD Broad habitat types are shown in order of extent of habitat not fishing intensity. The EMODnet habitat group 'Upper bathyal sediment or Lower bathyal sediment' includes large areas beyond legislated fishing depth limit (1000 m) and combining this with the lower bathyal unfished habitat results in underestimates in SAR and other metrics

MSFD broad habitat type	Extent of habitat (1000 km^2)	Swept area 1000 (km^2)	Average fishing intensity (I-1)	Prop. of area in fished grid cells (I-2)	Prop. of area fished per year (I-3)
Circalittoral mud or Offshore circalittoral mud	29.00	124.22	4.28	0.90	0.87
Offshore circalittoral mud	6.45	18.13	2.81	1.00	0.79
Circalittoral sand	6.61	14.63	2.21	0.90	0.71
Upper bathyal sediment or Lower bathyal sediment	12.34	7.99	0.65	0.30	0.14
Offshore circalittoral sand	1.15	2.79	2.42	0.98	0.91
Circalittoral mud	0.35	0.88	2.56	0.90	0.71
Infralittoral sand	1.65	0.39	0.24	0.06	0.05
Circalittoral rock and biogenic reef	0.37	0.24	0.63	0.29	0.22
Circalittoral mixed sediment	0.10	0.01	0.07	0.22	0.07
Infralittoral rock and biogenic reef	0.36	0.00	0.00	0.01	0.00
Infralittoral mud	0.10	0.00	0.00	0.00	0.00
Offshore circalittoral mixed sediment	0.02	0.00	0.28	1.00	0.27
Infralittoral mixed sediment	0.01	0.00	0.01	0.20	0.01
Infralittoral coarse sediment	0.00	0.00	0.00	0.00	0.00
Unknown	0.04				