DELIVERABLE 5.5

SEAwise report on predicting effect of changes in 'fishable' areas on fish and fisheries

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SEAWISE

Executive summary

This report aims to investigate the available tools for predicting the impact of various spatial management options on fisheries distribution, yield, profitability, and selectivity. Such spatial plans may affect the remaining 'fishable' areas by displacing and concentrating the fishing pressure, and so may alter stock abundances, distributions, size- and species catch composition and fuel expenditure and cost. The report provides early insights into how spatial plans that exclude certain fishing activities may affect these outcomes. Spatially explicit approaches are used, along with scenarios of underlying stock productivities and distributions, to assess the performance of spatial management measures. Scenario-based testing is conducted to examine the interrelated effects of management options and stock productivity. A major aspect of the work involved gathering and organizing information on specific zones from several sources such as Natura2000, CDDA, SPA, SAC, and UK-defined areas. We found that most of these zones did not have any previous management plans in place that would outline fishing restrictions. Therefore, we developed a method of assigning limitations to certain fishing techniques based on the perceived vulnerability of specific areas to these practices. This approach has allowed for an examination of how these restrictions potentially affect fish and fisheries.

Initially, we used **a static approach** in anticipating the potential fishing effort displacement to measure the impact of fishing in the Northeast Atlantic area. Our research shows that while such spatial management measures may reduce fishing opportunities, it may be possible to offset in the short term some of these spatial opportunity losses by fishing in nearby locations (Figure 1). On the Med side, an analysis of fishing effort displacement from restricted areas in the Adriatic Sea is exemplified in a before/after situation, showing that the effort is not reduced but redistributed and can further redistribute far from the restricted areas.

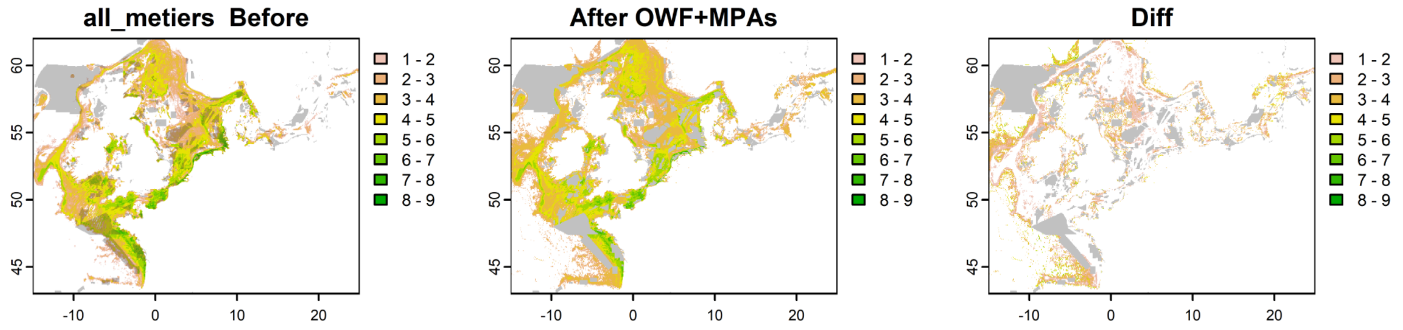

Figure 1. Static evaluation of effort displacement effect on the EU fleet Gross Added Value (categorized in million euros) before/after implementation of spatial restrictions excluding all fishing activities from currently designated conservation areas in Northeast Atlantic EU waters and UK EEZ

If in the short term, spatial management may increase operating costs by displacing the effort, this may eventually be recovered in the long term if the stock is recovering from previous overfishing. To determine whether conservation measures (such as Marine Protected Areas) that limit specific fishing techniques and areas could help mitigate the negative effects of fishing, a more advanced approach to fisheries management is required. This involves using **a dynamic approach** deploying spatial bioeconomic models that consider changes in environmental drivers and spatial restrictions, allowing it to assess potential changes in fishing effort facing, for example, new regulatory or ecological conditions. While bioeconomic models require more data and assumptions to forecast "alternative futures", they offer a more comprehensive approach to fisheries management, which is particularly useful as testing MPAs effects in real life is a challenge. A suite of bioeconomic models has been deployed to provide preliminary findings about the effect of spatial restrictions on fish, fisheries, benthos and bycatch:

- International fisheries active in the North Sea were modeled using DISPLACE, testing the implementation of spatial restrictions to specific fishing techniques. Based on the simulations, the benthos status improved in areas where bottom fishing was excluded from previously fished areas and decreased in newly fished areas.

However, the gain by EU closure areas was limited and no change in fish size selectivity detected as these areas are not really significant for bottom fishing and have not been initially designated to modify selectivity.

- In the eastern Ionian Sea, different spatial restrictions for fishing techniques were evaluated using the DISPLACE model. While there may have been advantages to the fishing restrictions, there has been an increase in both unwanted catch and fishing effort, and no significant improvements were observed in the harvesting of adult fish. The alternative scenarios tested were insufficient to make fishing fleets more selective. Additionally, certain fishing fleets were economically adversely affected.
- East Adriatic trawlers may benefit from being forced closer to shore after the closure of their traditional fishing grounds while the Italian trawling fleet experiences higher steaming costs, likely due to the closure of nursery grounds and FRAs and redistribution to other areas. ECOSPACE predicted that the mean trophic level of fish caught in deeper waters, closed to bottom trawlers but still accessible to pelagic fisheries, will increase. ECOSPACE indicated a marked rise in biodiversity in the central Adriatic area under the closures scenario. The reported outcome for ECOSPACE should be considered preliminary as it may have been influenced by the assumptions used to build and parameterize the model.
- ECOSPACE predicted a significant rise in biomass for the southern North Sea in response to area closures. Fish biomass could increase by up to 15%. However, this increase may not be sufficient to compensate for the decline in biomass outside the MPA from more pressure on specific fish species. This, in turn, caused a decrease in overall catches. Within the MPAs, all fishing fleets experienced losses of up to 50%, while outside the MPAs, there was an increase of up to 13% in catches. Nonetheless, the gains outside the MPAs did not compensate for the losses incurred due to the closures.
- ECOSPACE investigation on how spatial fisheries management affects the food web and fisheries in the eastern Ionian Sea was used to evaluate the spatial distribution of fishing effort for two scenarios - one with existing closed areas and another with possible future closed areas. Preliminary findings indicate that if all fishing activities are restricted from MPAs (as in the second scenario), there is an increase in fishing effort throughout the study area, rather than just around the MPAs.
- Using an agent-based model of the southern North Sea and the German fisheries, spatial restrictions were shown to possibly result in reduction in fishing effort, concentration of fishing effort in the remaining open areas, longer steaming times, and lower profits. The spatial scenarios heavily affect the German shrimp fishery due to large overlaps with coastal shrimp fishing grounds, while flatfish and Nephrops fisheries are less affected. Scenarios reduced the fishing effort of all métiers suggesting that switching métiers and relocating fishing effort could not negate the impact of spatial fishing closures.
- In the North Sea, the OSMOSE model was used to test scenarios of effort redistribution and effort reduction. The results indicated a slight increase in the biomass of demersal species, but a significant decrease in the biomass of pelagic species. Both scenarios showed an increase in the relative biomass of protected, endangered, and threatened (PET) species when effort was reduced. Additionally, changes in the food web led to an increase in the catch of commercial species above minimum conservation size.
- A spatial BEMTOOL is being implemented applied to the Adriatic and western Ionian Seas active and passive demersal gears fleet segments. The effort data for the main ports in the study area was explored to identify the fishing grounds that are more frequently visited by fishers and to gain insights into their fishing strategies.

In summary, prohibition of certain fishing techniques in all currently designated MPAs has minimal impact on the fisheries economy of most fleet-segments examined and fish populations in the short term. This is primarily because these areas are preserved due to their significance as hotspots of EU marine biodiversity, rather than selected for a high abundance of commercial fish. Some segments, however, may require >15% extra effort to break even. In an upcoming study, SEAwise partners will investigate conservation areas the selectivity of fish size.

Contents

1. SEAwise background

The SEAwise project works to deliver a fully operational tool that will allow fishers, managers, and policymakers to easily apply Ecosystem Based Fisheries Management (EBFM) in their own fisheries. With the input from advice users, SEAwise identifies and addresses core challenges facing EBFM, creating tools and advice for collaborative management aimed at achieving long-term goals under environmental change and increasing competition for space. SEAwise operates through four key stages, drawing upon existing management structures and centered on stakeholder input, to create a comprehensive overview of all fisheries interactions in the European Atlantic and Mediterranean. Working with stakeholders, SEAwise acts to:

- Build a network of experts - from fishers to advisory bodies, decision makers and scientists - to identify widely accepted key priorities and co-design innovative approaches to EBFM.
- Assemble a new knowledge base, drawing upon existing knowledge and new insights from stakeholders and science, to create a comprehensive overview of the social, economic, and ecological interactions of fisheries in the European Atlantic and Mediterranean.
- Develop predictive models, underpinned by the new knowledge base, that allow users to evaluate the potential trade-offs of management decisions, and forecast their long-term impacts on the ecosystem.
- Provide practical, ready-for-uptake advice that is resilient to the changing landscapes of environmental change and competition for marine space

The project links the first ecosystem-scale impact assessment of maritime activities with the welfare of the fished stocks these ecosystems support, enabling a full-circle view of ecosystem effects on fishing productivity in the European Atlantic and Mediterranean. Drawing these links will pave the way for a whole-ecosystem management approach that places fisheries at the heart of ecosystem welfare. In four cross-cutting case studies, each centered on the link between social and economic objectives, target stocks and management at the regional scale SEAwise provides:

- Estimates of impacts of management measures and climate change on fisheries, fish and shellfish stocks living close to the bottom, wildlife bycatch, fisheries-related litter and conflicts in the use of marine space in the Mediterranean Sea,
- Integrated EBFM advice on fisheries in the North Sea, and their influence on sensitive species and habitats in the context of ocean warming and offshore renewable energy,
- Estimates of effects of environmental change on recruitment, fish growth, maturity and production in the Western Waters,
- Key priorities for integrating changes in productivity, spatial distribution, and fishers' decision-making in the Baltic Sea to create effective EBFM prediction models.

Each of the four SEAwise case studies will be directly informed by expert local knowledge and open discussion, allowing the work to remain adaptive to change and responsive to the needs of advice users.

1.1 The role of this deliverable

This deliverable is the first of two deliverables that will describe predictions of the impact of spatial management options on fisheries distribution, yield, profitability and selectivity. The present report provides evaluations of the effect of spatial management measures on the current fisheries effort allocation potentially displacing it to change catch amount of harvested stocks. This first investigation forms the basis for the conditioning of existing fisheries and ecosystem modelling tools including management strategies employing a combination of management measures (spatial as well as non-spatial).

Spatially-explicit modelling is used to predict and evaluate the performance of spatial management measures with scenarios of underlying stock productivities and distributions informed from Tasks 5.2 and 5.4, and fisheries from Task 5.3. SEAwise evaluated already designated spatio-temporal closures to protect fish habitats, sensitive areas or bycatch and target species, with possible selectivity changes and technical measures or TAC and effort management when fully implemented and enforced.

The scenario-based exploration of interlinked effects of management options and stock productivity will, in the second deliverable to come, predict fisheries distribution, yield, profitability, selectivity and ecosystem effects spatially. Established spatial modelling tools are to be conditioned to the case studies, with the choice of method reflecting on the focus and on the type and quality of data available.

1.2 Contributors

Table 1. Names and roles of contributors to this deliverable.

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1.3 Acronyms and abbreviations

AIS: Automatic Identification System

AER: Annual Economic Report (A STECF deliverable)

BACI: Before After Control Impact experimental design

CFP: Common Fisheries Policy

CDDA: Common Database on Designated Areas

EAFM: Ecosystem Approach to Fisheries Management

EBFM: Ecosystem Based Fisheries Management

EEA: European Environmental Agency

EEZ: Exclusive Economic Zone

FDI: Fisheries Dependent Information (a STECF database)

FRA: Fisheries Restricted Area

FUI: Fuel Use Intensity

GAM: Generalized Additive Models (a type of SDM)

GFCM: General Fisheries Commission for the Mediterranean

GSA: A geographical subarea in the Med as defined by GFCM

IPCC: Intergovernmental Panel on Climate Change

MPA: Marine Protected Area

MSP: Maritime Spatial Planning

MSFD: EU Marine Strategic Framework Directive

NATURA 2000: sites name from the designation of conservation areas from the Birds and Habitat EU directives

NEA: Northeast Atlantic

OWFs: Offshore Windmill Farms

OECM: Other Effective Conservation Areas

PET: Protected Endangered and Threatened

RBS: Relative Benthos Status

SAC: Special Areas of Conservation

SCI: Sites of Community Importance

SDM: Spatial Distribution Modelling

STECF: Scientific, Technical and Economic Committee for Fisheries

TMR: EU Technical Measures Regulation

VME: Vulnerable Marine Ecosystem

VMS: Vessel Monitoring System

VPUF: Value per unit of effort

2. Improved understanding of spatial restriction effects

SEAwise is aiming to advance the ecosystem approach to fisheries management in EU fisheries and area-based management and spatial measures are a key management tool. The evaluation of these measures requires spatial models to also account for the fact that biological processes take place in space and are influenced by changes in environmental variables that occur across different seasons, areas, and regions. Similarly, the fishing fleets' activities are also a function of space and time, as they determine where and when to fish, which ultimately impacts the profitability of their operations.

Because of these ecological and economic considerations, spatial phenomena are important factors to consider when evaluating spatial restrictions of fishing practices, such as No-Take Zones, as a management tool for EBFM. These are often established to limit the status deterioration of sensitive species and habitats, also acting as a reservoir of individuals or recruitment for exploited stocks. Such spatial plans may affect the remaining ‘fishable’ areas by displacing and concentrating the fishing pressure, and so may alter stock abundances, distributions, size- and species catch composition and fuel expenditure and cost.

Hence, besides already existing area-based measures following the EU Habitats Directive (92/43/EEC) and the Birds Directive (2009/147/EC) that led to designate the EU Natura 2000 sites in the early 2000s, new management objectives have been recently introduced with the EU Fisheries package (EC, 2023) as part of the international Biodiversity Strategy for 2030 and the EU Green Deal, which targets protecting 30% of the surface area of the EU waters, including 10% strictly protected i.e. excluding any human activities. SEAwise foresees that part of these surface area will come from enforcing strict protection over areas that have been already designated vulnerable to some fishing techniques.

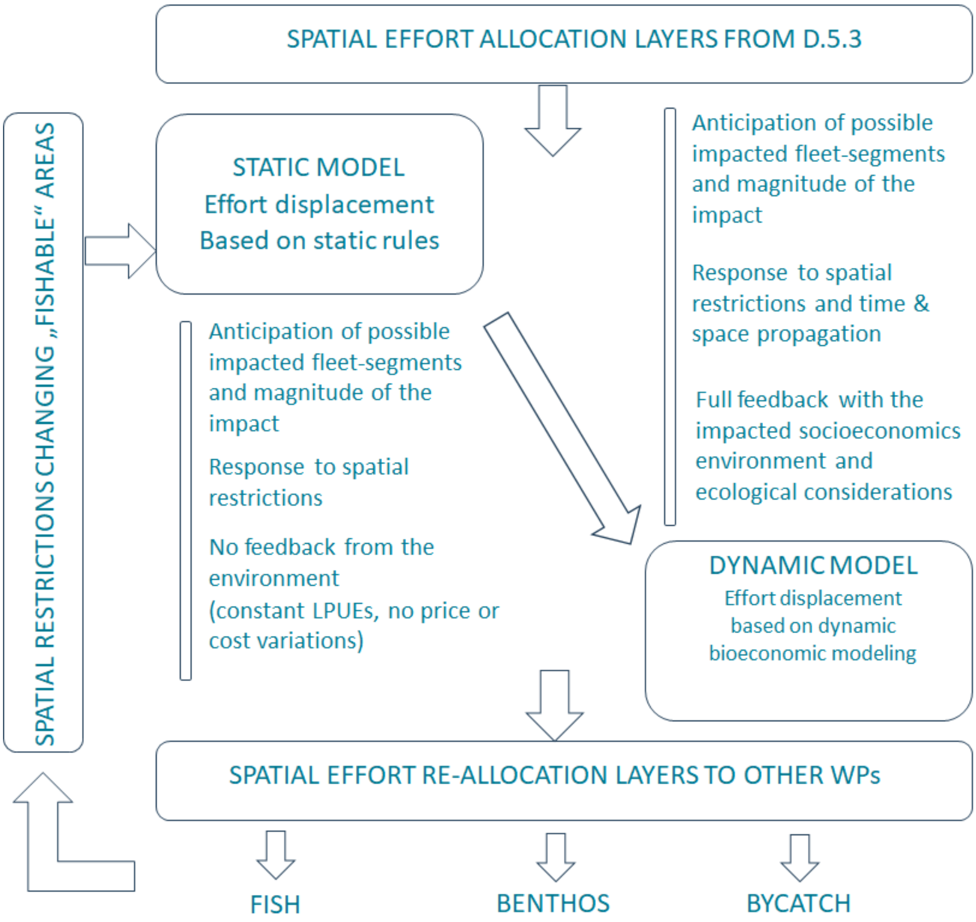
SEAwise D5.1 concluded that there are few studies on the factors that determine fisheries distribution, and fewer more on how a change in marine areas available for fishing would affect fish and fisheries. When studies are available, they are almost exclusively focused on trawl fishing in the North Sea. While knowledge on the effects of habitats on species, and therefore on spatial fishing opportunities, did exist, this was restricted to the Baltic Sea and North Sea and studies addressing this outside these areas were close to non-existent. This contrasts with the interests of consulted stakeholders (see SEAwise D5.1 2022) that focused on factors causing changes to the distribution of commercial fish/shellfish (climate change, MPAs, species interactions, pollution, habitats and invasive species) and fisheries (windfarms, MPAs, Marine spatial planning) as well as the other human impacts with spatial characteristics (other human activities).

The first activity in SEAwise was to review the potential impacts of spatial management on fisheries, starting from the effect that would result from enforcing restrictions on already existing areas (mainly the Natura 2000 sites and the nationally designated conservation areas). The primary goal was to gather and organize data necessary for evaluating effects on historically fished areas across SEAwise case studies, identifying potential areas for fishing, and predicting changes in these areas under different area-based management scenarios.

Following this, we started with a static view of fisheries displacement and gradually moved towards a more complicated view, taking account of the dynamic nature of the exploitation and the resources and opportunities within the fisheries. The ultimate goal will be to include the effect of a changing climate (IPCC scenarios). Such scenarios and fishing strategies should be explored in a second phase with spatial dynamic bio-economic models of fisheries wherever possible.

This task describes the predicted impact of spatial management options on fisheries distribution, yield, profitability, selectivity, and fuel use, including the feedback on the exploited and non-exploited marine living resources. For this task, SEAwise has adopted a stepwise approach (see Figure below). First, SEAwise has created a shapefile that lists all the restricted areas in EU waters. The file specifies restrictions on certain fishing practices depending on the site's vulnerability. This vulnerability may be due to the type of habitat or, the species present in the area, or a combination of both.

Second, we continued by overlaying the identified spatial restrictions onto existing fishing effort allocations for specific activities and used a static approach to apply a spatial displacement scenario based on the expected profitability of a fishing zone. We used static effort reallocation rules or fishers' behavioural rule modules based on the main findings of Task 5.3, which identify expected revenue on zones as a major driver, to anticipate where effort could be displaced. In such an approach, the ´fishable area´ is assumed to be within the existing explored area already fished, minus the area excluding fishing activities (from fisheries regulations or other uses of the marine space). While understanding the location choices of fishers can provide insight into the potential for displacement in spatial planning processes, it is very challenging to capture other possible drivers that apply to all types of fisheries (see SEAwise D2.5), and this has not been attempted in this first static evaluation. Deploying more sophisticated approaches, like the existing dynamic bioeconomic models presented later in the document, can capture additional decision-making factors.



This report describes the initial runs of bioeconomic models in various regions. These findings serve as a foundation for exploring potential scenarios related to changes in marine space usage and fisheries opportunities. Chapter 5 of this report provides details on the models' architecture and capabilities and discusses how they can be utilized to analyse the impact of spatial restrictions using a "BACI" (Before/After/Control/ Impact) approach. In particular, the first insights are presented of how ECOSPACE can be used in the southern North Sea, or the Adriatic Sea, or DISPLACE in the Ionian Sea or the North Sea, and OSMOSE in the North Sea.

This task delivers to other SEAwise studies, especially “2.2. Economic and climate impacts of fishing” is expecting input from 5.5, or “4.2 effects of fishing on bycatch” is expecting input from 5.5, or WP6 is largely linked to 5.5 spatial management scenarios, with products including:

- An overall spatial layer for spatial restrictions in EU waters per type of fishing techniques (bottom trawling, netting, longlining) depending on the perceived site vulnerability
- Fishing activities split in spatial layers per economic fleet segment before/after effort displacement

These outcomes will be used to reach the SEAwise deliverable D5.6 objectives with first insights into the conditioning of bioeconomic spatial fisheries models. These bioeconomic spatial fisheries models will test the effects of change in fishable areas induced by spatial restrictions identified by SEAwise, added to possible effects induced by climate change. The final product will eventually feed into “Task 5.6: Synthesis of predicted impacts of spatial changes”.

3. Spatial data layers

SEAwise has identified that the data needed for predicting the effect of a change in the ´fishable´ area should ideally comprise spatial information layers on:

- Species distribution (D5.2)
- Fishing footprint (D5.3)
- Habitat maps (Essential Fish Habitats, fish sensitive habitats)/changes (D5.4)
- Hotspots of PETS (D4.2)
- Benthic impact layers (D4.3)
- Hotspots of marine litter (D4.5)
- Conservation areas (NATURA2000, MPAs, etc.)
- Other restricted areas to fishing (wind farms, aquaculture sites, mining, drilling sites, etc.)
- Areas under spatial management (e.g. spatio-temporal closures) like FRAs and VME in the Med (GFCM measures)

Most of the datasets mentioned above, have been successfully compiled within SEAwise. However, uncertainty still arises from the windmill parks' spatial information, given the discrepancies between the publicly available dataset (available from EMODNet) and the one owned by a private company (4COffshore). The public dataset has then been complemented by freely available online visuals delivered by the more extensive reporting owned by 4COffshore. Habitat maps collating habitat-related features as driving factors influencing the possible spatial redistribution of effort were also unavailable from SEAwise, other than sediment types (from EMODNET). Therefore no attempt was made to use this possible factor in fishing effort allocation.

Certain types of fishing technique are also being constrained by conservation areas defined in the EU fisheries regulation, for example, VMEs areas defined in FAO 2009 (International guidelines for the management of Deep-sea fisheries in the high seas) including criteria that relates to uniqueness, the functional significance of the habitat, fragility, life history traits that make recovery difficult, structural complexity. VMEs are being identified in EU waters (ICES/NAFO WGDEC, ICES WKEUVME 2020, see ICES 2018, GFCM 2022) and exclusion of bottom-contacting gears have been recently introduced (EC 2022). In addition in the NEA, fishing effort spent within the 400-800m bathymetric zone is not allowed to exceed the historical fishing footprint.

3.1 Fishing Footprint

3.1.1 North East Atlantic

VMS data were aggregated at 0.05 x 0.05 degree resolution before use in this current study. The fishing effort dataset has fishing effort (in hours fished and kw hours fished, per Level 6 metier, vessel length category, year, month, and 0.05 by 0.05 deg c-square, a latitude and longitude added. The procedure has merged DCF level 6 metiers with really low number observations (less than 1000 in the entire series), giving them the suffix _0_0_0. If those metiers had too low levels of observations they are merged to a MIS_MIS category. This was all done to ensure compliance with EU GDPR. There has also been some other (minor) data manipulation for this reason.

3.1.2 Eastern Ionian Sea (GSA20)

Fishing effort for bottom trawl (OTB) was based on VMS data analysis and expressed in days at sea and fishing hours (D5.3). Temporal resolution: quarter; spatial resolution: csquare (0.05*0.05 degrees) also available and in a finer scale

0.01*0.01 dd. The VMS dataset ensures compliance with GDPR. Fishing effort for small-scale fisheries (LOA<12m) was estimated separately for gillnets (GNS), trammel nets (GTR) and longlines (LLS) based on a Multi-Criteria decision analysis method (MCDA, Kavadas et al., 2015). The method has been further expanded to include fishing effort estimations from EU Fisheries Dependent Information datasets (FDI; https://stecf.jrc.ec.europa.eu/reports/fdi) and finally producing effort maps expressed in days at sea and fishing hours (D5.3). Temporal resolution: quarter; spatial resolution: csquare (0.05*0.05 degrees) also available and in a finer scale 0.01*0.01 degrees.

3.1.3 Adriatic Sea and western Ionian Sea

The fishing footprint information for the Adriatic Sea (GFCM Geographical Sub-Areas - GSAs - 17-18) and Western Ionian Sea (GSA19) was derived from AIS aggregated data provided by Global Fishing Watch platform (GFW, https://globalfishingwatch.org/). Vessel information of all the fishing vessels included in the GFW database was cleaned and merged with official registers (GFCM 2022 Fleet Register was used as reference database). Vessel data were cleaned by removing inconsistencies and duplicated records, and was used to reclassify GFW fishing effort data according to the fishing gear classification adopted by GFCM fleet register. Effort data at daily temporal resolution and 0.01° spatial resolution were aggregated at a spatial resolution of 0.05° c-squares, at both monthly and annual resolution. The analysis ensures compliance with GDPR. The MCDA analysis was applied to the Adriatic Sea and Western Ionian Sea study area to estimate the fishing intensity of small scale fisheries (LOA<12m) underrepresented in AIS data. A hotspot analysis has been done using of Getis G statistics for identifying the hotspots and persistence areas of effort allocation[1].

3.2 Fish distribution

The ICES workshop co-organised by SEAwise Task 5.2, ICES WKFISHDISH2, analysed a large amount of historical scientific survey data, stored in the DATRAS and MEDITS databases and developed guidelines on how to pre-process these data, analyse them with state-of-the-art species distribution models (SDMs), and define metrics on how to compare species distributions. Distribution maps were generated separately for the Mediterranean Sea and the Northeast Atlantic, spanning the Baltic Sea, North Sea, Celtic Seas, Bay of Biscay and Iberian Coast.

Environmental covariates are further selected to provide forecasting projections under selected climate change scenarios (see section 5.3). For the species considered in this analysis, SEAwise D5.2 noted that temperature seems to have the main effect on density, though it does not necessarily have strong effects on spatial distributions. More work is needed to better capture the uncertainty related to climate forecasts, which has been ignored in the D5.2 study.

The models used in this D5.2 study are well-suited to illustrate how species distributions developed over time and may evolve in the future. Nevertheless, they have limited explanatory power in terms of underlying mechanisms such as local depletion or recruitment pulses, migration, or changes in size structure, etc. that drive changes in species distributions. Therefore, D5.2 recommends gathering more information on species/regions/fisheries when trying to understand changes in spatial distribution.

3.3 Sensitive habitats

At the time of this study, information in the form of GIS shapefiles is not available for essential fish habitats per species (nurseries, feeding etc.) and vulnerable benthic habitats covering the spatial extent of the fishing activities. SEAwise work in D5.4 mainly focused on nursery areas that are often coastal and mostly visited by small-scale fishing. Regarding

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[1] (see https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-statistics/h-how-hot-spot-analysis-getis-ord-gi-spatial-stati.htm)

nurseries, D5.4 found that when considering stock at maximum sustainable yield, restoring the surface of juvenile habitat increased both catches and level of biomass. Restoring habitat quality of nurseries increases catches and biomass, but also the level of sustainable fishing mortality. The report stated that gains from fisheries management could be greatly increased if nursery areas were restored. D5.4 provided some support to document that the degraded quality of coastal ecosystems impacts the productivity and restoration of a large part of marine species exploited by fisheries.

Empirical evidence has been gathered in Task 5.4 showing that most marine species could have preferential habitats, but no evidence is provided to link to sediment types that would help our present work to design new proposal for spatial restrictions founded on sediment types (Figure 3.1 below). Basing proposals on a coastal strip is however suggested. See further information at

https://sextant.ifremer.fr/eng/Data/Catalogue#/search?isTemplate=n&from=1&to=30&sortBy=dateStamp&sortOrder=desc&languageStrategy=searchInDetectedLanguage&any=zone%20fonctionnelle

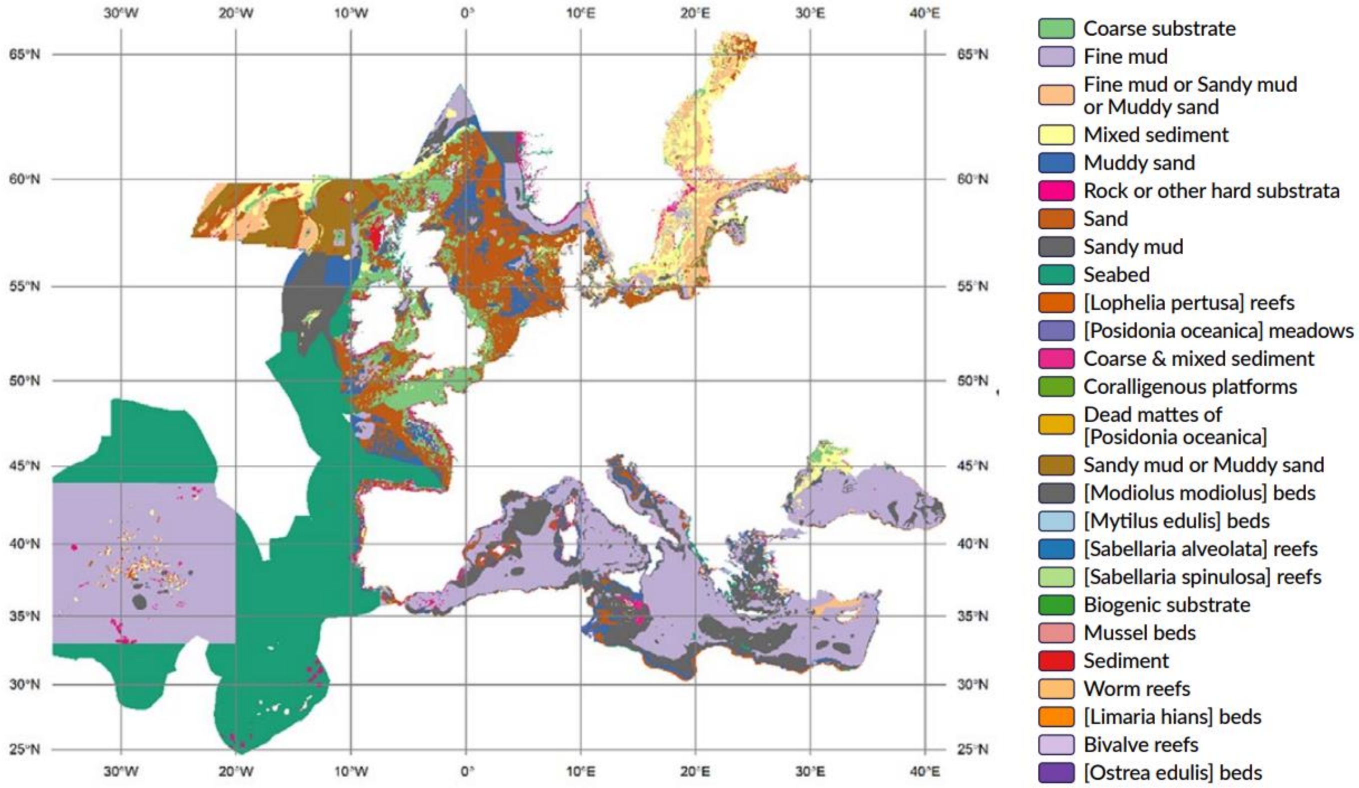

Figure 3.1. Substrate2011. Seabed Habitat classification (source: EMODnet broad-scale seabed habitat map for Europe Substrate2011 retrieved at https://www.emodnet-seabedhabitats.eu/access-data/download-data. Classified habitat descriptors → Substrate type). For this study, the area extent is clipped on the area defining the MSFD areas and shown in Mercator projection.

3.4 Offshore wind farms (OWF) and other uses

SEAwise has access to OWF localisation data from the EU EMODNet platform. However, the public data there differs from the privately-owned data found on the 4COffshore commercial service. For the purpose of this study the publicly available data were complemented from visuals obtained from the 4COffshore online platform depicting the map of OWFs locations (accessed on June 2023). Most of these areas are however concession areas which will therefore eventually not be entirely covered by the OWFs. Oil platforms, gravel extractions, and shipping lanes are not considered in the calculation of the surface extent of the fishable area. This is due to the fact that their surface extents are relatively smaller in comparison to OWFs concessions.

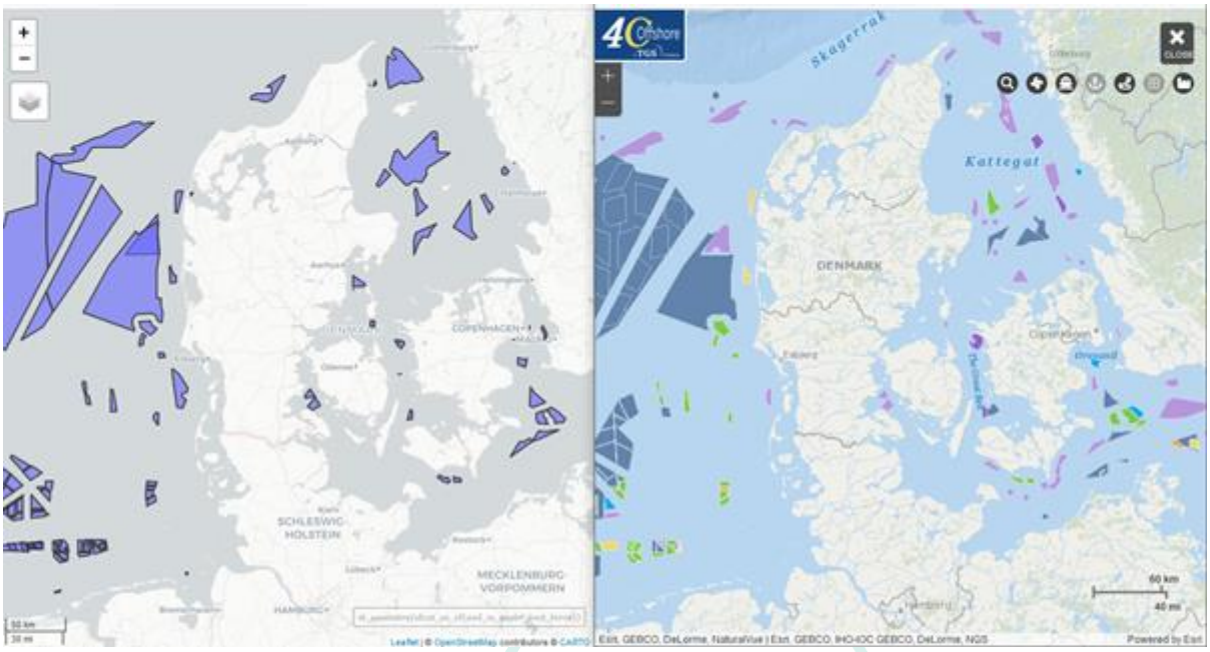

Figure 3.2. A zoom-in on screenshots demonstrating differences in the localisation of OWFs in part of North Sea and Baltic Sea between publically available EMODNet data (left) and the privately owned data (right). Screenshots in made in June 2023.

3.5 Spatial management areas

There are currently several regulations in place in EU waters that exclude partly or totally the fishing activities including:

- Non-trawlable areas: in the Med, non-trawlable areas are areas under 50m depth (or under 3nm) and >1000m depth, in NEA >800m in depth
- EU Natura 2000 sites (often missing an associated management plan e.g. see the CINEA MAPAFISH)
- Nationally based designated areas (CDDA)
- 2019 EU Technical Measure Regulation (closed areas to fishing to certain gear types)
- EU Deep-sea access regulation (where demersal trawlers should stick to the historical footprint) ending up to close 87 boxes to bottom contacting gears fishing defined and enforced in 2022
- Areas designated by regional conventions (e.g. HELCOM, GFCM)

In addition to these existing restrictions, the European Commission has recently communicated a vision for an EU Action plan to protect and restore marine ecosystems for sustainable and resilient fisheries (EC, 2023). The vision includes a roadmap to phase out all bottom trawling activities in already designated areas by 2030 (Figure 3.3) and from any newly designated MPAs. The EU environmental targets defined under the EU Biodiversity strategy for 2030 consist of 30% protected per EEZ surface area, including 10% strictly protected.

In this study, SEAwise valuated the first set of management areas by reviewing existing conservation areas with varying levels of spatial restriction, implementation status, and enforcement (among Natura 2000 and CDDA sites). The analysis excludes spatial restrictions that are meant to manage fisheries and protect exploitable stocks as defined by the Technical Measures EU Regulation (TMR). This is because these restrictions are not expected to lead to new effort displacement beyond what could have been observed in historical data. In a second phase, SEAwise will consider new protected areas that meet environmental targets where appropriate.

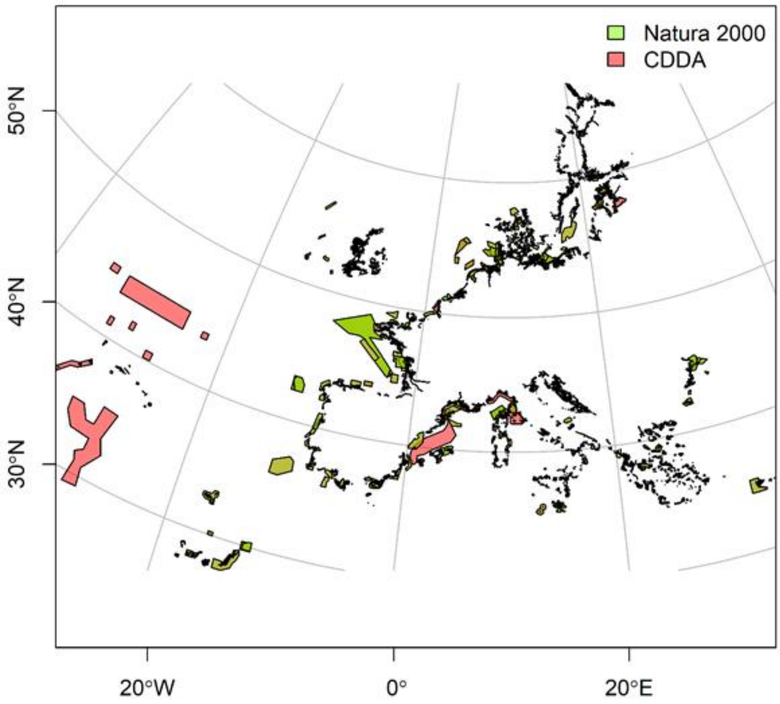

Figure 3.3. Natura 2000 sites and CDDA designated in EU waters from merging the Natura 2000 dataset, available at https://sdi.eea.europa.eu/data/b1777027-6c85-4d19-bdf2-5840184d6e13?path=%2F with the European inventory of nationally designated areas (CDDA), available at https://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-1

3.5.1 Designated conservation areas in the Northeast Atlantic (NEA)

Designated sites in the NEA were retrieved from public databases for the UK and the EU (Figure 3.4). The fisheries restrictions in the designated sites are not systematically documented, which is criticized to result in ineffective protection from fishing (Perry et al., 2022). SEAwise documented publicly available information on fisheries restrictions in two ways: (1) restrictions currently in place and (2) a scenario of possible future restrictions.

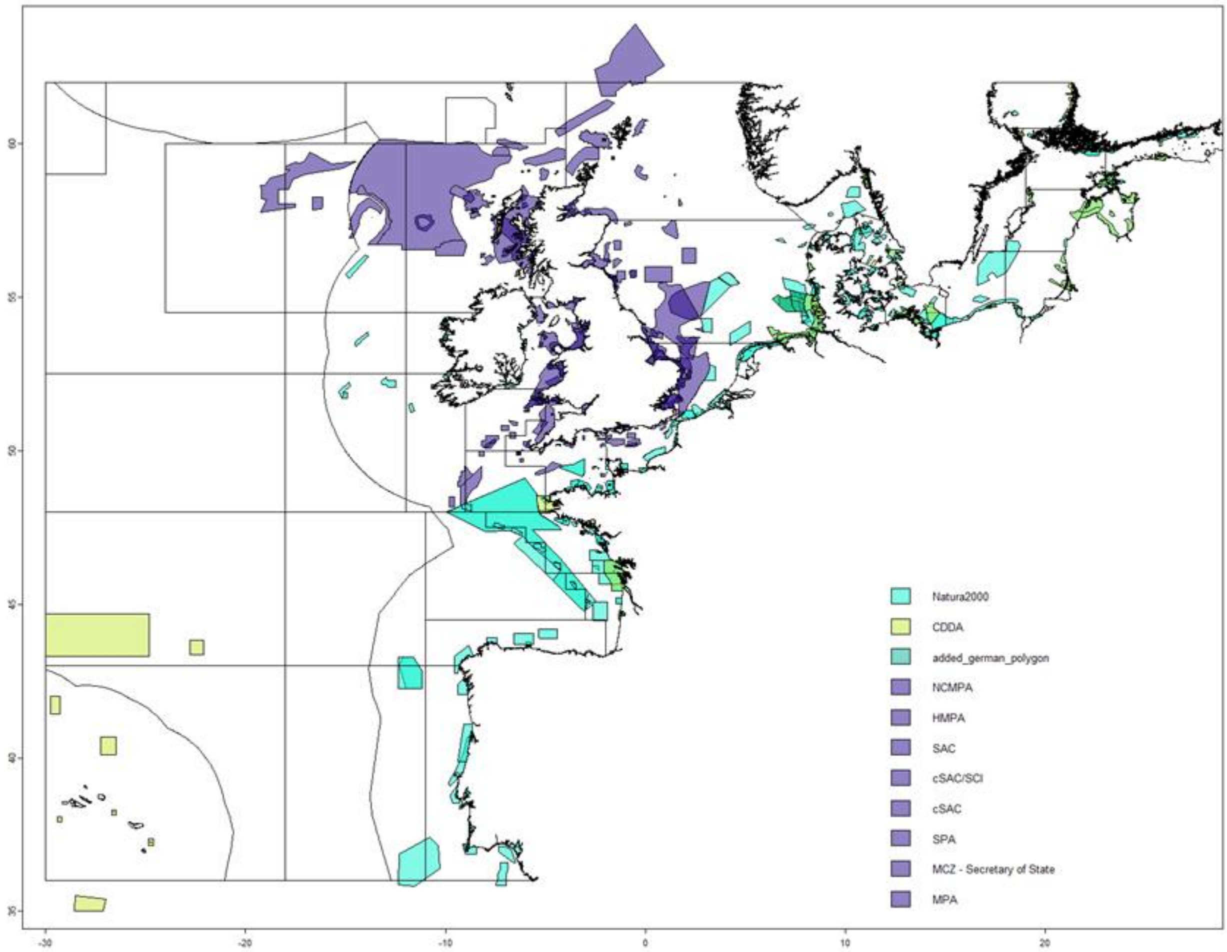

Figure 3.4. Designated sites of conservation interest in the Northeast Atlantic. Sites in the European Union are based on Natura 2000 (bluish) and CDDA sites (green). UK Marine Protected Areas (MPAs) are defined as Special Areas of Conservation (SACs), Special Protection Areas (SPAs), Marine Conservation Zones (MCZs), Nature Conservation MPAs, proposed Highly Protected Marine Areas (HMPAs) and candidate areas (preceeded by ‘c’) (purple).

3.5.2 Databases used for delineation of designated conservation sites in NEA

The UK designated sites were retrieved from the Join Nature Conservation Comittee (JNCC) datahub (downloaded 14/06/2023), including offshore MPAs (https://hub.jncc.gov.uk/assets/ade43f34-54d6-4084-b66a-64f0b4a5ef27), Special Areas of Conservation (SACs) with marine components (https://hub.jncc.gov.uk/assets/598a60db-9323-4781-b5a8-dcf0ca3b29f9), and Special Protection Areas (SPAs) with marine components (https://jncc.gov.uk/our-work/spas-with-marine-components/). Three additional Highly Protected Marine Areas (https://www.gov.uk/government/publications/highly-protected-marine-areas/highly-protected-marine-areas-hpmaswww.gov.uk)) designated in July 2023, and four Nature Conservation MPAs in Scotland that were designated in December 2020 (https://www.nature.scot/professional-advice/protected-areas-and-species/protected-areas/marine-protected-areas-mpas) were added.

The EU designated sites were limited to two comprehensive European databases, managed by the European Environmental Agency (EEA): the Common Database on Designated Areas (CDDA) and the Natura2000 database. CDDA sites are partially overlapping with Natura2000 sites.

A map with a graphical interface of the Natura2000 database can be accessed online (https://natura2000.eea.europa.eu/, 4 September 2023). The network of Natura2000 sites are intended to build an ecological network composed of sites designated under the 1979 Birds Directive (Special Protection Areas or SPAs) and the 1992 Habitats Directive (Sites of Community Importance or SCIs, and Special Areas of Conservation or SACs). The Natura2000 database has a longstanding history. SEAwise used the reported database as retrieved from the EEA: https://www.eea.europa.eu/data-and-maps/data/natura-14, which covers reporting in 2021 (revision 1, October 2022).

The CDDA is the European Inventory of Nationally Designated Protected Areas, holding information on designation types creating protected areas. SEAwise retrieved the delineation of the sites from the EEA: https://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-17, which covers reporting until March 2022 (version 20).

3.5.3 Restrictions currently in place in designated conservation sites in NEA

Restrictions in UK sites were obtained directly from the devolved administrations. For Scotland, existing management measures are available from the NMPi mapper (https://marinescotland.atkinsgeospatial.com/nmpi/, layers include 'Marine and nature conservation management in the MPA network' and 'Other area based measures contributing to the MPA network'). For England, specific bylaws for fisheries management was obtained from the Marine Manaagement Organisation's website for offshore MPAs (outside 6nm) (https://www.gov.uk/guidance/marine-conservation-byelaws), however, it was not possible to obtain restriction information for English inshore MPAs. The Department of Agriculture, Environment and Rural Affairs (DEARA) in Northern Ireland provided information on current restrictions in place, whilst it was not possible to obtain any information on any restrictions in Welsh waters.

CDDA and Natura2000 are mostly, but not always overlapping. Spatial management measures may be taken at the dimension of the entire designated site, or by sub-areas within the sites. Figure 3.5 illustrates that the Sylter Outer Reef and the Eastern German Bight can be split into multiple sub-areas which have different spatial restrictions. Fishing is, for instance, banned for all bottom trawlers except for shrimp beam trawlers in a small subarea of the delineated site.

Fisheries restrictions are specified in national management plans of the designated sites. The specifications of management measures, including fisheries restrictions, were requested by the EC from national authorities. It was mandatory for national authorities to report whether a management plan exists, but it was optional to report on the specific details of the conservation measures, such as fisheries restrictions. As the reporting of conservation measures was optional, and the reporting format was not standardized, responses from national authorities were lacking, not uniform and sometimes referred to other websites in the native language of the EU member states. Although reporting was standardized through Standard Data Forms (e.g. https://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=DE1209301#6), reporting of conservation measures was not. Both the complicated nature of restrictions (e.g. restriction in subareas of designated sites) and the lack of uniform reporting of conservation measures necessitated an alternative approach to understand which restrictions were taken in the designated sites.

SEAwise collaborated with the ongoing MAPAFISH project (CINEA/EMFF/2020/3.2.6 Specific Contract Lot 1 No.09, and Lot 2 No.10) to identify the current fisheries restrictions in place in the EU designated (database retrieved in June 2023). The MAPAFISH project documented fisheries restrictions by means of a questionnaire filled by project consortium partners, including partners from Belgium (ILVO), Canary Islands (IEO-CSIC), Denmark (DTU), Estonia (UTARTU), Germany (Thünen institute), Ireland (MI), Latvia (BIOR), the Netherlands (WMR, WEcR), Poland (NMFRI), Sweden (SLU), UK (MRAG, Cefas), or sent to relevant authorities. Fisheries restrictions were not in place in 51% or no answer was received (10%), while the remaining restrictions related to spatially explicit, spatial and temporal, effort or catch restrictions. Open, descriptive answers described restrictions on commercial fisheries. The MAPAFISH category on commercial restrictions was re-coded to restrictions that are currently in place for long-liners, netters and bottom-contacting gears, and resulted in four categories: (1) No restrictions (2) No fishing allowed (3) No fishing allowed with specifications (e.g. within-site spatial or temporal measures, catch or effort limitations) and (4) No information is available. Category 2 and 3 were merged, assuming that partial fishing restrictions (e.g. constrained by season, subarea or depth) applied to the entire site across all seasons. Partial restriction will thus result in full displacement over a fishery. Although this is a strong assumption, this simplification enabled us to analyse the effect of spatial fishing restrictions on the scale of sea basins (i.e. SEAwise case studies).

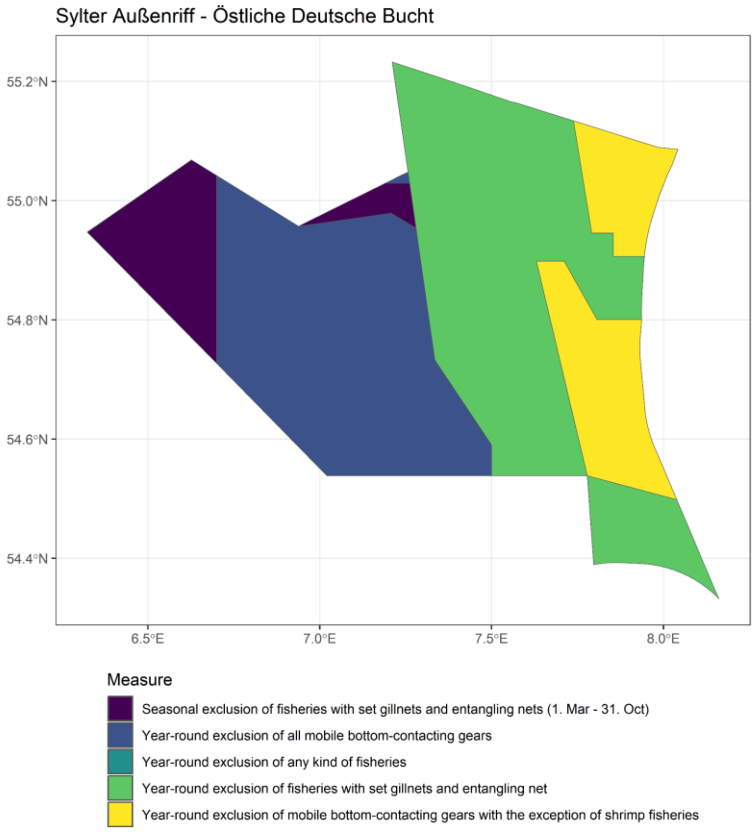

Figure 3.5. German conservation sites in the North Sea that exemplify fishing management plans on higher resolution than publicly available Natura2000 and CDDA sites.

3.5.4 Scenario of possible restrictions in designated conservation sites in NEA

As management restrictions were not uniformly reported, and as future restrictions in already existing designated areas are anticipated in the EU Action plan, SEAwise also developed a scenario whereby fisheries restrictions for longliners, netters and bottom trawlers are expected based on the characteristics of the designated sites. Because of the high overlap between CDDA and Natura2000 sites in the NEA (Figure 3.4), SEAwise focused on Natura2000 sites only to identify plausible restrictions for fisheries. As the reporting of conservation measures of the respective management plans was optional and therefore hard to obtain at regional scale (see above), a second attempt to assess fisheries restrictions was made by investigating the ‘IMPACT’ tables of each Natura2000 site. These ‘IMPACT’ tables comply with the Standard Data Forms (EC 2011/484/EU) and list the threats and pressures of the Natura2000 sites, including fisheries. Fisheries are listed under code F02 (‘fishing and harvesting aquatic resources’), and further subdivided in more categories, including F02.01 and F02.02 for professional passive and active fishing respectively.

Most of the Natura2000 sites, however, did not have sufficient information to assess the intensity of fishing pressure either, and therefore, a third way of assessing scenarios for fisheries restriction in designated areas of conservation interest was followed. SEAwise assessed the feature which led to the designation of the Natura2000 sites. These features included marine habitats and species that are mentioned in the EU Directives, which were subsequently assessed for their vulnerability to fishing, classified as longlining (lns), gillnetting (gns) and bottom trawling (bt).

Marine habitat vulnerability

The EC guidelines for the establishment of the Natura2000 network in the marine environment (EC 2007: https://ec.europa.eu/environment/nature/natura2000/marine/docs/marine_guidelines.pdf, website visited on 5 September 2023) report that nine marine habitat types were listed in Annex I of the Habitats Directive as natural habitats types of community interest whose conservation requires the designation of special areas of conservation (SAC’s), being:

* 1110 Sandbanks which are slightly covered by sea water all the time

* 1120 Posidonia beds (*Posidonia oceanica*)

* 1130 Estuaries

* 1140 Mudflats and sandflats not covered by seawater at low tide

* 1150 Coastal lagoons

* 1160 Large shallow inlets and bays

* 1170 Reefs

* 1180 Submarine structures made by leaking gases

* 8330 Submerged or partially submerged sea caves

The vulnerability of these habitats for fisheries was evaluated by the N2K Group (N2K, 2015), also used in (Perry et al., 2022). The vulnerability of habitat was classified by Natura2000 sites using a conservative approach (Worst Case Scenario). When a site is classified as ‘probably vulnerable’ to beam trawls, but ‘possibly vulnerable’ to multi-rig otter trawls and bottom pair trawls, it was assessed as probably vulnerable to all bottom trawls. One Natura2000 site can contain multiple marine habitat types (e.g. BEMNZ0001 contains both habitat types 1110 and 1170). The vulnerability of the Natura2000 sites was classified following a worst-case scenario approach, implying that a site with, for instance, a ‘probably vulnerable’ and ‘possibly vulnerable’ habitat type, was classified as ‘probably vulnerable’. Furthermore, we also accounted for the percentage of the total area of the site that was covered by habitats that were ‘probably vulnerable’ to a particular gear. Following the step in the previous paragraph, a site was classified as probably vulnerable, and then filtered these sites to those where at least 10% or 25% of the total site area was covered by ‘probably vulnerable’ habitat. There were 11 anomalous entries within the data forms for specific sites and habitats, here, we assumed the habitats had a high percentage of cover. Sites with at least 10% area coverage were probably vulnerable to bottom trawling in more than half of the records, while about one third was probably vulnerable for long lining and gill netting.

Species vulnerability

A list of species that are protected under the Bird’s or Habitat’s Directive are reported using Standard Data Forms for the Natura2000 sites. Standard data forms report species under Annex II-IV of the Directives, which SEAwise retrieved from tabular data forms provided by the EEA, more specifically the “SPECIES” csv-file in this link: https://sdi.eea.europa.eu/data/dae737fd-7ee1-4b0a-9eb7-1954eec00c65?path=%2FTABULAR%2FCSV. Species were classified in taxonomic groups: marine mammals, birds, fish and invertebrates. Sites were considered vulnerable to bottom trawling when ‘Invertebrates’ were listed, vulnerable to gillnetting when birds, cetaceans or pinnipeds were listed, and vulnerable to long lining only when birds were listed.

Habitat and species vulnerability combined

Possible future restriction in the NEA included (1) hypothetical restrictions based on the occurrence of species under the Bird’s or Habitat’s Directive and (2) hypothetical habitat restrictions where >25% of the surface area of the designated site was assigned as a ‘probably vulnerable’ habitat for either bottom trawlers, longliners or gillnettters.

SEAwise scenarios for fisheries restrictions in designated conservation areas in NEA

Restriction for bottom trawlers (‘bt’), longliners (‘lns’) or gillnetters (‘gns’) in Natura2000 sites were classified according to the criteria stipulated above, and resulted in the following possible scenarios (Figure 3.6):

- current = current restrictions in place
- current_habitat = current restrictions in place plus hypothetical habitat restriction
- current_spp = current restrictions in place plus hypothetical directive species restriction
- Notrescurrent = No current restrictions in place or in hypothetical scenario
- Notrescurrent_habitat = No current restrictions in place but hypothetical habitat restriction
- Notrescurrent_habitat_spp = No current restrictions in place but hypothetical habitat and directive
- species restriction
- Notrescurrent_habitat = No current restrictions in place but hypothetical directive species restriction

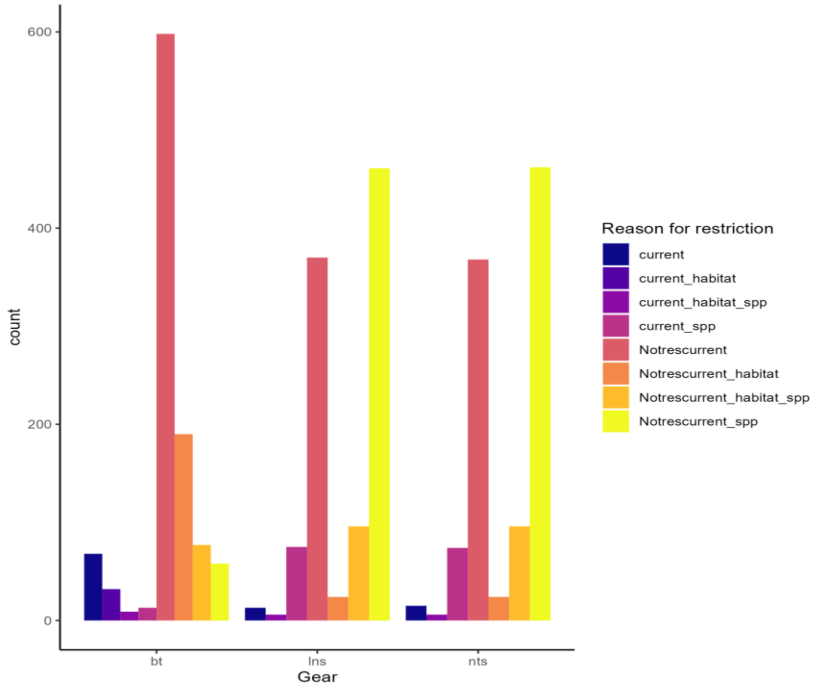

Figure 3.6. Restriction for designated conservation areas in the NEA. Reasons for restrictions are explained in the text, and include current restrictions and a scenario of potential restrictions based on the vulnerability of habitat features and/or species protected the EU Habitat’s and Bird’s Directives. Gear type defined as bt: bottom trawling; lns: longlining; nts: netting.

3.5.5 Designated conservation areas in the Mediterranean

The Mediterranean Sea hosts a sizeable number of Marine Protected Areas (MPAs), these being a network of designated conservation areas that aim to protect and conserve the marine ecosystems and biodiversity of the region. These areas are established by various countries bordering the Mediterranean and are governed by a variety of national and international regulations and agreements.

Based on **preliminary** results of the on-going project MAPAFISH-MED (CINEA/EMFF/2021/3.1.2/SI2.868140-SC02), the EU Mediterranean & Black Sea member states host at least 1200 diverse MPAs (see Figure 3.7). More than half of them have a coverage area of less than 10 km^2, with the median coverage area of an individual MPA being just over 13 km^2. Information was retrieved from the WDPA database, using the EEA (CDDA and Natura 2000 datasets, https://www.eea.europa.eu/en/datahub/datahubitem-view/f60cec02-6494-4d08-b12d-17a37012cb28) and the MAPAMED database. MAPAMED (MArine Protected Areas in the MEDiterranean) is a cartographic database of key information on Mediterranean Marine Protected Areas (MPAs), potential Other Effective area-based Conservation Measure (OECMs), and more broadly on sites of interest for marine conservation.

Figure 3.7. Designated sites of conservation interest in the EU Mediterranean & Black Sea.

The complexity of the governance in individual EU countries and the region as a whole poses a real challenge to assess their status and account for management purposes. Numerous (44) designation types at national level exist and the MAPAFISH-MED approach suggested that a better classification would be to narrow them down to three: 'Regional-SCI' and 'Regional-SAC' (these being Natura2000 sites)[2], and 'National'. 76% of all sites in the European Mediterranean and Black Sea are Natura 2000 sites. Significant spatial overlapping between 'regional' and 'national' MPAs leads to conflicts among local and international (EU) regulations. About 28% of Natura 2000 sites are in areas already protected by nationally designated MPAs, while this proportion being virtually 100% in the Black Sea. In contrast to the findings of the 'sister' project MAPAFISH in North European waters, less than 15% of the MPA management authorities in the Mediterranean & Black Sea responded to the MAPAFISH-MED questionnaire survey and a minor 4% reported that the MPAs are actively managed. Conclusively, the lack of basic knowledge on the management of most Mediterranean MPAs does not allow for a basin-wide investigation; individual approaches at local scale are provided later on in chapters 4 and 5.

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[2] SCI (Site of Community Importance): a site which, in the biogeographical region or regions to which it belongs, contributes significantly to the maintenance or restoration at a favourable conservation status of a natural habitat type in Annex I or of a species in Annex II and may also contribute significantly to the coherence of Natura 2000 referred to in Article 3, and/or contributes significantly to the maintenance of biological diversity within the biogeographic region or regions concerned. Habitats Directive (92/43/EEC)

SAC (Special Area of Conservation): a site of Community importance designated by the Member States through a statutory, administrative and/or contractual act where the necessary conservation measures are applied for the maintenance or restoration, at a favourable conservation status, of the natural habitats and/or the populations of the species for which the site is designated - Habitats Directive (92/43/EEC)

4. Static GIS evaluation of the fishable area

Area-based management and associated spatial restrictions of marine space for fishing are likely to result in an effort displacement. Other uses of marine space will also induce some exclusion to fishing (e.g., the growing renewable energy sector). To document possible displacement and consequences on harvested living stocks and marine habitats, the present study initiated a tool to assist fisheries researchers and experts in short-term anticipation of possible effort displacement alongside alternative options for spatial management. This work is to predict the effect of changes in 'fishable' areas on the socioeconomic of fisheries, at least on the short-term horizon, given that no prediction on the underlying fished stock trajectories is made. The fishable area is defined as the marine space left for fishing but also the space suitable for fishing given the physical constraints of the marine environment.

The study has merged several datasets to conduct an economic impact evaluation of the proposals for fishing restrictions at the fleet-segmentation level defined by the EU STECF AER dataset. The opensource tool can be found online[3]. The study applied this segmentation specific to the EU fleet and split the evaluation into two parts:

- An evaluation of the available fishable areas and the impacted EU fleet segments in terms of GVA, gross and net profits, and the crew engaged in the impacted segments. This also disaggregates the possible socioeconomic impact of each restriction alongside the different scenarios in defining those restrictions.

- An evaluation of the possibility for compensation and economic implications by displacing the fishing effort toward surrounding areas or other fishing grounds. In such effort displacement, the main driver was assumed to be the economic return the vessel operators may expect from the still-open fishing grounds.

The present spatial tool can apply to the entire EU fleet or a regional subset of it (e.g. Baltic Sea, Celtic Seas, Bay of Biscay, North Sea, West and East Med). For the entire EU fleet active in the Northeast Atlantic area (for which the coupling of economic data to fine spatial effort data has been done here), the main findings show that overall, by analyzing the finely spatially resolved data available, the socioeconomic impact of enforcing the proposed restricted areas would affect certain fleet-segments negatively, while some others will not be affected.

A slight change affecting GVA may lead to a large change in profitability, given some extensive fixed capital assets engaged in those fisheries, and sometimes negative initial profit. Negative profit might add to the loss of spatial opportunities, possibly affecting the concerned segments' engaged crew if saving on labor costs is seen as a solution to balance losses. The static study of effort allocation does not address possible important drivers in fleet dynamics, including fishing outside the known historical footprint (2018-2021), a change in catch rates (LPUEs) depending on the total effort on sites, and the ecological implications on the marine ecosystem productivity as a consequence of adding extra fishing effort on surrounding habitats. On the other hand, if the tested spatial plans have been found to have some impact, it does not preclude some future benefits on future fishing opportunities from protecting some marine space or from displacing away toward more rewarding fishing grounds. The present study has looked at potential short-term effects only and does not claim to gain insights into long-term dynamics or changes in labour costs and engaged crews in the medium term; to investigate this, it would need to use some bioeconomic spatial models that would also include population dynamics and ecological considerations, as developed within the bioeconomic models mobilized for SEAwise, that will be further reported in the second deliverable (D5.6).

As a disclaimer, the study identified that the limited availability of data poses a major issue in getting accurate estimates at a level of aggregation that matters to policymakers. Hence, it has not been possible to avoid a mismatch between available finely spatially resolved effort data (issued from the VMS) and the EU fleet economic data (STECF

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[3] https://github.com/frabas/FishSpatOverlayTool/tree/master

AER dataset), especially for the UK fleet, which has been passed down into the final dataset, and for the missing countries that has not delivered to the analysis such as Sweden (SWE) and Portugal (PRT). Those country-specific spatial effort allocations have been re-injected into the coupled dataset using overall effort country shares known from the AER at the cost of large assumptions.

4.1 Data source used in the socioeconomic evaluation

4.1.1 STECF AER datasets

Issued every year, the Annual Economic Report (AER) on the European Union (EU) fishing fleet provides a comprehensive overview of the latest information available on the structure and economic performance of the EU Member States fishing fleets. The AER datasets collate effort, landings and economic information at the fleet segment level. A fleet segment is a group of similar vessels, defined using a combination of a vessel length group, main fishing technology and geo indicator (when applicable), operating predominantly in a Supra-region.

There is a 2-year lag in collating the AER data due to the time required to process the data. Hence, the data up to 2021 are available at the time of the present study. The present study recalculates the part of the AER economic indicators impacted by the area-based management scenarios tested here with a spatial overlay analysis (see next sections). The re-estimated economic indicators as defined in STECF (2022) are:

- Gross Value Added is the net output of a sector after deducting intermediate inputs from all outputs. It measures the contribution to GDP made by an individual producer, industry or sector. It is expressed as:

  GVA= (LandingsKg * PricePerKg) + OtherIncomes - UnpaidLabour – VarCosts - FixedCosts

- Gross profit is the normal profit after accounting for operating costs, excluding capital costs. Also referred to as gross cash flow, i.e. the flow of cash into and out of a sector or firm over a period of time. It is expressed as:

  GrossProfit = GVA –PersonnelCosts

- Net profit is the difference between revenue and explicit costs, and opportunity costs. Explicit costs include all operational costs, such as wages, energy, repair and other variable and non-variable costs. Net profit differs from gross profit in that it includes depreciation and opportunity costs of capital. It measures the efficiency of a producer in society's view by evaluating the total costs of inputs (excluding natural resource costs) in comparison to outputs or revenue. It is expressed as:

  NetProfit = OperatingProfit – CapitalOpportunityCosts- (valueOfPhysicalCapital * (1-(100-AnnualDepreciationRate)/100))

4.1.2 Aggregated VMS data provided by SEAwise partners

The study uses fine spatially resolved data to increase the accuracy in the landings, effort and economic estimates impacted by the proposals for closed areas. An improved geographical resolution such as the one defined by the VMS data with an accurate delineation of the core fishing grounds improves the estimation of the effort displacement effects compared to the use of coarser data. Aggregated data reflect the actual distribution of the fishing activity depending on the grid cell resolution in use i.e. the 0.05-degree VMS c-squares grid cells.

Aggregated VMS data were issued from a SEAwise data call via ICES. The collected data described in SEAwise Task 5.3 were merged VMS/Logbook data for fishing activities in the Northeast Atlantic which is the base for providing documentation on the spatial distribution and impact of fisheries. The VMS-related data treated for the present study are annual fishing effort in aggregated 0.05 c-square cells segmented for each type of bottom-contacting gears and passive gears (metier DCF level 6) and vessel size category (e.g., VL1218, VL1824, VL2440, VL40XX). The ICES datacall products contain information on member state, year, month, number of vessels within time-space frame, anonymized vessel ID, C-square (0.05 degrees both longitudinal and latitudinal), metier 4, 5 and 6, mesh size, average fishing speed (in knots), fishing effort (in hours), average vessel length (in m), average engine kW, kW fishing effort (in hours *kW), total weight of the catch (in kg), total value of the catch (in euro) and average gear width (in m) if available. However, Task 5.5. had only had access to an aggregated version of the dataset for confidentiality reasons.

The aggregated VMS data includes data from Belgium BEL, Spain ESP, France FRA, United Kingdom GBR, Ireland IRL, Netherlands NLD. Portugal PRT and Sweden SWE data were not available. The AER data contained data for DEU, ESP, FRA, IRL, POL, PRT, SWE, DNK, NLD, EST, FIN, LVA, LTU, and BEL. The study focused on the most recent period 2018-2021 data, to get estimates of effort allocation that fits current or ongoing fishing activities.

As a disclaimer, it is important to note that, as per Brexit since 2019, The UK fleet has not been included in the AER reporting for the period examined because no longer collected by the EU DCF. Therefore, the UK activity included in the VMS dataset has been reduced in the final coupled data to AER. This is a major drawback but unavoidable, given that the VMS delivered to Task 5.5 needed to be country-specific data.

For the purpose of the analysis conducted in the Mediterranean basin, high resolution AIS effort data were used to conduct the analysis covering the Adriatic Sea (GSA17, 18) and the West Ionian Sea (GSA 19) to increase the accuracy of effort and economic estimates impacted by the closure areas. In particular, effort data were aggregated for the three GSAs at 0.01° c-square resolution to depict the distribution and the displacement of the fishing footprint derived by the implementation of management measures in the study area. The fishing footprint has been aggregated at gear and vessel length category (e.g., VL1218, VL1824, VL2440) in order to facilitate the merging with economic data.

It should be highlighted that AIS is not mandatory equipped on vessels with LOA lower than 15m that are underrepresented in AIS. For this reason the vessel length category "VL0612" was not considered in the analysis. Furthermore, even if vessels are more and more equipped with AIS devices, the fleet of Albania and Montenegro appears to be underrepresented in the fishing footprint provided by AIS data from GFW.

4.1.3 Estimation of a fishable area

The spread of fishing activities observed spatially deduced from the spatial VMS data and that constitute the "fished area" is indirect information of the fishable areas (Table 4.1). The estimate of the fishable area is less certain as it has yet to be known to which extent fishing is physically feasible in all parts of the marine space. Hence, totaling all the spatial extent available of marine space as estimates of the fishable area is likely to be an overestimation given that only some of the allowed area for fishing is supposed to constitute a fishable area. For example:

- The low actual fished area proportion in the Baltic Sea (Table 4.1) is likely the result of the distribution of the fishing opportunities driven by environmental constraints modulating the species spatial and seasonal distributions alongside their tolerance range (to the anoxic areas, salinity gradient, etc.) (see Task 5.2). Ideally, to refine the estimations, it would be needed to overlay the fished areas with the potential areas of the fish being targeted by each fleet segment. Such analysis requires well-informed spatial layers per fish species, as provided by SEAwise Task 5.2, combined with the information of the targeted species by each fleet segment, a piece of information that was not available in the input (VMS) dataset, or too uncertain at the AER fleet-segmentation resolution.

- It is also expected that certain fishing practices are constrained by the suitability of the seafloor and sediment types for trawling (rocky bottoms, deep-sea areas, etc.), as well as current regulations in place to prevent certain areas from being fished (e.g. exclusion of certain fishing techniques in a coastal strip, depth limit for high seas)

Table 4.1. The proportion of fishable areas actually fished during the 2018-2021 period per ecoregion. Estimates were obtained from the gridded VMS data at 0.05 by 0.05-degree resolution (excluding Norway, Sweden and Portugal), assuming a grid cell to be fished if containing more than 10 hours of fishing. The fishable area is defined here as the area with bathymetry < -800m where fishing is allowed (as specified for the Northeast Atlantic areas of EU waters in the EU Deep Sea Access Regulation of 2019), disregarding all other uses of the marine space or environmental factors that could have prevented the fishing.

	Fished km2	**Proportion of the fishable area fished**
North Sea	376983.76	0.648
Baltic Sea	48673.42	0.138
Celtic Seas	316676.63	0.799
Bay of Biscay	102949.84	1.000

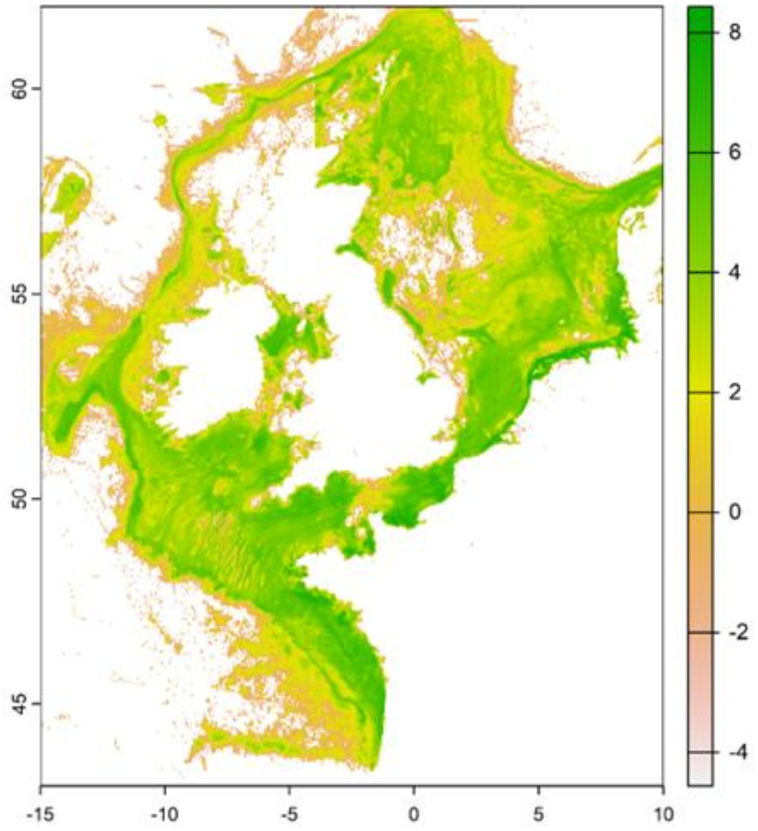


Figure 4.1. VMS data (log of Fishing Hours) in NAO collated by SEAwise for this study. Extract for countries BEL DNK ESP FRA GBR IRL NLD and all gears types. The available VMS data to Task 5.5 were aggregated per EU DCF metier Level6, and the country information was lost due to confidentiality issue (compliance to the EU GDPR).

For comparison, the analysis conducted for the Adriatic Sea and West Ionian Sea for the estimation of the "fishable areas" informs us about the areas where fishing is feasible (Table 4.2). In particular, the assumption was made that the regions already fished define the suitable fishable area.

Table 4.2. The proportion of the fishable areas actually fished during the 2017-2022 per GSA.

GSA	fishable area (km^2)	Proportion of the fishable area fished
17	76970.3	0.93
18	26194.67	0.77
19	19317.25	0.90

The higher proportion in GSA17 is related to the wider continental shelf and in GSA19 to having a very narrow fishable area along the coast line. In Figure 4.2 the mean annual fishing footprint estimated for the 2017-2022 period is reported.

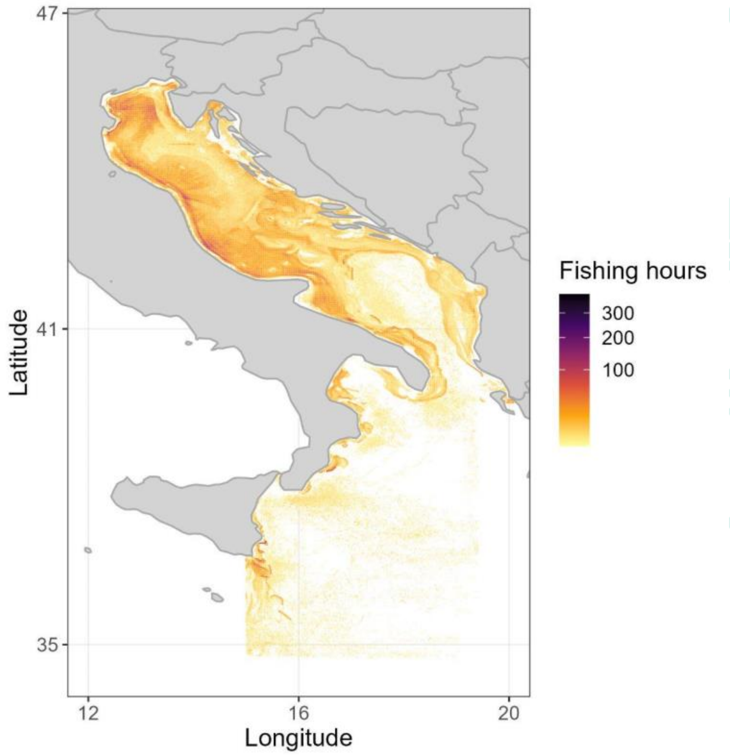


Figure 4.2. Mean annual effort (expressed in Fishing Hours) for the GSAs 17, 18 and 19

4.1.4 Merging AER and VMS/AIS datasets

The procedure to merge the AER dataset with the aggregated VMS dataset is acknowledging that the AER dataset contains the record of landings, effort and economic variables alongside a fleet segmentation that combines the country, the fishing technique, and the vessel size category. Conversely, the VMS dataset contains the information on landings and effort disaggregated over a 0.05-degree c-square grid and per EU DCF métier level6. The developed merging procedure here transfers the spatial information to the AER by arranging the link between the two datasets using a shared key (the fleet segment) defined as the combination of a country, fishing technique and vessel size category. A robust merging procedure is implemented where the merging with a complete key is done first (vesselSizeCategory- FishingTechnique-subRegion), then a degraded key is used on the leftover, unmatched datasets (vesselSizeCategory-FishingTechnique), and finally, a third level of degradation of the key is used (vesselSizeCategory) for the remaining unmatched part.

Once the merging alongside the shared key is done, the VMS effort in each 0.05-degree c-square and for each fleet segment is used to disaggregate the AER landings weight and value, the kWeffort, and the economic variables (i.e. other income, unpaid labour, personnel costs, variable costs, and other non-variable costs) that are eventually used to compute c-square-based GVAs following the equation described earlier. The spatially disaggregated AER economic variables have been expressed in value per unit of kWeffort, which allows recomputing each economic variable in each c-square by multiplying with the disaggregated kWeffort found in the c-square. Some other economic variables do not require spatial disaggregation and have been kept aside from the merging but can be used later to compute the net profit from any change that would impact c-square-based GVAs (i.e. induced by a displacement of effort).

The species information has not been kept along the merging, and species landings have been aggregated per fleet segment before the merging to save extensive computation time. However, from the merging, the catch rates in each grid cell are deduced from the recorded landings and effort in the AER, which is further used to recompute hypothetical catches alongside effort displacement scenarios.

Unfortunately, the transmitted aggregated VMS data to this study did not hold the country information because of the confidentiality issue (EU General Data Protection Regulation GDPR), which prevented further refining the accuracy of the AER spatial disaggregation split by country-specific fleet segment. The AER country allocation of effort per country that is further splitting the effort among countries spatially is making the analysis at the fleet segment level uncertain in this regard.

The robust merging efficiency matched all VMS data with AER data, as 100% is successfully merged with VMS in fishing hours or kW hours. However, the robust merging of VMS with the AER data may, in some occurrences, induce some effort allocation where they were none observed. All non-area-informed efforts have been evenly reallocated to areas-informed records to correct this artifact.

A similar analysis was carried out on the Adriatic Sea and West Ionian Sea to estimate the impact derived by the application of the management scenario. The analysis aimed to disaggregate the economic variables spatially along the fishing activities. In particular, the AIS fishing effort data derived from Global Fishing Watch (GFW), and aggregated at different fleet segment levels, were merged with the economic variables derived by AER data call.

The economic data at GSA level were made available by the SEAwise data call. The AIS data from GFW were merged with GFCM Fleet Register to derive spatial layers by fishing technique and vessel length category. Both effort and economic data were segmented at GSA, fishing technique, and vessel size category level to guarantee a high level of matching between the two sources of information for the Demersal trawls and seines (DTS) fleet segments, being the more representative fishing technique operating in the study area. For this reason, fishing effort data at fishing technique level of demersal trawls and seiners, where available, were aggregated at DTS level. Even if the effort data were available since 2017 to 2022, economic data were available only up to 2020. Hence the 2017-2020 time frame was considered to conduct the merging.

AIS effort data in each grid cell and for each “year-GSA-vessel length class” combination was used to disaggregate the AER landings values and the economic variables (i.e. other income, unpaid labour, personnel costs, variable costs, non variable costs). The Gross Value Added (GVA) at c-square cell level was estimated for each “year-GSA-vessel length class” combination with the formula reported in the section 4.1.1. In case of cells partially included in closure areas in the analysis (i.e. FRAs, MPAs, Natura 2000 sites), the estimation of the GVA was further splitted according to the portion of effort observed inside and outside the closure areas.

4.2 Socioeconomic analysis of the impacted fleets by the closed areas based on the merging of AER and VMS datasets

4.2.1 Estimation of a change in fishable area from the overlay effect of restricted areas proposals estimated with the coupling of AER to VMS

The effort impacted by conservation areas' proposals for spatial restrictions can be specific to each fleet segment and depends on the type of restrictions (i.e. some areas exclude bottom trawling specifically, some others the longliners, and some others the netters, and some several types of activities, see Figure 4.3) which relates to the type of vulnerability these areas have to fishing activities depending on the ecosystem components that require protection (benthos, marine birds and mammals).

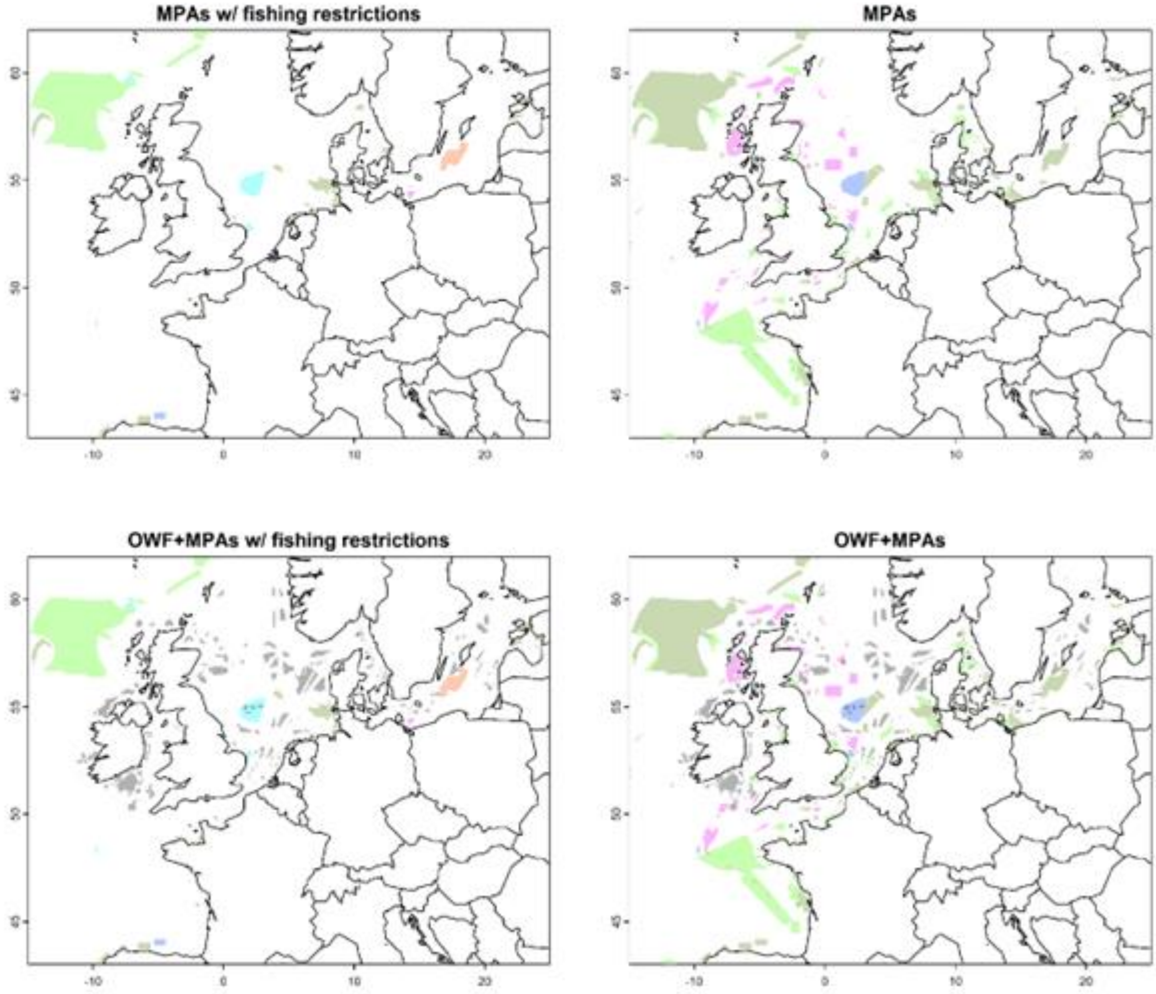
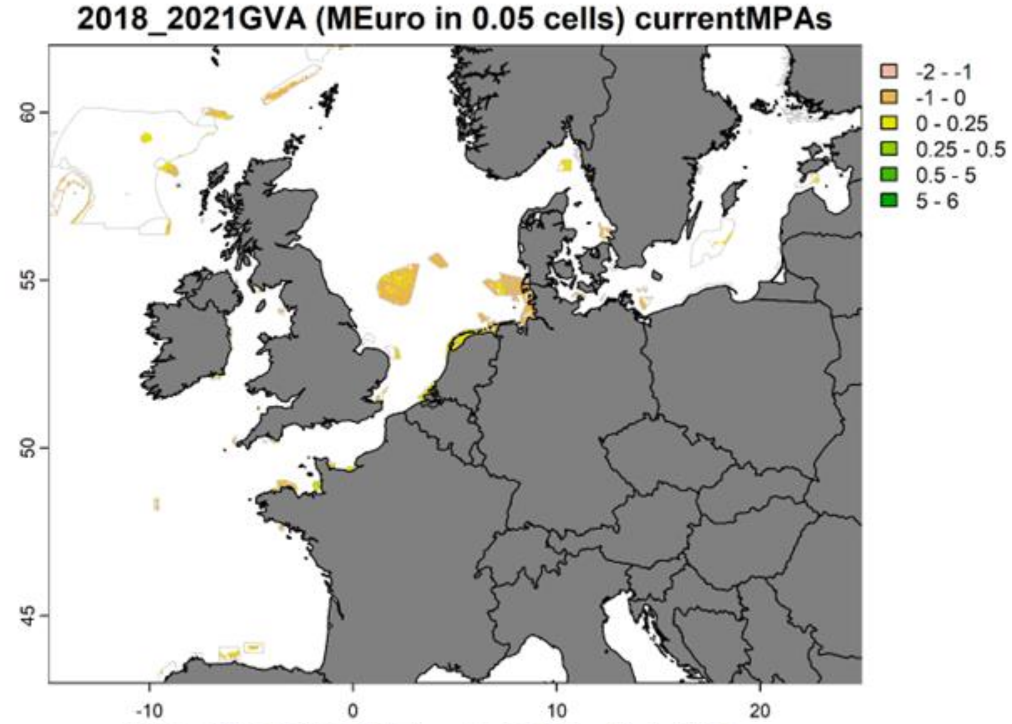


Figure 4.3. Restricted areas to fishing and scenarios, with “MPAs with fishing restrictions” implementing exclusion from the current MPAs to specific fishing activities (in magenta for bottom trawling, in cyan for longliners, in yellow for netters; other colors arising from overlap), “MPAs” comprehending the entire MPA network where no restrictions to fishing are currently in place, and the same two scenarios but in combination with the exclusion of all fishing activities in Offshore Windmill Farms concession areas (OWF, in grey).

Based on the fishing activities mapped spatially from the VMS dataset, landings and landings value by species/stocks and fishing effort in the fishable areas at the fleet segment level during the most recent period 2018-2021 was analysed, based on the AER fleet segmentation. The analysis includes calculating the percentage of the value of landings (by species/stocks and in total) in each closure and the reduction of effort using a representative time series, i.e. 2018-2021. If restrictions were implemented in the designated MPAs it would represent a reduction by up to 36% of the fishable surface area in the Bay of Biscay, but 10% in the less impacted Baltic Sea (Table 4.3), where MPAs do not overly major fishing grounds (Figure 4.4).

Table 4.3. Estimates of the proportion of fishable areas left to fishing per ecoregion or occupied by the restriction following the different scenario proposals for restriction to fishing, after accounting for an estimate of the total fishable area defined as all marine areas >800m in NEA.

Region	Scenario	Restricted km2	Area left (km2) to fishing	Proportion of the fishable area occupied
North_Sea	OWF	41188	543662	0.070
Baltic_Sea	OWF	11106	352547	0.031
Celtic_Seas	OWF	19062	399524	0.046
BoB	OWF	257	119274	0.002
North_Sea	Current MPAs	30852	553999	0.053
Baltic_Sea	Current MPAs	17251	352547	0.047
Celtic_Seas	Current MPAs	3550	415036	0.008
BoB	Current MPAs	5845	113685	0.049
North_Sea	MPAs	78955	505896	0.135
Baltic_Sea	MPAs	37952	352547	0.097
Celtic_Seas	MPAs	50427	368159	0.120
BoB	MPAs	42800	76731	0.358
North_Sea	OWF+currentMPAs	70672	514179	0.121
Baltic_Sea	OWF+currentMPAs	28029	352547	0.074
Celtic_Seas	OWF+currentMPAs	22569	396017	0.054
BoB	OWF+currentMPAs	6102	113429	0.051
North_Sea	OWF+MPAs	117991	466860	0.202
Baltic_Sea	OWF+MPAs	48730	352547	0.121
Celtic_Seas	OWF+MPAs	69375	349211	0.166
BoB	OWF+MPAs	42828	76703	0.358



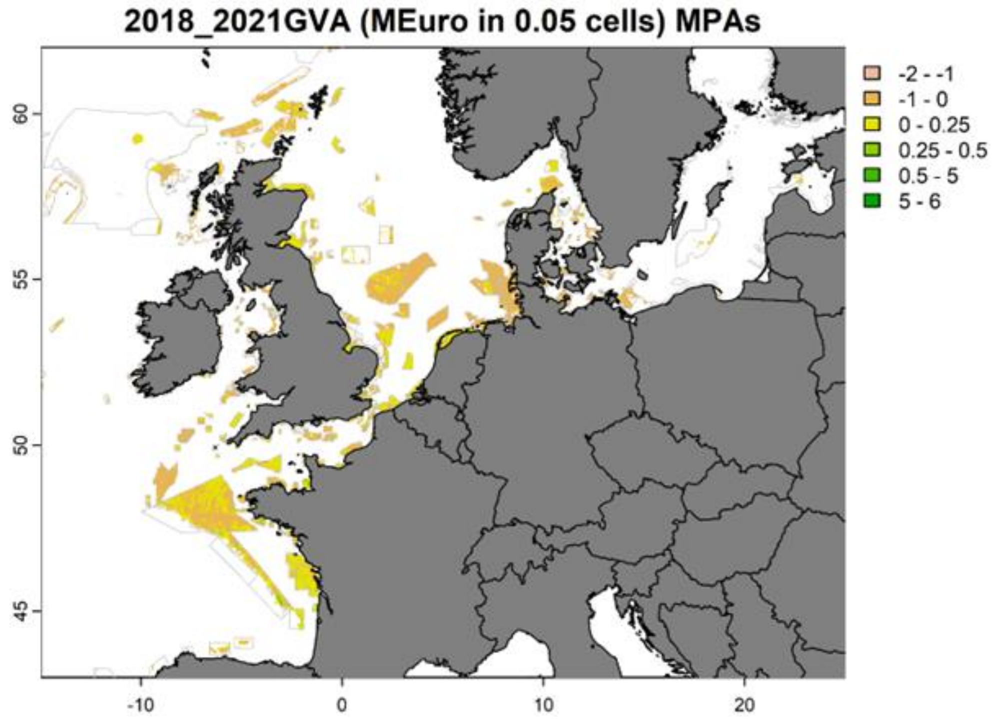


Figure 4.4. estimates of averaged Gross Value Added (GVA) lying within the NEA restricted areas alongside the spatial scenarios. All activities >800m are excluded (in reality, passive gears are still allowed in an area deeper than 800m in the EU waters of the NEA area).

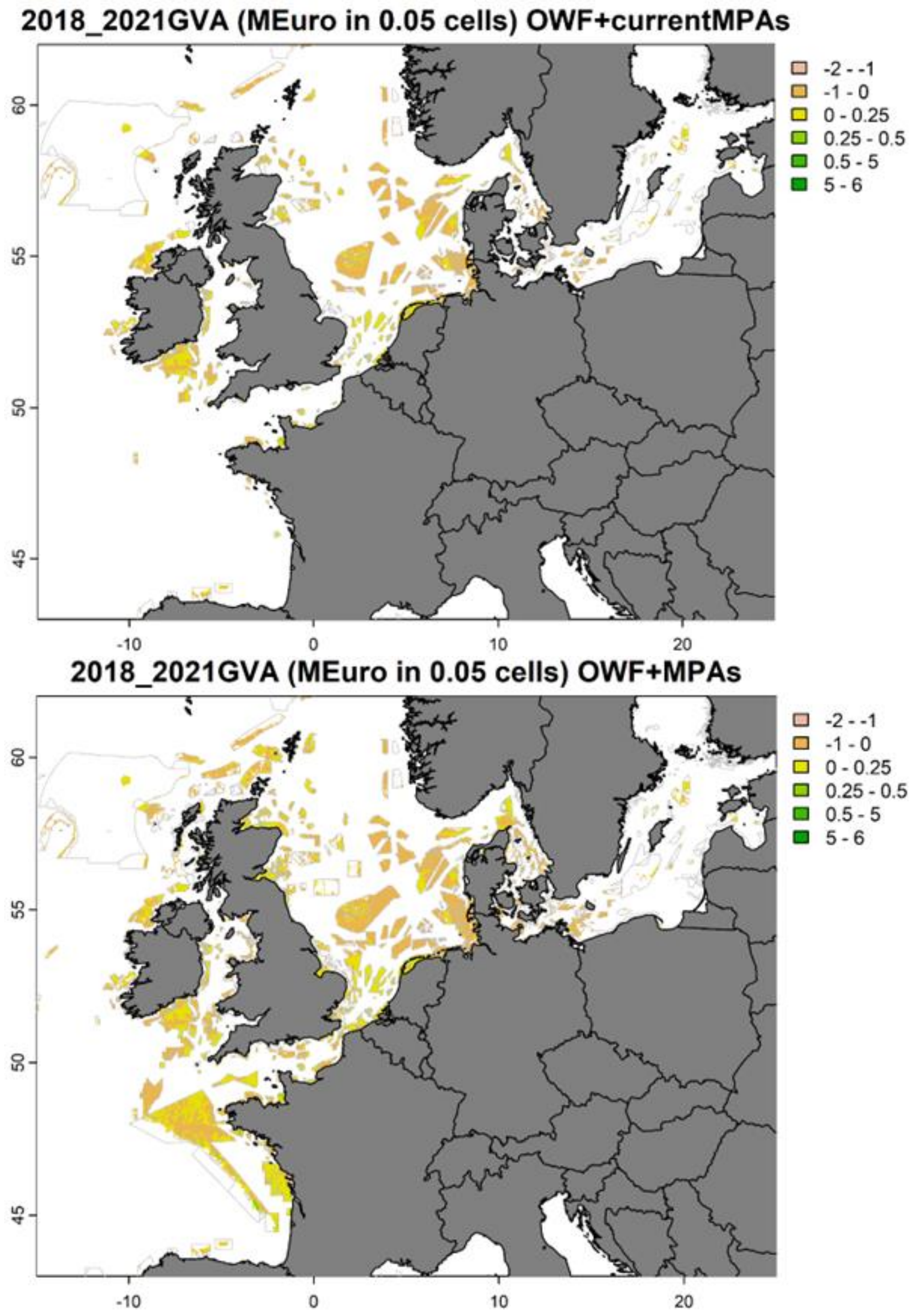


Figure 4.4 continued. estimates of averaged Gross Value Added (GVA) lying within the NEA restricted areas alongside the spatial scenarios. All activities >800m are excluded (in reality, passive gears are still allowed in an area deeper than 800m in the EU waters of the NEA area).

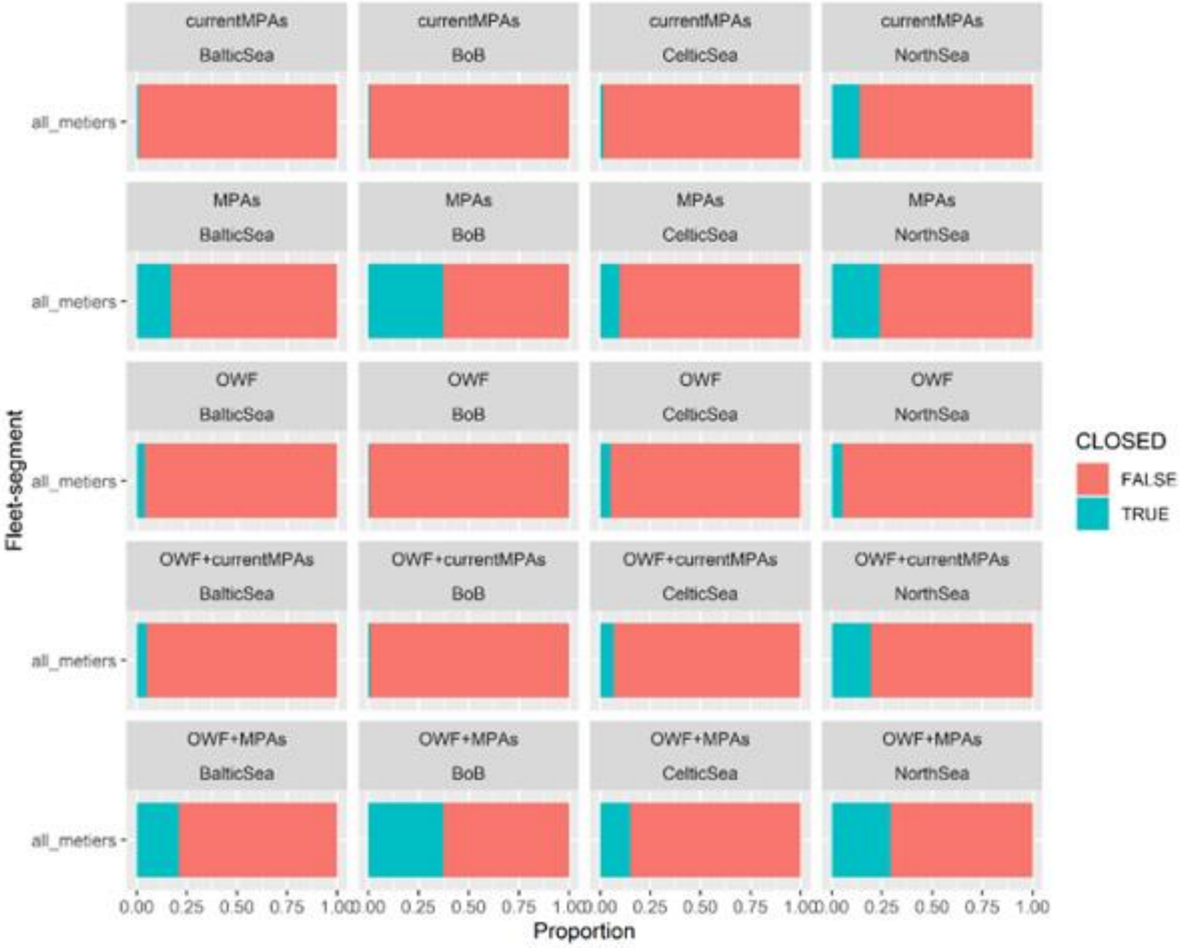


Figure 4.5. The proportion of the fishing effort (average of 2018-2021) impacted by the different proposals (currentMPAs, MPAs, OWF, OWF+currentMPAs, OWF+MPAs) in the ecoregions covered by the data (blue). Here, because all metiers have been pooled, the estimates do not include metier-specific restrictions effects.

Figure 4.6. The proportion of the fishing effort (average of 2018-2021) impacted by the different proposals (currentMPAs, MPAs, OWF, OWF+currentMPAs, OWF+MPAs) in the ecoregions covered by the data (blue). Here, the estimates do include possible metier-specific restrictions effects (i.e. area-specific restrictions to longliners, to netters, or to bottom trawlers depending on the habitat vulnerability to these fishing techniques).

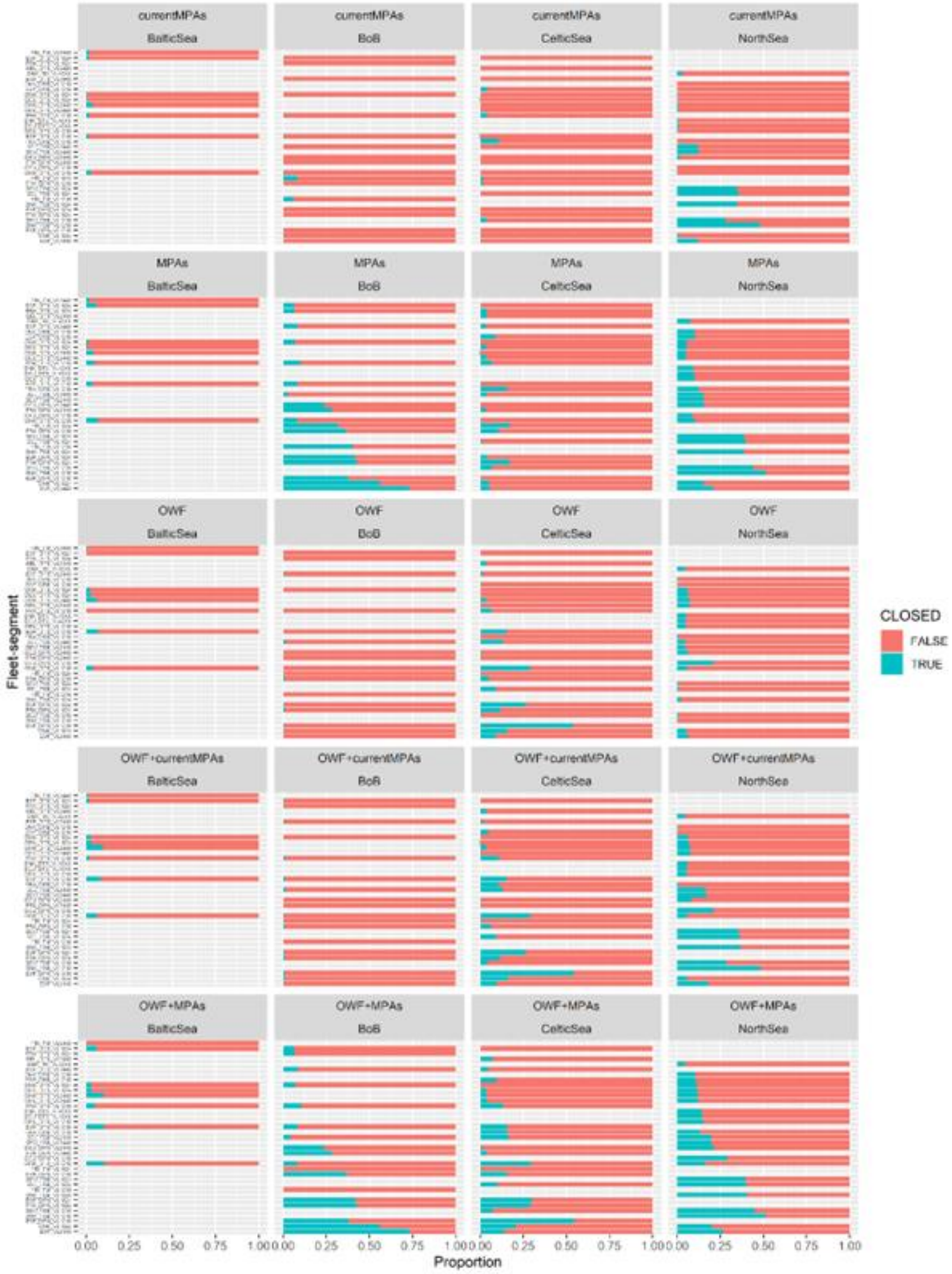


Figure 4.7. The proportion per AER fleet segments of the fishing effort (average of 2018-2021) impacted by the different proposals (currentMPAs, MPAs, OWF, OWF+currentMPAs, OWF+MPAs) in the ecoregions covered by the data (blue). Here, the estimates do include metier-specific restrictions effects (i.e. area-specific restrictions to longliners, to netters, or to bottom trawlers depending on the habitat vulnerability to these fishing techniques).

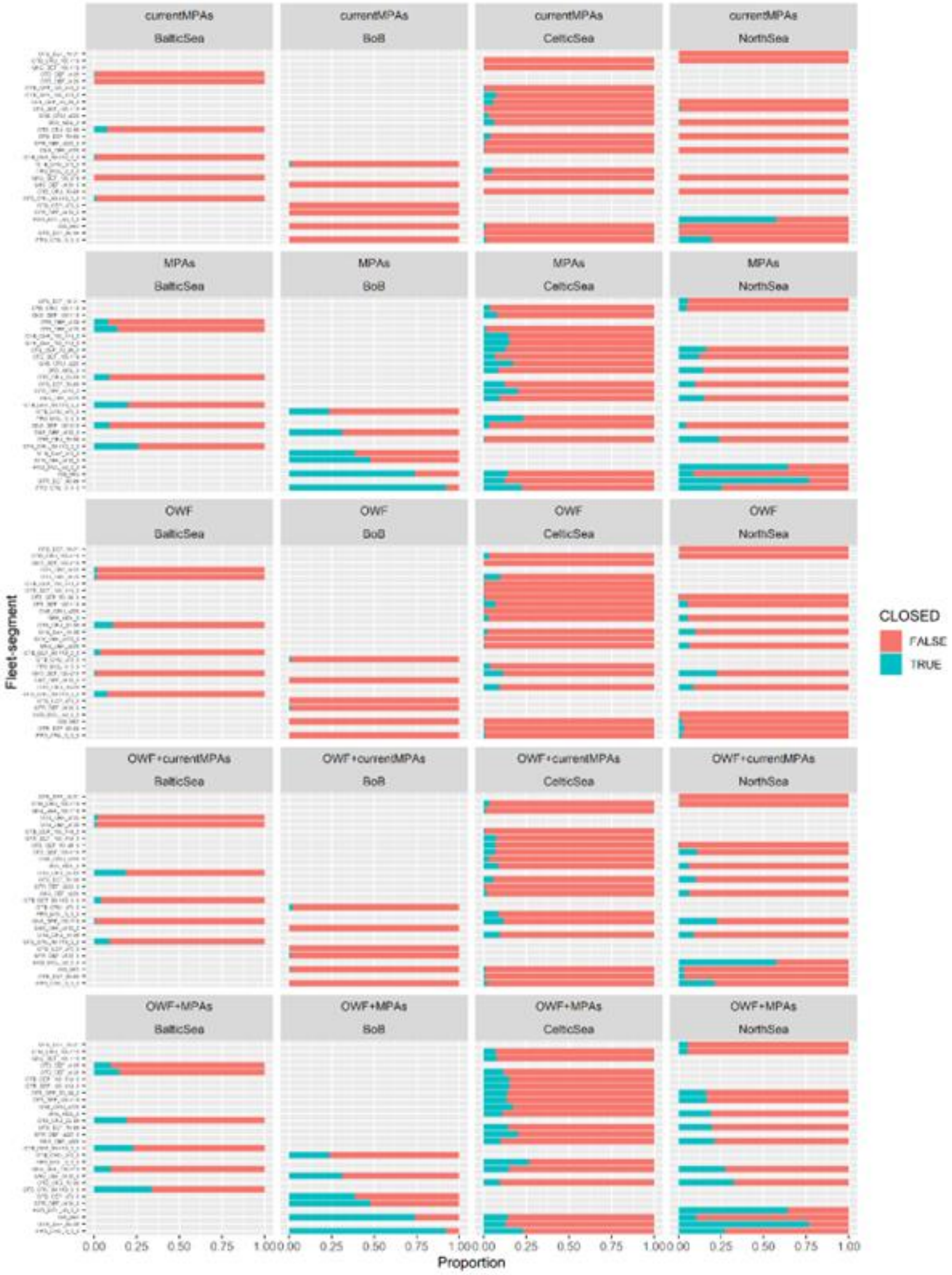


Figure 4.8. The proportion per fleet segment of the fishing effort as in previous Figure but for VMS DCF Level 6 fleet segmentation from the country-pooled aggregated VMS dataset. (only segments with >5000 fishing hours overall in restricted areas are shown)

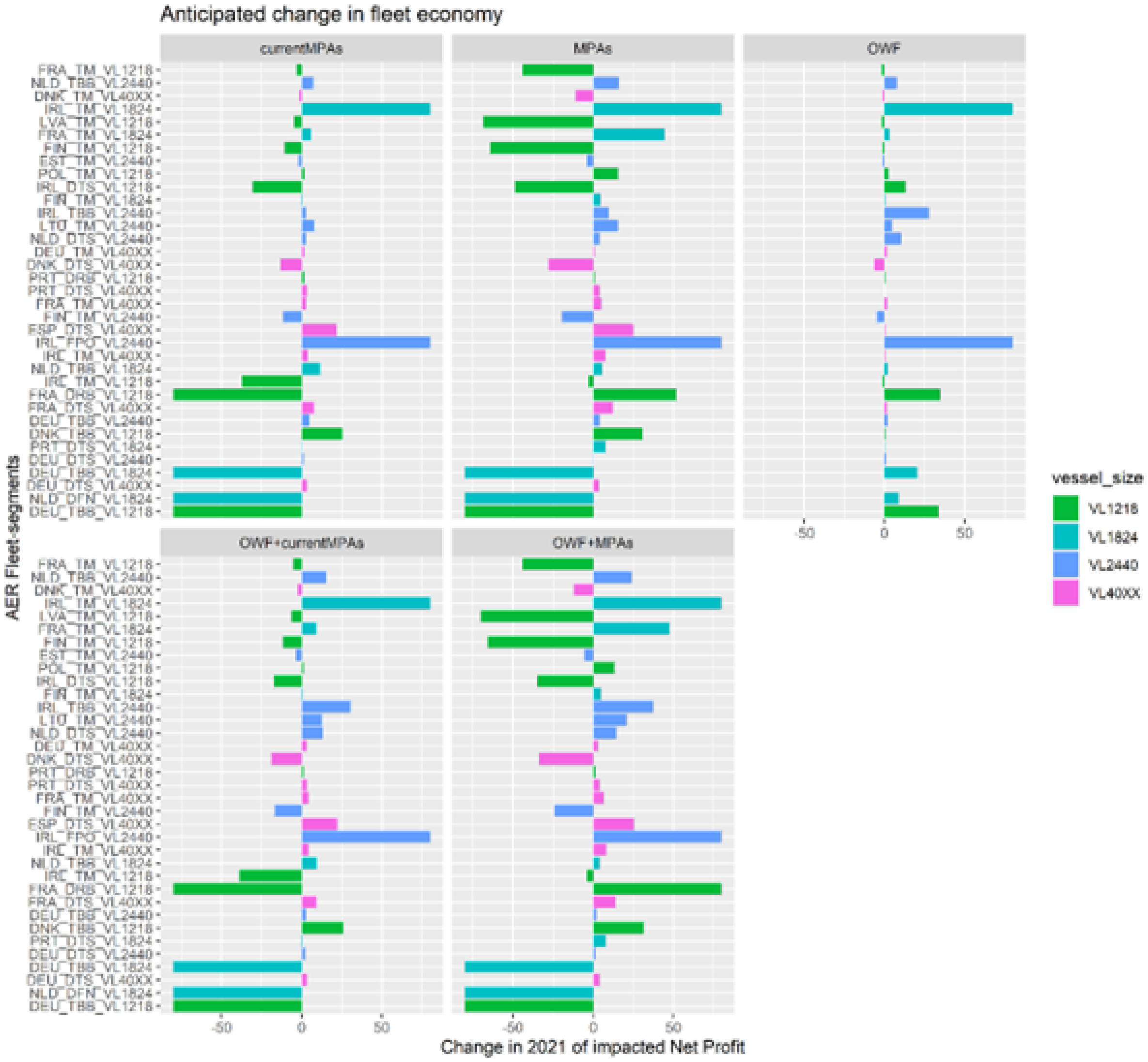


Figure 4.9. Anticipated economic change from the overlay analysis for the top 40 EU fleet segments impacted by the closure. Fleet segments with strong effects capped to -80% to 80% for readability. No displacement effect is assumed; therefore, a positive value results from removing fishing from restricted areas delineating historically unprofitable areas. Note that examining change for pelagic gears are not relevant if the tested spatial restrictions would only apply for mobile bottom contacting gears.

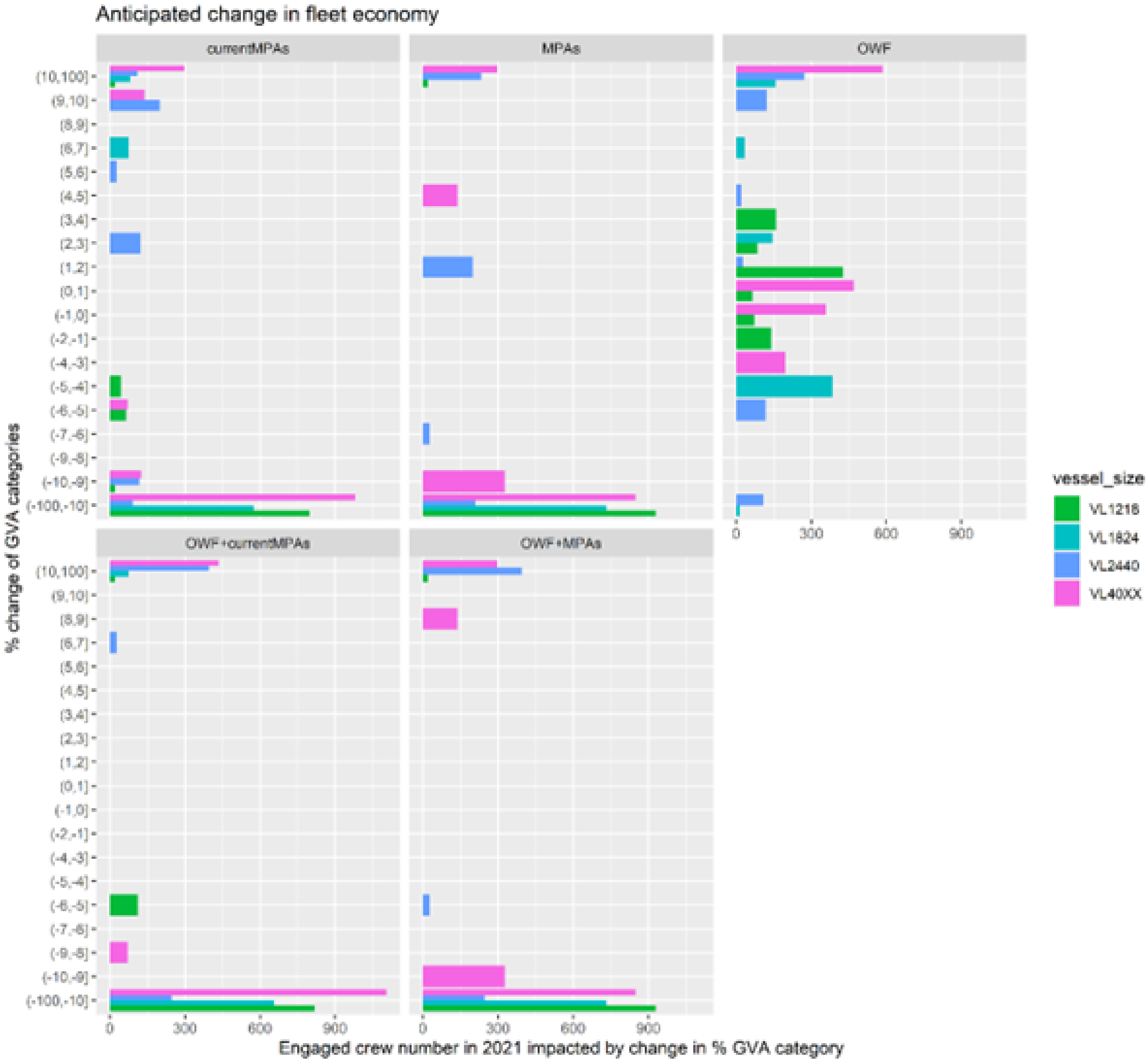


Figure 4.10. Anticipated impacted crew members from the overlay analysis for the top first 40 EU fleet segments impacted by the closure, per class of GVA. The impact can be positive or negative.

The case study of the Adriatic Sea and of the Western Ionian Sea was also explored. The study area covered the Adriatic Sea and the Western Ionian Sea and is characterized by the presence of different closure areas at different levels of implementation, partly or totally excluding the fishing activities (Figure 4.11).

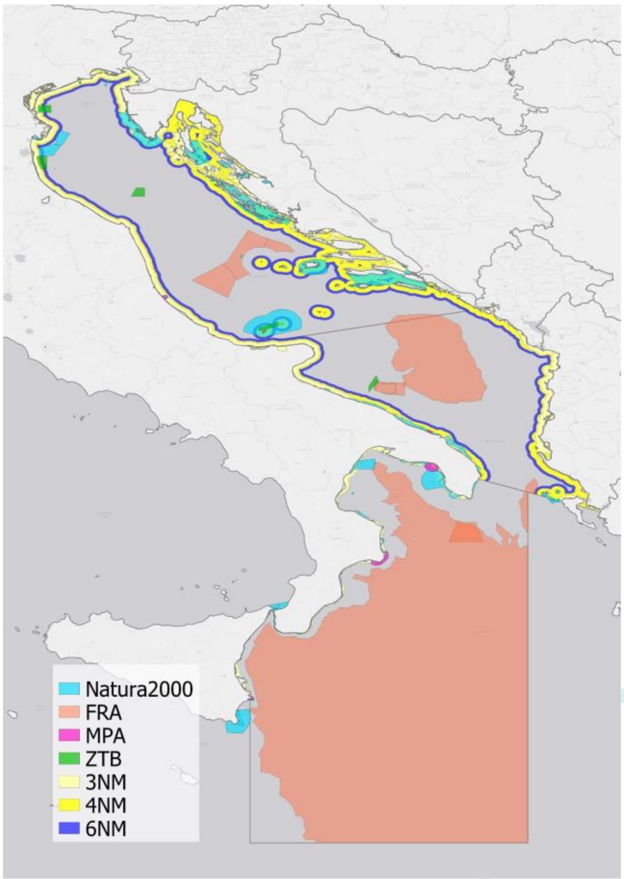


Figure 4.11. Areas with spatio-temporal restrictions to fishery in the GSAs17-18-19. FRA: Fishing Restricted Areas; MPA: Marine Protected Areas; ZTB: Biological Conservation Areas (“Zone di Tutela Biologica” in Italian); 3NM, 4NM, 6NM: Restricted width of coastal strips in Nautical Miles

Table 4.5. Estimates of the proportion of fishable areas left to fishing and occupied by the different restriction areas. The fishable area is defined here as the area with depth < 800m where fishing is allowed.

Closure area	Restricted km^2	Area left (km^2) to fishing	Proportion of the fishable area occupied
MPA	408.5	122219.6	0.002
FRA	155999.6	118984.4	0.029
ZTB	754.8	121826.6	0.005
3NM	17544.2	114508.8	0.065
4NM	30670.8	102341.0	0.164
6NM	40443.6	93303.9	0.238
Natura2000	9376.4	115333.9	0.058

Using the spatial mapping of fishing footprint derived from the AIS data, we conducted an analysis for the estimation of the amount of fishing effort likely impacted by the closure of the restricted areas (Figure 4.12). The analysis was conducted yearly considering the most recent period (2018-2022). The bottom trawling (OTB) being the most represented gear in the study area and also the most represented gear in the GFW AIS data, the analysis was conducted for OTB and the other active gears pooled together. The impact of the implementation of spatial restrictions on fishing effort in conservation areas varies for each fleet segment and depends on the specific type of spatio-temporal restrictions in place.

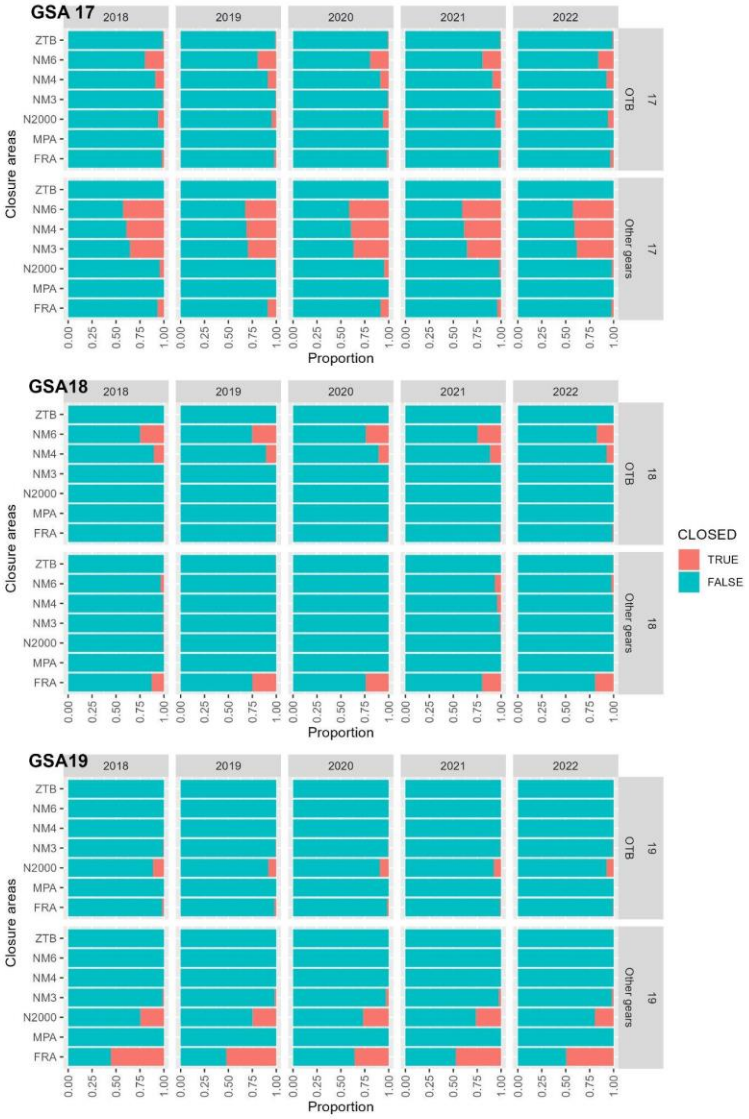


Figure 4.12. Proportion of the fishing effort by year (2018-2021) likely impacted by the closure of different restricted areas in GSAs 17, 18 and 19 (red). The analysis was conducted for the OTB, the most active fleet in the study area, and the other gears pooled together at GSA level.

The restriction areas still impacted by OTB fishing effort in GSAs 17 and 18 are the 4NM and 6NM from the coast line (Adriatic MAP closures areas), due to the limited temporal closure for a continuous period of at least eight weeks along the year. Being this ban related only to the towed gear targeting demersal stocks the "other gears" category in Figure 4.12 shows a higher proportion of activity in comparison to OTB, at least in GSA17. The little proportion of OTB activity observed in GSA 19 inside the Natura 2000 sites is likely due to the limited effectiveness of the sites' implementation in this area and also because such GSA is far from the coastal closure areas. On the other hand, the ZTB and AMP seems to be effectively implemented in all the three GSAs, though these results might be also amplified by the low dimension of these closure areas, especially for MPA, in comparison to the AIS data resolution provided by GFW.

4.2.2 Displacement effect based on coupled AER-VMS/AIS datasets

Different scenarios on the possible effort allocation are proposed and analysed, with an effort reallocation differentiated between fishing gears. In case the effort displaced may not compensate for the loss, the minimum effort level required to break even is calculated. The limits and likelihoods of scenarios and the assumptions behind them are further discussed hereafter. It is, however, already recalled here that the “fishable area” is defined as the marine space left for fishing but also the space suitable for fishing given the physical constraints of the marine environment. The present study assumes that the already fished area defines the suitable environment for fishing and did not investigate further if the habitat extent suitable for fishing might possibly change from factors external to fishing (e.g., induced by climate change). With this laminar assumption, the fraction of the historical effort impacted by the proposals for the closed areas can be displaced to the surrounding areas that have already been visited by the fishing fleet in the past.

The study evaluates the possible change in catches and the economic return that such a displacement could induce. However, the method used (i.e. GIS raster layers) for the displacement effect study prevents distinguishing individual polygons' effect. It is therefore assumed that the effect results from implementing them all (alongside fleet segment specifications depending on the scenario).

The study investigated two ways for a hypothetical redistribution of the fishing effort in reaction to the closed areas:

- A uniform (i.e. profit-free) redistribution over areas of the impacted effort toward areas already visited by the fleet segment. In practice, the total impacted effort by the closed areas of a given scenario is evenly re-distributed over all the c-squares visited by the fleet segment during the period 2018-2021.
- A weighted redistribution of the impacted effort alongside the historical c-square GVAs, where more (i.e. on a log scale) effort is displaced toward historically high GVAs recorded for the fleet segment during the period 2018-2021 studied. It should be noted that to avoid bias in case the fleet segment is not used to optimise on expected economic return, this weighted redistribution is not compared to the historical one but to a recalculated baseline (i.e. a comparable counterfactual) that accounts for optimal redistribution of the same amount of the impacted effort alongside spatial GVAs, closed areas included.

After the redistribution occurs, the catches that were historically recorded inside the closed areas are cancelled, and new catches outside the closed areas are computed, accounting for the extra effort added to the c-squares and their specific LPUEs. The economic variables, including the GVA, are also recomputed based on the new catches and spatialised costs.

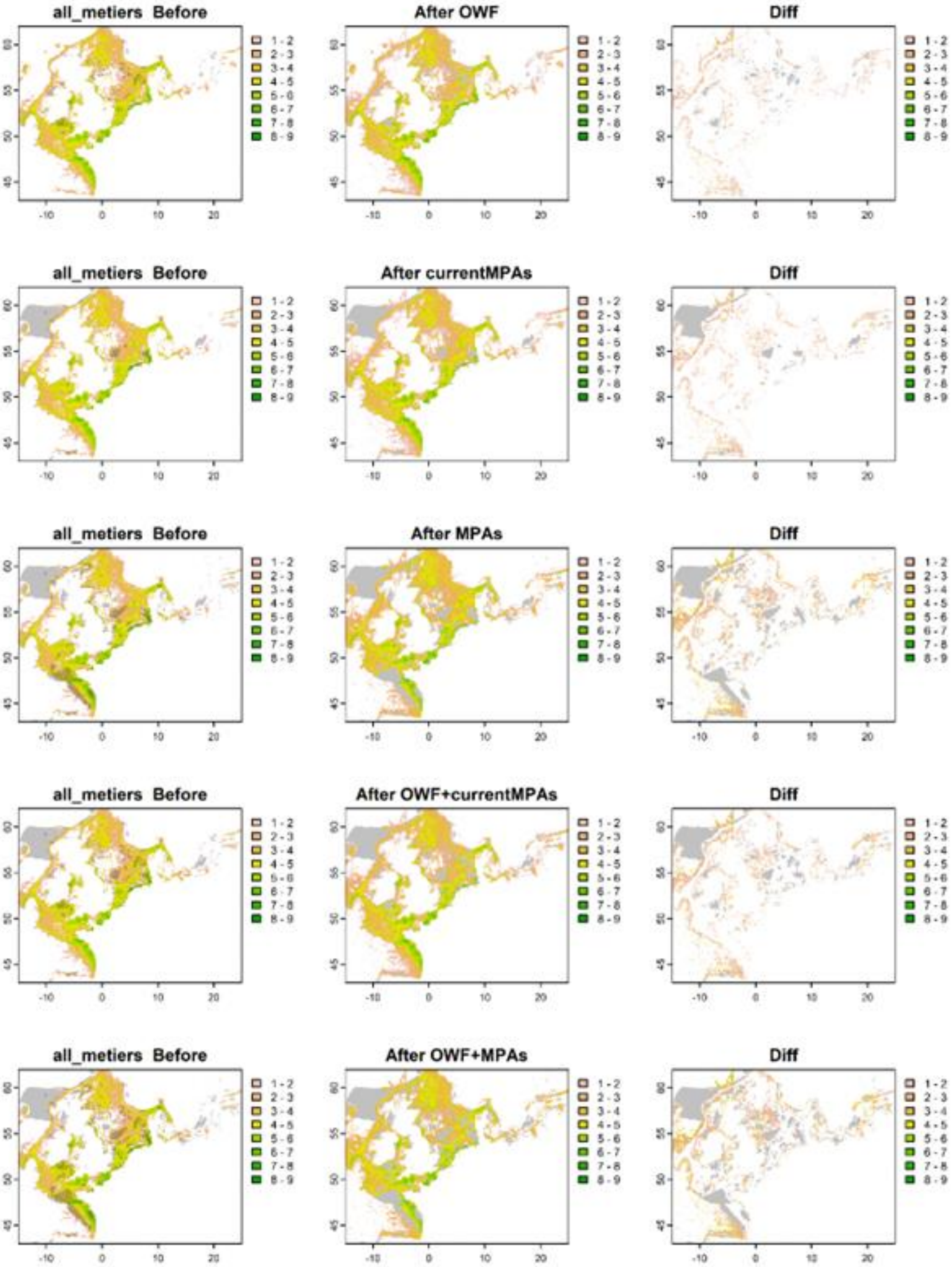


Figure 4.13. Example of fishing effort displacement, under the assumption of redistribution alongside more weight given to high GVA areas, induced by excluding all fishing activities pooled within the scenario proposals for closures (grey polygons specific to scenarios) designated in the NEA EU and UK waters area. Dark transparent grey shows the initial overlap in the Before situation. Specific fleet-segment closures were not used to produce this particular outcome.

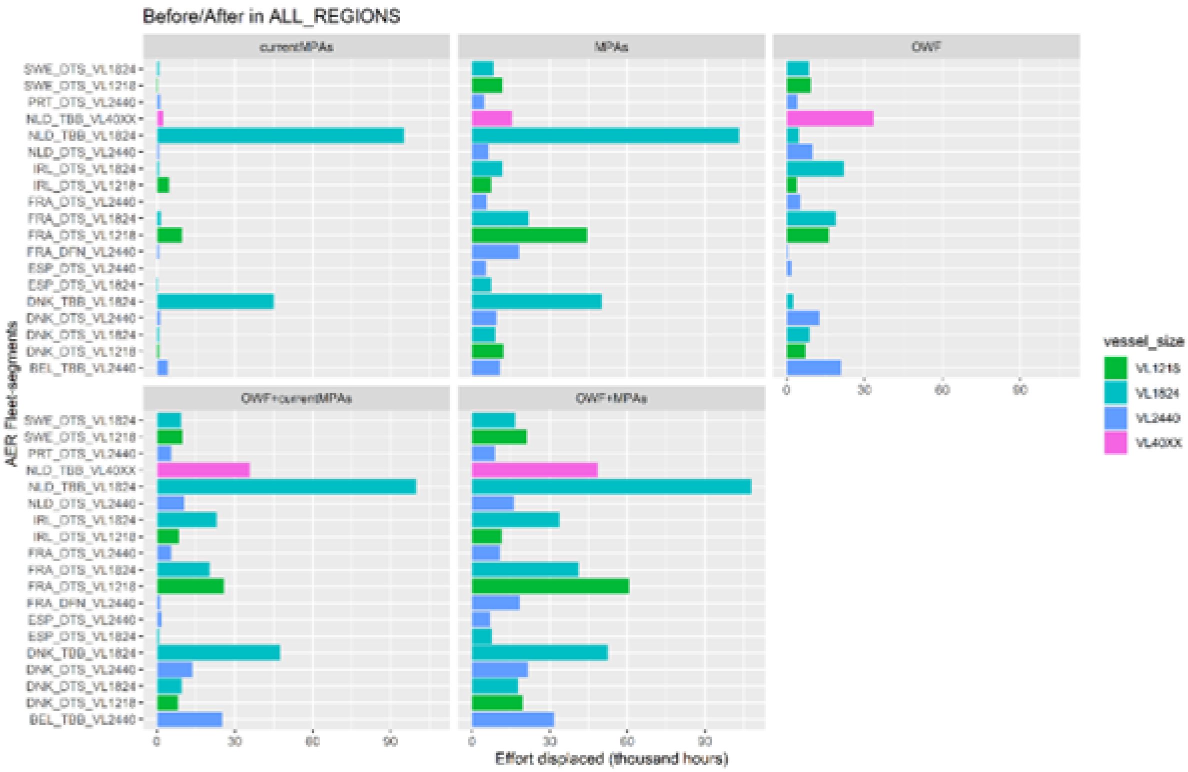


Figure 4.14. Fleet-segment-specific amount of average 2018-2021 effort impacted by the closed areas for the three scenarios in the NEA of the EU and UK waters.

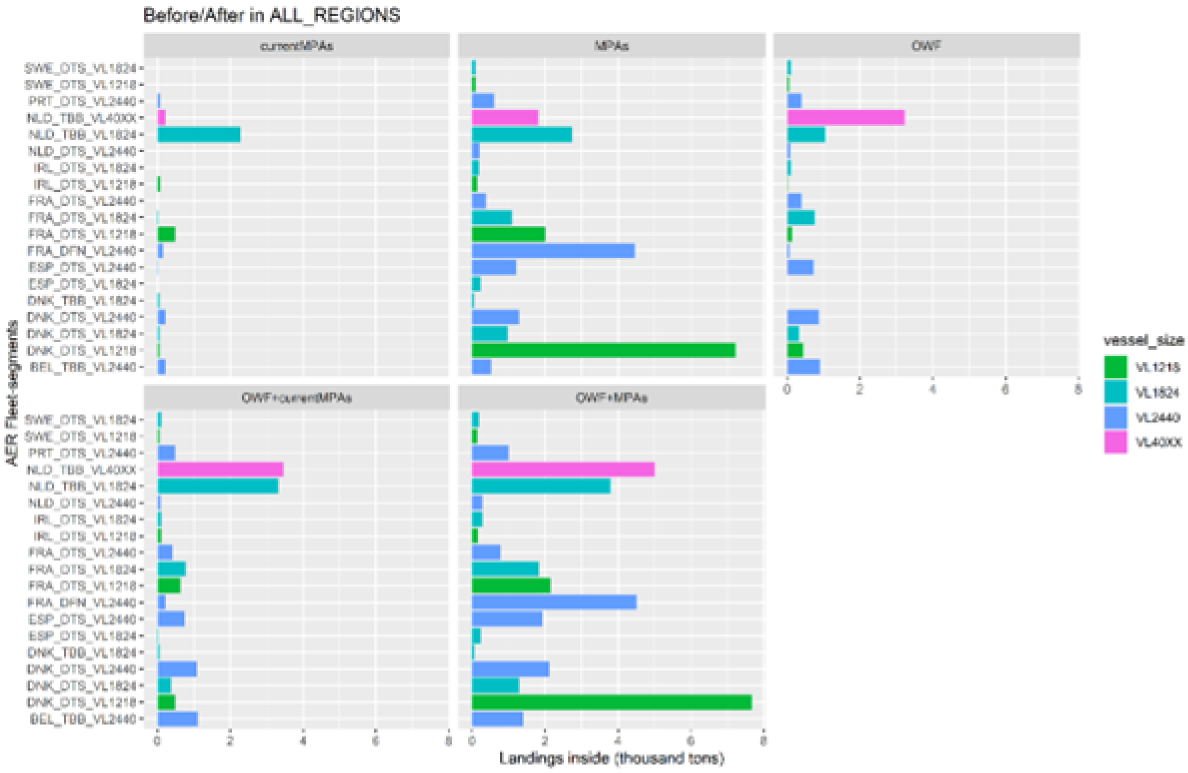


Figure 4.15. Fleet-segment-specific amount of average 2018-2021 landings impacted by the closed areas for the three scenarios in the NEA of the and UK EU waters.

For most of the fleet segments, there is a possible gain after the redistribution of effort (up to three times more for DNK_TBB_VL1824), either uniformly or optimised based on the spatialised GVAs (Figure 4.13). The difference between the two effort redistribution assumptions (uniform vs. spatialised GVA-based) is small likely because the displaced amount of effort is also not large (Figure 4.14). Such a gain may result from efforts deployed at the end of the fishing ground that is not rewarding enough compared to the cost induced for operating the fishing in those areas.

There are, however, some fleet segments, DNK_DTS_VL1218, SWE_DTS_VL1218 or FRA_DTS_VL1218, and many other minor fleets that would likely be adversely affected by a redistribution with loss in GVA after the implementation of the closed areas which is not compensated by a redistribution of the effort, whatever the scenarios, and the hypothesis on the way the effort displacement may occur. In such an adverse effect the effort required to break even is up to 40% for some of those fleet segments (Table 4.6). Such effort increase requirement to break-even in GVA gives a proxy of the fuel use increase and associated cost that would come with it.

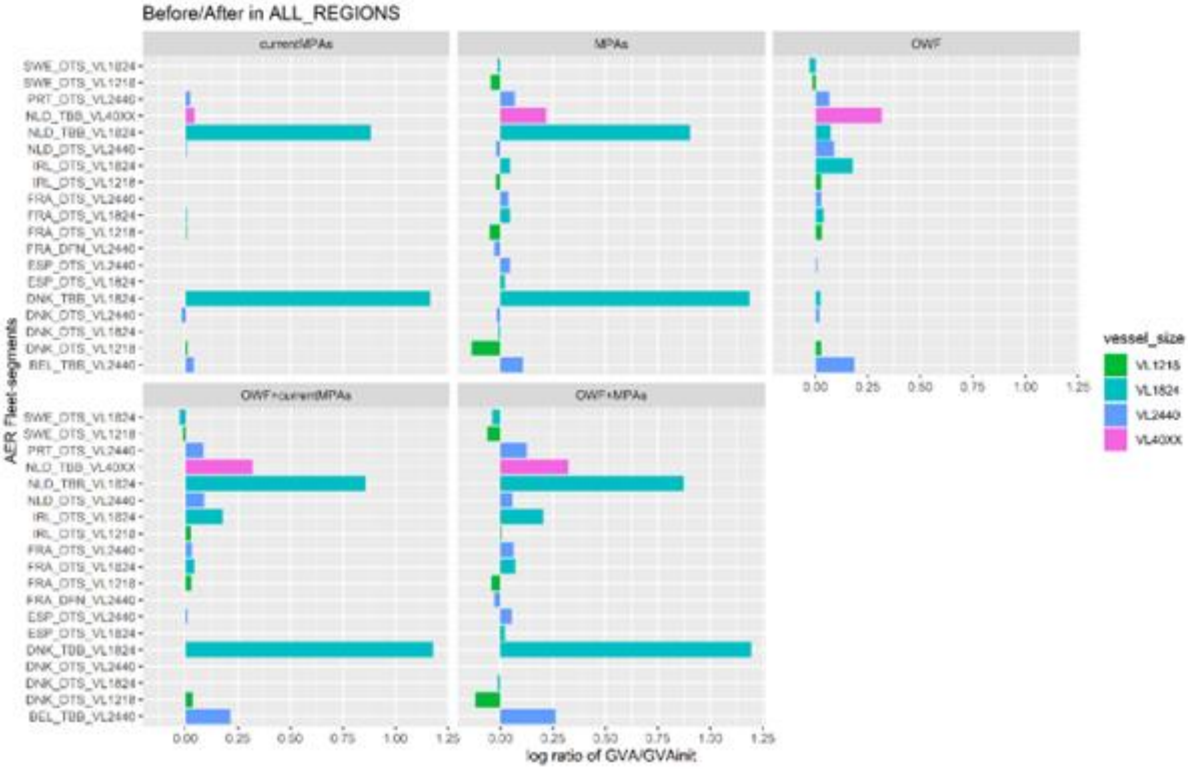


Figure 4.16. Fleet-segment-specific effects on GVA of a weighted fishing effort redistribution of the part of the average 2018-2021 fishing effort impacted by the closed areas for the five scenarios in the NEA of the EU waters. A positive value on the log scale indicates a larger GVA obtained after the effort redistribution, and vice versa. Exponentiating the log-value gives the factor, e.g. a log-ratio at 1 gives a 2.71 times greater GVA after than before the effort displacement. Only the top 20 fleet segments in overall effort deployed in the region are shown.

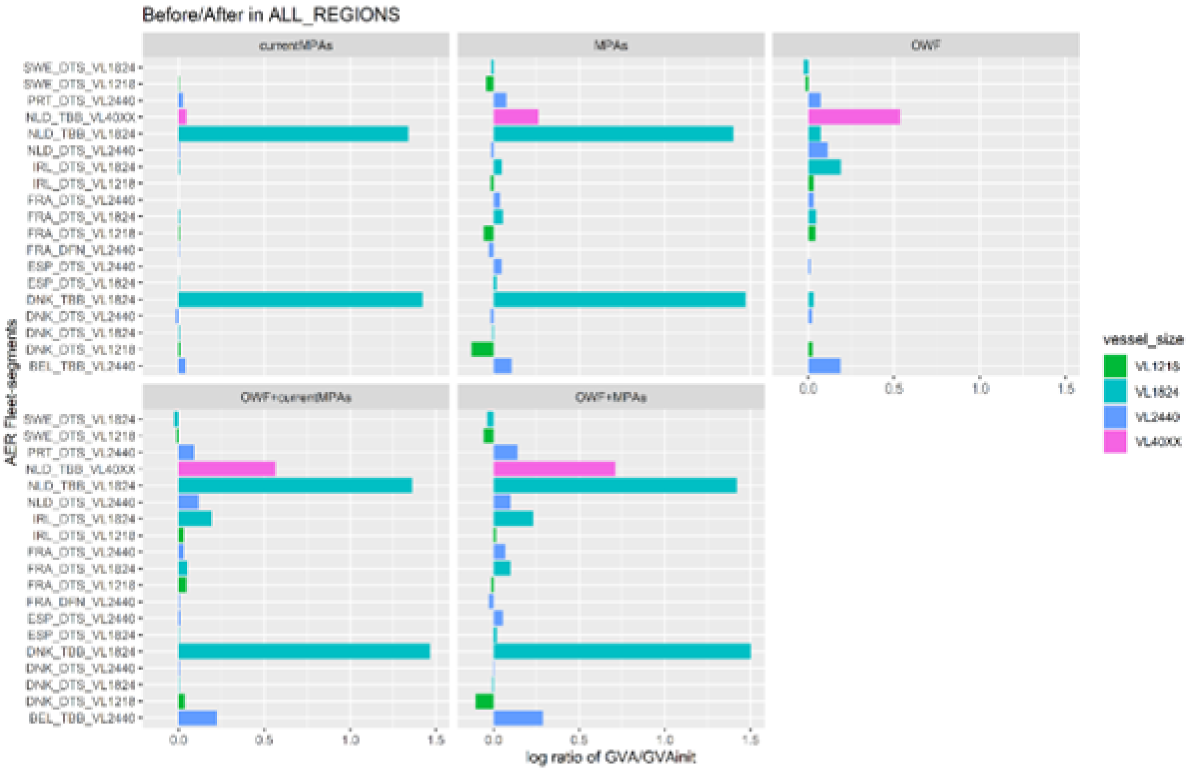


Figure 4.17. Fleet-segment-specific effects on GVA of a uniform fishing effort redistribution of the part of the average 2018-2021 fishing effort impacted by the closed areas for the three scenarios in the SWW and NWW. As Figure 4.16.

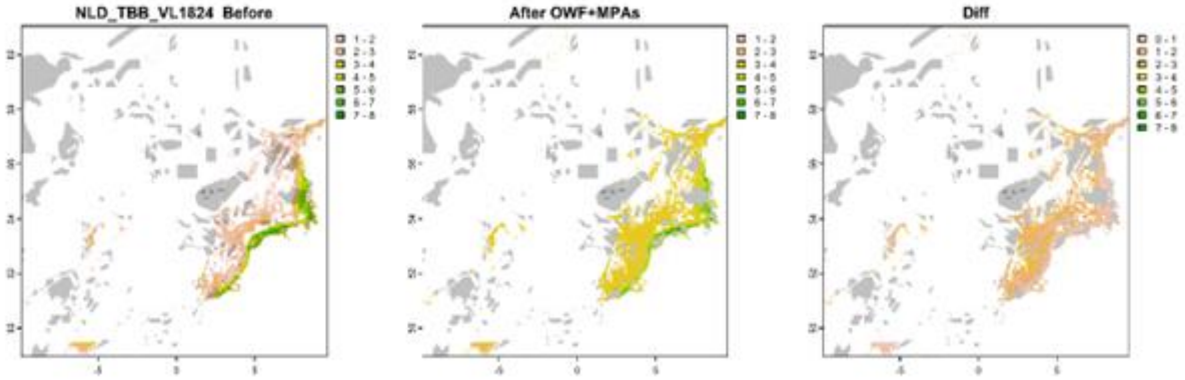


Figure 4.18. Illustration for the fleet segment NLD_TBB_VL1824 of the difference in effort allocation induced by the effort displacement from restricted areas (here to bottom fishing) toward the surrounding areas (here toward the areas with historically high GVAs). The grey areas show the polygons for restrictions to fishing for the scenario OWF+MPAs, and dark grey is the same but with overlap.

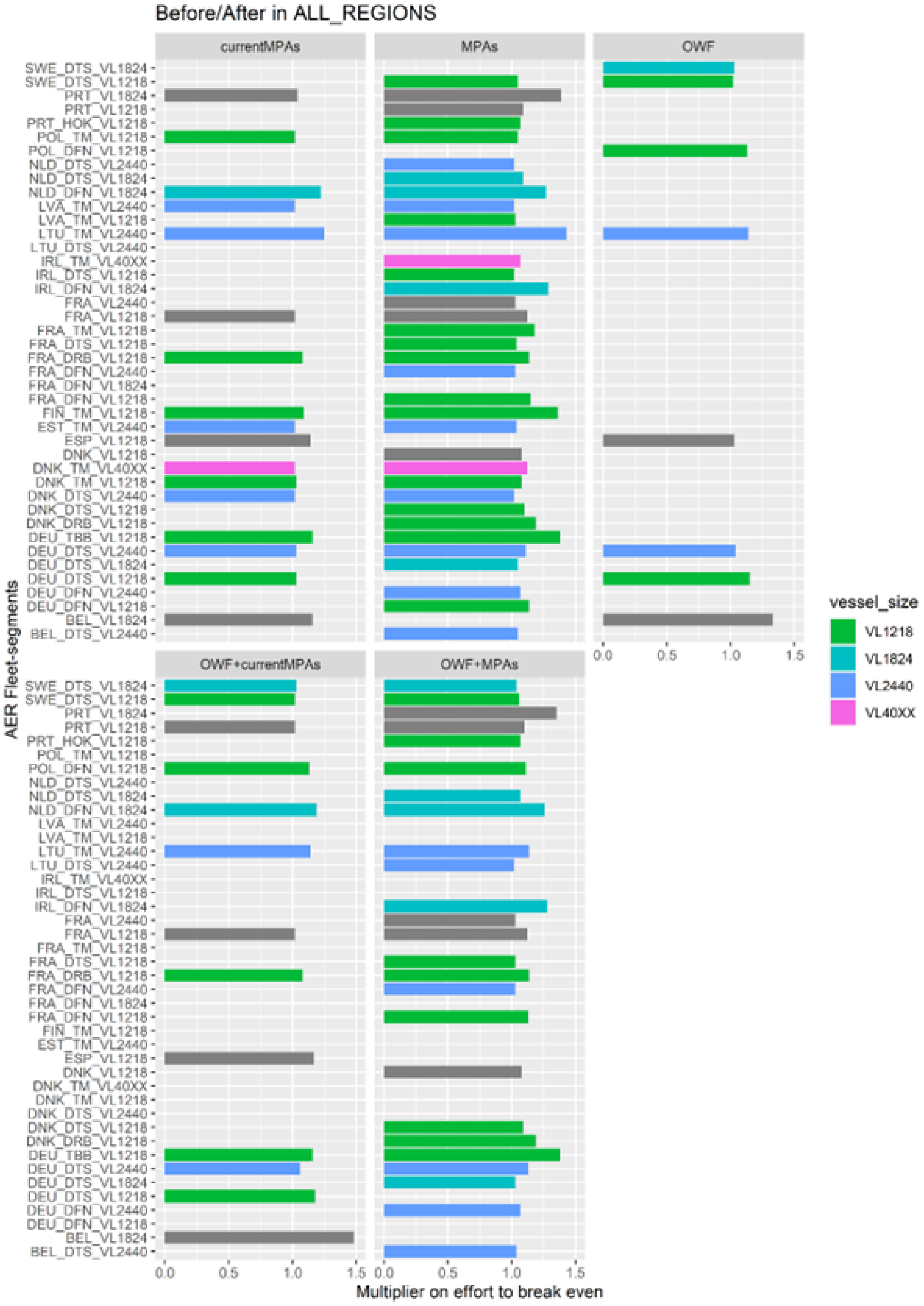


Figure 4.19. Fleet-segment-specific extra-effort multiplier required to compensate and break even in reaction to immediate impact from the closed areas for the three scenarios in the NEA of the and UK EU waters. Note that examining the possible effect on pelagic gears TM is not relevant of the spatial restrictions would apply to bottom contacting gears only.

Table 4.6. The extra fishing effort required to break even if restriction scenarios are implemented. For example, 1.16 means that 16% extra effort of the baseline effort is estimated to be required so that the GVA would equate to the baseline GVA, all other factors being equal. Only fleet segments with GVA less than the baseline GVA after reallocation are listed. Scenarios shown are "currentMPAs" i.e. already restricting MPAs, or "MPAs" i.e. in case restrictions are implemented and enforced in the currently designated MPAs of the EU marine waters.

fleet-segment	**scenario**	**Effort multiplier**	**fleet-segment**	**scenario**	**Effort multiplier**
BEL_VL1824	currentMPAs	1.16	BEL_DTS_VL2440	MPAs	1.05
DEU_DTS_VL1218	currentMPAs	1.03	DEU_DFN_VL1218	MPAs	1.14
DEU_DTS_VL2440	currentMPAs	1.03	DEU_DFN_VL2440	MPAs	1.07
DEU_TBB_VL1218	currentMPAs	1.16	DEU_DTS_VL1824	MPAs	1.05
DNK_DTS_VL2440	currentMPAs	1.02	DEU_DTS_VL2440	MPAs	1.11
DNK_TM_VL1218	currentMPAs	1.03	DEU_TBB_VL1218	MPAs	1.38
DNK_TM_VL40XX	currentMPAs	1.02	DNK_DRB_VL1218	MPAs	1.19
ESP_VL1218	currentMPAs	1.14	DNK_DTS_VL1218	MPAs	1.10
EST_TM_VL2440	currentMPAs	1.02	DNK_DTS_VL2440	MPAs	1.02
FIN_TM_VL1218	currentMPAs	1.09	DNK_TM_VL1218	MPAs	1.08
FRA_DFN_VL2440	currentMPAs	1.08	DNK_TM_VL40XX	MPAs	1.12
FRA_TM_VL1218	currentMPAs	1.02	DNK_VL1218	MPAs	1.08
LTU_DTS_VL2440	currentMPAs	1.25	EST_TM_VL2440	MPAs	1.04
LVA_TM_VL1218	currentMPAs	1.02	FIN_TM_VL1218	MPAs	1.36
LVA_TM_VL2440	currentMPAs	1.22	FRA_DFN_VL1218	MPAs	1.15
POL_DFN_VL1218	currentMPAs	1.02	FRA_DFN_VL1824	MPAs	1.03
PRT_VL1218	currentMPAs	1.04	FRA_DFN_VL2440	MPAs	1.14
			FRA_DRB_VL1218	MPAs	1.04
			FRA_DTS_VL1218	MPAs	1.18
			FRA_TM_VL1218	MPAs	1.12
			FRA_VL1218	MPAs	1.03
			FRA_VL2440	MPAs	1.29
			IRL_DFN_VL1824	MPAs	1.02
			IRL_DTS_VL1218	MPAs	1.07
			LTU_DTS_VL2440	MPAs	1.43
			LTU_TM_VL2440	MPAs	1.03
			LVA_TM_VL1218	MPAs	1.02
			LVA_TM_VL2440	MPAs	1.27
			NLD_DFN_VL1824	MPAs	1.09
			NLD_DTS_VL1824	MPAs	1.02
			POL_DFN_VL1218	MPAs	1.05
			POL_TM_VL1218	MPAs	1.07
			PRT_HOK_VL1218	MPAs	1.09
			PRT_VL1218	MPAs	1.39
			PRT_VL1824	MPAs	1.05

For the case of the Adriatic Sea and Western Ionian Sea, we have examined how the application of management measures likely impacts the displacement of the fleet within the study area. We focused on the implementation of the Jabuka/Pomo Pit Fishery Restricted Area (FRA) and the MAP spatio-temporal closures. The analysis estimates the effects of these closures on the DTS fishing effort footprint observed in 2017, which was prior to the establishment of the FRA (Figure 4.20). In particular, Zone A was completely closed to bottom contacting gears (e.g. bottom-set nets, bottom trawls) since 2018, while in Zones B and C the fishing activities are prohibited for two months each year. The MAP closure of the 6 NM from the coast are defined for the same period.

The effect of the management measures was explored estimating the amount of Gross Value Added (GVA) by fleet segment observed in 2017 in the closure areas defined by the current scenario and then displacing it in the areas explored by each fleet, proportionally to the observed GVA. The present study assumes that the already fished area defines the suitable environment for fishing. The fraction of the historical effort impacted by the proposals for the closed areas can be displaced to the surrounding areas that have already been visited by the fishing fleet in the past. The study evaluates the possible change in the economic return that such a displacement could determine.

The study's findings indicate that the closure measures have the most significant impact on fleet segments that primarily operate in the Northern Adriatic Sea (GSA17). Specifically, vessels within the length range of 18 to 24 meters are particularly affected by these measures (Figure 4.20). The displaced GVA is preferentially allocated in the areas offshore along the Italian coasts (Figure 4.21).

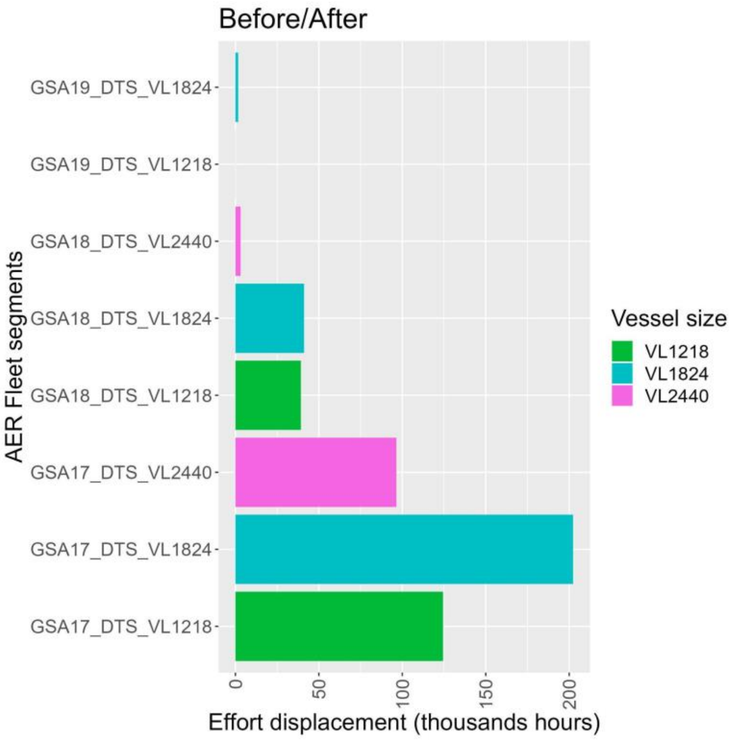


Figure 4.20. Fleet-segment-specific amount of 2017 effort impacted by the closure defined in the explored scenario.

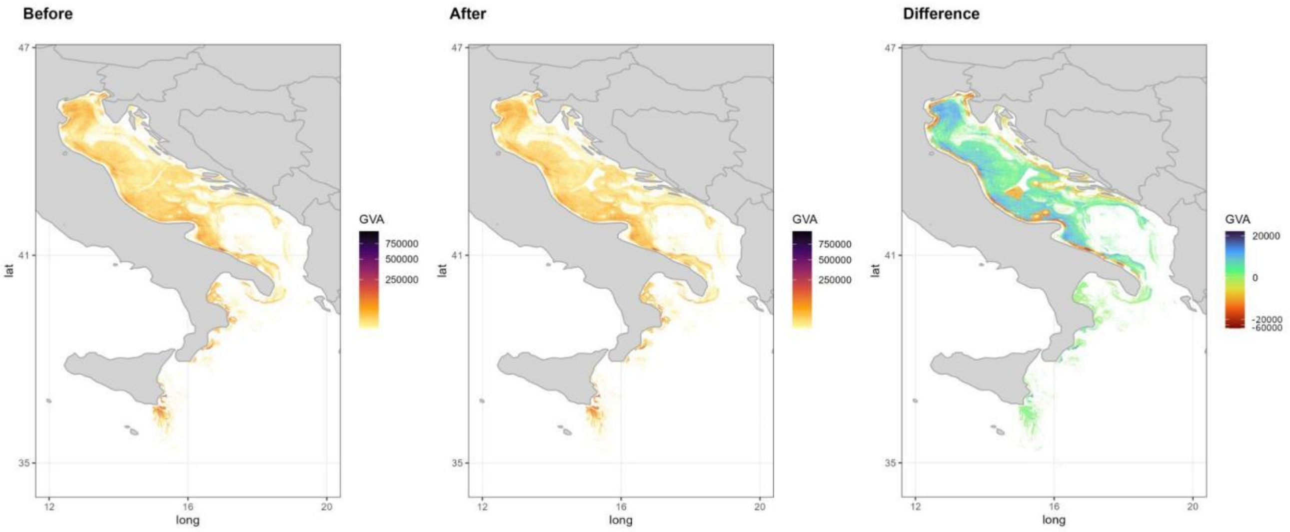


Figure 4.21. GVA displacement induced by the reduction of the fishing activities as defined by the closure scenario explored.

The effect of the implementation of the Jabuka/Pomo Pit FRA was further explored following a Before–After–Control–Impact (BACI) analysis. The method to assess the effectiveness of the management measure and its application adopted was adapted from that used by Chiarini et al. (2022). The FRA, established in late 2017 was divided in three different zones: A, B and C, encompassing different levels of closure, previously described. In Figure 4.22 the map of the FRA zonation is reported. A fourth area, surrounding the external borders of the FRA, was defined for the BACI analysis purpose, using a buffer area of 6NM. This area was used as control area, being not regulated by any management measure.

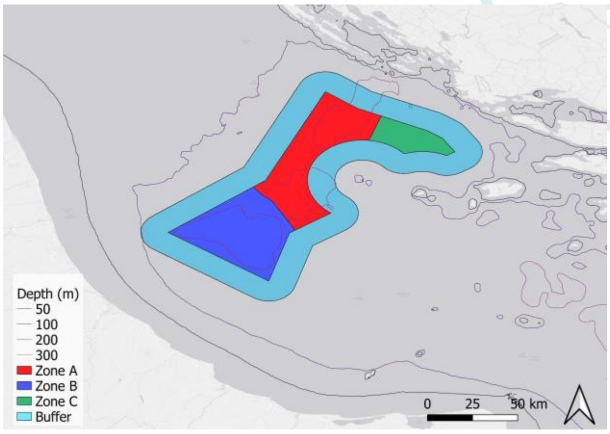


Figure 4.22. Map of the Jabuka/Pomo Pit Fishing Restricted Area zonation implemented in late 2017. In red the Zone A, in blue the Zone B and in green the Zone C. The light blue area outside the FRA borders is a buffer area set for the purpose of BACI analysis.

The "Before" period was up to the FRA implementation in 2017, while "After" was set including effort data up to 2021. The comparison between the two periods for each of the four areas was conducted by mean of an ANOVA analysis (Figure 4.23).

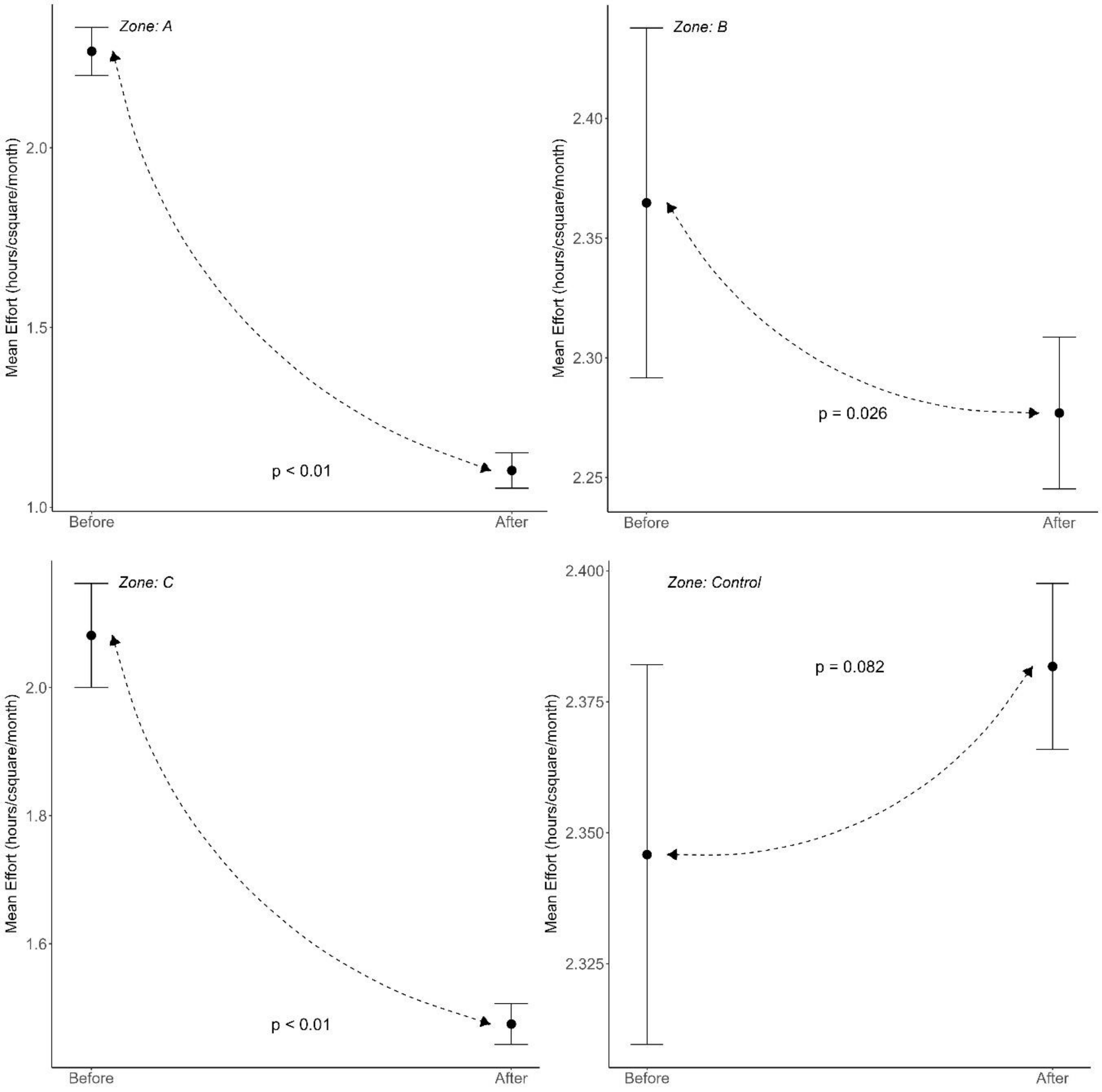


Figure 4.23. Results of the BACI analysis to assess the effect of the implementation of Jabuka/Pomo Pit FRA in the Northern Adriatic Sea comparing for each area of the FRA zonation the mean effort before (2017) and after (2018-2021) the FRA implementation. P values are related to the ANOVA conducted in the BACI analysis.

The BACI analysis (Figure 4.23) clearly shows the effectiveness of the fishing restriction (FRA) implementation in the study area. The fishing effort level of bottom trawl (OTB) vessels was significantly reduced in all the three zones of the FRA since its establishment. The greater amount of effort reduction was observed, as expected, in the Zone A, in which the activities of fishing contacting nets was prohibited all year round since the end of 2017. In the buffer Zone (control zone), a slight effort increase was observed, though this was not statistically significant. Following the results obtained in the displacement scenario, the reallocation of the fishing effort has likely not affected the neighboring area of the FRA but has redistributed instead along a larger area.

4.2.3 Potential effects of displacement on fish species from a static view

Overlaying the species distribution deduced from SEAwise Task 5.2 with the restricted areas allowed us to detect what are the species with the lowest density inside the restrictions, or, on the contrary, the species that have likely higher density outside the restricted areas. The restricted areas might overlay hotspots of density only for a few species (in green in Figure 4.24 below), and most of the species have an average density that is higher outside restricted areas, whatever the scenario (Figure 4.24). An effort displacement from the restricted areas toward the surrounding areas might therefore induce an increase in catch rate for these species, as long as catch rates relate to population density.

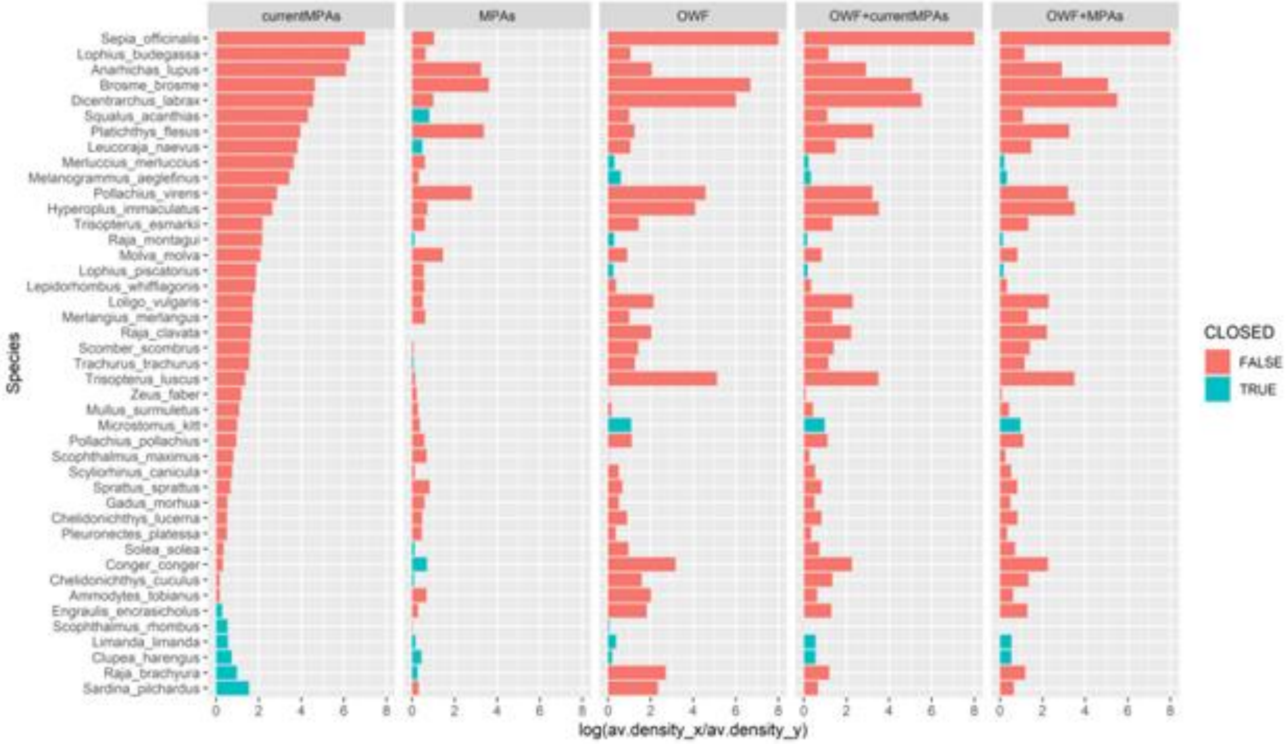


Figure 4.24. How many times more the density is bigger in a given type of area (closed or opened) given by the ratio of average density of each species in a type of area (either closed or opened) over the other type of area, the restricted areas being defined by the restriction scenarios. For example, it is found that there is exp (1.537)=4.65 times more of Sardina_pilchardus inside the currentMPAs than outside in terms of density of individuals. On the other way around, there is almost null density inside the currentMPAs for Sepia_officialis. For all species investigated in D5.2.

4.2.4 Limitations of the study and conclusion of the static approach

The geographical scale at which the evaluation is done can affect the estimated effects. Using fine spatial resolution, such as the VMS dataset (0.05 degrees), demonstrated that it is possible to provide estimates on the short-term socioeconomic impact of the closed areas on the impacted fleet segments. Indeed, ICES (2022) considers the aggregated VMS 0.05 spatial grid resolution as appropriate to map mobile bottom contacting gears fishing activity, given the minimum frequency of VMS position collection and average fishing speeds of vessels towing those gears, inherent uncertainties in vessel positioning. Mapping the fishing effort that arose from other activities, such as passive gears, is less certain, given the inherent difficulties in estimating the soaking time (i.e. the time nets or hooks are active in the water at fishing) using the VMS data only. However, the mapping of the activities and, therefore, the identification of the origin of the revenue from the catches is likely still well captured spatially. Another problematic issue with geographical scale arises from the mismatch between the resolution of the data and the possible size of an individual protected area which can be smaller than the grid size. If aggregating the fisheries data is not possible, then some workarounds can be used such as the apportionment of the size of the protected area to the size of a grid cell, an approximation we have applied in the presently reported static study.

By nature, the ICES VMS datasets describe the fishing activities at the DCF métier Level 6, which is close to what defines "fisheries" (i.e. combinations of a fishing technique used during a specific season for specific target species). On the other side, the STECF AER data is aggregated at a coarser level which constrained the final resolution of the fleet segment used in the present study, even if the AER economic variables have been disaggregated spatially, accounting for the spatial effort distribution per DCF métier Level 6. Impacted AER fleet-segments could, in most cases, encapsulate several different fisheries which will not be impacted the same way by the spatial plans, some potentially more impacted than the study could show if targeting deep-sea species specifically. However, aligning to the coarser AER fleet segment level was unavoidable to account for the entire fleet economy and compute profit indicators. Besides, there are inherent uncertainties linked to the method for spatially disaggregating the AER economic variables, as these variables are not spatial by nature. Hence, when anticipating the effort displacement, it is assumed that the travelling or distance-to-coast effect is neglectable (one unit of effort of a given fleet segment has the same cost whatever this distance), and therefore only the cost per unit of time effort is considered in disaggregating costs spatially, which in some occurrences might make the possibility for effort displacement overly optimistic.

The aim of the protection is to ensure the long-term conservation of fish stocks and their supportive vulnerable habitats by limiting significant adverse impacts on marine habitats and therefore contribute to the objectives of the EU Common Fisheries Policy. To account for effects in the medium to the longer-term horizon, the analysis should be complemented with some ecological considerations to accurately determine the benefits of such closed areas. Those considerations are, for now, missing and were out of the scope of the present evaluation. Those effects are investigated in section 5 where socio-ecological dynamic models are deployed and will be further complemented in a second deliverable D5.6. related to SEAwise Task 5.5.

It is expected that the population dynamics of the target stocks will also influence the future allocation of fishing effort in space in response to changes in stock distribution which is not captured here when looking at historical effort allocation only. Developing a bioeconomic Management Strategy Evaluation (MSE) would make it possible to test, for the biological side, for alternative natural mortality rate and future changes, alternative somatic fish body growth and future change, the effect of differences in age-composition and variation in catchability of fish of varying size, changes in spatial distribution, changes in ocean's carrying capacity and effects of recovering stocks. On the economic side, an MSE would inform on various changes in the economic context of exploitation (price, costs, capital, etc.). Hence, it should be clear that no benefit is shown here from protecting marine habitats and recovery, etc., only because only short-term effects are investigated here. The evaluation does not estimate long-term dynamics; to investigate this, it would need to use some bioeconomic spatial models in an MSE setting and including, e.g. spatial connectivity modelling.

Concerning the socioeconomic evaluation, it should be noted that it is not straightforward to translate a change in an economic variable into a short-term or long-term impact on the engaged crew or a change in the number of engaged crew. Such a relationship is highly hypothetical and has not been used here, also because the evaluation found that there is no negative GVA induced by the spatial plans that could lead some stakeholders to reduce the engaged crew in order to save on labour costs.

How the single operators will react to closed areas is not known exactly. A spectrum of reactions might be expected from redistributing the effort toward other highly profitable fishing grounds, toward fishing grounds that are already well known, or reducing the effort at sea during a certain period of the year to counteract lower economic returns. A redistribution assuming fisheries involved in large-scale fishing (>12m) are profit-optimiser fishing, as has been done in the present evaluation, seems the most reasonable hypothesis in the possible skipper's decision-making given the small extent of the closed areas investigated. However, as described in SEAwise D2.5, fishers can prefer to optimise other targets than profits, such as having the largest catch, avoiding risks or new areas, or they can simply do what they always do (personal habits) and always go to the area they know because they have always fished on the grounds 'of their father and grandfather' (family tradition). They can also decide not to comply with the rules and do something unexpected (Batsleer 2016) or their behaviour can be driven by social factors not per se related to the amount of catch, such as trip duration (Bastardie et al. 2010, Schadeberg et al. 2021).

Overall, by analysing the finely spatially resolved data, the socioeconomic impact of enforcing the proposed spatial plan would affect the average Gross Value Added (GVA), with Net Profit sometime exceeding 80% loss for several bottom fishing fleet-segments (DEU_TBB_VL1218, DEU_TBB_VL1824, IRL_FPO_VL2440, DEU_TBB_VL2440, DNK_TBB_VL1218, FRA_DTS_VL2440, DNK_DRB_VL1218), but would mainly affects DNK_DTS_VL1218 negatively because of no possibility of offsetting the loss of spatial opportunities by displacing the effort toward surrounding areas, unless the fleet increases its effort by 5 to 10% to break-even. Only a few areas are susceptible to affecting specific fisheries, with some impact that can be offset by displacing the effort toward other fishing grounds. It also depends on the type of proposals as eventually not impacting the same segments. However, as expected it is found that the more extensive Scenario OWF+MPAs is also impacting more than other scenarios. At this overall scale it is not known if the adverse effect arises from a few locations. A possible mitigation measure might pay particular attention to those impacting sites and maybe less to the chosen scenario.

The VMS data coverage does not include smaller vessels (<12 m), although these vessels will also likely be affected by the closures, especially by those closer to the shore.

On some occasions, a slight change affecting GVA can lead to a large change in profitability, given some extensive personnel costs and fixed capital assets engaged in those fisheries, and sometimes with negative initial profit. Negative profit might add to the loss of spatial opportunities, possibly affecting the concerned segments' engaged crew if saving on labour costs is seen as a solution to balance losses.

If the tested spatial plans have been found to have some impact (and the larger the restricted area, the larger the impact is), it does not preclude some future benefits on future fishing opportunities from protecting specific marine habitats or from displacing fishing effort away toward more rewarding fishing grounds. The present study has looked at short-term effects only and does not investigate long-term dynamics and possible effects of protecting part of the harvested populations, neither on effects of changing labour costs in the medium term. To research this, bioeconomic spatial models would be necessary that allow for more dynamic decision-making and include ecological considerations, e.g. population dynamics.

5. Dynamic evaluation of the restriction on fishable areas in a BACI-style

Observational data to estimate the effect of restricting space available for fishing is often unavailable, and experimental studies are not feasible. Here, we propose adopting the BACI style, combining the best of experimental studies design for modeling BACI scenarios to improve robustness of outcomes. SEAwise aims at forecasting the space available to fishing in 2030 and/or 2050 with fish spatial distribution or population dynamics possibly affected by climate scenarios IPCC Regional Concentration Pathways (RCP) 4.5W/m^2 and RCP 8.5W/m^2, and the role of spatial restrictions in managing those fisheries. In this task, SEAwise does not come up with such suggestions, but instead aims at testing existing proposals for spatial plans.

The following section describes the methodologies/models that are used. The SEAwise baseline scenario that is common as far as possible to all simulation platforms is also described.

5.1 A common baseline scenario

SEAwise scenarios should be consistent across SEAwise Tasks (i.e. aligned with Task 6.3 and 6.4, deliverables in month 18). Hence, the parameterisation of the biological part should be as close as possible to the same parameterisation used for task 3.5 to forecast stock developments in a base scenario (i.e. no environmental changes). If not possible, the parameterisation (i.e. stock recruitment relationship(s), biological parameters as M, weight at age etc.) should be chosen as close as possible in line with the latest benchmark decisions (if available). Uncertainty should be included at least for the biological parameters (i.e. recruitment) whenever possible. In addition, assessment and/or advice error in an MSE shortcut approach may be added if feasible.

5.1.1 North East Atlantic case studies

In total 3 scenarios are run in tasks 6.3 and 6.4:

- A "status quo" effort/F scenario. The effort/F is set to the average of the last three years *OR* to the value of the most recent year if trends are obvious. No further management is assumed.
- A "min" scenario. The ICES FMSY harvest control rule is applied with FMSY as target for each stock. The fleets/metiers stop when the first quota is exhausted. The scenario implies a strict implementation of the landing obligation.
- A "pretty good yield" scenario: The same as the min scenario, but fishing at the "FMSY upper" level is allowed when stocks are in good status; i.e. above Btrigger at the beginning of the advice year. In addition, a buffer to year-to-year advice variability could be introduced, such that TACs are limited to max. +/- 20 percent from one year to the next. The scenario is somewhat more flexible in the use of the upper FMSY range, possibly releasing some choking behaviour when most-limiting stocks are in good status.

For task 6.4 an additional case-specific scenario was run that mimics the current situation in the region regarding fleet dynamics, uptake of quotas or likelihood of certain species/stocks becoming choke species under the current level of implementation and control of the landing obligation.

5.1.2 Mediterranean case studies (Central and Eastern Mediterranean)

For *Central Mediterranean Case study* the GFCM MAP for demersal stocks in the Adriatic (Recommendation GFCM/43/2019/5), establishing maximum capacity and effort limits for both bottom and beam trawlers, is considered for the baseline. The MAP is aimed at achieving the MSY target in 2026 for all key stocks through a fishing effort regime.

For *Eastern Mediterranean Case study* (GSA 20) there is still no MAP, but there is the national management plan for OTB which has been in action since 2013 and several management measures for small-scale fisheries (SSF). The management measures in this national plan are generally based on MSY targets in line with the EU-MAP objectives.

For Mediterranean Case study the same scenarios are explored for tasks 6.3 and 6.4:

- Status quo (same effort as in 2022);
- Effort reduction to achieve the F0.1 (used as FMSY proxy) of the most overexploited stock in 2026;
- Effort reduction to achieve a combined FMSY (or PGY) on all the target stocks;
- FMSY range (low and upper, 2 scenarios) of the most overexploited stock. One of these additional scenarios could be overlapping with scenario 3, thus it could not be necessary to run both scenarios of point 4.

For Mediterranean case studies, the identification of the stocks limiting catch opportunities could not be made, since no species TACs are currently in force for demersal fisheries. The focus in task 6.3 for this case study will be on the underutilization of the less overexploited stocks and the consequent economic losses.

5.2 Common spatial scenarios

This task has listed a certain number of ongoing spatial fishing restrictions which can help anticipate their effects on the environmental, economic and social sustainability pillars of the EU CFP. These areas include EU Natura 2000 sites and nationally designated conservation (CDDA) sites. The TMR closed areas to some fishing specifications have not been included yet because they pose a specific challenge when a seasonality is attributed to the restriction. As in other sections, it was assumed that already fished areas do constitute the “fishable” area.

In the upcoming SEAwise D5.6 report, we will deliver deeper into future plans that could limit fishing activities in certain areas, including the common spatial restriction layer that was developed in section 3. SEAwise may also explore other proposals if they are submitted by other tasks (mainly SEAwise WP4) in an attempt to mitigate unwished adverse effect that a displacement of effort could create, or because some components of the marine ecosystem would gain at being protected to ensure long term conservation and ocean productivity (e.g. area with high concentration of fish below the minimal conservation reference size, or sensitive habitats etc., see WP4). Among these constraints are:

- all bottom trawling phase out from current MPAs by 2030 (EC, 2023) 10% strictly protected (e.g. based on a spatial persistence analysis of population distributions)
- protection of sensitive habitats (SEAwise T5.4)
- new OWFs plans
- Other uses (including e.g. pollution from contaminants)

5.3 Common climate scenarios

SEAwise D5.2 has applied a suite of species distribution models (SDM) to estimate historical species distribution from survey data. The study has also exposed modelling work that attempts to predict the future stock distribution under climate change. Predictions have been done under two different circumstances that were defined by the IPCC RCP 4.5 and RCP 8.5. As a general outcome of SEAwise D5.2 however, the spatial distribution of exploited populations has not been predicted to be extensively affected in the time frame horizon (2030 or 2050). For the species considered in this analysis, temperature seems to have the main effect on density, though it does not necessarily have strong effects on spatial distributions. What could be more impacting is the climate change induced effects through a change in temperature and water salinity regime on population vital rates such as rate of recruits and growth characteristics (see also Bastardie et al. 2022). Such temperature related effects will be incorporated as much as possible into the operating models of the bioeconomic models deployed for SEAwise D5.6. In addition, Species Distribution Models (SDMs) have proven to have limited explanatory ability when it comes to the underlying mechanisms that drive changes in species distributions. These mechanisms include local depletion or recruitment pulses, migration, and changes in size structure. To investigate these effects, it is recommended to use spatial bioeconomic (mechanistic) models as they would be more suitable platforms for this purpose.

5.4 A synopsis table of case studies

Model capabilities differ between different approaches depending on whether they could include food web modelling, an explicit age or stage-structuration, a disaggregation of the fishing activity into effort, catchability and selectivity per fleet segment, gear or individual vessel, fisheries management with some sort of Harvest Control Rules (HCRs), etc. Table 5.1 summarizes some features of the different bioeconomic models used in the present study including the handled dimensions (fisheries, fleet, fishers, fish, benthos, bycatch, invasive species, OWFs, etc.), the possibility for modelling fishers´ decision-making (e.g. see SEAwise D.2.5) and ideally a detailed description of the behavioural module embedded in the used model. The table also informs on the capability of the model to address a common baseline scenario (aligned with SEAwise WP6 Baseline scenarios about effort level, mixed fisheries issue, HCR, biological reference points, fleet economy etc.). Ultimately, such a baseline constitutes a common denominator to compare model outcomes with WP6 scenario outcomes.

Table 5.1. Main features of the bioeconomic models used in the SEAwise D5.5 (and coming D5.6) studies

FEATURES	**DISPLACE**	**BEMTOOL**	**ECOSPACE**	**OSMOSE**	**southern North Sea ABM**
Model approach and capabilities	Individual vessels agent-based model coupled to age and length stage-structured population dynamics, plus food web (size-spectra)	Fleet-segment explicit activities coupled Age and length -structured	Fishing mortality per fleet-segment and life stage-based population dynamics, plus food web	Individual-based food web model of fish feeding on lower trophic levels and an effort based approach to fishing	Agent-based model for German southern North Sea fishing vessels with complex human decision-making beyond pure profit maximization
Handled Dimensions	Fisheries (metier), Fleet, Individual based model for fishing vessels, Fish, benthos, bycatch, OWFs	Fisheries, Fleet, Fish stocks	Fisheries, Fleet, Fish stocks	Metier level, Individual based model for fish stocks	Vessel, metier, and fleet. Individual daily decisions.
Spatial dimension	Explicit	Implicit in this version; explicit spatial component in development	Explicit	Explicit	Explicit

A baseline scenario aligned with WP6 requirements	Possible (IPCC scenarios; FMSY and LO scenarios; Pretty Good Yield scenario)	Possible (IPCC scenarios; FMSY and LO scenarios; Pretty Good Yield scenario; change in selectivity, catch limits)	Possible (IPCC scenarios)	Possible (IPCC scenarios; LO scenarios)	Unlikely. No population dynamics included
Indicators	Fishing mortality, Recruits levels, Landings, discard/unwanted catches, SS, GVA, Net Profit, Employment, Wages, CR/BER, Landing value small scale fisheries vs. landings Large scale fisheries	By fleet (small and large scale) fishing mortality; Landings and discards; Revenues, GVA, Gross and Net profit; employment (FTE); RofTA; RoI, CR/BER; SSB, recruits levels, Spawning Potential Ratio.	Ecological indicators i.e. Total biomass/catch, fish biomass/catch, commercial biomass/catch, Kempton's Q, Shannon index, biomass/catch of IUCN Red List species, biomass/catch sea turtles&mammals&birds, trophic level of catch/community	Ecological and fishery indicators (see also WP4) i.e. Total biomass, Spawning Stock Biomass (SSB), Total catch, Landings, Discards, bycatch (PET species), length/ weight	Temporal: profits, revenues, costs, savings, fishing effort, steaming time, landings, fuel use, daily metier decisions Spatial: fishing effort, steaming time, landings, depletion coefficient
Climate-induced effects	Yes, on spatial distribution and biological population dynamics	Yes (in the version on development), biological population dynamics	Yes, spatial driver	Yes, spatial distribution and lower trophic level input, resulting biological population (food web) dynamics	None
Spatial restrictions tested	Natura2000+CDDA+ (OWFs) spatial layer	Not yet	First restrictions tested for Natura2000+CCDA in North Sea	MPAs as described in the provided shape file	MPAs (Natura2000 & CDDA) + OWFs (4COffshore)
Possible synergies with other models in the same area	Partly (In North Sea, comparable/complementary to OSMOSE or ECOSPACE outcomes)	ECOSPACE in Adriatic and Western Ionian Sea (GSAs 17-18-19)	Partly (In North Sea, comparable/complementary to OSMOSE or ECOSPACE outcomes)	Partly (In North Sea, comparable/complementary to DISPLACE or ECOSPACE outcomes)	Partly, (ECOSPACE and DISPLACE North Sea)
Possible synergies with other models across areas	Yes (comparable across regions, e.g. North Sea, Ionian Sea)	No	Yes (comparable across regions, e.g. North Sea, Ionian Sea)	Yes (comparable across regions, e.g. North Sea, Ionian Sea)	No

5.5 Baseline run of dynamic bioeconomic spatial fisheries models and spatial restrictions per case study

5.5.1 International fisheries in the North Sea with DISPLACE

The DISPLACE modelling platform (Bastardie et al., 2014) was developed to be a comprehensive management strategy evaluation tool to assess how fish stocks and fisheries are affected by different spatial fishery management options, with further consideration of ecological uncertainties for example related to climate change scenarios. The core of DISPLACE is a spatial bio-economic model for simulating the movement of individual fishing vessel agents combined with an underlying spatial population dynamics model (Figure 5.1). DISPLACE is an open-source project and the details of all calculations and other technicalities can be found online in the code as well as the documentation that comes with it. DISPLACE can be used jointly with spatial management designation tools. Hence, spatial plans may come from fish stock distribution persistence analysis identifying relevant areas (for example, juvenile aggregation areas like in Rufener et al. 2023) or from pre-existing spatial plans like in the present study.

In DISPLACE, individual agents optimize their decision-making on the fly depending on their given catch rates by zones and the expected cost to reach the zone and return to the harbour. Each vessel depletes the target stocks individually, which further depends on the gear type in use. The bioeconomic DISPLACE model integrates fishermen's decision-making processes to simultaneously evaluate economic and ecological sustainability of a fishery. The model combines a spatial explicit agent-based model for fishing vessels that covers allocation of actual fishing effort and includes movements to or from a fishing area, between fishing areas, or rest at ports, with a spatially explicit, size-structured population model. Data-tree-structure algorithms are used to model the movements of individual vessels and decisions, after which the shortest path between a port and a fishing ground (or vice versa or between fishing grounds) is determined. A vessel depletes a stock at a node each time step t (hourly), according to the stock distribution, the catch rate of a specific vessel at a fishing ground, and the selectivity of the gear used.

Simulations also account for vessels from different countries that might deplete the same stocks and fisheries regulations, such as, for example, the year-specific quotas (TACs) for stocks or spatial or seasonal restrictions that would be specific to some type of fishing techniques. The model calculates individual profits by analyzing revenues and costs for fishing operations, including possible changes with (what-if) scenario-based testing. In this perspective, it is worth mentioning that DISPLACE is meant to predict effort displacement resulting from environmental changes or spatial allowance, not actual or historical fishing effort allocation.

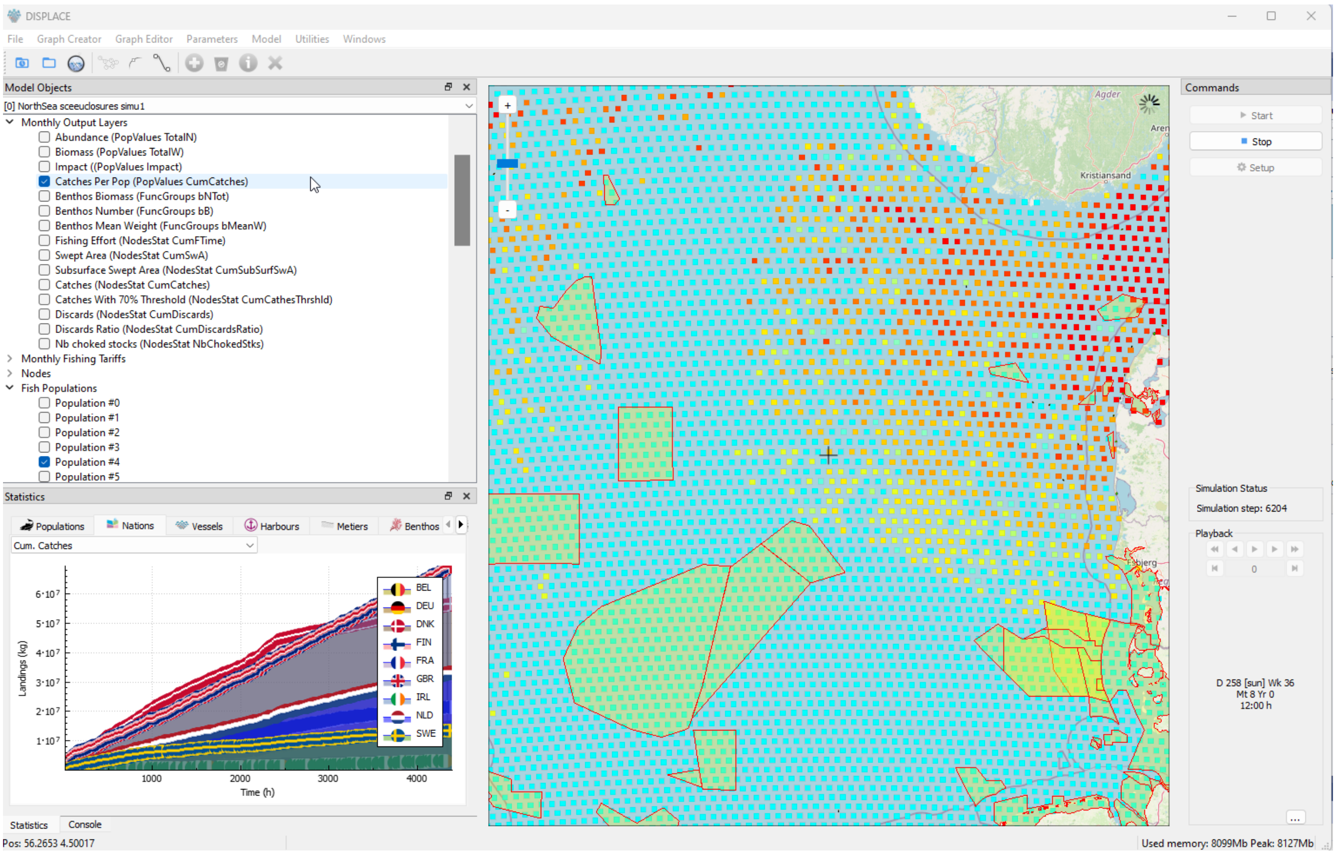
DISPLACE is an agent-based model that tracks indicators at the individual fishing vessel scale including fuel consumption, its associated cost for operating the fishing and a measure of energy efficiency (Fuel Use Intensity FUI in liter per kilo landed, and Value Per Unit of Fuel VPUF). Individual profitability is also computed from trip-based modeled revenue and cost data and further aggregated per fishing activity or harbour community if needed for reporting. Ideally, DISPLACE would capture interlinked dynamics incorporating feedbacks and non-linear processes between seafood markets, policy options, fisher´s decision-making and the harvested stock (tropho)dynamics (Figure 5.2). Accounting for the spatial dimension is also a prerequisite to capture local impacts of fishing on seabed and benthic habitats (Figure 5.3), which in turn affect harvested stocks and supportive ecosystems.

In this Task, SEAwise has conditioned the DISPLACE platform for the International North Sea fisheries by informing fish and fisheries parameters to run a baseline run that fits the needs of SEAwise investigation and has tested the spatial restrictions excluding certain fishing techniques depending on the assessed specific vulnerability to them (see section 3) from designated areas (Natura2000+CDDA) currently with or without a management plan in place.

In the second deliverable to come (D.5.6), alternative spatial plans will be investigated by testing scenarios with DISPLACE North Sea that could combine:

- Brexit effects on EU fleet (if a zonal attachement implemented)
- Conservation areas in EU and UK waters (from the spatial restrictions collated in section 3, but also from areas identified in other WPs)
- Excluding fishing activities from concessions reserved for OWFs
- A combination of Conservation areas + OWFs + Brexit

Here, first insights are provided in modelling a baseline DISPLACE scenario contrasted against testing the implementation of a spatial plan at the North Sea scale (see Table 5.2 of scenarios).



[0] NorthSea sceeuclosures simu1

Monthly Output Layers
- ☐ Abundance (PopValues TotalN)
- ☐ Biomass (PopValues TotalW)
- ☐ Impact ((PopValues Impact)
- ☑ Catches Per Pop (PopValues CumCatches)
- ☐ Benthos Biomass (FuncGroups bNTot)
- ☐ Benthos Number (FuncGroups bB)
- ☐ Benthos Mean Weight (FuncGroups bMeanW)
- ☐ Fishing Effort (NodesStat CumFTime)
- ☐ Swept Area (NodesStat CumSwA)
- ☐ Subsurface Swept Area (NodesStat CumSubSurfSwA)
- ☐ Catches (NodesStat CumCatches)
- ☐ Catches With 70% Threshold (NodesStat CumCathesThrshld)
- ☐ Discards (NodesStat CumDiscards)
- ☐ Discards Ratio (NodesStat CumDiscardsRatio)
- ☐ Nb choked stocks (NodesStat NbChokedStks)

Monthly Fishing Tariffs

Nodes

Fish Populations
- ☐ Population #0
- ☐ Population #1
- ☐ Population #2
- ☐ Population #3
- ☑ Population #4
- ☐ Population #5

Simulation Status
Simulation step: 6204

D 258 [sun] Wk 36
Mt 8 Yr 0
12:00 h

Pos: 56.2653 4.50017

Used memory: 8099Mb Peak: 8127Mb

Figure 5.1. A random snapshot of the DISPLACE North Sea application showing the simulated accumulated catches by different North Sea nations. The visual on the map here shows the amount of North Sea cod caught, and the spatial restrictions specific to fishing techniques (bottom trawling, or longlining, or netting) as referred in section 3. The Norway fleet is missing.

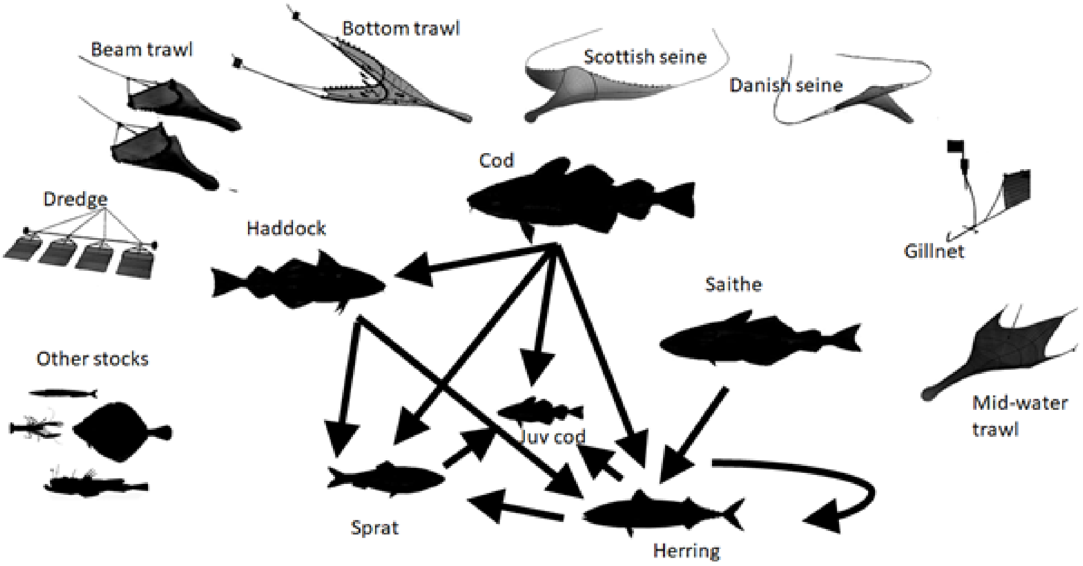
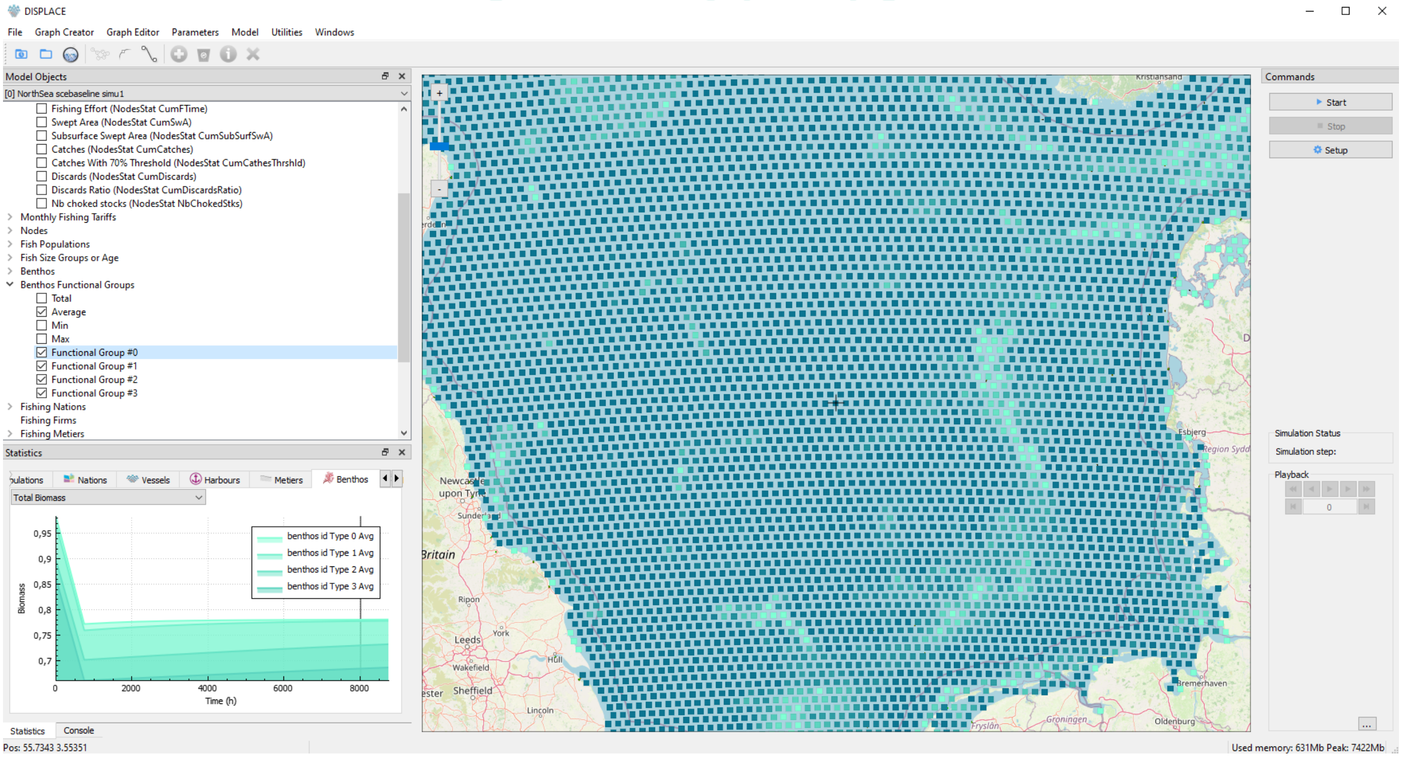


Figure 5.2. Foodweb modelled in the SizeSpectra DISPLACE module (unpublished but documented on the DISPLACE github repository) informing the adult and juvenile diet matrices preferences with relationships deduced from North Sea SMS model foodweb (ICES 2013), and also showing the various fishing techniques modelled in DISPLACE.



☐ Fishing Effort (NodesStat CumFTime)
☐ Swept Area (NodesStat CumSwA)
☐ Subsurface Swept Area (NodesStat CumSubSurfSwA)
☐ Catches (NodesStat CumCatches)
☐ Catches With 70% Threshold (NodesStat CumCathesThrshld)
☐ Discards (NodesStat CumDiscards)
☐ Discards Ratio (NodesStat CumDiscardsRatio)
☐ Nb choked stocks (NodesStat NbChokedStks)

☐ Total
☑ Average
☐ Min
☐ Max
☑ Functional Group #0
☑ Functional Group #1
☑ Functional Group #2
☑ Functional Group #3

Figure 5.3. A random snapshot of the DISPLACE North Sea application showing the Relative Benthos Status indicator (RBS) on sites as defined by ICES WGFBIT. Values from 0 to 1 per benthos community longevity group, here all groups pooled. See also SEAwise D4.4.

Table 5.2. Tested closure scenarios for D5.5 related to effects of spatial management measures suggested outside SEAwise. Scenario testing organised as a “BACI style” i.e. assessing outcomes from situations before the plan (e.g. baseline), or after the plan (e.g. EU Closures), inside MPAs, or outside MPAs (if effort displacement is explicitly modelled).

Scenario naming	**DISPLACE Graph name**	**Métiers impacted**	**Period**	**Remarks**
Baseline	1	None	NA	FMSY + Landing Obligation (LO) regime. An enforced LO means a vessel stop fishing as soon as the vessel has exhausted one of its target stocks quotas
EU Closures	201 (Natura2000+CDDA .shp)	spatial restrictions specific to fishing techniques (bottom trailing, longlining, netting, see section 3)	All months	FMSY + LO regime + closed areas
EU Closures + exclusion of non-UK fleet from UK EEZ	202 (Natura2000+CDDA .shp + UK_EEZ.shp)	same as 201 plus exclusion from UK EEZ for all non-UK vessels	All months	FMSY + LO regime + closed areas
EU Closures + Climate Change (CC)	201 (Natura2000+CDDA .shp)	same as EU Closures scenario	All months	FMSY + LO regime + closed areas + climate change effects. Details: *ad hoc* climate change effects on cod, plaice, herring, sprat, affecting growth: 0.8*Linf; 1.5*K. Effect on SSB-R of cod, plaice and herring: ricker: 0.9*alpha. 1.5*beta Effect on SSB-R of Sprat: 1.1*alpha

The data depicted in Figure 5.4 suggests that fishing activity outside the restricted zones resulted in higher simulated catches. This could be due to a shift in fishing efforts from protected areas towards outside regions, leading to a concentration of fishing activities in a smaller area. It remains uncertain whether the potential loss of spatial opportunities resulting from a hypothetical Brexit zonal attachment would be offset by the expected increase in catches in the southern North Sea according to the model. Further research is needed to determine if the same group of vessels would be impacted.

Based on the expected economic benefits, it appears that implementing spatial restrictions for vessels using active or passive fishing gear will increase profitability. However, if passive gear is used and an exclusion of the UK EEZ is implemented, profitability may decrease (as shown in Figure 5.7). Further analysis will be conducted to explore these findings in greater detail. It should be noted that the simulations were impacted by the effects of climate change, which reduced opportunities for North Sea cod and plaice.

Regarding the impact of fishing on the seafloor, the model reveals that a part of the benthic community residing on the seafloor is experiencing stress in the North Sea. This is especially those species with a life expectancy of over 10 years (Figure 5.5), which overlaps with the fishing effort. This stress is caused by the higher frequency of trawling compared to the slower recovery rate of these long-lived species, which is slower than that of short-lived species. However, the model does not reveal large change in Relative Benthos Status after implementing restricted areas after 10y. Overall, the difference is not striking, looking at the wide scale, likely because the impact is low in most areas and the overall swept area is not reduced but displaced instead, even slightly increased in case of exclusion of the EU fleet from the UK EEZ (Figure 5.6 in BACI style). Based on the simulations, the RBS increases in areas where bottom fishing does not occur, and decreases in areas where it does. However, the benefits from EU closure areas do not appear to be captured as these areas are not really significant for bottom fishing. This should be checked in detail in a newer version of the model.

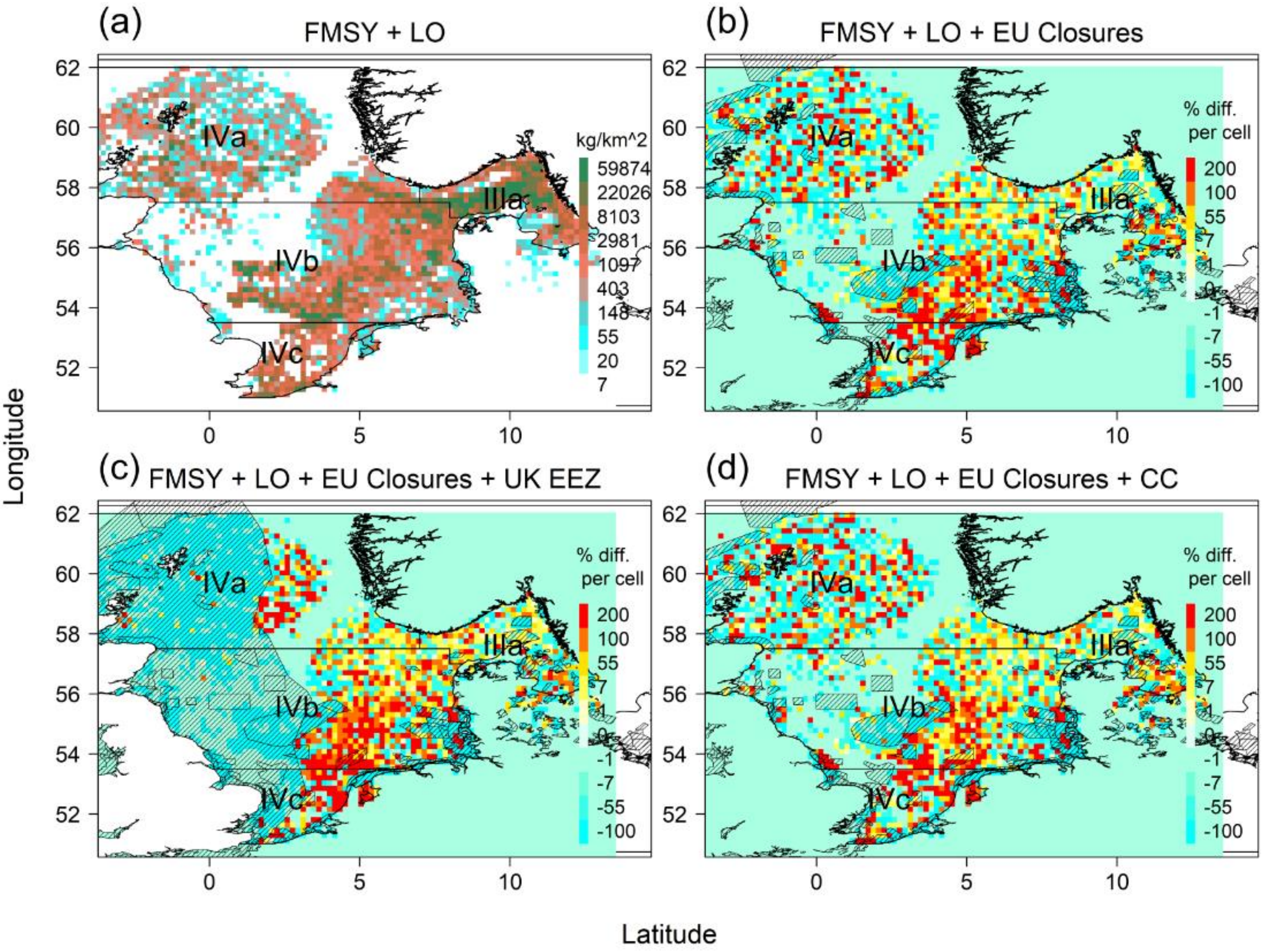


Figure 5.4. Modelled catches with DISPLACE in a 10y horizon from the activities of the International fisheries in the North Sea, without constrains (a), or with spatial plans including b) EU Closures (see section 3), c) EU closures plus exclusion from the UK EEZ of all non-UK vessels, d) EU Closure plus assumption on effects of climate change (CC) on vital rates (growth and recruitment success). Gridding cells by 0.175 degree resolution.

The economic returns compared to the fuel efficiency of catching fish indicate that long-term fishing may not be sustainable in the current version of the model. This is based on a 10-year horizon analysis, which shows that the anticipated Gross Value Added (GVA) decreases for all fleet-segments in fishing nations except Germany (as depicted in Figure 5.8). However, the profitability decline will be less severe if the EU closures are implemented. It is also interesting to note that climate change positively impacts the French fleet, which is unexpected. These initial findings will be further examined and detailed in D5.6.

Validation is a challenge in fisheries models because of the numerous interactions that create the integrated dynamics, which is further largely perceived through other models. Nonetheless, it can be argued that these anticipatory predictions are not meant to represent the actual future but mimic changes in an integrated evaluation such as the DISPLACE testing platform. The simulation studies should be regarded as a guide for present action. In any case, the DISPLACE North Sea application provided initial results that will be strengthened in a revised version to be presented in D5.6, which will also explore spatial scenarios proposed by the SEAwise community

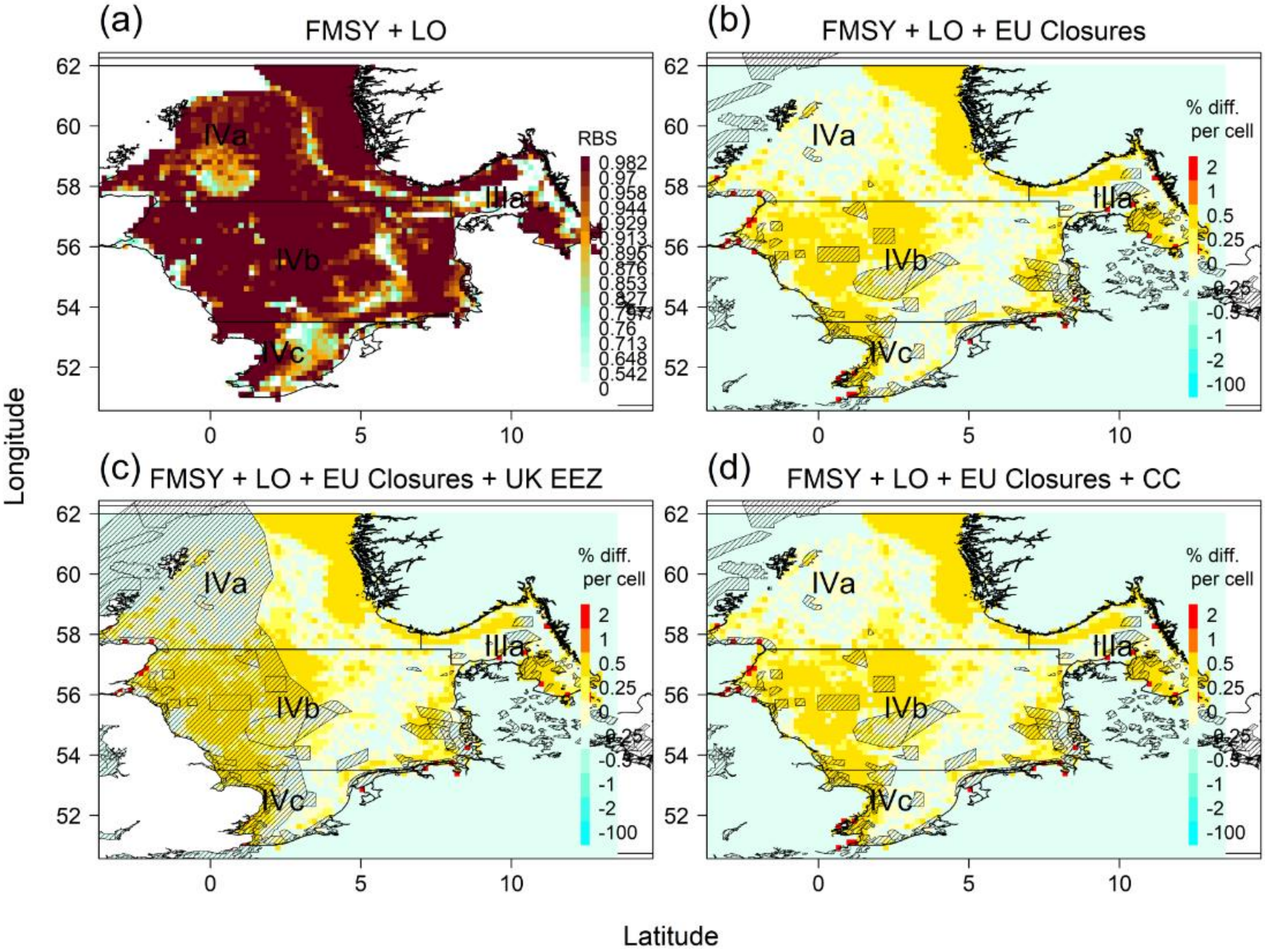


Figure 5.5. Relative Benthos Status (RBS) for longevity group >10y and modelled with DISPLACE North Sea application, baseline (a) and relative change across scenarios (b), (c) and (d). RBS is a value between 0 and 1. Close to 0 values mean the longevity group will never reach its age of longevity.

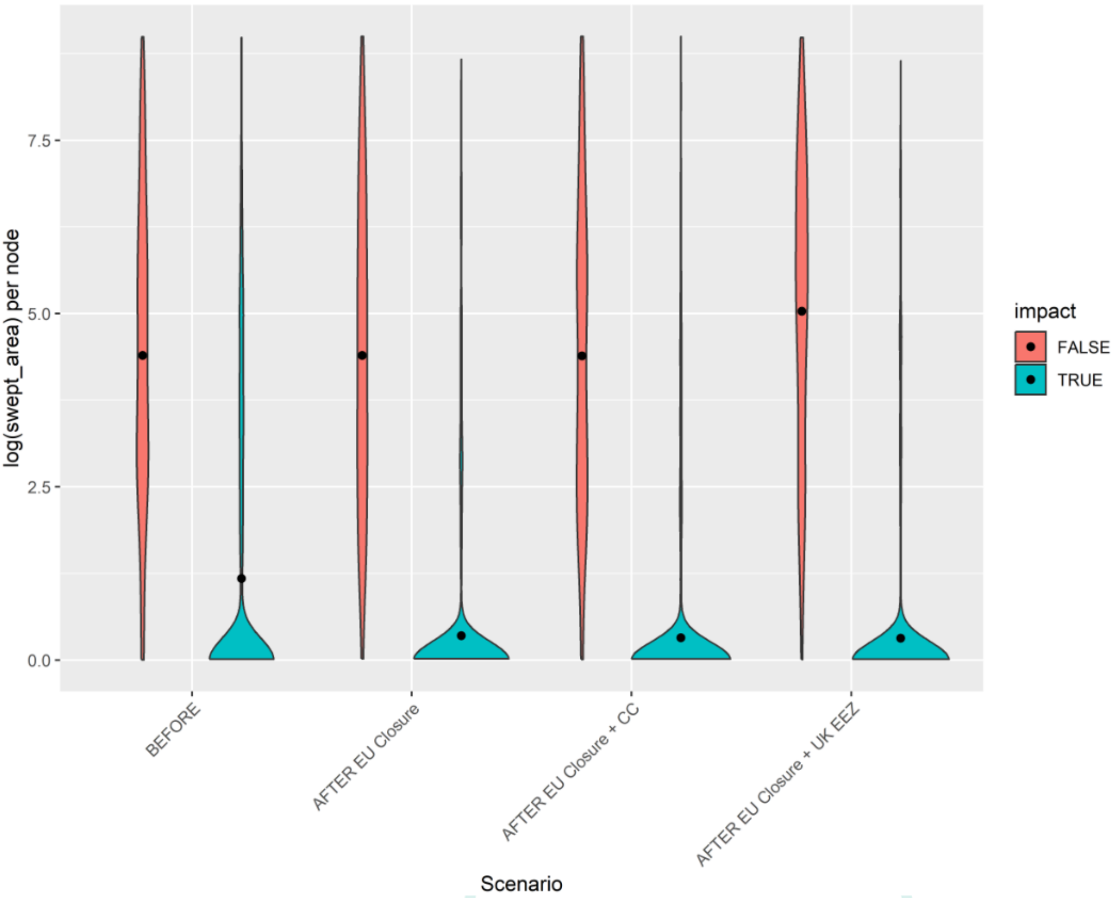


Figure 5.6. Preliminary outcome of the scenario-testing with DISPLACE on overall swept area (by bottom fishing) displayed in a Before/After/Control/impact (BACI) settings. The Before situation is given by the baseline scenario. The After situation is given by alternative scenarios. The impact (in green) is given by an average over all cells lying within the EU-UK spatial restrictions directed to bottom fishing, while the Control (in red) is given by the average over all cells lying outside the EU-UK spatial restrictions. 1000 cells were randomly selected in each Impact/Control category with the aim of comparing two balanced sampling sets. The black dot gives the mean estimate.

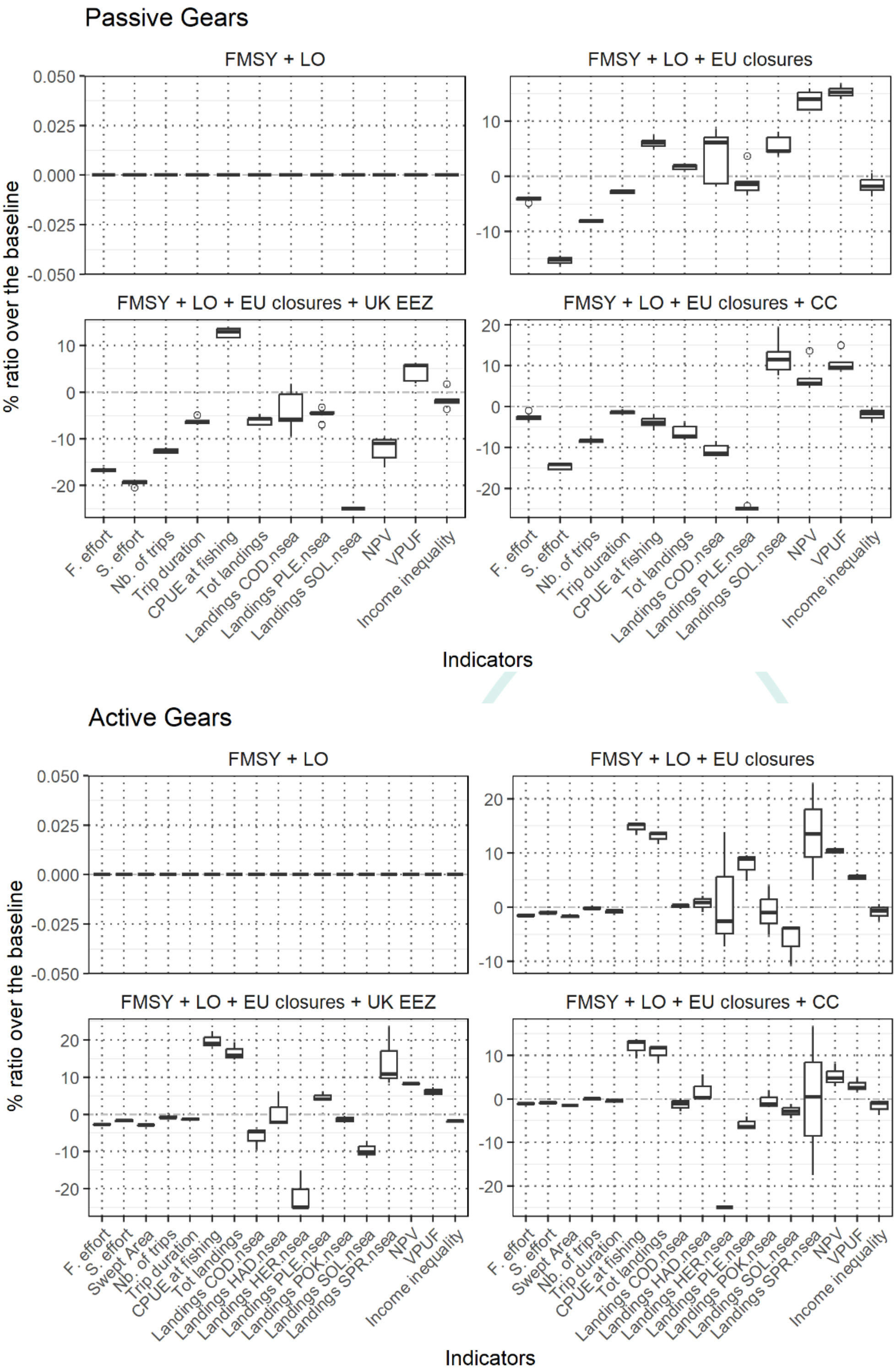


Figure 5.7. Indicators aggregation over the 10y horizon simulated with the DISPLACE North Sea application. Top panel from all vessels using passive gears as predominant gear, bottom panel from all vessels using active gears pooled.

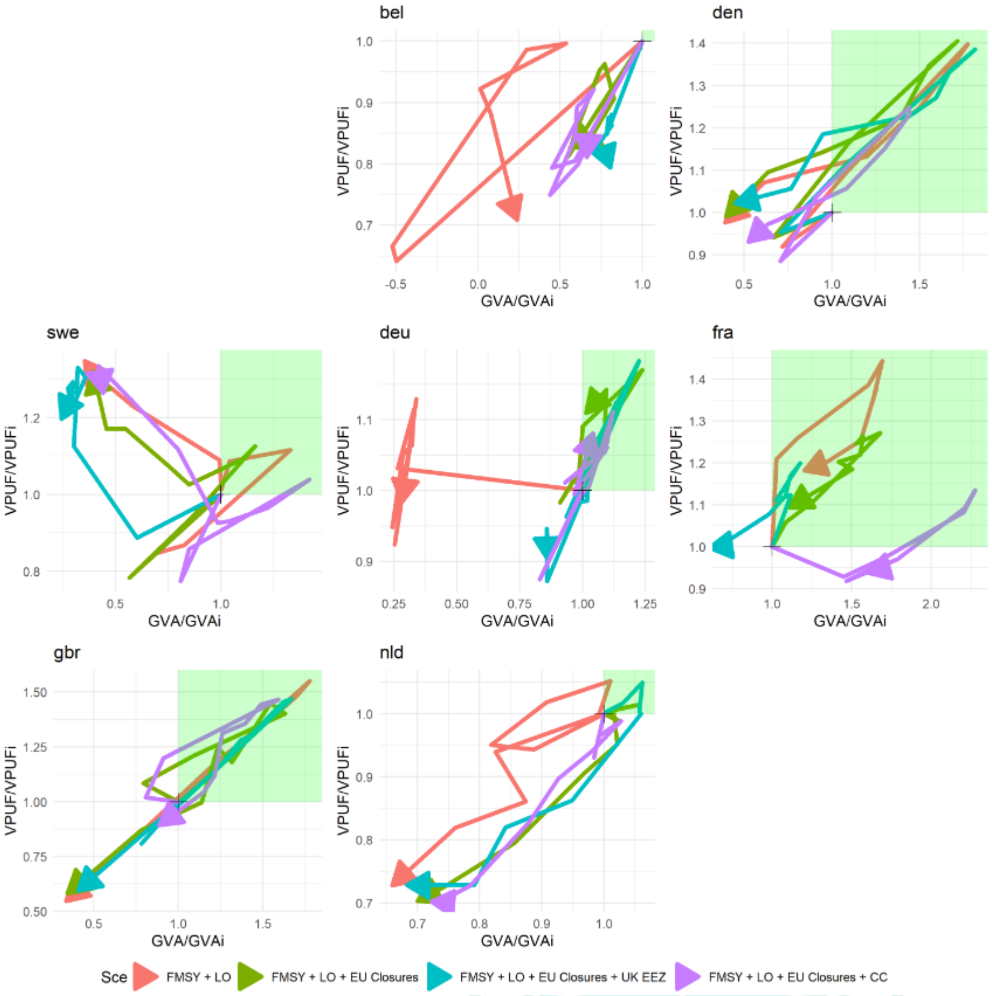


Figure 5.8. A bi-dimensional plot of average scenario outcomes on country-based (all métier confounded) ratios of Value per unit of fuel VPUF/VPUFi (initial) and Gross value added GVA/GVAi (initial) as simulated temporal trajectories from 2020 to horizon 2030. Countries are bel: Belgium, den: Denmark, swe: Sweden, deu: Germany, fra: France, gbr: UK, nld: The Netherlands. The ratio at 1 on both indicators (symbol '+') gives the initial estimates in 2020—the wished green corner for the drift of the indicators in the top right.

5.5.2 DISPLACE in Eastern Ionian Sea

Fisheries features /population dynamics and baseline application

In the eastern Ionian Sea (GSA 20) the DISPLACE model (Bastardie et al., 2014) has been conditioned for investigating the effect of displacing fishing effort to alternative grounds based on various spatial and time specific management options. The DISPLACE modeling framework involves methods to assess and provide advice on the bio-economic consequences for the fisheries and fish stocks of different fishermen decisions and management options. It is an agent-based model developed to support maritime spatial planning and management issues, while it is able to incorporate spatial and temporal details to gain an understanding of the integrated fisheries, behavioral and resource dynamics (https://displace-project.org).

Information related to the spatial distribution of fishing effort, species abundance, biological parameters/traits of fish stocks and other fisheries-related and economic data are incorporated in the parameterization of the eastern Ionian sea DISPLACE application (Figure 5.9). The model has been previously parameterized based on Maina et al. (2021), while updates are already integrated and others are ongoing based on outcomes from other Tasks (e.g. SEAwise T4.2, T5.2, T5.3) and additional analysis performed during this Task.

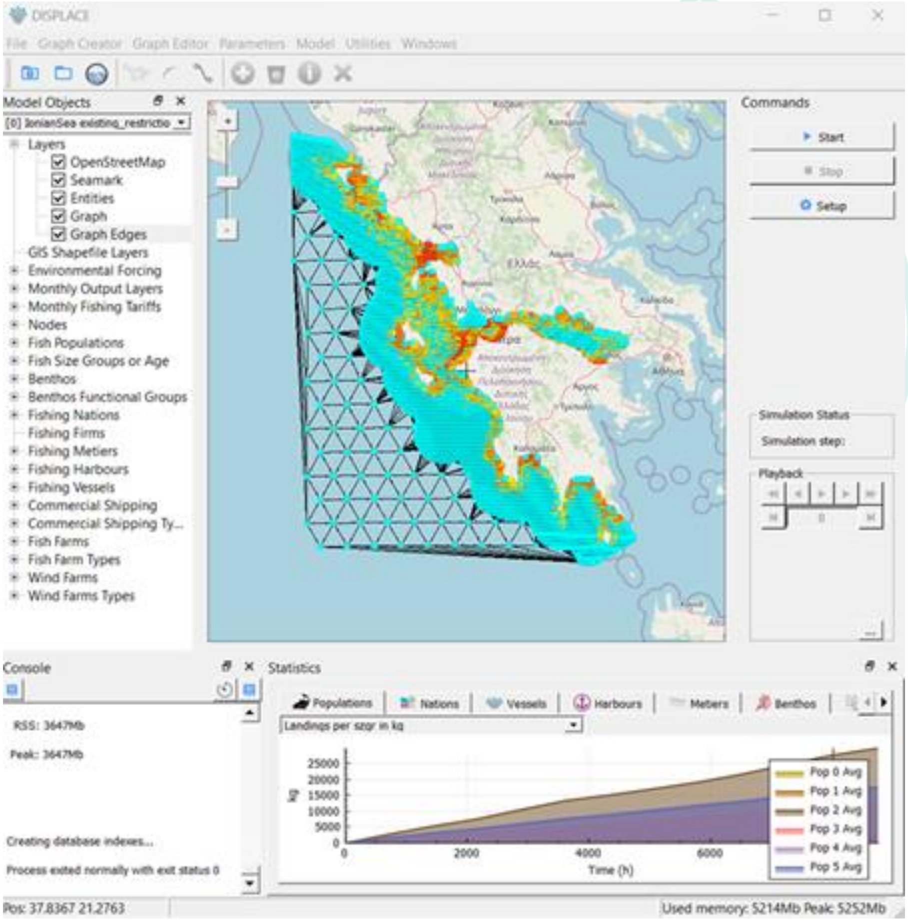


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Figure 5.9. DISPLACE applied to the Greek fisheries in the eastern Ionian Sea.

Five fishing fleets were incorporated in the eastern Ionian Sea application, covering the bottom trawlers (OTB), purse seiners (PS), gillnets (GNS), trammel nets (GTR) and longlines (LLS). All Greek OTB and PS are equipped with Vessel Monitoring System (VMS) according to Commission Regulation EC 2003, while in the eastern Ionian Sea 27 OTB and 40 PS vessels are registered. SSF comprise approximately 95% of the entire Greek fishing fleet (~3500 SSF vessels are registered in eastern Ionian Sea). Greek SSF vessels are mainly <12 m of total length and are not equipped with VMS/AIS monitoring devices. The spatial distribution of fishing effort for OTB and PS is informed from the VMS data analysis, while effort for small scale fisheries (i.e. GNS, GTR, LLS) is informed after applying a Multi Criteria Decision Analysis - MCDA (see details for VMS and MCDA analysis in SEAwise D5.3). Several environmental/climate and other fisheries related factors, as well as STECF Fisheries Dependent Information (FDI) on fishing effort for GNS, GTR and LLS were incorporated in the MCDA approach. The MCDA provided fine-scale fishing effort estimations for the small-scale fisheries that have LOA < 12m and are not equipped by monitoring devices (Kavadas et al., 2015). The study area was partitioned into a regular grid of 1 × 1 km cells and fishing effort for each fishing fleet was estimated as the accumulated time spent on fishing in each cell in the year 2020, and expressed in fishing hours (h).

The DISPLACE model is informed with spatial information for commercial and non-commercial species. In the SEAwise project, the eastern Ionian Sea case study is mainly focused on hake, *Merluccius merluccius* (HKE), deep water rose shrimp, *Parapenaeus longirostris* (DPS) and red mullet, *Mullus barbatus* (MUT) which are highly important species in the study area. Additionally, black-bellied anglerfish, *Lophius budegassa* (ANK), horse mackerel, *Trachurus trachurus* (HOM) and common Pandora, *Pagellus erythrinus* (PAC) were also modeled and incorporated in the DISPLACE baseline simulation. All the above species are of high commercial importance for the Greek fisheries and represent 19% of landings in volume and 27% in value in the study area (extracted from IMAS-Fish database: Kavadas et al., 2013). Moreover, the spatial distribution of abundance for certain bycatch species' i.e. Longnose spurdog, *Squalus blainville* (QUB), bullray, *Aetomylaeus bovinus* (MPO), and smoothhound, *Mustelus mustelus* (SMD) were used as explicit stocks in the DISPLACE. The above species have been assessed as critically endangered, vulnerable and data deficient, respectively, in the Mediterranean Sea by the IUCN Red List of Threatened Species while their occurrence in the eastern Ionian Sea can be important at a regional level (Jabado et al, 2023). The spatiotemporal distribution of each species' abundance was obtained by Generalized Additive Models (GAMs) conditioned by dedicated smoothers. Such smoothers provided models flexible enough to elaborate predictions on a year-quarter basis. For capturing any effect and spatial variation along with the growth of the individuals, different models were applied for "small" as well as on "medium" and "large" individuals (for commercial species) which were pooled together (SDM method is further described in D5.2). Predictions were applied in a grid of 1 × 1 km cells and the abundance in kg/km2 was estimated for the year 2020.

Monthly spatio-temporal closures were incorporated in the DISPLACE eastern Ionian Sea application and further tested in the simulations (Fig 5.10). Based on the EU legislation, trawling is prohibited within 3 nautical miles of the coast or within the 50 m isobath where that depth is reached at a shorter distance from the coast and within 1.5 nm of the coast for any depth (EC, 2006). According to the national legislation, the period from the end of May up to the end of September and approx. one week in December (24-31/12) is prohibited for bottom trawling in all Greek territorial waters. Bottom trawl is also prohibited in many other areas (e.g. Messolonghi lagoon, Amvrakikos gulf) for the entire year. Additional temporal restrictions for bottom trawlers exist in the gulf of Kerkyra (i.e. eastern part of Kerkyra) and in Korinthiakos gulf where fishing is banned from the beginning of April until the end of November, as well as in Patraikos gulf were fishing is banned from the beginning of March up to the end of November. Generally, trawlers (as well as purse-seiners, data not shown) are subject to more restrictions than small-scale fisheries. Annual restrictions for small-scale fishing activity exist mainly in the southern part of Zakynthos, Messolonghi lagoon, selected ports of Kefalonia Island, Itea and Galaxidi gulfs. Another restriction applying to the SSF fleet is the ban of the targeted fishing of hake (i.e. no more than 20% of the catch can consist of hake individuals) during February. In addition, the DISPLACE is informed with information related to the selectivity of the fishing gears, stock abundances per age, stock biological traits and stock prices data (see details on Maina et al., 2021).

Greece has 144 MPAs with a marine constituent larger than 5% of total MPA area. They are governed by a variety of national and international regulations and agreements. However, spatial overlapping between 'regional' and 'national' MPAs leads to conflicts among local and international (EU) regulations. Furthermore, based on a series of surveys targeting the national MPA management authorities, it was revealed that very few MPAs are actively managed.

Investigating scenarios linked to the real scope, targets and aspirations set for the MPAs when initially established, was not possible as these are in fact unknown for most of the MPAs. So scenarios were built in a region-wide manner, similarly treating all MPAs regardless of designation type (NATURA2000, SCA, SCI, National etc.).

Baseline and alternative management scenarios

Preliminary simulations under DISPLACE were first performed to calibrate the Ionian Sea application and evaluate whether it was able to mimic the historical data. The final settings obtained from this calibration process constitute the Baseline simulation. A total of ~3600 "agent" vessels were simulated, corresponding to 27 bottom trawlers, 40 purse seiners and 3526 small-scale fishing vessels.

The alternatives tested for fishery spatial management scenarios intend to assist the identification of effective management options in the eastern Ionian Sea. Scenario testing informs on how much both the stocks and fisheries might be sustained and benefit (or not) by restricting fishing activities in Marine Protected Areas (Figure 5.10). It is based on the recent aspiration of the European Commission to protect and restore marine ecosystems (EC, 2023). For that reason, DISPLACE was projected for the next 7 years (from 2020 to 2027) to evaluate the effect of displacing fishing effort to alternative fishing grounds and measuring the effects on fisheries economics and exploited stocks. In particular, two alternative management scenarios were tested; they are described in Table 5.3.

Table 5.3. Baseline and alternative management scenarios tested.

Scenario	Description	Spatial closures	Period
Baseline	The business as usual (status quo)	*Existing fisheries restrictions in place	*annual/monthly
Scenario 1	Restricting bottom trawl (OTB) from MPAs	* + MPAS	* + annual MPAs restrictions
Scenario 2	Restricting bottom trawl (OTB) and small scale fisheries (SSF) i.e. gillnets, trammel nets and loglines from MPAs	* + MPAS	* + annual MPAs restrictions

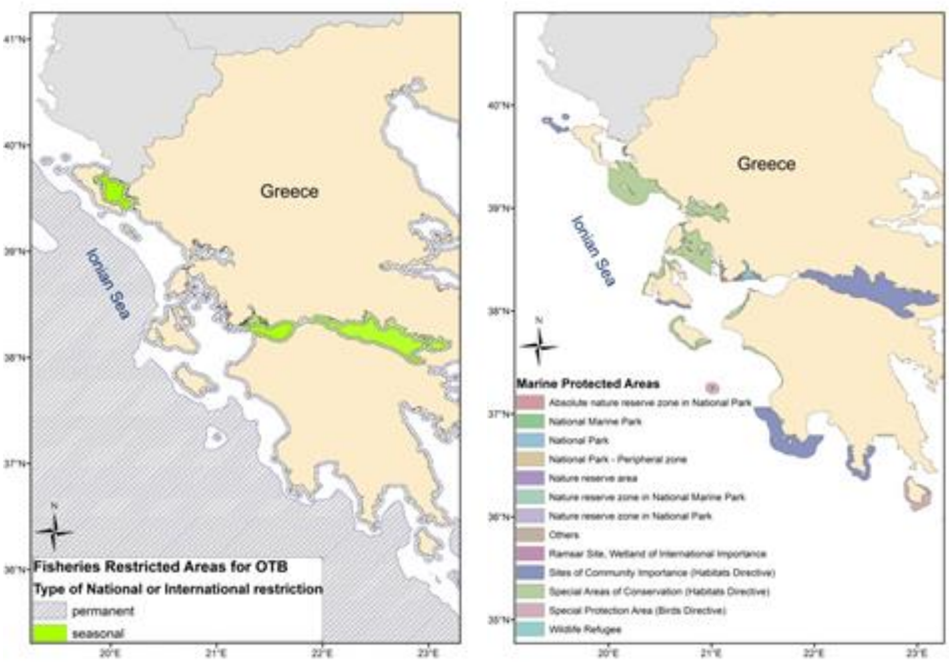


Figure 5.10. left: Existing national or international restrictions for bottom trawlers (in place) incorporated on the baseline simulation. right: Marine Protected Areas that are used for exploring additional annual restrictions on bottom trawl or other fishing gears (Scenario 1 and 2).

The scenario outcomes were aggregated and compared with the baseline over:

- biological indicators including Fishing mortality (F), Spawning Stock Biomass (SSB), total catches, landings, and discards as well as catch, landing and discard rates (CPUE; LPUE; DPUE)
- fishing and trip indicators including fishing effort, steaming effort, number of trips, trip duration.
- economic indicators including Gross Value Added (GVA: Revenue minus the fuel cost, expressed in euro) and Value Per Unit Fuel (VPUF: monetary value of landed fish per unit of fuel in liter) were also compared between the alternatives and the baseline scenario.

In particular, we compared the outcome of each scenario against the baseline status quo situation, and we quantified the changes by running 50 stochastic replicates in a Monte Carlo setting. The replicates allowed accurate quantification that includes uncertainty intervals around the estimated changes. For the simulated outcomes, we estimated

- the level of relative change (applied on spatial outcomes) *(1)*,
- the percentage relative to the baseline (applied on certain indicators*) (2)*, and
- the order of magnitude applied on certain economic indicators *(3)* as follows:
    - *Alternative management scenario/(Alternative management scenario + Baseline scenario) (1)*
    - *(Alternative management scenario/Baseline scenario*100)-100 (2)*
    - *Log10(Alternative management scenario/Baseline scenario) (3)*

The Baseline runs showed that the spatial distribution (e.g. fishing effort, landings) and the overall (aggregated) estimations (fishing mortalities, SSB) generated by the baseline runs, were similar to the input data.

Scenario 1- Restricting bottom trawl from MPAs

Restricting bottom trawling in certain areas led the impacted fishing vessels to increase their effort in the surrounding areas (Patraikos, Kerkyraikos and Lakonikos gulfs; Figure 5.11). The spatial distribution of landings was also higher in those gulfs while their origin changed to these areas for all species under investigation (Figure 5.12).

The overall amount of catches is higher by approx. +12% for bottom trawl OTB and +4% for small-scale fisheries (SSF) on average for all stocks pooled after a 7-year time horizon. Additionally, landing catch rates for *M. merluccius* and *M. barbatus* were higher for SSF and OTB targeting these two particular species (Figure 5.13). The fishing effort was lower by approx. -3% for SSF, while steaming efforts were by + 20% higher. Trip duration was by +4% higher for SSF (Figure 5.13).

Although several OTB and SSF vessels were not notably impacted in terms of gain in Value per Unit of Fuel, a proportion of SSF vessels (approx. from 10% to 40 % of vessels depending on the fishing gear) is adversely impacted from the closures (Figure 5.14). Additionally, the closure has negatively influenced the outcomes related to the gain in GVA for several SSF vessels (approx. from 30% to 60% of vessels depending on the fishing gear). A part of the SSF fleet is not notably affected (approx. from 20% to 40% of vessels) while a small part (~ 5 to 10%) is benefited. Apart from a 10% of OTB vessels that are negatively influenced in terms of GVA, all other vessels were not notably impacted and some of them were slightly benefited (Figure 5.14).

Fishing mortality changed in average by approx. -48% for *P. longirostris*, -27% for *M. merluccius* and −5% for *M. barbatus,* while SSB was higher by +12%, +19% and +8% for the studied species respectively (Figure 5.15). The catch of small and large individuals was higher for DPS and HKE in relation to the baseline scenario (Figure 5.16). On the other hand, the catch of undersized and adult MUT was not notably influenced (Figure 5.16). Finally, a decreasing trend through the simulated years is occurring in the catch of large individuals of HKE and MUT (figure 5.16).

Scenario 2- Restricting all fishing gears from MPAs

The impacted fishing vessels highly increased their effort in the available areas (i.e. gulfs of Patraikos, Kerkyraikos, Amvrakikos, Killini etc.) as emerged from the scenario of restricting fishing (i.e. OTB, SSF, PS) in the MPAs (Fig. 5.11). The spatial distribution of landings was also higher in those areas for all species under investigation (Fig. 5.12).

The overall amount of catches is higher by approx. +30% for bottom trawl and higher by approx. +5 % for SSF on average for all stocks pooled after a 7-year time horizon (Figure 5.13). Additionally, landing rates for *M. merluccius* were higher for OTB by +12%, while for *M. barbatus* were lower by -10%. The landing rates for SSF were approx. +30% higher for *M. merluccius* and -5% lower for *M. barbatus* (Figure 5.13). Moreover, the fishing effort was higher by approx. +27% for SSF while steaming efforts were by -33% lower (Figure 5.13). Number of trips was also changed for SSF by +5% and trip duration by -15% (Figure 5.13).

Most OTB vessels were positively influenced in VPUF and GVA. On the other hand, several SSF vessels were adversely impacted from the closure in VPUF or GVA (Figure 5.14). Fishing mortality changed in average by approx. -98% for *P. longirostris*, -72% for *M. merluccius* and −40% for *M. barbatus* while SSB was higher by +15%, +20% and +10% for the studied species respectively (Figure 5.15).

The catch of small and large individuals was higher for DPS, HKE and MUT in relation to the baseline scenario (Figure 5.16). On the contrary, the catch of large individuals of MUT was slightly lower. A decreasing trend through the simulated years is also occurring in the catch of large individuals of HKE and MUT, while an increasing trend is occurring both for small and large individuals for DPS (Figure 5.16).

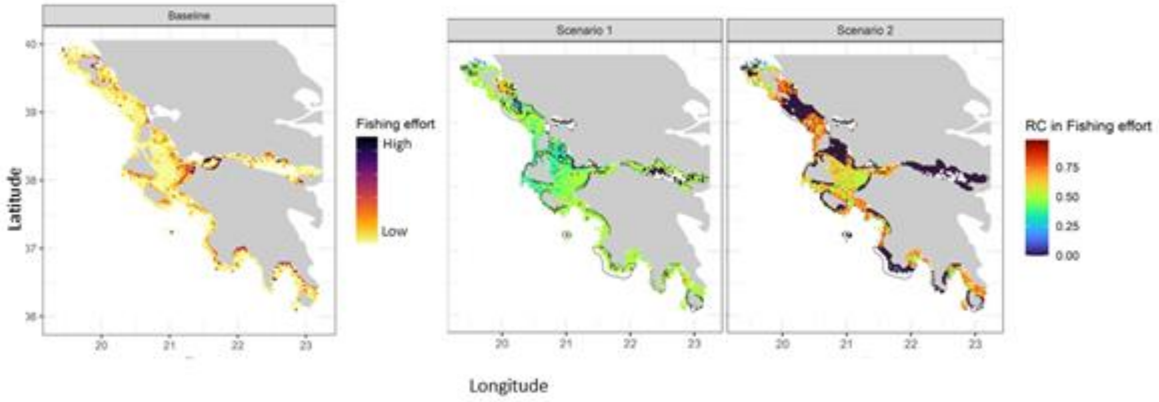
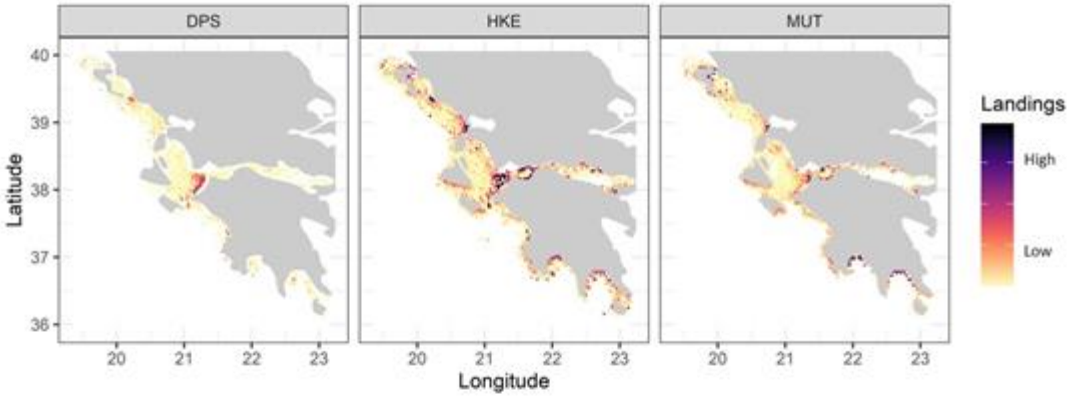
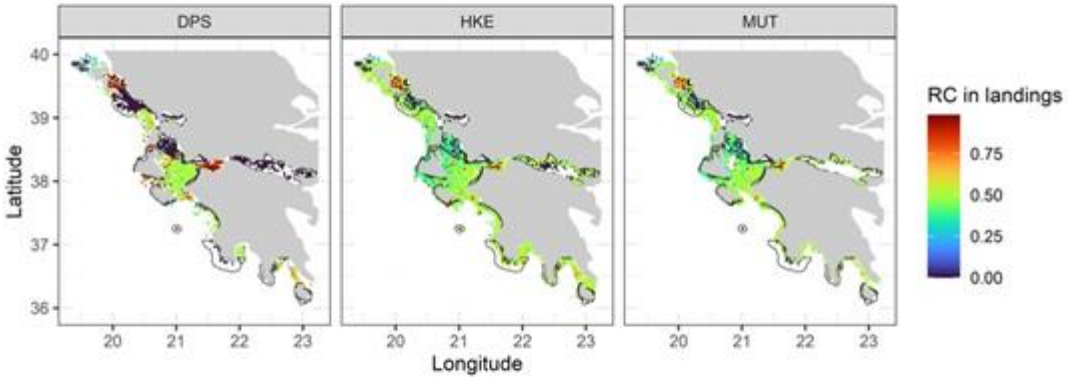


*Figure 5.11. Left: Baseline spatial distribution of fishing effort (for all métier). Middle and Right: Relative change (RC) (per grid cell 1*1 km) of scenario 1 and 2 (0.5 means no difference). Fishing effort is given as the accumulated fishing hours respectively over 7-year simulation averaged over the 50 replicates.*

a) Baseline



b) Scenario 1



c) Scenario 2

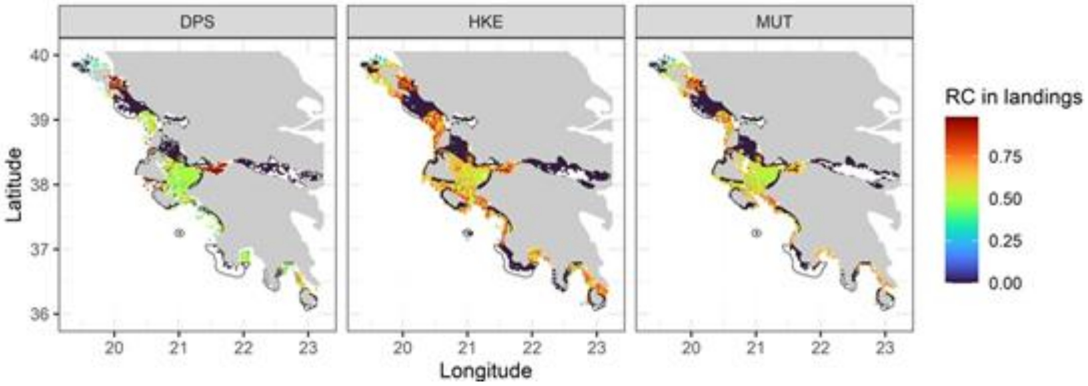


Figure 5.12. Accumulated landings (for all métier) and Relative change (RC) per stock for scenario 1 and 2. Landings are given as the accumulated tons respectively over 7-year simulation averaged over the 50 replicates for the following stocks: Parapenaeus longirostris (DPS), Merluccius merluccius (HKE) Mullus barbatus (MUT).

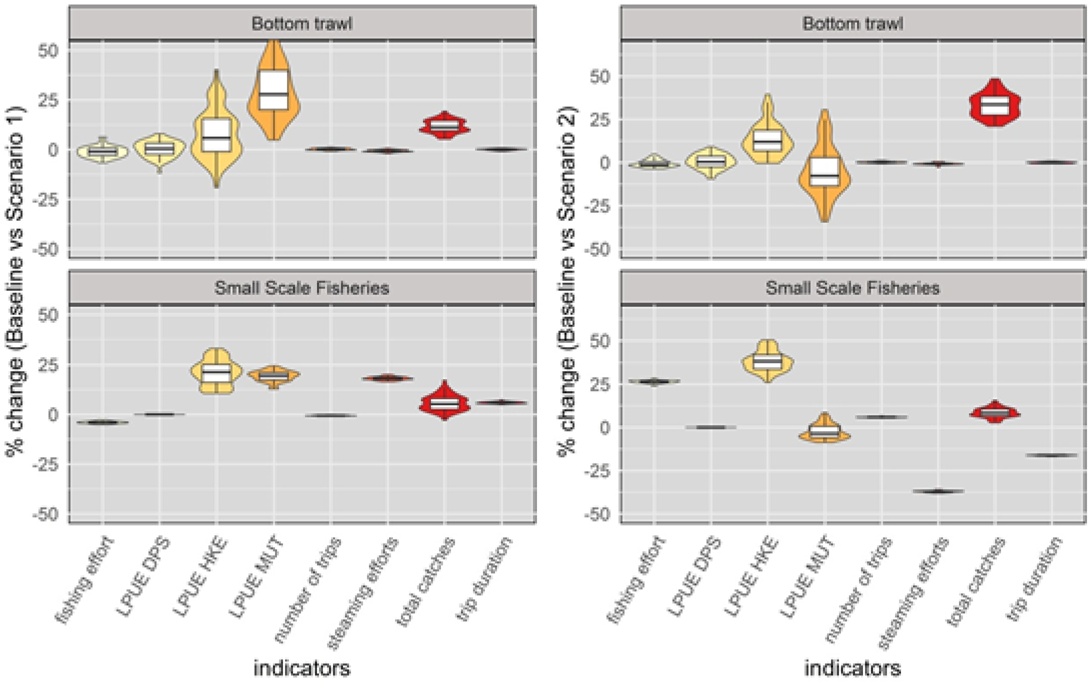


Figure 5.13. Indicators aggregation over the 7y horizon simulated with the DISPLACE eastern Ionian Sea application. Left: Scenario 1-restricting bottom trawl from MPAs, Right: scenario 2–restricting all fishing gears from MPAs. LPUE: Landings per unit effort, DPS: Parapenaeus longirostris, HKE: Merluccius merluccius, MUT: Mullus barbatus.

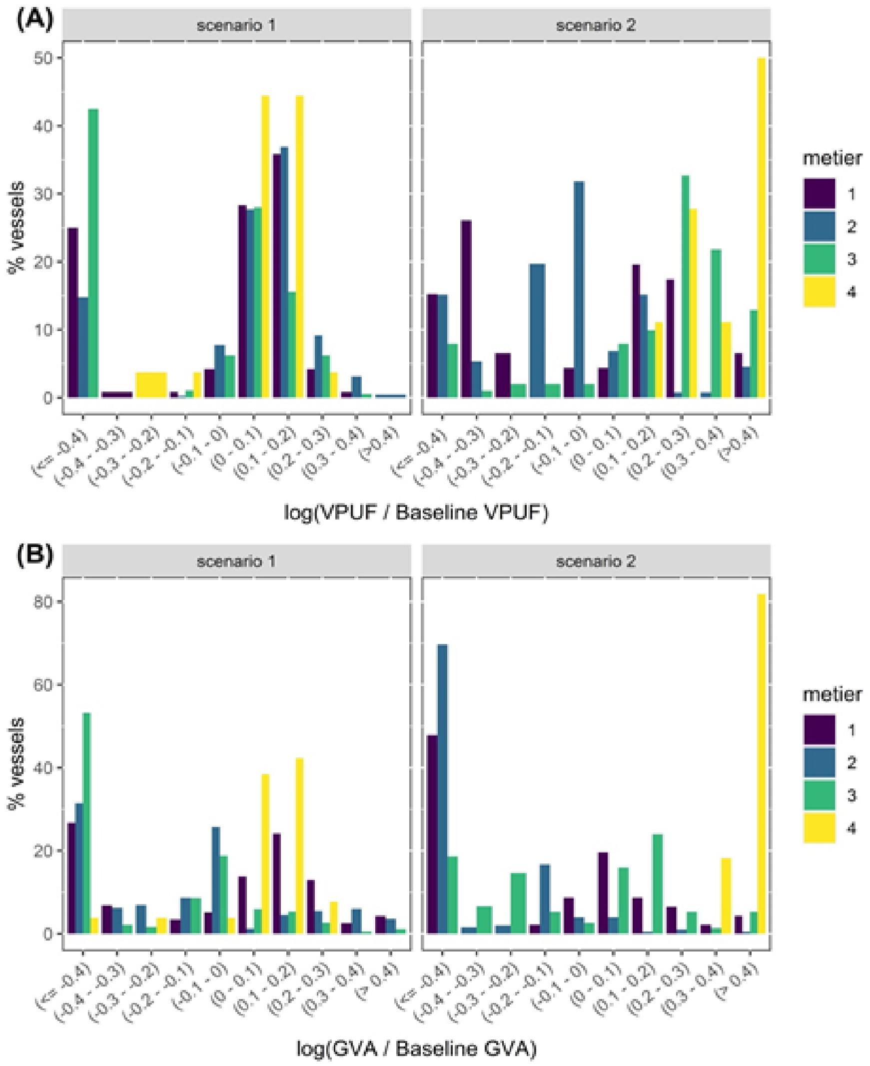


Figure 5.14. Barplots showing the percent of vessels classified per metier (1“gillnet", 2“trammel net”, 3“longline”, 4“bottom trawl”) for each category. Each category indicates the gain compared to the baseline scenario in terms of: A) value per unit of fuel-VPUF and B) Gross Added Value-GVA. The ratios are log-transformed for convenience with a 0 indicating an identical outcome between the scenario and the baseline.

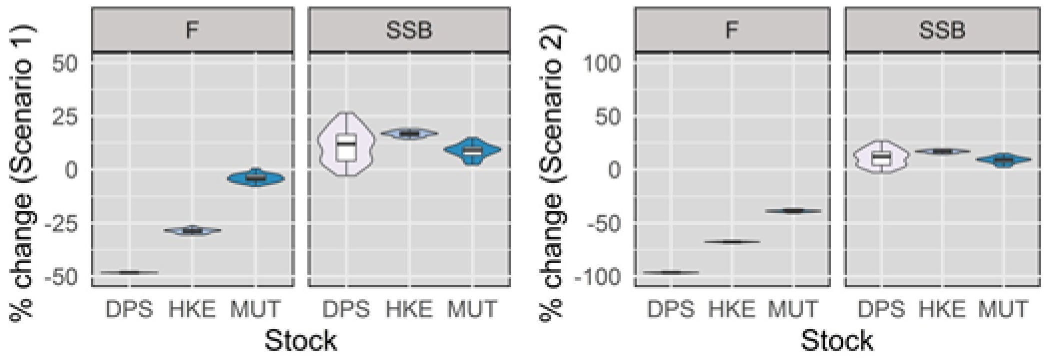


Figure 5.15. Comparison of aggregated scenario outcomes (50 stochastic replicates per scenario) on the fishing mortality (F) and Spawning Stock Biomass (SSB) for the scenarios 1 and 2 for the following stocks: Parapenaeus longirostris (DPS), Merluccius merluccius (HKE), Mullus barbatus (MUT). The percentages are relative to the baseline condition for F and SSB and were estimated for the last simulated (7^{t}h) year.

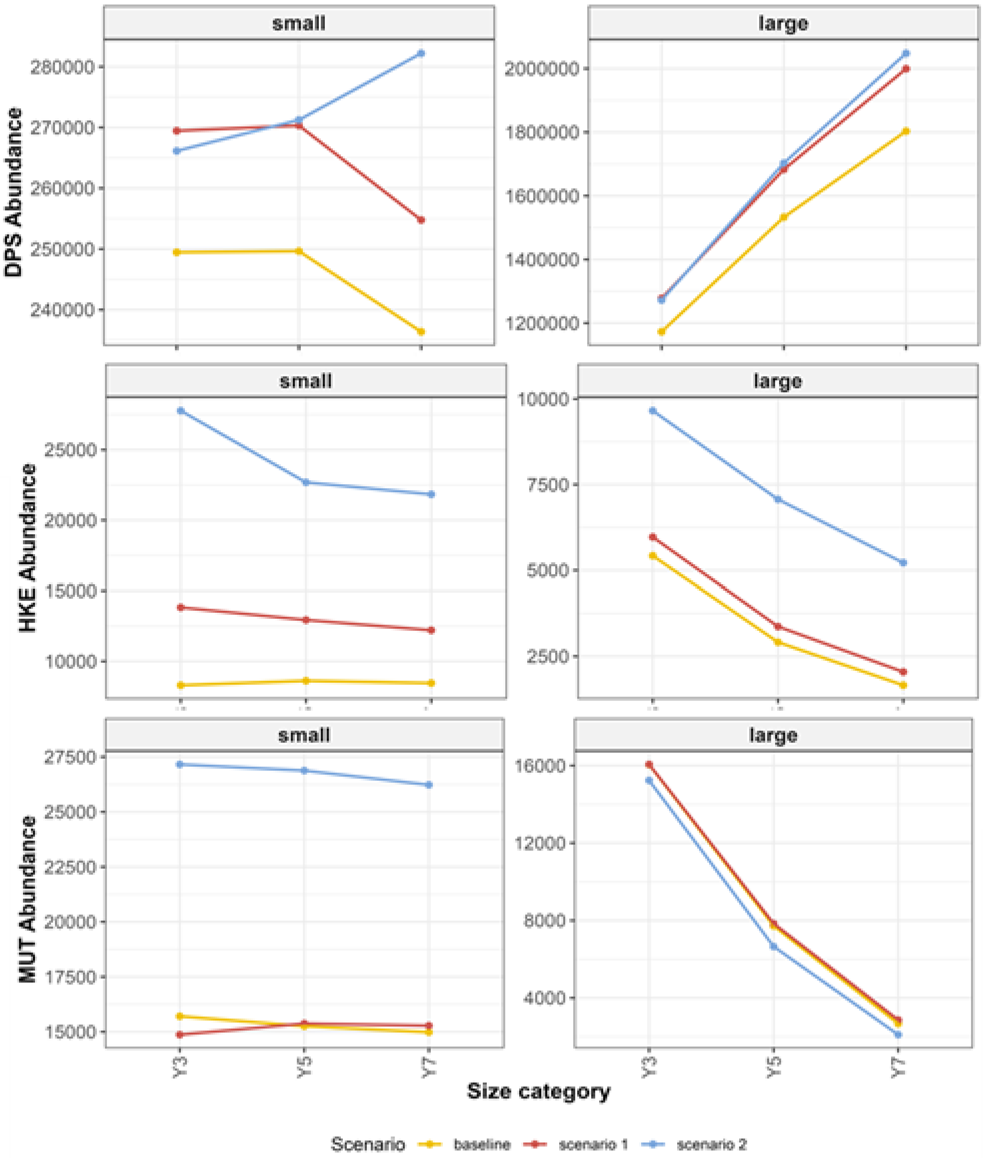


Figure 5.16. Total catch in terms of abundance (expressed in N/1000). Results are shown by size category and simulated year (“Y3”year 3, “Y5” year 5, “Y7” year 7). Size categories are defined as follows: HKE (small ≤ 20 cm and large > 20 cm), MUT (small ≤ 10 cm and large > 10 cm), DPS (small ≤ 2 cm and large > 2 cm).

Annual restrictions on bottom trawling inside MPAs lead to higher landing rates for hake HKE and mullet MUT for small-scale fisheries (SSF). Apart from the higher landing rates for MUT, the landing rates of Otter Bottom Trawlers OTB were not notably influenced. Although there are benefits for the stocks in the 7-year simulation horizon, the catch of undersized individuals is higher in most cases. Additionally, most OTB vessels were not markedly (or slightly positive) influenced. On the other hand, several SSF vessels were negatively influenced in terms of fisheries economics.

Restricting all fishing gears from MPAs resulted in noticeable spatial changes in the fishing effort and the origin of catches from the investigated stocks. In the simulations, particularly the SSF sought to remain economically viable, therefore SSF effort is higher compared to the status quo situation. The benefits for stocks are obvious after the 7-year simulation horizon. However the catch of undersized species is even higher, while the catch of MUT adults is lower compared to the baseline. The closure has positively affected OTB in terms of fisheries economics but at the cost of several SSF vessels.

Although some benefits might occur as a result of the fishing restrictions in MPAs, the unwanted catch has increased. In addition, a decreasing trend also occurred in the catches of adult fish during the simulated years. This might be an indication of increased exploitation of larger fish that is possibly resulted from the fishing effort displacement to other areas. At the same time, several SSF vessels were affected negatively from the closures in contrast to OTB vessels that are benefited particularly when restrictions occur in MPAs for all fishing gears. Such findings indicate that both alternative scenarios do not allow all fishing fleets to remain economically viable and failed to make the fleets more selective, aiming for a more balanced exploitation of small and large fish in the eastern Ionian Sea. Making the fishing fleets more selective (by improving the fishing gear codend or/and encouraging spatial selectivity) is among the CFP objectives, while this is important to be considered in the alternative scenarios that will be investigated in the second SEAwise deliverable D5.6.

It should be highlighted that our findings are preliminary, and further work is needed to perform simulations for more than 7 years and to investigate the scenario effects on the individual vessel profit. Such work will be included in the second deliverable (D.5.6).

Up to now, the model was conditioned with annual data on the spatial distribution of fishing effort and species abundance. Given that the model supports a finer quarterly-based resolution of input spatial data, we are working on informing the model with more analytical spatiotemporal information on fishing effort and abundance of commercial species (this process is ongoing and in a good level). Nonetheless, simulations allow for consideration and reconstruction of the intra-annual variability of these components, since the fishing effort patterns are highly affected by the tested spatiotemporal fisheries restrictions that are already included in the baseline run.

Future work intends to investigate fisheries related alternative scenarios such as fishing effort controls, spatiotemporal closures and improving selectivity etc. and possibly exploring combinations of these management options (input from stakeholders will be very useful here). In addition, we could explore some management options for reducing the impact of fishing on sensitive species or habitats.

Spatial plans to be tested may be based on species distribution of occurrence and risk assessment outcomes. These risks are mapped based on GAMs and Productivity-Susceptibility analysis (PSA, method further described in D4.2) for elasmobranchs species (MPO, SMD, QUB) encountered by various fleets (OTB, LLS, GNS, GTR). This risk analysis was finalized in SEAwise D4.2. Moreover, the simulation may include specific habitat types such as the essential fish habitats (nursery grounds etc.) deduced from hotspot areas analysis (analysis is finalized in D5.4), or specific benthic habitats specific to GSA20 and informed for their Relative benthic status (RBS) indicators (aligned with ICES WGFBIT analysis, finalized in D4.4).

In conclusions, alternative scenarios that will be tested in D5.6 will mainly include:

- Spatiotemporal closures to protect essential fish habitats (e.g. nursery grounds)
- Spatiotemporal closures to protect other sensitive species/habitats (e.g. PET species, other areas for conservation priority)
- Fishing effort reduction or/and selectivity improvements

The final alternative scenarios to be tested in D5.6 will be defined in the next months.

5.5.3 ECOSPACE (Central Med - south Adriatic and western Ionian Seas)

This study used an ECOSPACE model, part of the Ecopath with Ecosim (EwE) modeling suite (Christensen et al., 2004) for the analysis of spatial effects of food web dynamics as a consequence of spatial management measures on the fisheries and ecosystems (Walters et al 1999; Walters, 2000). Recently, advancement in the ECOSPACE routine with development of a spatio-temporal framework facilitated extensive applications in multiple fields (Steenbeek et al., 2020, 2022; De Mutsert et al., 2023).

Ecospace extends the food web dynamics in bi-dimensional space across a grid of equally sized cells, for each of which an Ecosim model is run at every time step. In each cell, a value of biomass of the species is provided, based on the preference for the type of habitat, environmental drivers and others. The model redistributes fishing effort, derived from the underlying Ecosim model component, based on a gravity model that accounts for steaming cost (influenced by the distance of a given cell to any of the ports allocated to a given fleet) and revenues (based on the biomass of each species in the portfolio of the fleet of interest in a given cell, and the sale price per species for that given fleet). The ratio between revenues and costs is weighted by an exponential factor, the tuning of which regulates the sensitivity of the fleet’s distribution to costs and revenues. Effort can only be allocated to cells that are open to fishing to the given fleet. This allows evaluating the re-allocation of fishing effort upon placement of a spatial closure, taking into account also the spillover effect from within to outside the protected areas. Cells are linked through flow of biomass associated with mixing processes, regulated by dispersal parameters. Cells can be characterized by environmental information (e.g. temperature), management (e.g. open or close to fishing activity from a given fleet) or others (e.g. presence of habitat of importance). These inform the distribution of species through the Habitat Foraging Capacity (Christensen et al., 2014) which allows smoothing the distribution of species across the study area.

In the present study, the previously developed EwE model for the GSA18-19 (i.e. Central Mediterranean, south Adriatic and western Ionian Seas), developed for the SEAwise Deliverable 4.6 was extended to the North Adriatic (GSA 17). The model was reviewed, fitted and extended to the spatial dimension through the ECOSPACE module for the same area. The combination with GSA17 was achieved by retaining groups exclusively present in GSA 18-19, adding species and trophic groups present in GSA 17 as separate groups, and re-parameterising groups present across the whole area. For example, flatfish such as turbot and brill (*Scophtalmus rhombus* and *S. maximus*) are present but of minor importance in GSA 18 and 19; conversely, they are target species in GSA 17 and were modeled as a separate group; similarly for gurnards, and others. This approach produces an uncoupling between biological species and trophic groups that is thought to better represent the dynamics in the system. For example, it led to having groups of species (e.g. skates and rays) with one group for GSA 18-19 and one group, separated, for GSA 17. The assumption was that the fisheries will mostly insist on one component of the group, so that it would be unrealistic that excessive fishing effort in GSA 17 could lead to collapse of the group in GSA 19.

In terms of stocks and fleets considered, there is continuity with the EwE model developed for SEAwise Deliverable 4.6, and with the BEMTOOL model developed within this same Task (see section 5.5.8) which covers the same spatial resolution. In comparison with BEMTOOL, ECOSPACE includes additional species and trophic groups that are of high commercial or ecological importance, in order to duly account for the food web dynamics in the system.

The model includes 82 trophic groups, of which 9 key commercial species are modelled as multi-stanza, parameterised based on the respective endorsed stock-assessment (Figure 5.18). These are: Sole (GSA 17), Red mullet (GSA 17-18), Red mullet (GSA 19), Hake (GSA 17-18), Hake (GSA 19), Deep-water pink shrimp (GSA 17-18-19), Blue and Red Shrimp (GSA 18-19), Giant Red Shrimp (GSA 18-19), and Norway lobster (GSA 17). Other assessed species are included as biomass pool: Spot-tail mantis shrimp (GSA 17) and cuttlefish (GSA 17), as well as anchovy and sardine (GSA 17-18).

The model includes 37 fishing fleets, including trawlers (coded as DTS in DCF) and other fishing techniques as fixed nets, longlines, polyvalents (DFN, HOK and PGP). Different vessel length classes are also considered: <12 m, 12-18 m, 18-24 m, >24 m, from 6 countries: Italy, Slovenia, Croatia, Montenegro, Albania.

The time-dynamic component Ecosim has been fitted to time-series of biomass by group per year (obtained from the MEDITS survey), catch per group (from the STECF Annual Economic Report AER), and driven by fishing effort per fleet per year (obtained from STECF AER). For the assessed stocks, information was obtained from the latest stock assessments (GFCM WGSAD and STECF-EWG-2022), which included biomass and catch at age (matching the age structure in the model), fishing mortality (used to drive the model) and life-history parameters. The ECOSPACE module requires input of spatial layers of habitat, environmental drivers, and fisheries closures (MPAs, Natura 2000 sites, FRAs and others), available to the study (see section 3, plus European and GFCM sources) and we focused on the areas with spatial restrictions to fishery in the Case Study regarding GSAs 17-18-19 (Figure 5.17); in this map also the VMEs and nursery identified of key commercial species are reported.

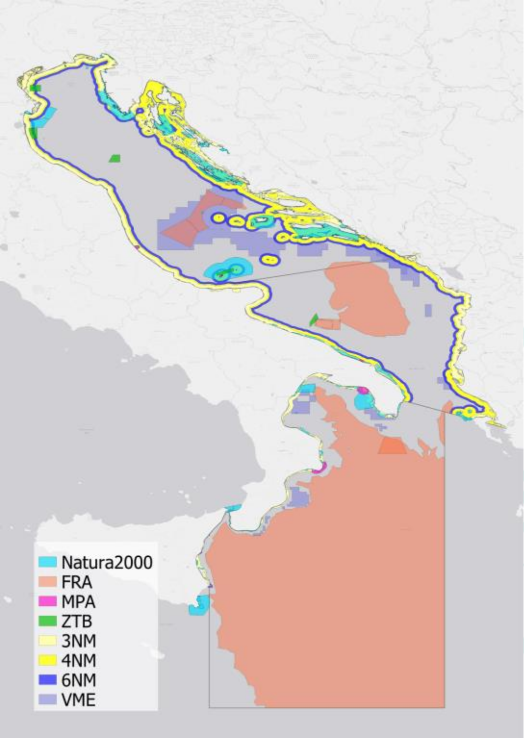


Figure 5.17. Areas with spatial restrictions to fishery in the GSAs 17-18-19, including nursery areas for the scenario 2 (see below).

Spatial distribution of effort and biomass, available as outputs of SEAwise tasks, have been used to qualitatively guide the parameterisation. In particular, effort maps by fleet produced in SEAwise Task 5.3 (obtained from Global Fishing Watch and the Fleet Register) with the species distribution maps and juvenile distribution of European hake and deep-water rose shrimp from SEAwise Task 5.2. Map of VMEs in deep waters of GSA18 (south Adriatic) have also been included. The association between species (e.g. depth preference) was based on the MEDITS survey; fleets' association or restrictions to given layers was based on external information (e.g. literature, unpublished analyses).

Scenarios:

- **Baseline**: Simulation from 2008 to 2018 (hindcasting) projecting ahead until the model reaches an equilibrium state (ca. 20-30 years). This scenario is used as reference to explore the effects of implementation of FRAs and new spatial measures. It includes all historical measures (3 NM closures, coastal MPAs and other spatial restriction at local level as ZTB – Zone di Tutela Biologica, i.e. Areas of Biological Conservation, Natura 2000 sites etc.), but excluding the main FRA recently established, Pomo Pit, and measures included in the Adriatic MAP (temporal-spatial closures) fully enforced from 2019.

- **Scenario 1**: hindcast from 2008 until 2020 and projections until the model reaches an equilibrium state with existing closures (Pomo Pit area and multi-annual plan MAP temporal-spatial closures, fully enforced since 2019. This serves as a “status quo” scenario to explore what would happen in the future if all and only the measures implemented as of 2020 were continued. It serves as “impact” against the baseline, testing the effectiveness of the measures already implemented, and as “control” against Scenario 2.
- **Scenario 2**: as scenario 1, with the following additional closures: Bari Canyon (a FRA in the GSA18) Otranto channel (a VME and area of high presence of red shrimps on which studies are ongoing for management purposes), depths 800-1000m (an extension of the current spatial closure beyond 1000 m depth on which there is a current consensus at GFCM level), nursery areas for hake and deep-water rose shrimp (areas identified downstream the results gathered in the SEAwise D5.2). The implementation of Bari Canyon was recently approved by GFCM and it is actually in implementation, while the other measures have been discussed in the official GFCM fora. This scenario serves as the “impact” to assess the effects of the planned and suggested measures.

All scenarios provided results “before” (year 2020), and “after” (at the end of simulation time, based on the model time to reach equilibrium state).

The scenarios were investigated in terms of the effects on effort redistribution, of total (spatially aggregated) catch, value and costs, of ecosystem indicators and of selectivity, compared across the three scenarios. Effort patterns are reported for the main fleets, selecting demersal trawler fleets (based on the two vessel length segments) for the North Adriatic (GSA 17) reported for the East and the West side of the basin separately; and for the South Adriatic (GSA 18) and Western Ionian (GSA 19). The results are reported as relative effort. The changes to catch, values and costs for the main fleets are reported as the percentage change in each variable comparing the status quo scenario and closure scenario against the baseline scenario. Fish selectivity is shown as changes in biomass and catches for the juveniles and adults of key commercial species comparing the two scenarios status quo and closure against the baseline.

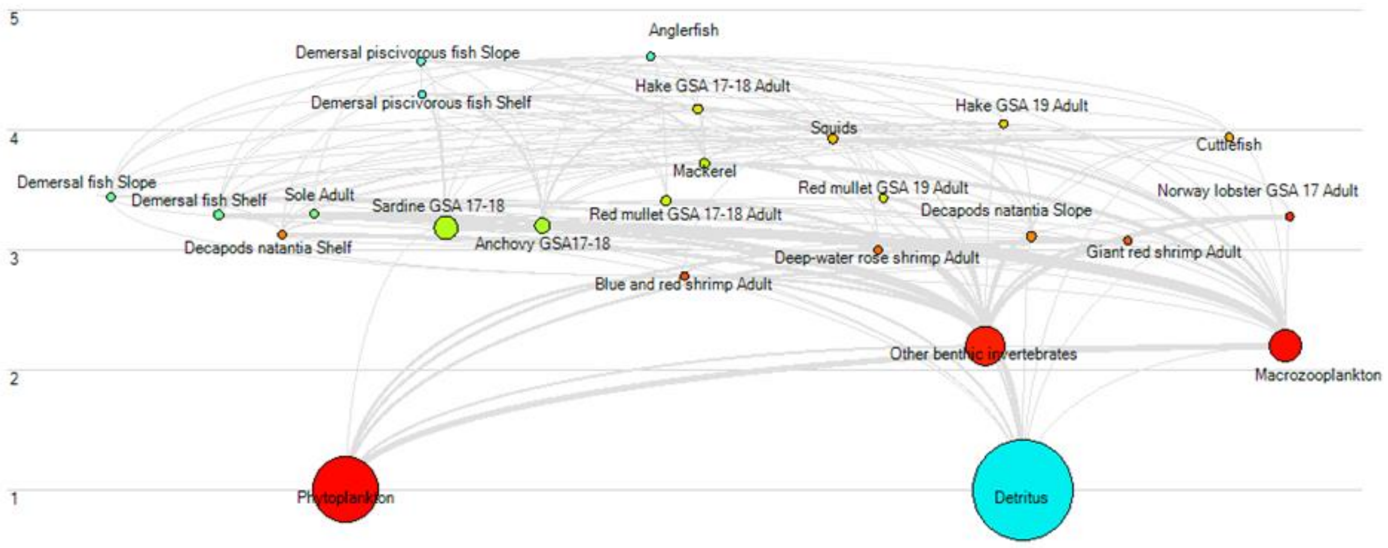


Figure 5.18. A simplified representation of the food web model of the Adriatic and Western Ionian seas in ECOSPACE. A selection of the 82 modelled groups is represented, including the key commercial species and some of the ecologically important groups.

Figure 5.18 shows a simplified representation of the food web model of the Adriatic and Western Ionian seas. Figures 5.19 to 5.26 show the effort distribution across the three scenarios for the main fleets targeting demersal resources. Effort is expressed as relative effort compared to the starting year of the hindcast, 2008, where a value of 1 indicates no change compared to 2008, a value between 0 and 1 indicates a reduction, and values above 1 indicate an increase. The plots report relative effort averaged across three years, after 10 years of simulation (following 13 years of model hindcast).

The effort changes across scenarios clearly show the effect of the closures in effort distribution. Especially for fleets in GSA 17 the onset of the Pomo pit (Scenario status quo) in the central Adriatic and the onset of the closure of the hake nursery area in the same region (Scenario closures) result in displacement of fishing effort. Notably, the effort is redistributed across suitable areas and the model predicts increasing concentration of efforts in coastal areas for this region. Similar patterns can be observed for the smaller, but relevant closures in GSA 18 and 19, with most effects visible in the Closure scenarios. In the South Adriatic the onset of the closure beyond 800 m depth and the nursery areas and Bari Canyon closures lead fleets to redistribute, in some cases to shallower and more inshore areas. In GSA 19, the closure of nursery areas forces the fleets to concentrate in restricted areas in the already narrow shelf – slope break, with stronger effort redistribution in localized areas.

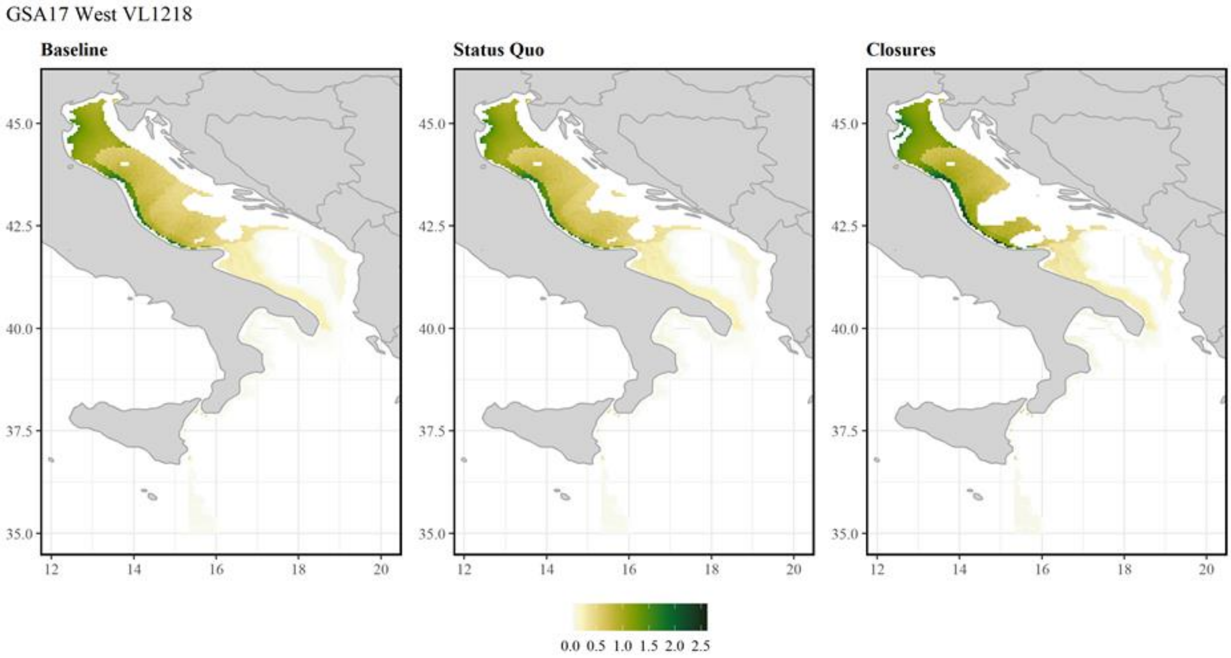


Figure 5.19. Relative fishing effort (compared to starting year) for demersal trawlers.

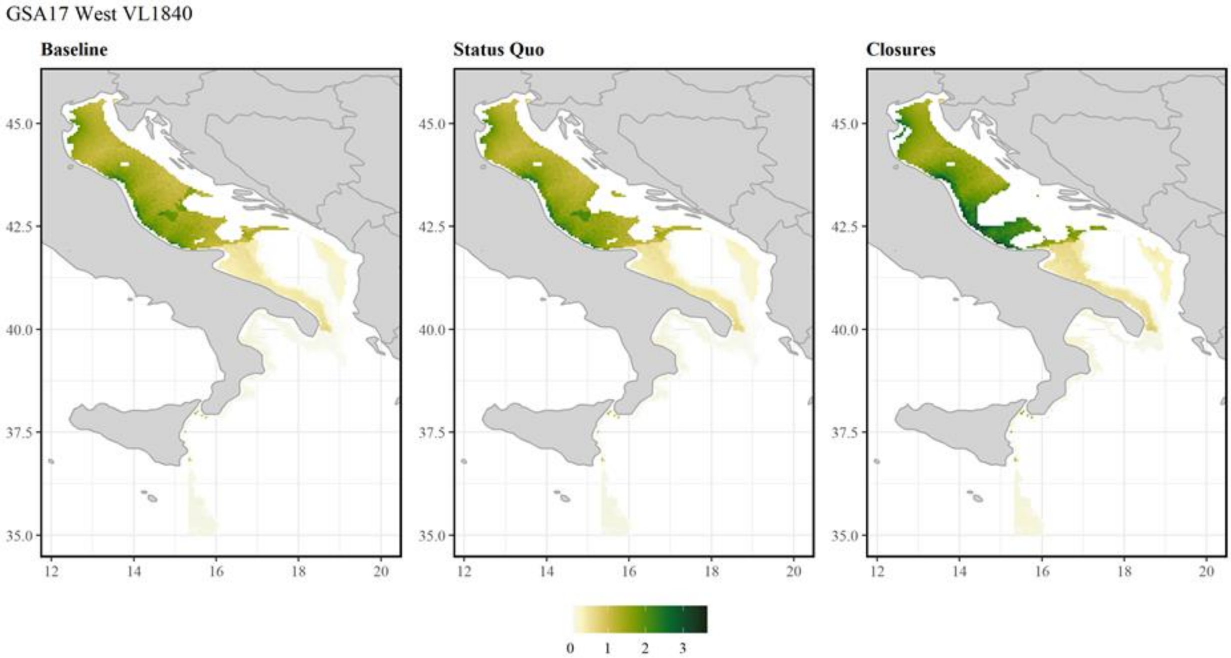


Figure 5.20. Relative fishing effort (compared to starting year) for demersal trawlers.

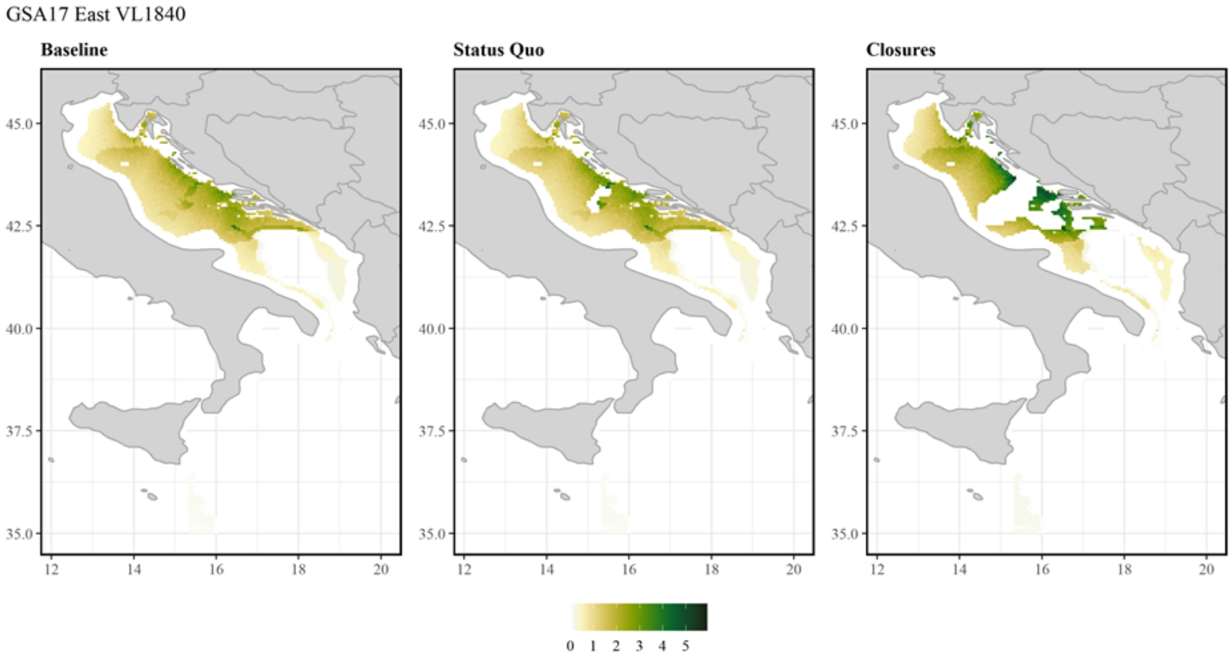


Figure 5.21. Relative fishing effort (compared to starting year) for demersal trawlers.

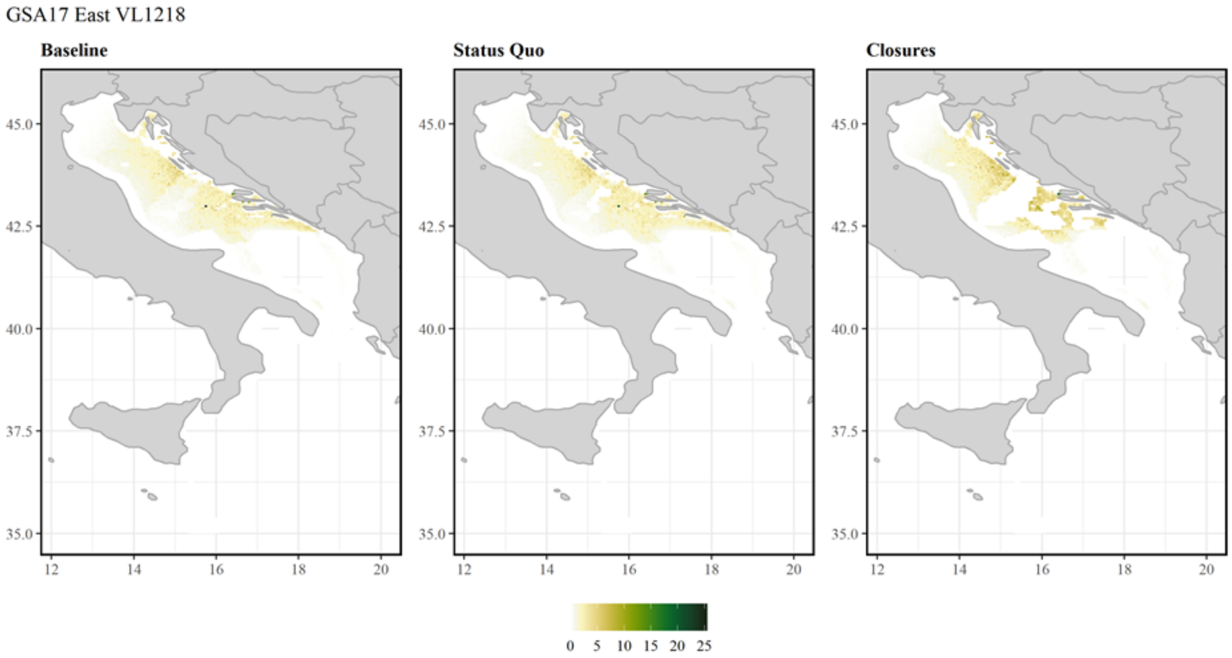


Figure 5.22. Relative fishing effort (compared to starting year) for demersal trawlers.

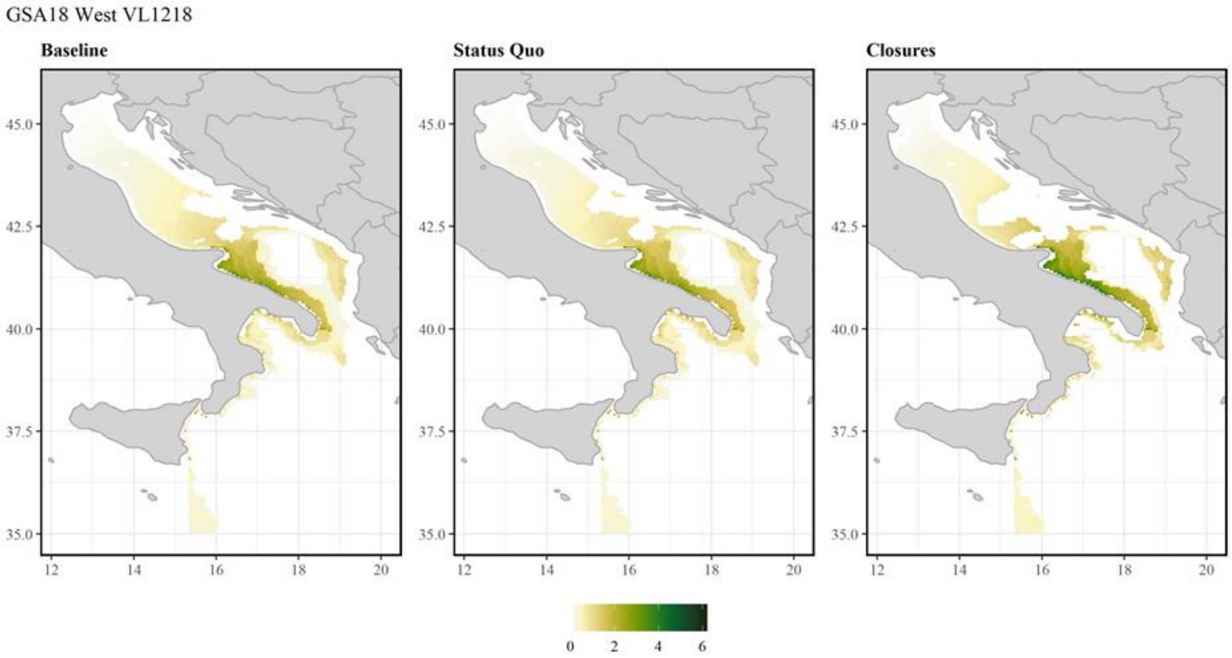


Figure 5.23. Relative fishing effort (compared to starting year) for demersal trawlers.

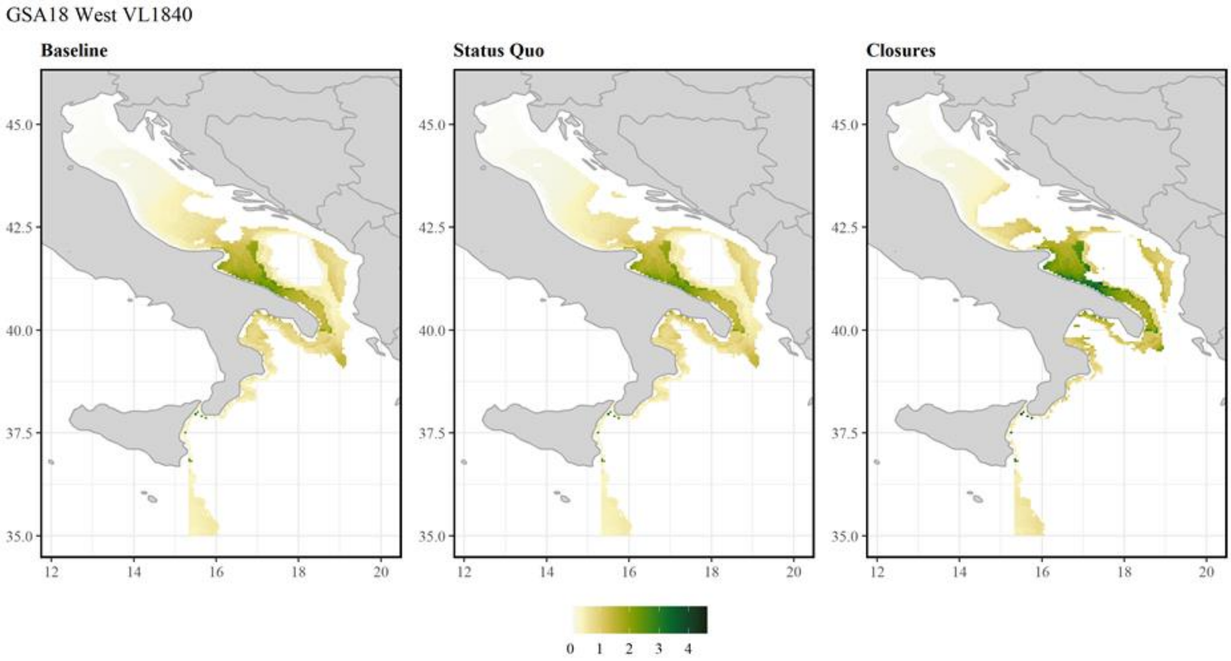


Figure 5.24. Relative fishing effort (compared to starting year) for demersal trawlers.

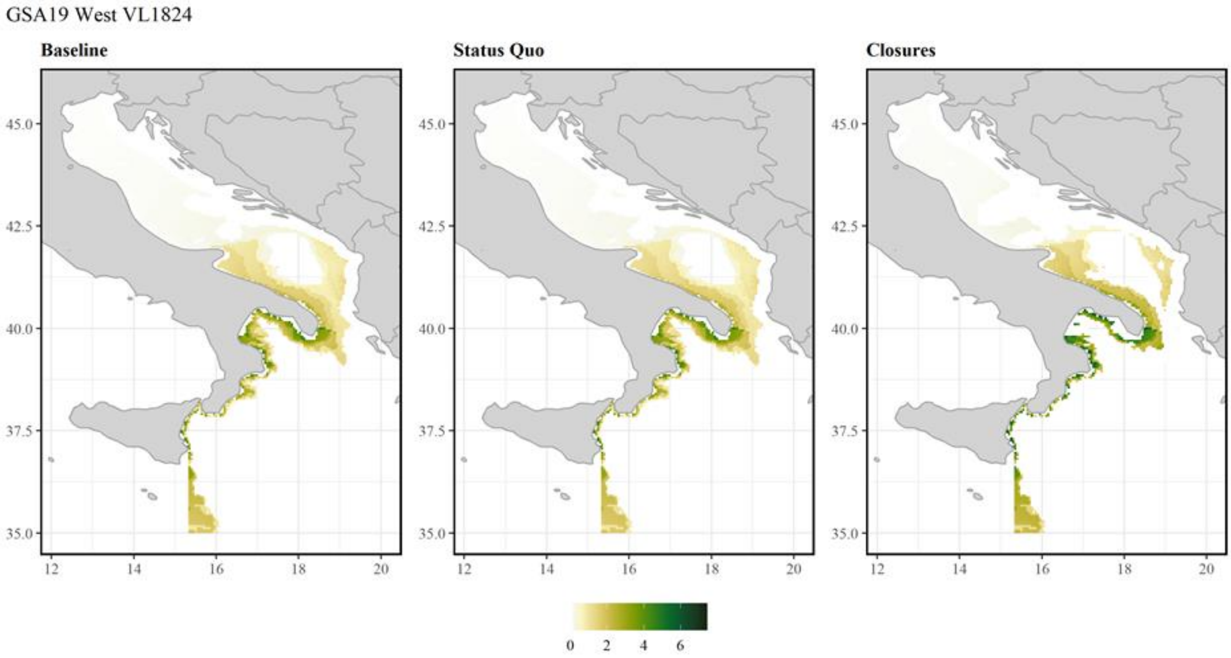


Figure 5.25. Relative fishing effort (compared to starting year) for demersal trawlers.

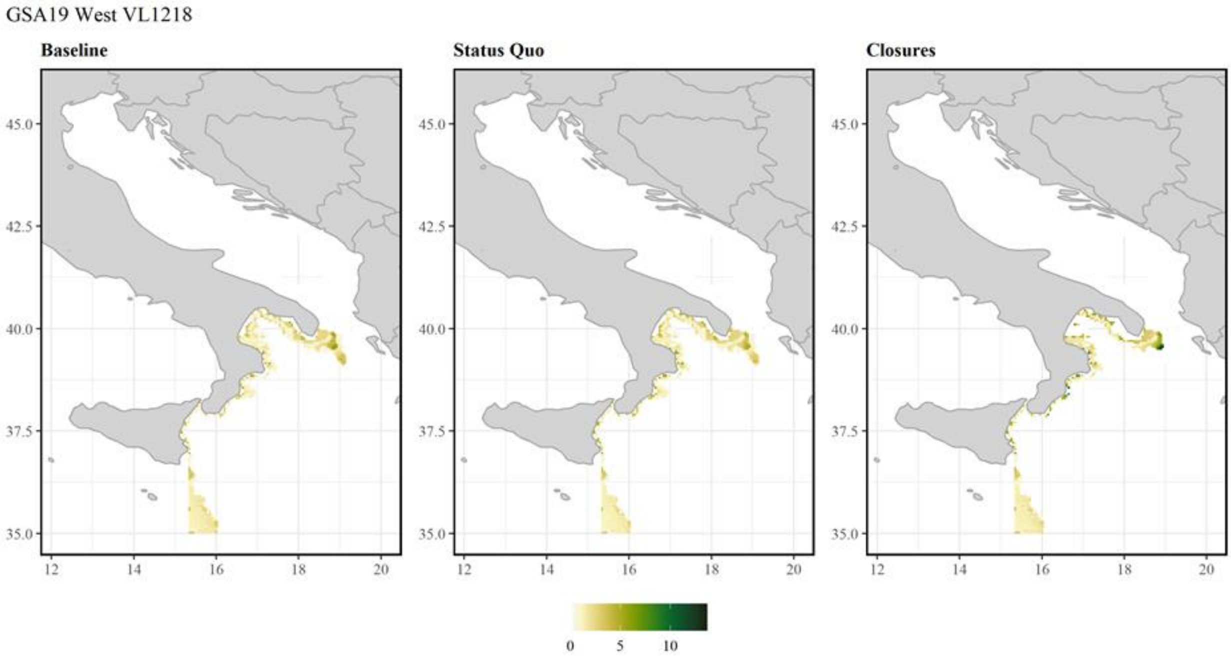


Figure 5.26. Relative fishing effort (compared to starting year) for demersal trawlers.

Table 5.4. Predicted changes (%) in catch, value and cost by fleet for the main fleets for the Status Quo and Closure scenarios compared to Baseline scenario.

	Catch change		Value change		Cost change	
Fleet	Status Quo	Closures	Status Quo	Closures	Status Quo	Closures
GSA17 West VL1218	-0.2%	0.4%	-0.2%	0.5%	-0.1%	-2.1%
GSA17 West VL1840	-0.6%	-2.4%	-1.0%	-4.1%	-0.3%	-2.1%
GSA17 East VL1218	0.7%	0.4%	1.1%	-0.4%	0.1%	-6.4%
GSA17 East VL1840	1.3%	-2.7%	1.5%	-8.9%	-0.1%	-3.7%
GSA18 West VL1218	-0.4%	1.5%	-0.3%	0.0%	0.5%	2.1%
GSA18 West VL1840	-0.3%	3.7%	-0.1%	0.2%	0.5%	1.1%
GSA19 West VL1218	0.2%	0.4%	0.4%	0.9%	1.7%	1.6%
GSA19 West VL1840	-1.6%	4.6%	-1.2%	2.5%	2.1%	5.2%

The spatial redistribution resulted in changes of the total catch of the individual fleets, as well as of the total value (revenues) and total cost, which in ECOSPACE is a proxy of fuel cost (all other costs being constant in time, and only steaming cost influencing the overall cost). Value is obtained in ECOSPACE as a product of catch per species per fleet and the respective price per unit of catch, which is species-fleet-specific. A decline in value may indicate, for example, loss of catches of profitable species (Table 5.4). A reduction in value may be caused either by a decline in the stocks that drive the fishery, or by the fleets being forced by spatial closure to redistribute to less productive areas.

As ECOSPACE reports total catch, value and costs per fleet as relative values, these are reported here as percentage change in the scenarios Status Quo and Closure compared to the Baseline (Table 5.4), and highlighted with shades of red (increase) or blue (decrease). The results need to be interpreted with care, as modeled fleet distribution and the resulting catch, cost and value may be influenced by underlying assumptions on both species distribution, and fleet behavior. Nonetheless, the predictions for demersal trawlers fleets are considered to capture well the fleets’ spatial dynamics.

Individual fleets may benefit or suffer from the closure, with little correlation to the type of gear or country. For example, the East Adriatic trawlers seem to be positively impacted in terms of costs, being forced closer to shore with the closure of their traditional fishing ground. Conversely, many of the Italian trawling fleets undergo an increase in steaming cost, possibly as a result of the redistribution to other areas with closure of nursery grounds and FRAs.

Moreover, the results show that the effects for the Status Quo and the Closure scenario are sometimes inverted. The catch patterns for DTS segment in Western GSA 18 and 19, for example, show reduced catches at the status quo, but an increase in catches is observed under the closure scenario. This could be a result of both larger recovery of commercial stocks under the Closure scenario and changes in fishing distribution, resulting from closures inshore, as demonstrated by the larger sailing cost for these segments in the Closure than in the Status Quo scenario. The fleets may thus catch more fish, but perhaps at a higher cost, or of lower desirability (the value also declines for these fleets). Hence overall, these fleets sustain larger costs, but have larger catches.

The results of Table 1 complement and contribute to explain the observed spatial effort distribution change in Figures 19 to 26. The most conspicuous example is in the central Adriatic, where the Pomo Pit closure area is in place already under the status quo scenario, resulting in lower effort in the area; in the Closure scenario, in addition, the redistribution caused by the closure of the large Hake nursery area results in clear increase in nearby zones. All fleets in GSA 17 are displaced toward the coastline, with shorter steaming distance and thus, as shown in Table 5.4, lower cost. This redistribution however results in lower value in the two segments VL18-40, which generally fish more frequently offshore.

The ecosystem indicators provide an understanding of the changes in the system diversity and in the structure of the food web (Figures 5.27-29). Under the closure scenario, ECOSPACE anticipates an increase of the mean trophic level of the catch (Figure 5.27) in the deeper waters closed to the demersal fisheries (but accessible to pelagic fisheries that target high trophic level pelagic predators, resulting in an increase in relative trophic level of the catches in this area) and, more importantly, a nuanced but visible change of the mean trophic level of the catches in the central Adriatic, that reflects the onset of the nursery closure. The mean trophic level of the community (Figure 5.28) shows little change across scenarios, indicating that the observed changes across the species are buffered when aggregating at the ecosystem level. The Shannon index of biodiversity (Figure 5.29) instead shows a change in biodiversity in the central Adriatic area, with an increase of biodiversity in the status quo scenario and a larger increase in the Closures scenario.

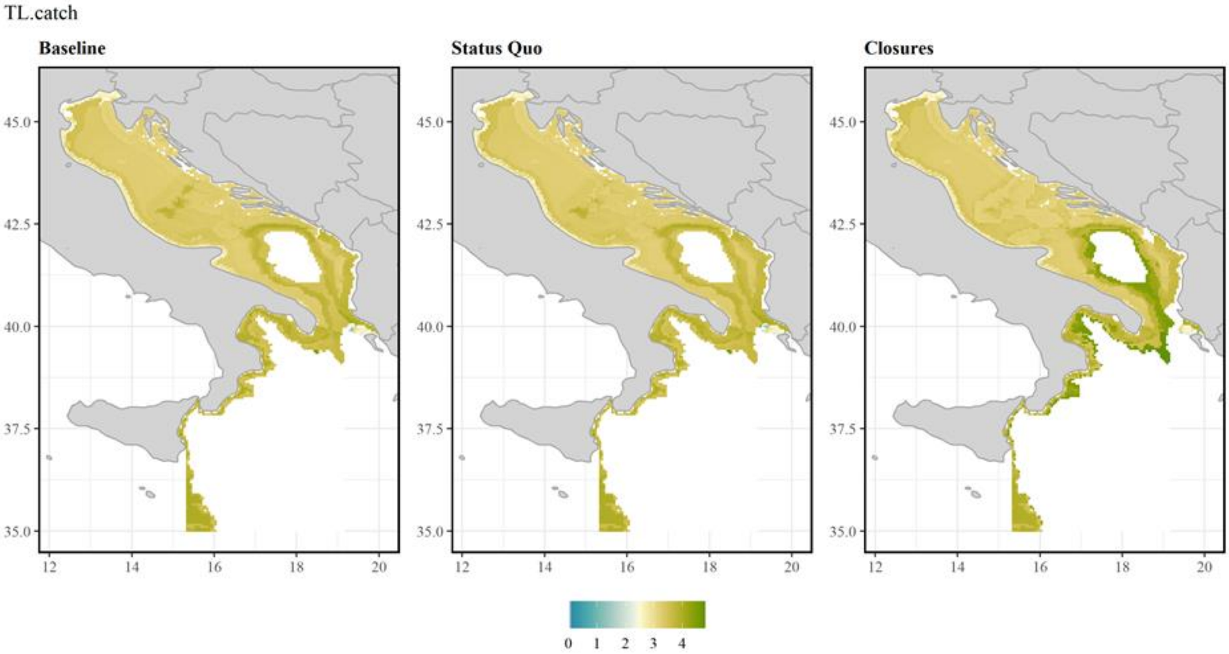


Figure 5.27. Mean Trophic Level of the catch across the study area in the three scenarios.

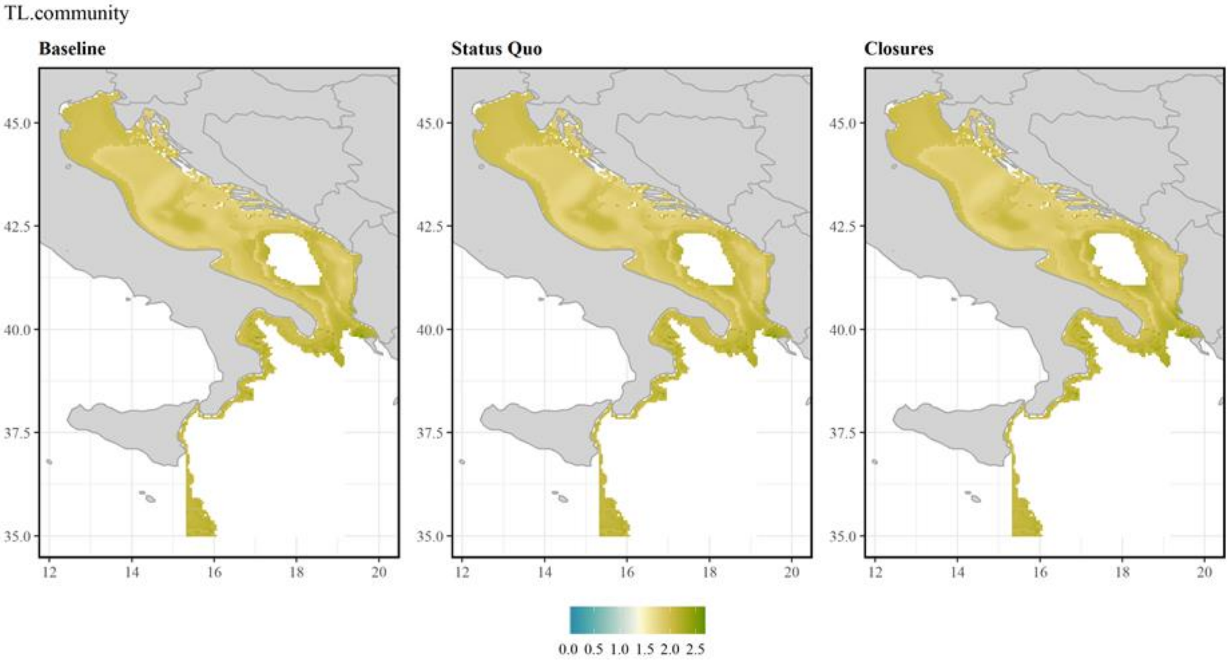


Figure 5.28. Mean Trophic Level of the community across the study area in the three scenarios.

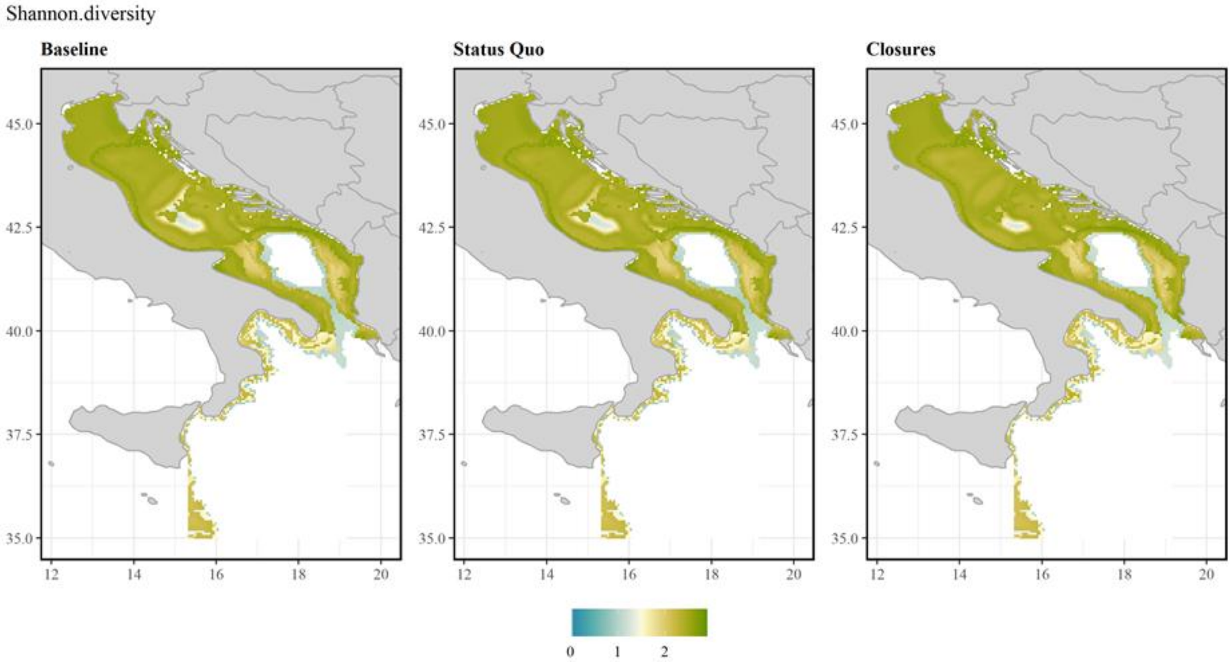


Figure 5.29. Biodiversity (Shannon Index) of the community across the study area in the three scenarios.

Clearly, ECOSPACE anticipates that some species may benefit in terms of biomass from the closure scenario (Table 5.5): Norway lobster in GSA 17 increased in biomass substantially, especially at the adult stage but also at juvenile stage. Large biomass increases were observed on the adults of hake (GSA 17-18), red mullet (GSA 19), and red shrimps in the simulations. These may be a result of the closure of the nursery area for these groups, the protection of which may benefit the adults in the long run. The juveniles of the same groups (Hake and the red shrimps in particular) show smaller, but not negligible increases. The status quo scenario did not achieve the same results: only for Norway lobster we observed a large increase in biomass, likely because of the protection in the Pomo pit area. The other species only marginally increased in this scenario, and only at the adult stage.

In this ECOSPACE application, catches showed different patterns (Table 5.5), with catches of red shrimp juveniles increasing substantially, as a result of the closure scenario, but no increase in the status quo scenario. Among the adult groups, catch increased for deep-water rose shrimp under the closure scenario, and declined for Norway lobster. These results may likely be influenced by assumptions in the species distribution, and thus requiring careful interpretation.

In some occurrences, an increase of biomasses in ECOSPACE corresponded to an increase in catches, pointing at a possible effective protection (on the juvenile class) of the closures, which allows the population to grow, for example for hake in GSA 17-18, added to identical catches of adult fish, possibly because of the closure to the important habitat for adults in the Pomo Pit. Norway lobster likely benefited from the closure in the ECOSPACE, however it becomes less available to fisheries. For both these species, the simulated patterns may be a result of the effort displacement.

Table 5.5. Predicted changes (%) in biomass and catch by species and life stage for the key commercial species for the Status Quo and Closure scenarios compared to Baseline scenario.

	Biomass		Catches	
Juveniles	status quo	closure	status quo	closure
Sole Juvenile	0.0%	1.0%	-1.5%	-0.1%
Red mullet GSA 17-18 Juvenile	0.4%	-0.4%	-1.6%	3.8%
Red mullet GSA 19 Juvenile	-1.5%	0.1%	-6.9%	-9.5%
Hake GSA 17-18 Juvenile	0.0%	11.4%	-2.0%	6.2%
Hake GSA 19 Juvenile	0.8%	-1.2%	0.1%	1.6%
Deep-water rose shrimp Juvenile	-0.3%	1.0%	0.8%	-1.5%
Red shrimps juveniles	-0.8%	2.9%	1.7%	49.6%
Norway lobster GSA17 Juvenile	8.1%	27.1%	-1.2%	-29.7%
Adults				
Sole Adult	0.2%	1.4%	-4.9%	-3.7%
Red mullet GSA 17-18 Adult	-0.2%	-0.6%	1.0%	4.8%
Red mullet GSA 19 Adult	2.0%	5.2%	-1.0%	-1.6%
Hake GSA 17-18 Adult	1.7%	14.7%	0.8%	-2.8%
Hake GSA 19 Adult	1.4%	0.0%	1.1%	2.7%
Deep-water rose shrimp Adult	-0.9%	-1.9%	-1.2%	10.0%
Red shrimps Adult	-1.2%	9.1%	1.3%	-3.7%
Norway lobster GSA17 Adult	27.4%	90.8%	-5.7%	-32.3%

The reported ECOSPACE outcomes here need to be considered as preliminary and potentially influenced to some extent by the assumptions used in the process of building and parameterizing the model. The model will be reviewed and refined toward the next Deliverable (5.6) in order to be used for additional spatial scenarios.

5.5.4 ECOSPACE in southern North Sea

The Ecopath with Ecosim (EwE) model for the southern part of the North Sea has been developed and published in previous studies (Stäbler et al., 2016, 2019; Püts et al., 2020; Bastardie et al., 2022). Within SEAwise, it has been presented in SEAwise D4.6. The present application reused the EwE model for the Greater North Sea (Mackinson & Daskalov, 2007), and places emphasis on economically valuable species and higher trophic levels. The Ecopath model represents ICES management areas 4b and 4c and the ecosystem's condition as of 1991, relying on the most dependable stomach data accessible during the "year of the stomach" (Hislop et al., 1997). The model encompasses a total of 68 functional groups (Figure 5.30), incorporating seven groups that have been subdivided into multi-stanza clusters to depict various life stages (Walters et al., 2010). These multi-stanza groups were implemented for Atlantic cod (*Gadus morhua*), whiting (*Merlangius merlangus*), haddock (*Melanogrammus aeglefinus*), herring (*Clupea harengus*), sole (*Solea solea*), plaice (*Pleuronectes platessa*), and brown shrimp (*Crangon crangon*). It includes 12 distinct Ecopath fishing fleets to represent fisheries activity (Beam trawl, beam trawl targeting sole, demersal trawl + seiners, pelagic trawl, sandeel trawl, nephrops trawl, shrimp trawlers, gears using hooks, drift and fixed nets, dredges, pots and others).

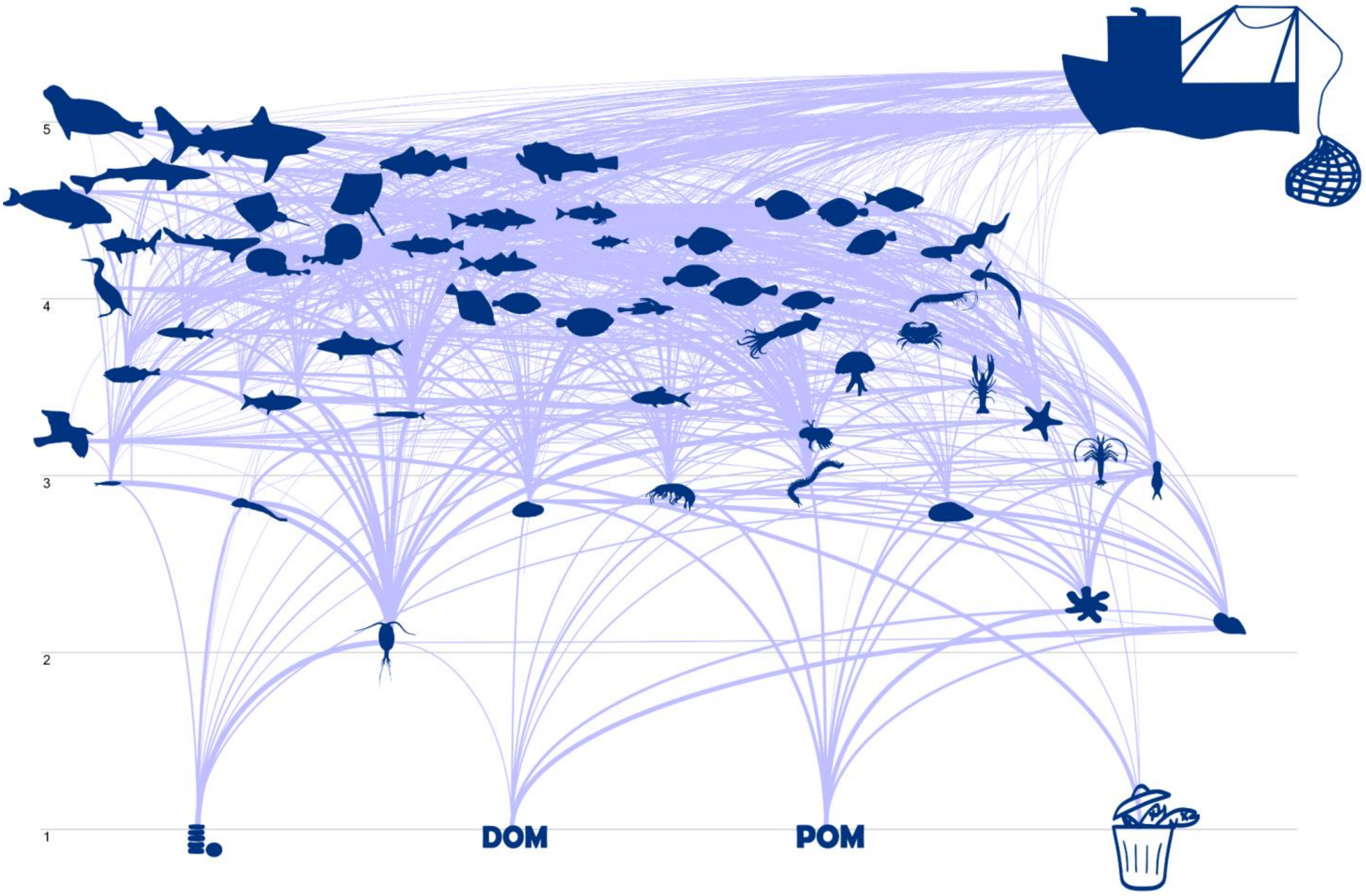


Figure 5.30. Food web in the southern part of the North Sea described in a Ecopath with Ecosim.

The temporal component Ecosim is currently fitted to data from 1991-2010. Temperature is included as an environmental driver for most functional groups. Present-day conditions were reproduced with mean annual sea surface temperature (SST) from 1991 – 2017, based on the Adjusted Optimal Interpolation (AHOI; Núñez-Riboni and Akimova, 2015). Temperature preference ranges (extracted from Aquamaps; https://www.aquamaps.org/) were implemented to link environmental responses of functional groups to changes in Sea Surface Temperature. The distribution of species within ECOSPACE is achieved by various drivers and dispersal rates. For species with a good survey data coverage, results of species distribution models were used to inform the model. These are implemented every 5 years to account for shifts in species distribution. Furthermore, spatially resolved temperature fields, sediment structures and depth profile ensure a good spatial representation of all functional groups. For detailed information on the southern North Sea EwE model see Stäbler et al. (2016 and 2019) and for the spatial parametrisation of Ecospace see Püts et al. (2020).

The model has been used to evaluate the impact of MPAs and OWFs as well as hypothetical closures within the study area (Püts et al., 2023). Extra scenarios simulated for this present study include current closures to fisheries as well as potential future closures as described in section 3.3.2. Closed areas for netters, longliners and bottom trawlers were extracted from the common shapefile for the study area of the southern part of the North Sea. These were implemented into the model onto the model specific grid raster.

We run ECOSPACE with a spin-up period of ten years, historic changes were simulated until 2010. From here on, conditions were kept constant and the model executed until it reached equilibrium. 4 runs were performed. A baseline scenario with no closures allows for an understanding of the general distribution of all functional groups in the model. This baseline scenario is used to compare the distribution of biomass, catch and effort after applying closures to the model area (Figure 5.31). First fishing was restricted for bottom contacting gears, longliners and nets in their respective MPAs with current and potential closures based on habitat protection. In the second step, the closures were applied based on species protection, and the third scenario included a closure based on habitat and species protection. Using the ECOIND plug-in (Coll and Steenbeek, 2017), trait-based ecological indicators were extracted. These indicators include biomass-based indicators (such as fish biomass, biomass of IUCN Red List of species at risk or biomass of birds and mammals), catch-based indicators (such as total catch, discards, catch of IUCN Red List of species at risk) and trophic-level based indicators (such as trophic level of the catch and the community).

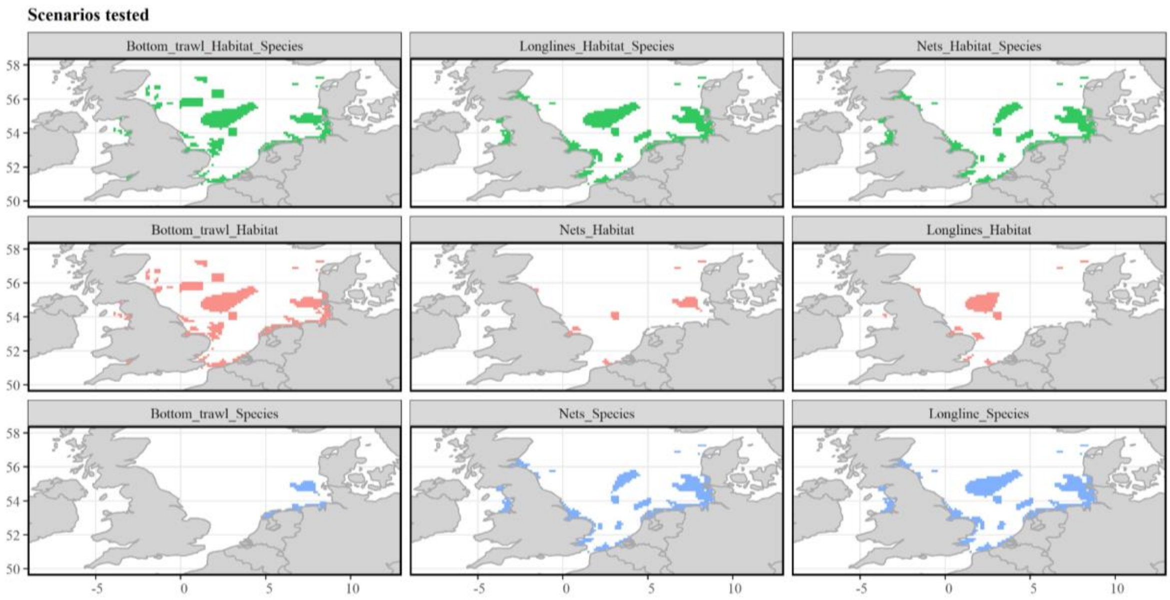


Figure 5.31. Closures for all impacted fleets for the three scenarios executed with ECOSPACE in the southern North Sea.

Ecological impacts of closures

While the overall impact of the closures did not seem to be strong for the selected ecological indicators, the impact was stronger when splitting the area into inside and outside closed areas. This was particularly visible for fish biomass and biomass of IUCN listed species. Inside closed areas, ECOSPACE anticipates a strong increase in biomass, especially for the scenarios including closures based on habitat protection. Fish biomass increased up to 15%, however this increase was not enough to outweigh the reduction of biomass outside the MPA. Closing the MPAs led to a redistribution of fishing effort in the remaining fishing areas, increasing the pressure on targeted species. The impact on total biomass, as well as Kempton's Q and Shannon diversity seemed rather small. It has to be noted that in these indicators all 68 functional groups are included, which may have very contradictory trends, blurring impacts on individual groups. Especially the indicator for total biomass is driven by invertebrate biomass (87% of the total biomass in the model), which is mainly not impacted by fishing directly but rather shifts due to changes in predator prey fields.

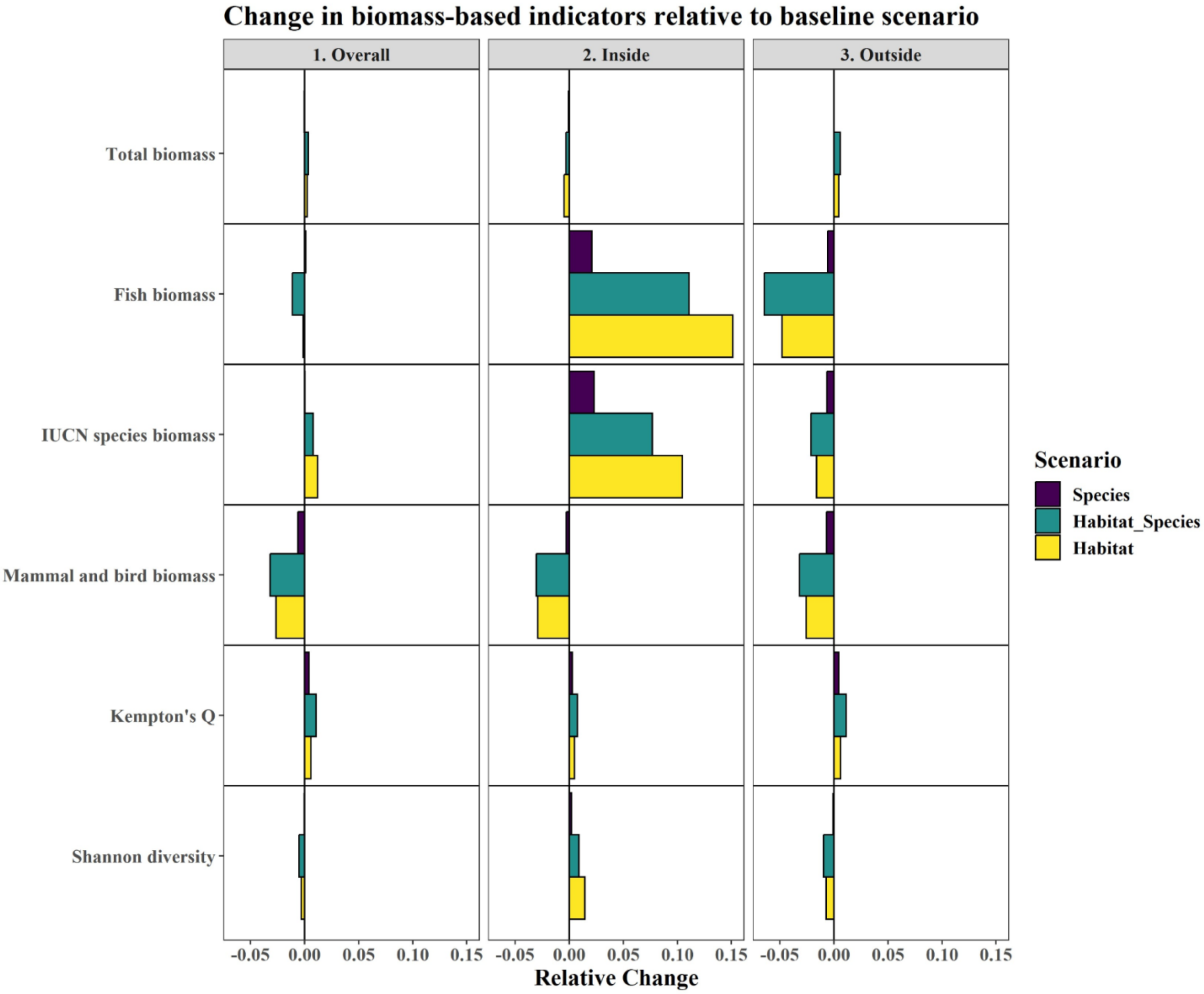
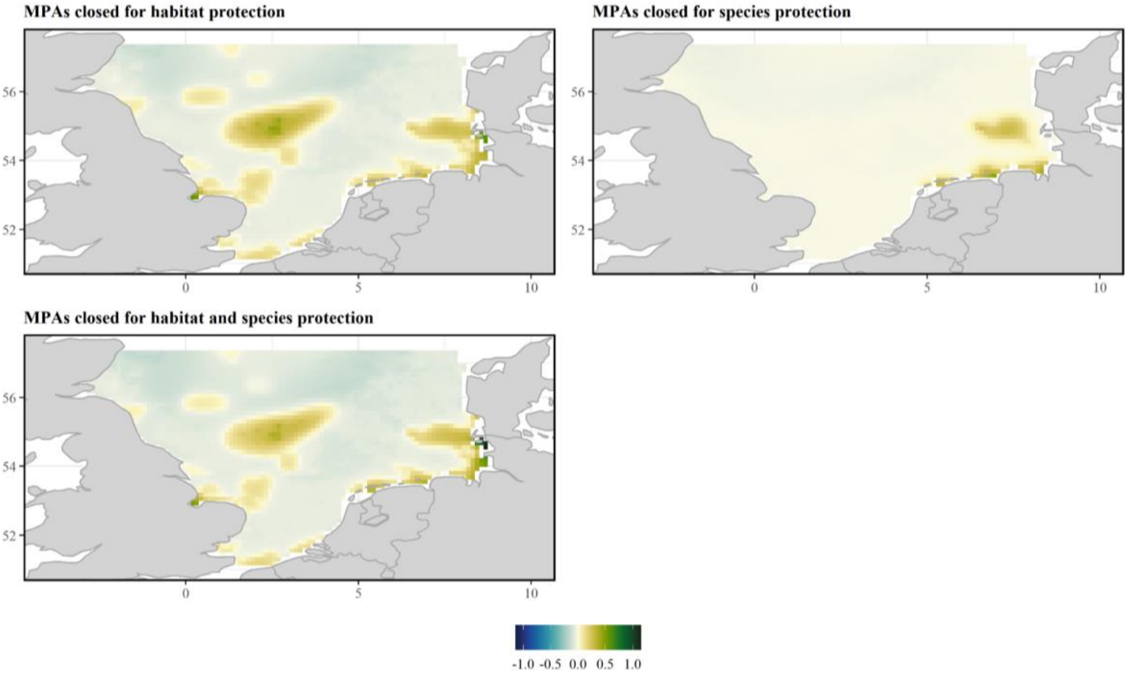


Figure 5.32. Impact of closures on biomass-based ecological indicators. Impact is relative to baseline (i.e. no closure) and shows the change within and outside the closures as well as the overall impact.

For most biomass-based indicators a shift in distribution could be detected. The contrasting distribution patterns of invertebrate biomass and fish biomass explains the impact of MPAs on the trophic interactions in the ecosystem (Figures 5.32-33). Including all MPAs closed for habitat protection increased the impact of MPAs immensely. This was mainly caused by the bottom contacting gears because fleets with bottom contacting gears are allocated into 6 fleets. In the habitat protection scenarios, the area that was closed to these 6 fleets is essentially bigger than for the other fleets (southern North Sea longliners and netters are represented by 1 fleet each).

Fish Biomass



Invertebrates Biomass

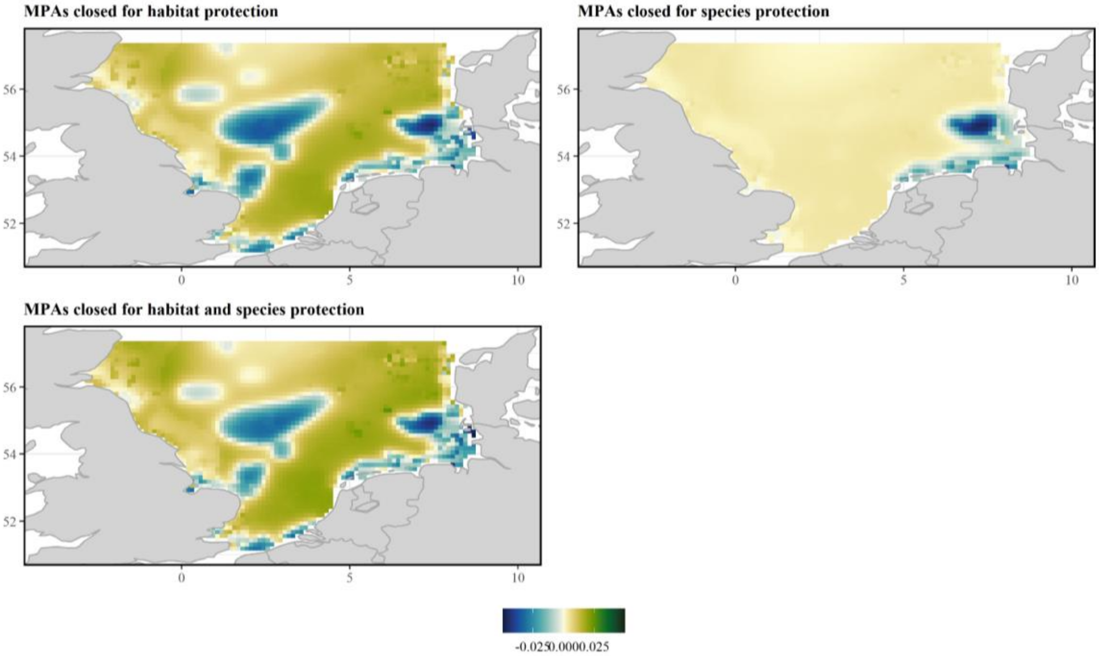


Figure 5.33. Fish and invertebrate biomass distribution relative to the baseline scenario with no closures. Green indicates an increase in biomass, while blue indicates a decrease.

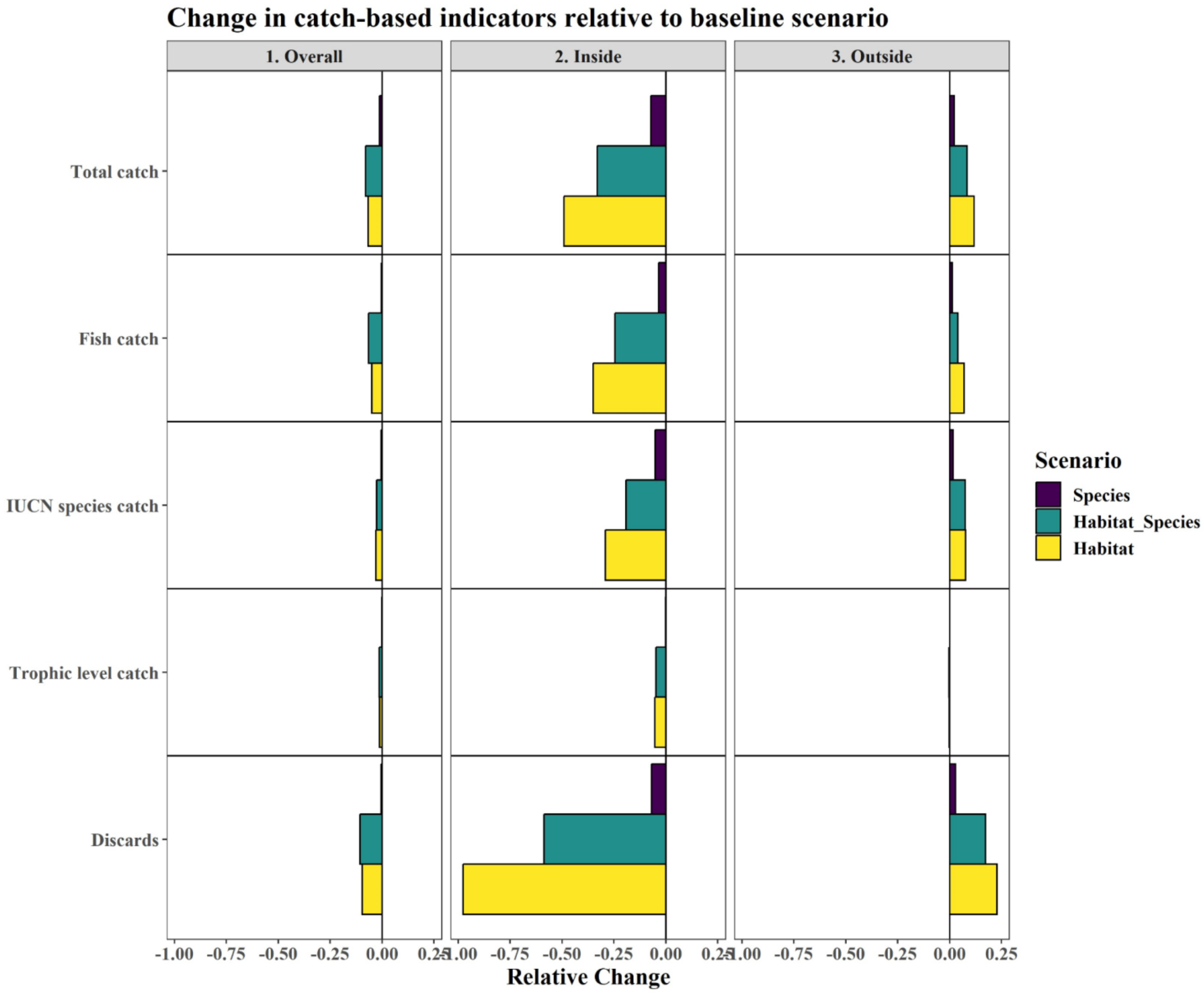
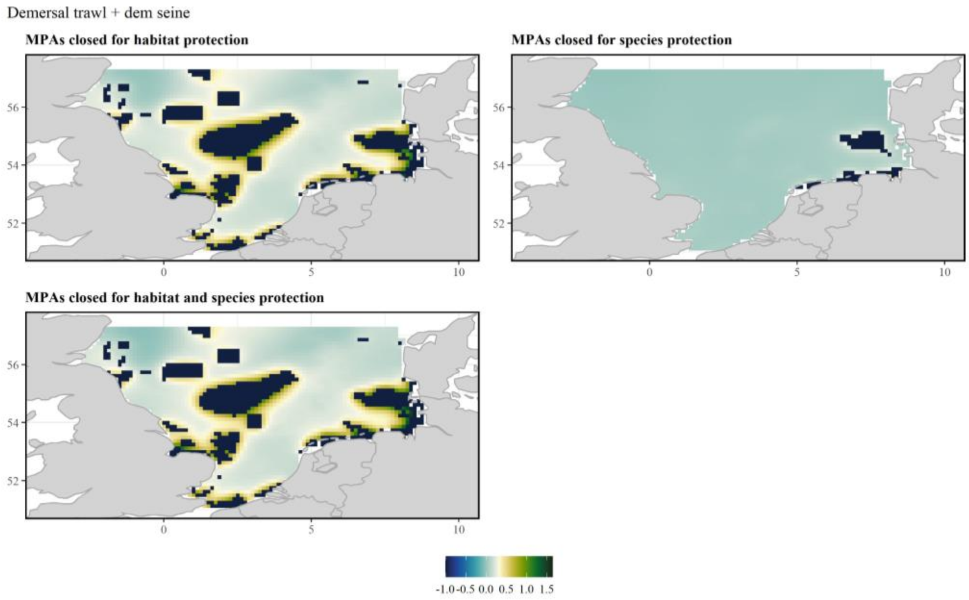


Figure 5.34. Impact of closures on catch-based ecological indicators. Impact is relative to baseline (i.e. no closure) and shows the change within and outside the closures as well as the overall impact.

The impact on catch-based indicators was noticeably stronger and contrasting to the biomass-based indicators. Despite the same amount of fishing effort as in the baseline, the closure of the MPAs led to an overall decrease in catches. While inside the closures the losses of catch volume were up to 50% among all fleets, we saw an increase outside the closures of up to 13% in catches (Figure 5.34). However, this increase did not outweigh the losses caused by the closures. Overall, the strongest impact was caused by closures for both habitat and species, while inside the closure the impact seems to be strongest for habitat only. It has to be noted, that fleets not affected by the closures are still allowed to catch inside these areas, which causes the differences between the scenarios.

Focusing on the distribution of fishing effort, the closures that incorporate the habitat protection MPAs demonstrated the strongest impact (Figure 5.35). For both example fleets (demersal trawl + seines and beam trawls), edge effects around the MPAs were visible. The effort in the remaining fishable areas was reduced slightly moving further away from the closures, while it increased quite strongly around the edges.



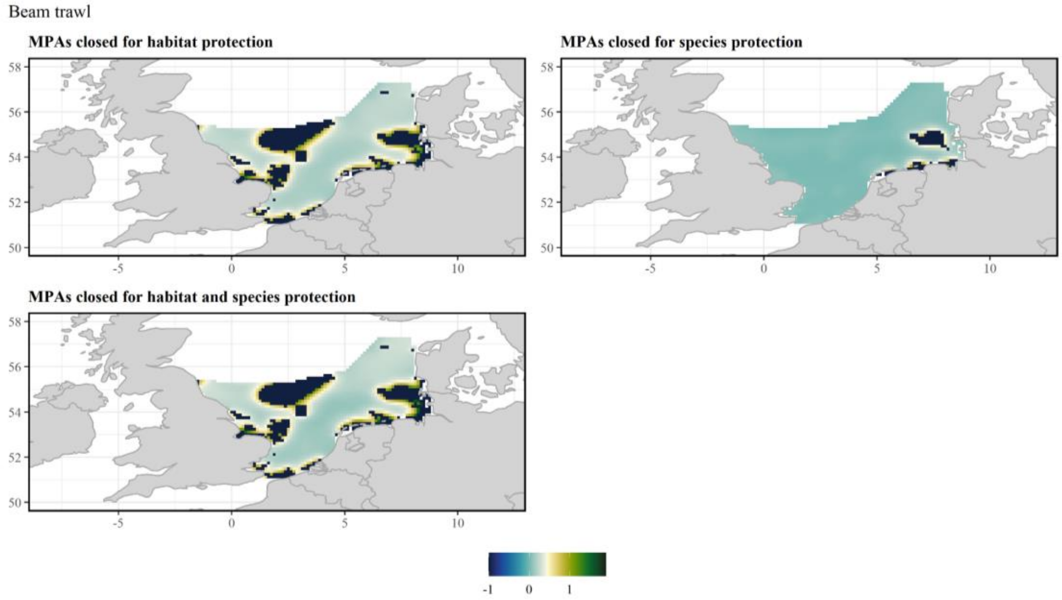


Figure 5.35. Effort distribution for demersal trawls and beam trawls relative to the baseline scenario with no closures. Green indicates an increase in effort, while blue indicates a decrease.

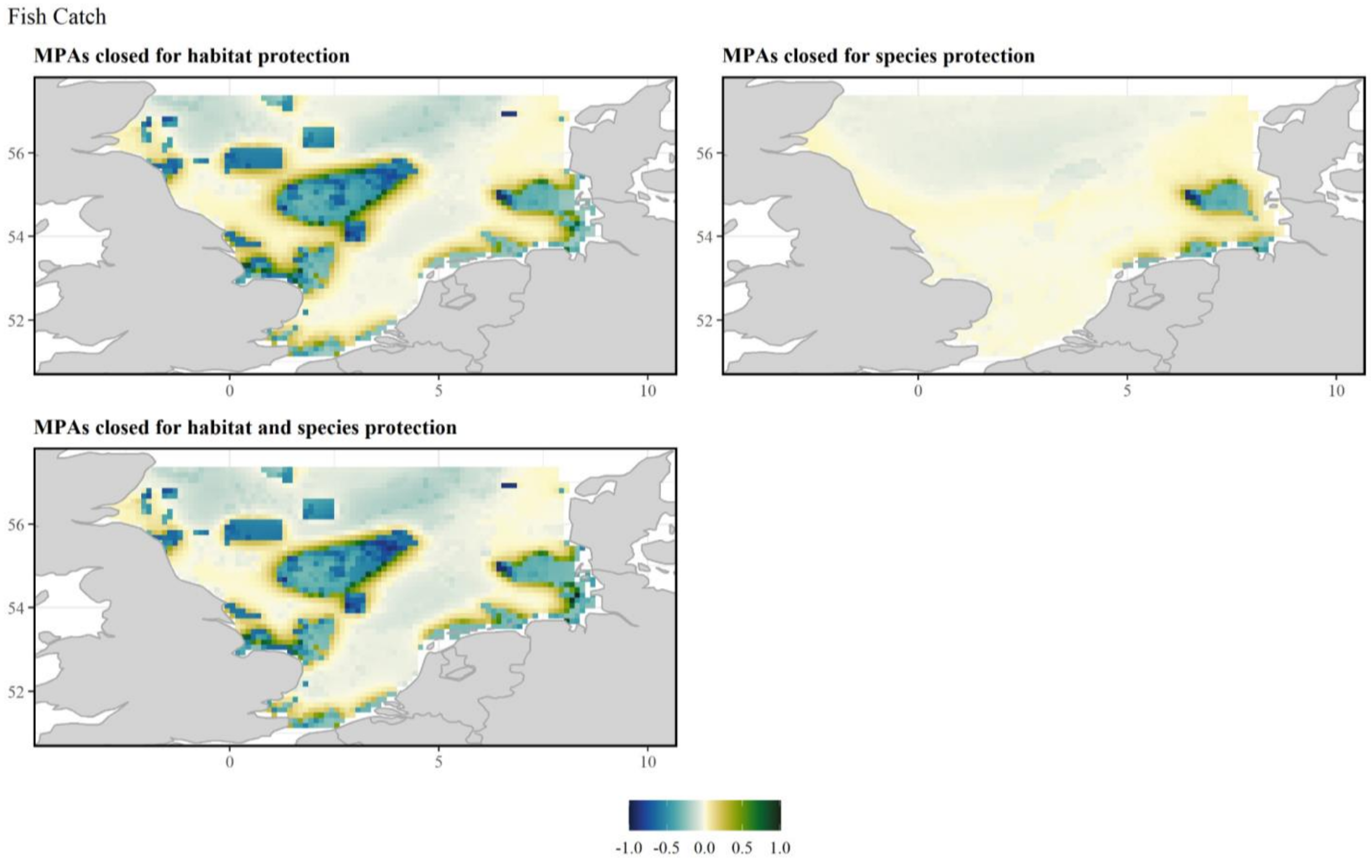


Figure 5.36. Effort distribution for demersal trawls and beam trawls targeting sole relative to the baseline scenario with no closures. Green indicates an increase in effort, while blue indicates a decrease.

Following the redistribution of effort, catch also increased around the borders of the MPAs. Scenarios with larger and more closures (i.e. including habitat protection) displayed again the strongest effect. Here as well a reduction in catches is visible further away from the exclusion zones. Unfortunately, the fleets in this model are allocated into 12 generalized gear groups without a port assigned, and are not as highly resolved as in the ECOSPACE model for the Central Med - south Adriatic and western Ionian Seas. Therefore, we can only get a general idea about the redistribution of the fishing fleet, but can not calculate for example fuel costs or changes in selectivity. Under- or overestimation of the impact of these hypothetical scenarios and possible spill-overs have to be considered conservatively, since there is always a trade-off when bringing a shape file onto a gridded area. Furthermore, other impacts such as climate change or the reduction in seafloor disturbance were not accounted for in the present model. Including such effects would impact the outcome of the model and potentially affect the overall impact of these management measures.

5.5.5 ECOSPACE Eastern Ionian Sea

The ECOSPACE model for the Eastern Ionian Sea (EIS) is based on the EwE model developed in SEAwise Task 4.4 which is described in detail in the Appendix G - Eastern Ionian Sea of the SEAwise deliverable D4.6. The Ecopath model for the EIS was implemented to an area of approximately 16,179 km^2 extending from coastal waters to 800 m depth, where fishing exploitation occurs. Ecopath version 6.6.8 (Christensen & Walters, 2004) was used to construct the model representative of the ecosystem in 1998-2000. Subsequently the time dynamic Ecosim module was fitted to time series of historical data between 2000 and 2020, in accordance with data availability. This model timeframe allowed us to encapsulate the significant changes that have occurred in fishing effort during the last two decades in an endeavor to link fishing pressure to changes in the structure of the ecosystem. On top of the Ecopath, we developed the spatiotemporal ecosystem model ECOSPACE as a tool to explore the impact of implementing new MPAs on food web and fisheries in the Eastern Ionian Sea.

The EwE model for the Eastern Ionian Sea aimed to place species of commercial importance into single-species or multi-stanza groups whilst species of less commercial importance or with limited data, were aggregated into multi-species groups. Functional groups were defined using functional and/or dietary similarities of species as well as their commercial significance in local fisheries. On this basis, we described the food web of the Eastern Ionian Sea with 57 functional groups (FGs) covering all trophic levels and encompassing the entire continuum of marine habitats (Figure 5.37). Apex predators comprised 9 functional groups of which marine mammals are represented in 5 and sea turtles, sea birds, large pelagic fishes and pelagic sharks each in one respectively. Fish comprised 25 FGs, cephalopods are represented with 5 FGs, decapods with 9 FGs while zoobenthos and planktonic organisms with 3 and 4 FGs, respectively. Primary producers were represented by phytoplankton while the microbial food web was indirectly considered in the detritus dynamics. Finally, although not present in EIS in 1998-2000, invasive species (*Etrumeus golanii*, *Callinectes sapidus*, *Penaeus aztecus*, *Lagocephalus sceleratus*) were included in the model as single-species FGs with very small biomass values in order to have the potential to address their impact on the food web with Ecosim simulations.

Concerning the clustering of fishes into 25 functional groups we attempted to describe the ecological and fishing reality of our ecosystem while trying to compensate for data limitations. Overall, pelagic fishes were represented with 11 FGs and demersal fish species comprised 14 FGs, while based on trophic guilds, 11 fish FGs were planktivorous, 7 were benthivores and 7 were piscivores. Four commercially important species in the area (anchovy, sardine, red mullet, hake) were split into multi-stanza groups in order to capture ontogenetic diet shifts and potential different exploitation patterns. Picarels, mackerels, horse mackerels, flatfishes and anglerfishes constituted single groups each according to the level of aggregation of landings data provided by the National Statistical Agency (ELSTAT, 2021) while sharks and rays & skates comprised two distinct FGs due to conservation concerns. Other species were included in aggregated groups based on similar functional characteristics (e.g., medium and large pelagic fishes), dietary similarities (e.g., piscivores fishes shelf and piscivores fishes slope) and spatial distribution (e.g., epipelagic fishes, mesopelagic fishes).

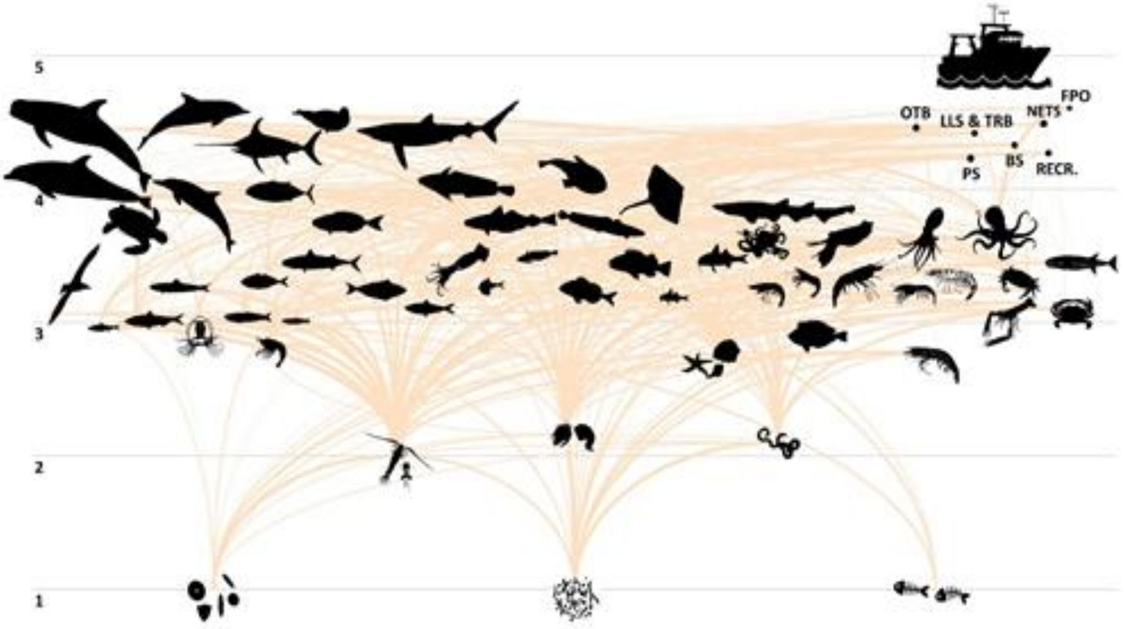


Figure 5.37. The food web of the Eastern Ionian Sea as described with Ecopath with Ecosim (EwE).

The Ecosim fitting used 23 and 29 biomass and catch calibration time series, respectively. Biomass time series for phytoplankton and zooplankton were taken from CERES (2018), stock assessment models were used for anchovy, sardines, red mullets and hake while for the rest of the FGs including benthopelagic, demersal and benthic fishes, cephalopods and decapods, time-series derived from scientific data collected by MEDITS. For large pelagic fishes we used Spawning Stock Biomass (SSB) provided in the stock assessments for the Mediterranean stock of tuna and Atlantic and Mediterranean stock of swordfish (ICCAT, 2016; 2019). On the other hand, catch time series were estimated by landing recordings provided by the National Statistical Agency of Greece (ELSTAT, 2021). Biomasses for all functional groups were entered into the model as relative values while catches as absolute. Whilst observed and estimated biomass and catch values may not align, model simulations should follow the general trends of the observed data. Fishing effort was expressed as annual days at sea and entered into the model as relative values. The environmental response functions that link the species or functional groups dynamics with temperature were obtained from AQUAMAPS (www.aquamaps.org) (Kaschner et al., 2021). Temperature functional responses impact the consumption rates of predators (Qij) and were incorporated into the model following the methodologies outlined in recent studies to simulate the impact of sea warming with Ecosim (Serpetti et al., 2017; Tsagarakis et al., 2022). The final calibrated model - the model showing the best fit to historical data and which satisfactorily reproduced trends for biomasses and catches for most functional groups, accompanied with a credible statistical behavior - included trophic interactions, primary production, temperature and fishing as drivers.

The ECOSPACE model applies the Ecosim equations over a grid of spatial cells connected through biomass exchange. Each cell of the map is defined as land or water, and land cells are assigned to one habitat, while every functional group and fleet can be assigned to one or more habitats by the modeler. In addition, ECOSPACE is capable of integrating niche modeling into the food web modeling approach by applying environmental responses to the FGs while the biomass of each FG is distributed to the cells also by considering their dispersion rates.

Grid size of the EIS model was defined at 199x160 cells with a cell size of 0.025 decimal degrees. The distribution of primary production (Copernicus Marine Service; https://marine.copernicus.eu/) and bathymetry data (EMODnet; https://emodnet.ec.europa.eu/) were included as base maps. Five habitat types were also defined based on substrate type available under the EMODnet Seabed Habitats project; sand and mud dominate the surface sediments in the area but seagrasses were also present. Functional groups were assigned to habitats on the basis of surveys of biomass distribution, species distribution models (D’Elia et al. 2009, Katsanevakis et al. 2009, Damalas et al. 2010) and expert knowledge. Spatially resolved environmental variables and functional responses of species to these variables were used to drive the distribution for 51 FGs. Specifically, spatial distribution of satellite Sea Surface Temperature data (SST) in °C, chlorophyll a (Chla) in mg m^{-3}, and Photosynthetically Active Radiation (PAR) in Einstein m^{-2} day^{-1} originated from OceanColorWeb (oceancolor.gsfc.nasa.gov). To encapsulate the effect of depth on the biomass distribution for the various FGs in Ecospace, we estimated their functional responses to depth with Generalized Additive Models (GAMs). GAMs were applied to the data from bottom trawl surveys (MEDITS) that were used to build the EwE models. The response functions that link species or functional group dynamics with temperature were obtained from AQUAMAPS (www.aquamaps.org) (Kaschner et al., 2021), while functional responses to Chla, applied for small pelagic fishes, derived from species distribution models (e.g. Tugores et al. 2011, Giannoulaki et al. 2013, 2017). The shape of the functional responses of multi-species FGs was defined after weighing the more abundant species. As a final step, the output distribution maps were qualitatively validated after visual inspection in comparison to published habitat models and small modifications were applied to some functional responses to increase the model's realism. Dispersion rates were assigned to FGs following De Mutsert et al. (2023) while the sources used for simulating prices and costs were both national (https://www.okaa.gr/) and international (https://www.eumofa.eu/). Finally, the multi-stanza model was chosen over the Individual Base Model (IBM), as it was faster in computation. Fisheries Restricted Areas (FRAs) of the model included existing permanent and seasonal closures for trawling, purse seining and small-scale fisheries (SSF) (Figure 5.38), all defined based on local, national and/or EU regulations.

We examined two spatiotemporal scenarios with ECOSPACE in order to explore the effect of spatial fisheries management on the food web and fisheries in the EIS. The first scenario (existing FRAs scenario) includes the existing spatial and temporal fishing restrictions in the area while the second (MPAs scenario) investigates the impact of the existing FRAs along with new permanent fishing restrictions for all fishing gears for the MPAs that have already been identified in the area, according to national and international legislations (Figure 5.38). For both scenarios the simulation period was 51 years (2000-2050) while temperature was kept constant from 2020 onwards.

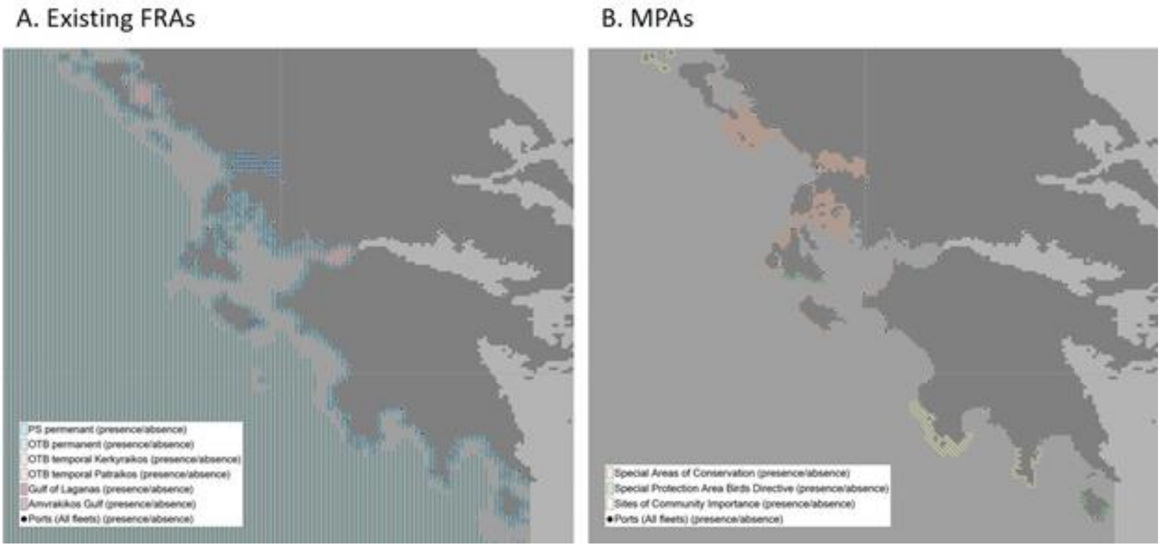


Figure 5.38. Existing Fishing Restricted Areas (FRAs)(A) and Marine Protected Areas (MPAs)(B) in the Eastern Ionian Sea (EIS).

Spatial distribution of fishing effort was predicted by the model for both scenarios. The results highlight that when all fishing activities are restricted inside MPAs, according to the second scenario, there is a displacement and an increase in fishing effort throughout the study area, rather than just the locations surrounding the MPAs (Figure 5.39). This effort is redistributed to the areas that had the highest fishing effort in the first scenario, such as the sea surrounding Corfu island and the shallower waters of Patraikos Gulf.

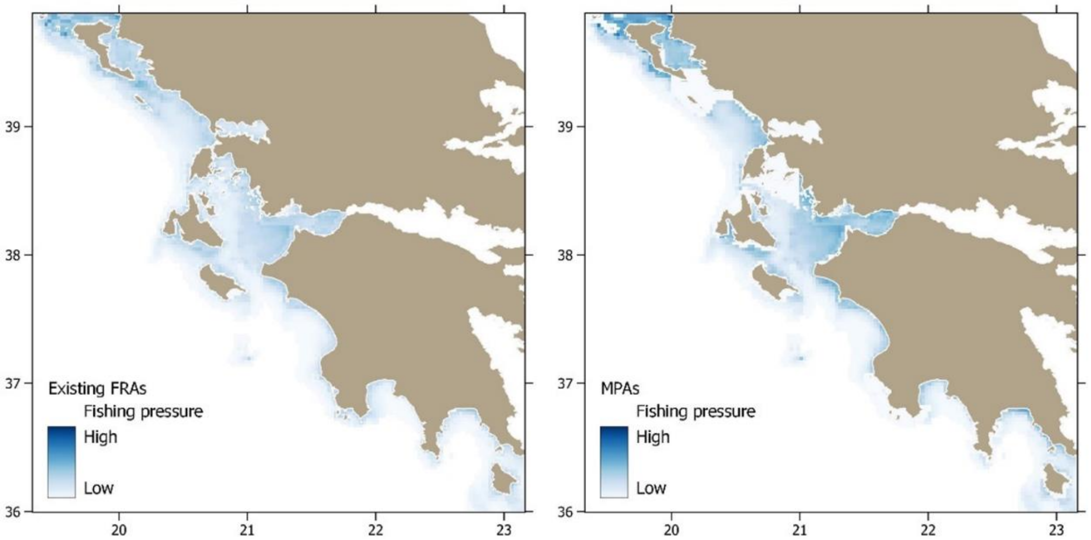


Figure 5.39. Spatial distribution of total fishing effort (FE) in the Eastern Ionian Sea after 50 years of simulations with ECOSPACE.

The first scenario corresponds to the image on the left and the second to the image on right.

We estimated total biomass and total catch values and the ratios of biomass to catch for all FGs, fish FGs, commercial species and IUCN Red List species, according to Table 5.1 (paragraph 5.4). Interestingly, both biomass and catches of all living FGs (0.2% and 14.3%, respectively) and fishes (11.5% and 14.5%, respectively) decreased with the fishing restrictions in MPAs in relation to the current state (Fig. 5.40). However, the second scenario produced higher values of biomass/catch ratios for all FGs (16.4%), fish species (3.5%), and IUCN Red List species (16.5%) and lower for commercial species (12.8%), in relation to the first. Concerning biodiversity, very small differences were observed between the two scenarios for Shannon' s Index regardless if it was estimated for the entire community or only for fishes, with H' values being slightly higher in the MPAs fishing restriction scenario (second scenario) than the first (current FRAs). These results suggest that the proposed fishing closures principally benefit high trophic level species (e.g. PET species), whereas commercial species seem to be affected negatively possibly due to complex trophic forcing and cascades propagating down the food web. Concerning biodiversity, the slight increase in Shannon's Index in the second scenario seems to be associated with an increase in evenness rather than biomass.

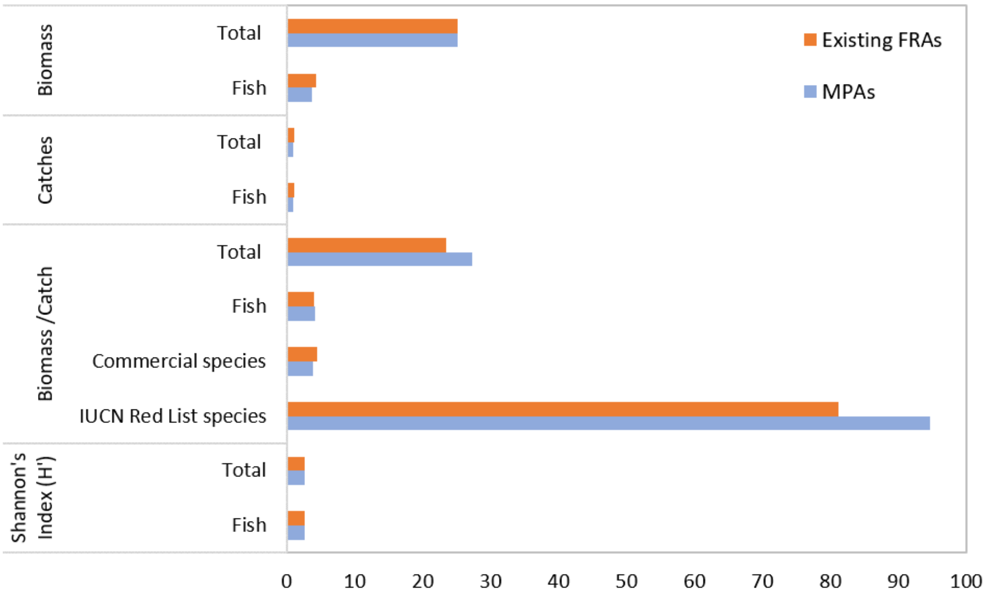


Figure 5.40. Biomass and catch related ecological indicators estimated with ECOSPACE model outputs for the Eastern Ionian Sea for the two scenarios.

Red mullet (*Mullus barbatus*), hake (*Merluccius merluccius*) and deep water rose shrimp (*Parapenaeus longirostris*) are species of high commercial importance in EIS in terms of both volume and landings (Kavadas et al., 2013). Our results showed that fishing closures led to an important decrease in total catches of red mullet (35%), a less severe decline was observed in hake catches (3%) while deep water rose shrimp catches slightly increased (2%). Among the three species, *M. barbatus* catches were negatively impacted throughout the study area by the fishing closures in the MPAs. Conversely, the effect of MPA fishing closures on *M. merluccius* and *P. longirostris* catches was positive in coastal waters and in the areas adjacent or close to the MPAs (Fig. 5.41).

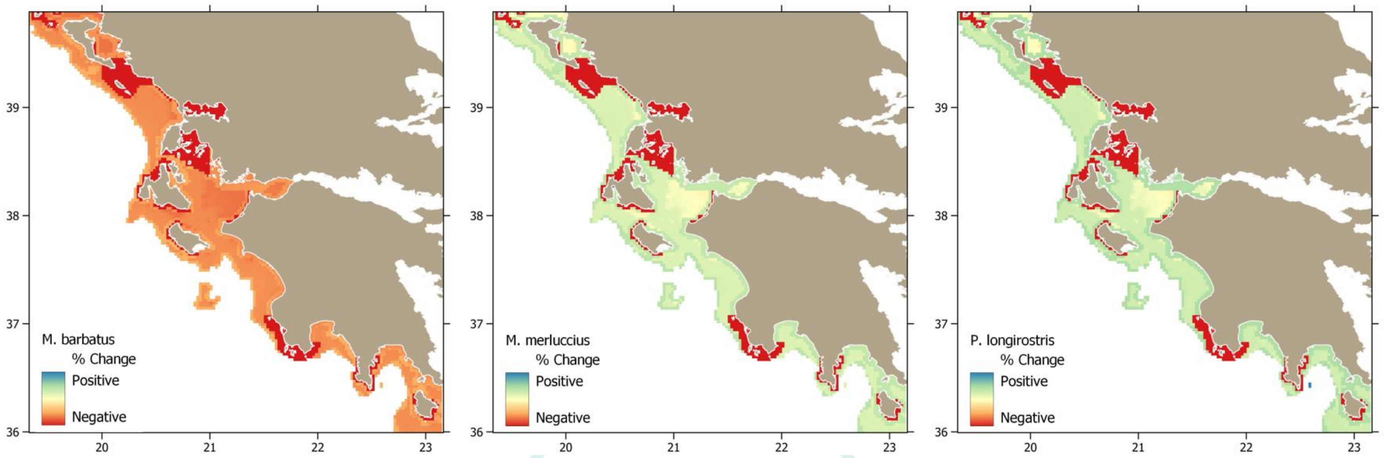


Figure 5.41. Relative change (%) in total landings for red mullet (Mullus barbatus), hake (Merluccius merluccius) and deep water rose shrimp (Parapenaeus longirostris) between the two scenarios according to the Eastern Ionian Sea ECOSPACE model.

Considering the bioeconomic impact of the exclusion of fishing activities from the MPAs, the model predicted that the redistribution of fishing pressure triggered a decrease in total catch (14.4%) and value (15.2%) for all the fleets while the decline in costs was minor (0.65%). The decreases in value may be related with a decline in stocks that drive the fishery (e.g., *M. barbatus*) or indicate a loss of profitable catches that could be associated with the spatial closures as the redistribution of fishing effort forces fleets to fish in areas with higher competition. Our results suggest that the MPA fishing closure scenario may not allow fleets to remain economically sustainable.

The presented findings are preliminary results of the ECOSPACE model for the EIS that require cautious interpretation. Climate change was not accounted for in the present model while temperature responses of many FGs in our model are subject to uncertainty since the baseline information came from a general database (AQUAMAPS) which despite being comprehensive, refers to global distribution ranges and does not account for regional or sub regional preferences of species environmental response. These temperature related traits might have unforeseen consequences for ecosystem interactions and affect the outcome of simulations.

5.5.6 Agent-Based Model (ABM) for German fleets in southern North Sea

This study focused on the German fisheries in the southern North Sea, composed of the near-coastal beam trawl fleet catching shrimps (CSH); the beam trawl fleet catching the flatfishes sole and plaice (PLE & SOL); and the otter board fleet catching plaice and Nephrops (OTB). Vessels using beam trawls are also able to use electric pulse trawls, although, in reality the latter were recently banned by the EU. We allowed pulse trawls in our model, because they are included in historical data (2012-2019) we used for model initialization. Apart from target species and spatial catch grounds, these fisheries differ from each other with regard to their socio-economic settings. Brown shrimp (CSH) fishery vessels are mostly owned by smaller family businesses, whereas trawlers for plaice and sole (PLE and SOL) are associated with larger companies. Our objective was to build an agent-based model (ABM) simulating the spatio-temporal dynamics of the three German fleets active in the southern North Sea. All the included fleets use bottom trawls, which is why we ignore fishing restrictions for longlines and gillnets as they are defined in this deliverable (see section 3.5)

While the above described fleets are static and are used to cluster agents into three groups with similar behavioral motivations, agents decide dynamically to engage into different métiers whenever they go fishing. Métiers are a combination of gear and target species and depending on their technical vessel characteristics and quota availabilities, every agent has a different pool of potential métiers to choose from. At each time step (every day), agents decide whether to go fishing (unless they are already on a fishing trip), and in what fishing métier to engage. External factors, such as sea wave height, fish prices and fuel prices influence the fishers’ decisions. In addition, we included a complex human decision-making framework, namely the Consumat approach, in which agents’ behavioral strategy is determined by their levels of satisfaction and uncertainty (Jager et al., 2000; Jager and Janssen, 2012). In our model, each agent has three satisfactions (personal, social, and existence) and two uncertainties (social and existence) that each stand for different behavioral motivations. We covered the economic aspect of decision-making that is usually covered in bioeconomic models, but also habitual and social (i.e. involving a social networks) aspects. As such, we modelled fisher’s decision-making by taking more into account than pure profit maximization, a phenomenon that is often observed when analyzing the behavior of small-scale fishers (Boonstra and Hentati-Sundberg, 2016; Christensen and Raakjær, 2006; Schadeberg et al., 2021). Depending on whether agents are satisfied/unsatisfied or certain/uncertain, they will engage in one out of four strategies that vary in complexity and social engagement. In general, satisfied agents engage in simpler strategies (e.g. repeating their last métier choice), whereas unsatisfied agents choose more complex strategies (e.g. evaluating several métier options). Uncertain agents engage in more social strategies (e.g. evaluating options of other fishers) and certain agents in more individual strategies (e.g. repeating their last métier option).

We used the described agent-based model to assess the impact of two scenarios of spatial fishing closures in the southern North Sea. In the first scenario, designated marine protected areas (MPAs) were closed to fishing based on hypothetical habitat and species protections as described in this deliverable (see section 3.5). In the second scenario, potential future offshore wind farms (OWFs) were closed to fishing in addition to no-take zone (NTZ). To create the OWF scenario, we used spatial polygons that were commercially purchased from 4COffshore (www.4coffshore.com, accessed 20.04.2022). In all scenarios, we included the plaice box which is a spatial fisheries management measure that prohibits fishing activity of beam trawlers with an engine size larger than 221kW. We compared both scenarios to a baseline that involved averaged market prices and environmental variables and present fishing closures (Figure 5.40).

Fishing effort decreased in both scenarios for every métier we included in the agent-based model (Figure 5.43). As expected, the scenario with No-Take Zone and Offshore Windmill Farms closed for fishing had a stronger impact than the scenario with only NTZs closed. There was not a single métier with a gain of fishing effort in either scenario, meaning that fishing restrictions in both scenarios overlapped to a large extent with fishing grounds and switching to other métiers was not sufficient for compensating the negative effects. Fishers targeting shrimp (CSH) are by far the majority in the southern North Sea and also represent the métier with the largest losses in terms of relative and total fishing effort (up to 50% loss; Figure 5.43). This is due to the coastal NTZ that covers the largest part of the CSH fishing grounds, whereas vessels using Otter Bottom Trawl (OTB) and targeting fishing grounds with plaice and sole are further offshore with more areas remaining available to fishing in the scenarios.

With this agent-based model, we cannot conclude whether a decrease in fishing effort can directly be translated into a lower fleet size. However, it is possible that such a severe reduction of 50% lowered fishing effort entails multiple fishers quitting fishing. If this capacity reduction happens, it would affect coastal communities and landing port infrastructures.

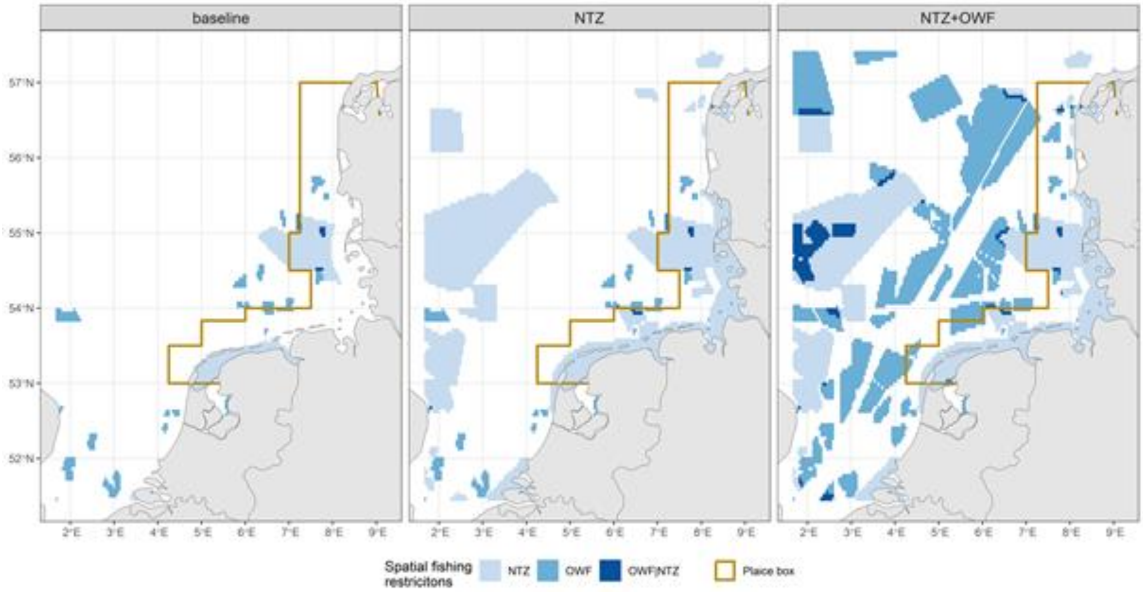


Figure 5.42. Maps depict the part of the North Sea that is included as study area in the agent-based model. Polygons show spatial fishing restriction in the baseline and two scenarios for potential future no-take zones (NTZ) and offshore wind farms (OWFs). Note that we assume NTZs and OWFs to completely exclude fishing with bottom trawl, whereas the plaice box only bans the activity of beam trawlers with an engine power larger than 221kW.

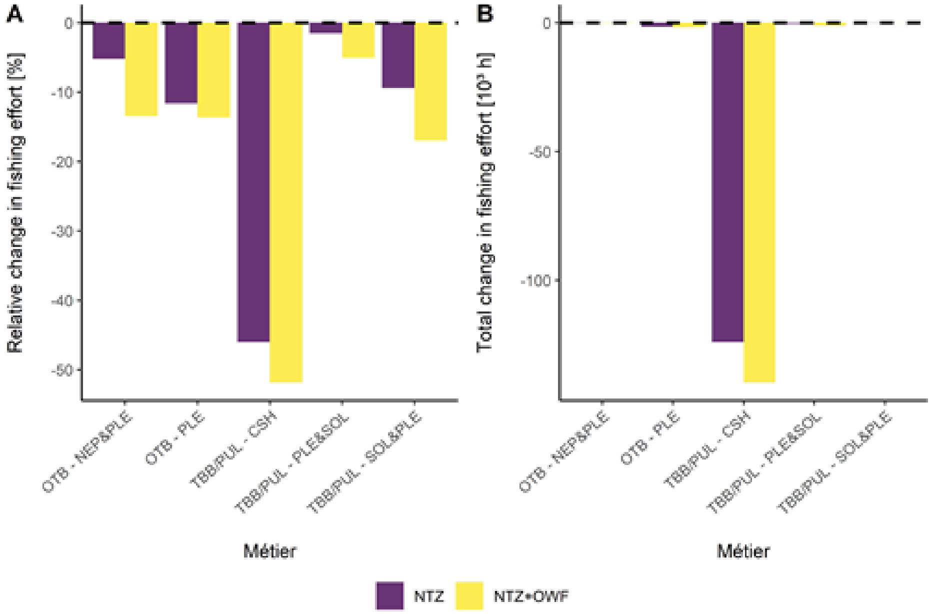


Figure 5.43. Relative (A) and total (B) change in fishing effort metier in the two scenarios for potential spatial fishing closures. Métiers depict a combination of gears and target species. OTB: otter bottom trawl; TBB: beam trawl; PUL: electric pulse trawl; NEP: Nephrops; PLE: plaice; SOL: sole; CSH: common shrimp.

Spatial fishing restrictions led to the displacement of effort into the remaining areas available to fishing (Figure 5.44). Even though the total amount of fishing effort decreased, it intensified in the open areas, which potentially might add more pressure on habitats and ecological communities overall.

Our Agent-Based Model has limited ecological details and simulates resource depletion as a factor that reduces catch per unit effort (CPUE) in spatial patches for every time it was fished by a vessel. This factor recovers at the end of every day simulating the resource recovery. We assume that the depletion and recovery factors are homogeneous across space, gear, and species, which is a strong simplification. The question remains whether the strong reduction of fishing effort in the many closed areas are able to sustain the few areas where fishing effort intensified through a so-called spill-over effect. Models with a stronger focus on ecological interactions are necessary to answer this question. In general, fishing effort also shifted further offshore, because of near-shore NTZ, which is especially the case for fishers targeting brown shrimp (CSH). This led to extended steaming times per fishing trip (Figure 5.45), which in turn increased fuel use and fishing costs. Rising costs lowered profits and therefore also the willingness of more rational agents to go fishing. Despite including behavioral motivations beyond profit maximization in our ABM, it still plays a role in their decision-making.

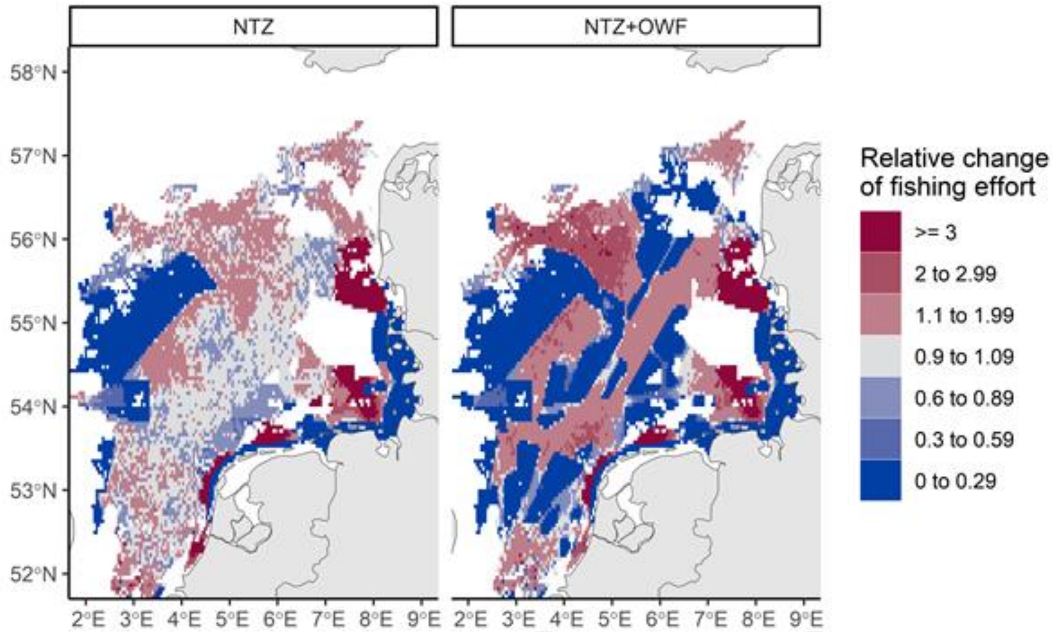


Figure 5.44. Relative change of spatial fishing (ratio of scenario / baseline) effort in the NTZ and NTZ+OWF scenarios in comparison to the baseline.

By applying our ABM, we gained insight into the effect of potential future fishing restriction on German fisheries in the southern North Sea. The model predicts that the spatial restriction scenarios would reduce fishing effort by up to 50%. This reduction was a combined effect of closed areas overlapping with catch grounds, higher local depletions in areas with intensifying fishing effort, and raised costs due to longer steaming distances.

We created scenarios by changing only a single feature, spatial fishing restrictions, and ignored other variables that might change in the future, such as population dynamics, climate change effects on catch rates, and market price dynamics. Moreover, agents could not change technical characteristics of their vessels or obtain new fishing quotas. Allowing for these adaptations in a next version of the ABM would make more realistic simulation by allowing more flexibility for the agents to adapt better to closed areas. In addition, more elaborate scenarios that include co-location strategies of fisheries and OWFs should be investigated. Changing more than variable, i.e. banning pulse trawls, in scenarios would be one step towards more realistic scenarios. Currently, co-location options of passive fishing gears in OWFs are explored and could be included in scenarios (Stelzenmüller et al., 2021), albeit practical issues to organise such co-location in practice need to be tackled first (Van Hoey et al. 2022).

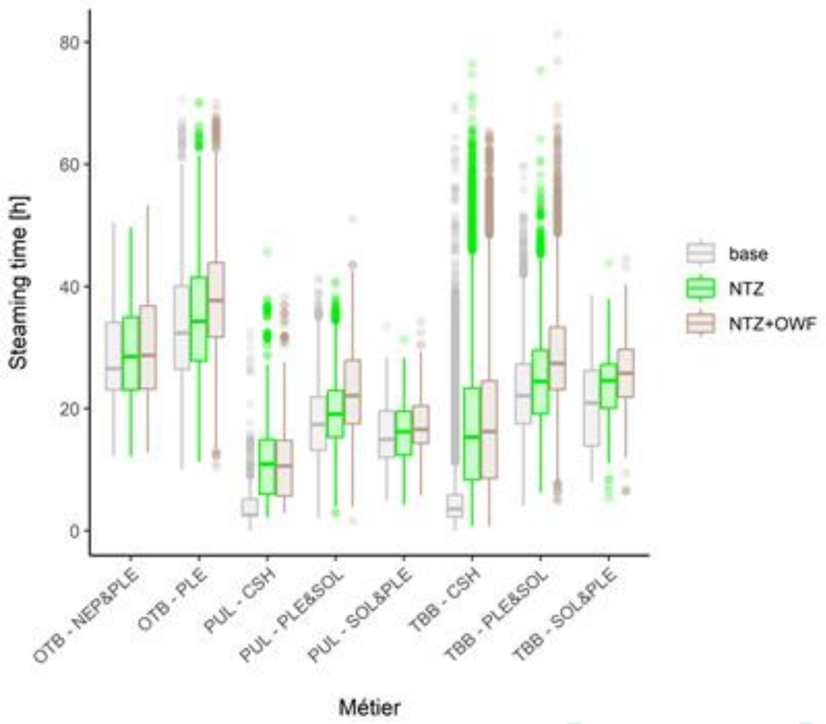


Figure 5.45. Change in steaming time per fishing trip and métier for the baseline and the two scenarios.

5.5.7OSMOSE application to North Sea

The OSMOSE model is used in SEAwise WP4, and described in detail in Van de Wolfshaar et al. (2021). We reused the model and included improvements made in the present study that concerns the description of effort and catchability, and the handling of spatial restrictions. OSMOSE is a size-based individual based model, where super-individuals are followed in time and space. Predation interactions are based on size of predator and prey. The current model includes 14 fish species: cod (*Gadus morhua*), dab (*Limanda limanda*), grey gurnard (*Eutrigla gurnardus*), haddock (*Melanogrammus aeglefinus*), herring (*Clupea harengus*), Norway pout (*Trisopterus esmarkii*), plaice (*Pleuronectes platessa*), saithe (*Pollachius virens*), sandeel (*Ammodytes sp.*), sole (*Solea solea*), spiny dogfish (*Squalus acanthias*), sprat (*Sprattus sprattus*), thornback ray (*Raja clavata*), and whiting (*Merlangius merlangus*).

The model domain used was Lat[51,61.5] Lon[-4,9] (Figure 5.46), and grid cell size is based on 1/9th ICES rectangle (20km longitude and 18.5km latitude). This spatial domain represents ICES areas 27.4.b, 27.4.c and part of 27.4.a. Biomass of phytoplankton, zooplankton and macro-invertebrates are used and were obtained from results from the biogeochemical ERSEM model (Butenschön et al. 2016), resulting from the CERES project, and applied to all simulations. The ERSEM results were converted to the OSMOSE grid and interpolated to an annual 24 time steps. For each run the year 2018 was used and repeated.

OSMOSE has been updated following the work of Van de Wolfshaar et al. (2021), to now include 14-metier classifications instead of 4-broad fleet categorisations. Fishing effort and catch data from the FDI STECF database was taken for the years 2016 – 2020, and used to identify fishing activities (métiers) with a significant contribution (>5%) of the total species specific landings. 14-métiers were selected (Table 5.6). Only the species where historical landings exceeded the 5% threshold were made available to be caught by the relevant metier. This selection resulted in 88% of the total landings biomass of OSMOSE model species being represented.

Fishing is simulated using spatially and temporally explicit effort, and species specific catchability based on the size of the fish. Métier specific, spatial distribution of fishing effort (fishing days) were averaged for the period 2016 – 2020. The resolution of the available FDI data was 9-times coarser than the OSMOSE model resolution, corresponding grid cells evenly distributed the effort to match the finer OSMOSE resolution. Temporal effort is only available by quarter, the effort was distributed evenly across the corresponding period to fit the OSMOSE model's time step. Mesh size associated with each of the métiers was implemented as a parameter in the model. L_{50} values pertaining to the selectivity are derived using species-specific selection factor and slope values, obtained from literature.

OSMOSE was calibrated using a genetic algorithm-derived technique to optimise SSB and Landings outputs to ICES and STECF FDI database values respectively, taking an average for the years 2016-2020. Negative log-likelihood was used as an indicator of model fit. A spin-up time of 40-years was used to account for the lifespans of different species, and the final year of model output is used for analysis. The model is used in an equilibrium setting and not as a hindcast representing former biomass estimates. The data and methods used and the resulting parameter values are reported in Van de Wolfshaar et al. (2021).

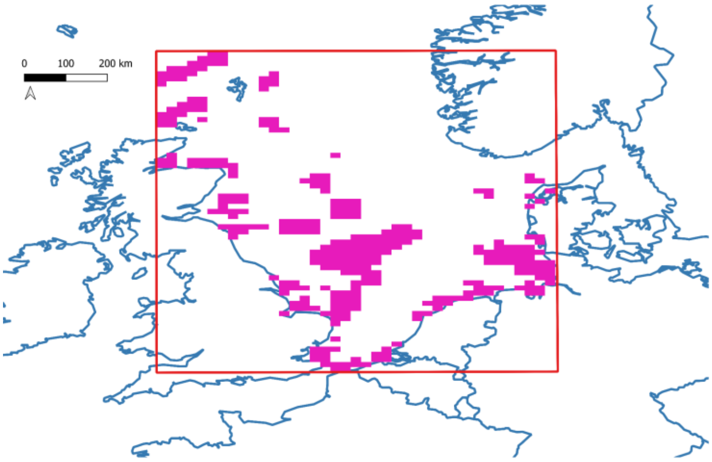


Figure 5.46. The North Sea coastline and the OSMOSE grid outline (red). In magenta are the grid cells representing no-fishing zones for bottom trawlers, obtained by rasterizing the MPA GIS shapefile of section 3.5.

Three scenarios are run; a baseline scenario without MPA's; an MPA scenario where effort is removed from MPA's and evenly redistributed across available fishing areas; and an MPA scenario where effort is removed from MPA's, as illustrated in Figure 5.47. The MPA scenarios are valid exclusively for the bottom trawling métiers (Table 5.6). The reduction in total area, based on the MPA's excluding bottom trawlers is 19.8%, resulting in an overall reduction of 16.4% in fishing days (Table 5.6). The effect of the MPA implementation differs between bottom trawling métiers, ranging from 5% to almost 45%. These differences highlight the importance of using a spatially explicit approach when dealing with area based management measures.

Table 5.6. Métiers selected in the current OSMOSE model with number of fishing days, reduced fishing days when implementing MPA spatial management scenarios for bottom trawlers, and the relative change in effort.

Metier	Fishing Days	Reduced Fishing Days	Effort Change (%)
OTB_DEF_100-119	6341.99	5144.72	18.88
OTB_DEF_16-31	447.03	404.10	9.60
OTB_DEF_70-99	3617.07	2675.15	26.04
OTB_DEF_Less16	1741.9	1250.40	28.22
OTB_DEF_more=120	14199.99	12572.05	11.46
OTB_SPF_16-31	290.9	235.96	18.89
OTM_SPF_16-31_0_0	1000.47	1000.47	0.00
OTM_SPF_32-69_0_0	1360.33	1360.33	0.00
PTB_DEF_more=120	4172.21	3957.87	5.14
PTB_DEF_more=120FDF	1308.38	1227.47	6.18
SSC_DEF_>=120_0_0	2934.02	2934.02	0.00
TBB_DEF_100-119	1195	660.40	44.74
TBB_DEF_70-99	19526.96	14934.41	23.52
TBB_DEF_more=120	3289.46	2996.71	8.90
Total	61425.71	51354.06	16.40

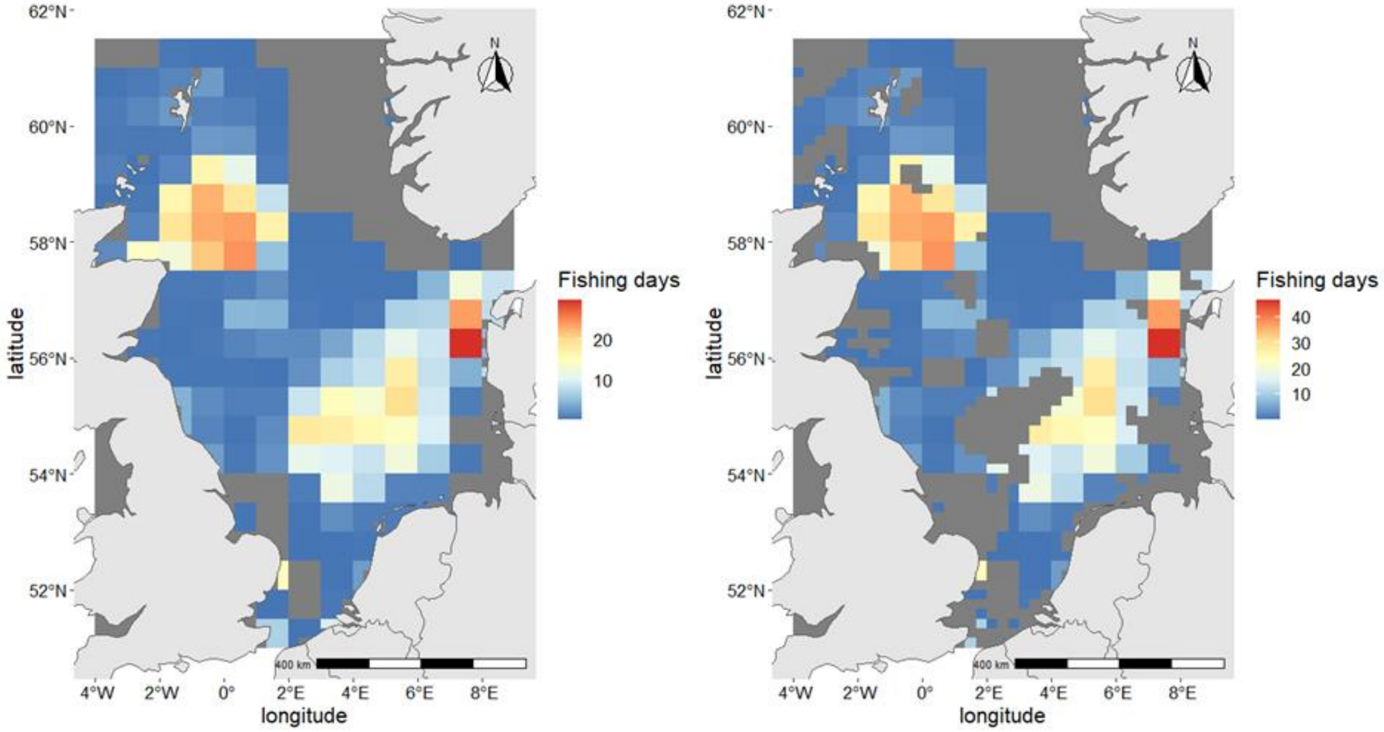


Figure 5.47. Illustration of the spatial effort distribution showing the OTB_DEF_100-119 metier derived by taking the average number of annual fishing days for 2016 - 2020 from the FDI STECF database. Grid resolution is inline with the OSMOSE model, 1/9th ICES rectangle (20km longitude and 18.5km latitude). Baseline effort scenario (left), effort redistribution scenario (right), and effort reduction scenario can be seen by using the baseline scenario legend (left) with the redistribution scenario map (right).

Total biomass decreased with both MPA effort redistribution and effort reduction scenarios (Figure 5.48). This is driven by a relatively small increase in biomass of the demersal species, but a larger decrease in biomass of the pelagic species. Relative Biomass of Protected, Endangered and Threatened (PET) species increased for both scenarios, especially when effort was reduced. The relative proportion of mature fish increased for the food web, the demersals, and the pelagics, despite the latter showing a decrease in relative biomass for both MPA scenarios (Figure 5.48). This overall biomass decrease in OSMOSE can be explained by indirect food web interactions, i.e. increased predation mortality of juveniles as a result of increased demersal and PET predators. When redistributing bottom trawl effort, PET species see the greatest relative increase in proportion at maturity, whereas we observe almost no change when reducing effort. In combination with the increase in biomass of PET species, effort reduction increased the biomass of immature PET species, potentially due to a reduction in fishing mortality. This is further supported by the relative increase in typical length of PET species for both management scenarios (Figure 5.49). Demersal and pelagic groups see a much greater increase of relative typical length in an effort reduction scenario compared to effort redistribution. The relative change of the typical length of the food web shows an overall increase.

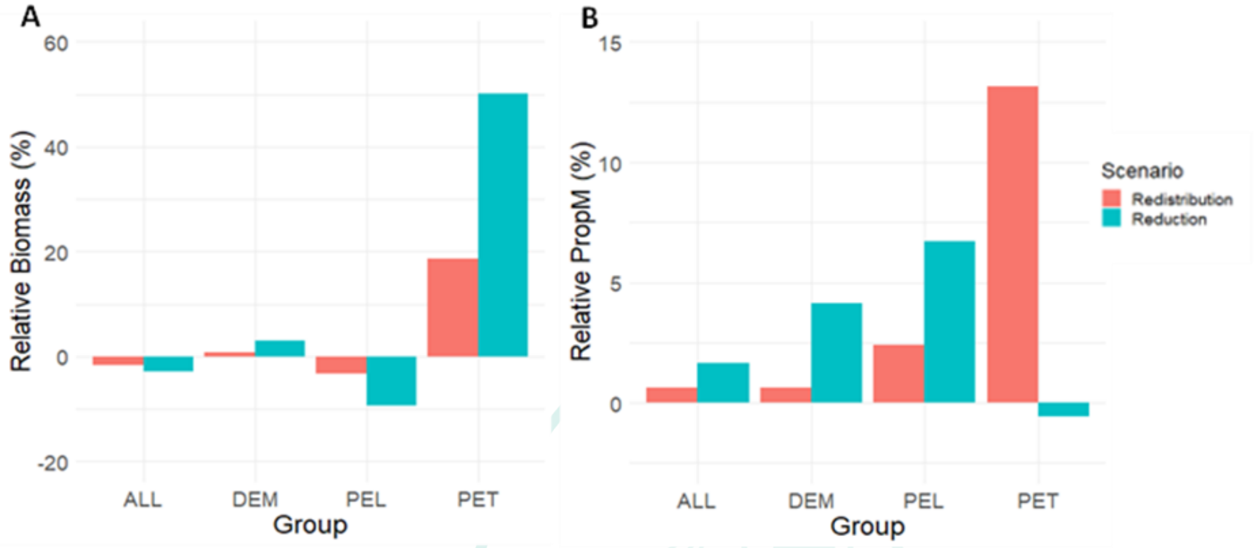


Figure 5.48. Values are obtained from the final year output of a 40-year OSMOSE run for each of the two scenarios; effort redistribution and effort reduction compared to the base scenario. Relative biomass (A) and relative proportion of mature individuals (B), for species groupings (All, Demersal, Pelagic, and PET).

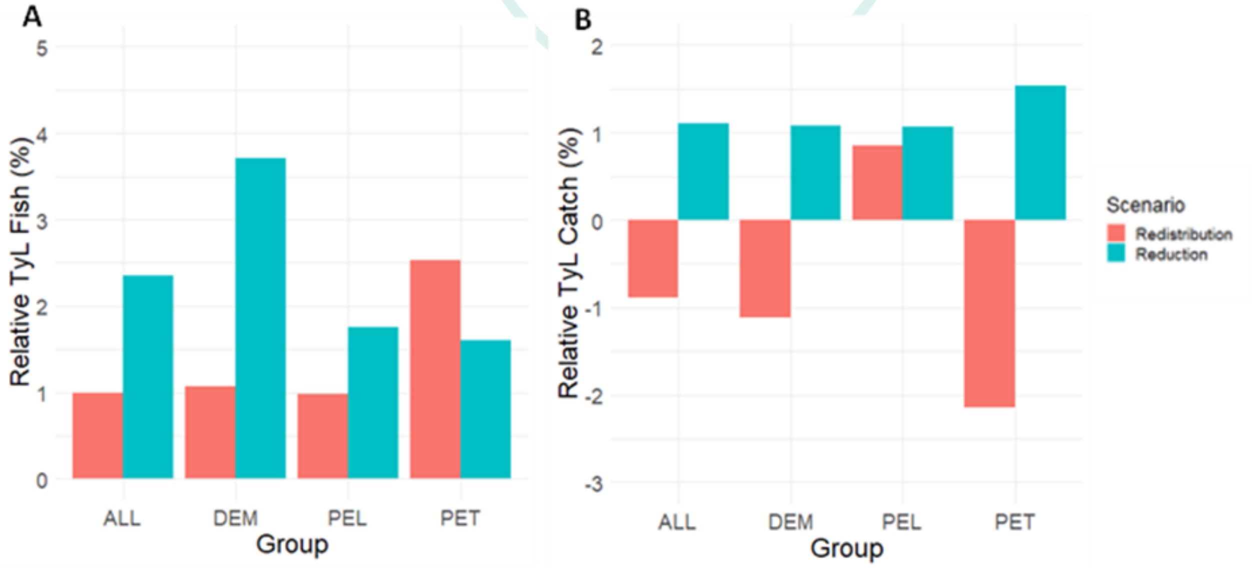


Figure 5.49. Values are obtained from the final year output of a 40-year OSMOSE run for each of the two scenarios; effort redistribution and effort reduction compared to the base scenario. Relative typical length of fish (A) and relative typical length of catch (under and over legal landing size) for species groupings (All, Demersal, Pelagic, and PET).

In OSMOSE, the catch above legal landing size increased for netters and trawlers, in both management scenarios, relative to the base scenario (Figure 5.50). This increase was much greater for the reduced effort scenario and despite a decrease in food web biomass. This corresponded with the increase in proportion of mature fish in the food web, because legal landing size and size at maturity are often similar, and as a result of increased biomass of target species (Figure 5.48). The increase in relative landings for trawlers in the effort redistribution scenario can be seen as a result of effort displacement to areas with higher target species densities. Netters also see an increase in the relative landings for both scenarios, despite a decrease in the pelagic group relative biomass. This can be explained by the fact that netter métiers were not subject to the effort restrictions of trawlers. Additionally, they are not limited to exclusively catching pelagic species. The change in catch of the netters is thus an indirect effect of changing the effort of the bottom trawlers and the resulting changes in the food web.

OSMOSE assumes that all catch below minimum landing size is taken out of the system, in line with the Landing Obligation. This is not the case for PET species which have a survivability exemption and are returned to the system following species and gear specific mortality. A clear decrease in the relative catch under the minimum legal landing size can be seen for netters and trawlers for the effort reduction scenario (Figure 5.50). The simulated decrease in catch under the minimum landing size is a reflection of the increase in OSMOSE of the size and proportion of mature fish in the food web. Redistributing trawl effort in the model showed a slight increase in relative catch under the minimum landing size, explained by the increase in spatially explicit fishing intensity. The relative typical length of catch, for PET and demersal groups, decreased for the redistribution scenario (Figure 5.49). This can again be explained by the relative increase in fishing intensity across the available area, in line with the results of Figure 5.50. This is not the case for the pelagic species where the typical length increases (Figure 5.49), due to spatial restrictions not being enforced, and food web effects. The effort reduction scenario increased the typical length in catches for all species groupings. Although the typical length of PET species increased in the model under an effort reduction scenario (Figure 5.49), interestingly the typical length of catch shows a relatively large decrease (Figure 5.49). These results, when combined with the reduced relative proportion of mature individuals for the PET group (Figure 5.48), show how sensitive PET species are to fishing pressure at early life stages.

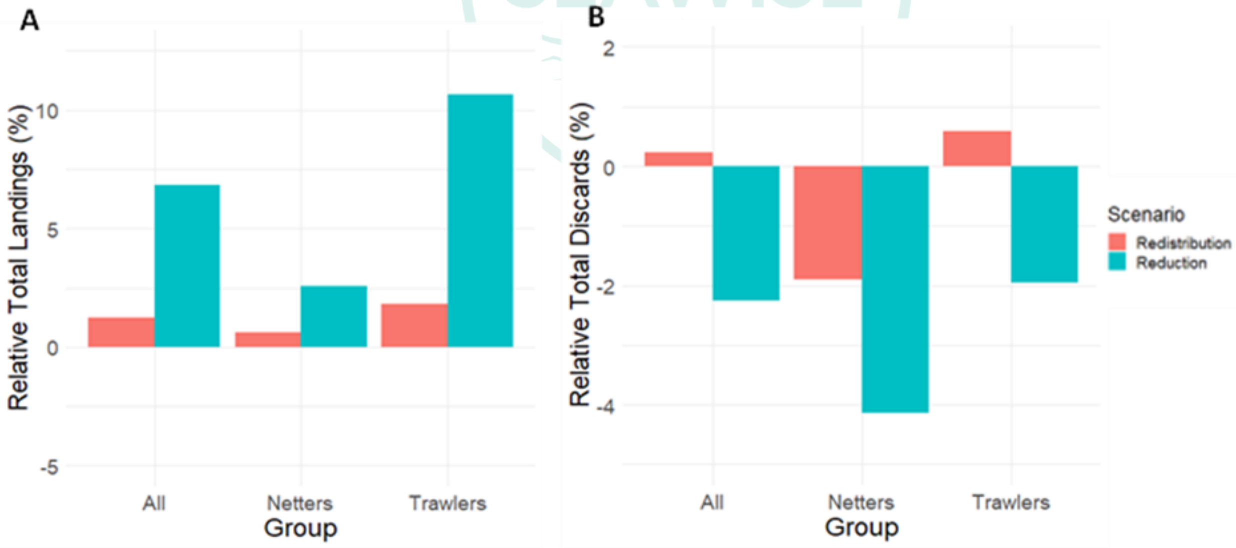


Figure 5.50. Values are obtained from the final year output of a 40-year OSMOSE run for each of the two scenarios; effort redistribution and effort reduction compared to the base scenario. Relative total landings (A) and relative total discards (catch under legal landing size) (B), for metier groupings (All, Netters, and Trawlers).

5.5.8 Spatial BEMTOOL for Central Med, Adriatic and Western Ionian Seas

The Adriatic and western Ionian Seas (GFCM Geographical Sub Areas - GSAs 17, 18 and 19) case study used BEMTOOL for modeling mixed fisheries in SEAwise. BEMTOOL is an integrated bioeconomic modeling tool that follows a multi-fleet and multiple species approach, simulating the effects of management scenarios on stocks and fisheries (e.g. STECF, 2019; 2020; 2021; 2022a and 2022b; Russo, Bitetto et al., 2017; Rossetto et al., 2015). The effects in mixed fisheries are measured by a suite of indicators with associated uncertainty. The model currently includes 24 fleet segments (Table 5.7) and has been expanded in respect to the model used in SEAwise WP6 to also include rapido trawlers operating in GSA 17 (TBB).

Table 5.7. Fleet segment modeled in BEMTOOL model in Adriatic and Western Ionian Seas by GSA.

GSA	**17**	**18**	**19**
Fleet segments modelled	ITA_17_PGP_0012	ALB_18_DTS_1224	ITA_19_HOK_0624
	HRV_17_DFN_0612	ITA_18_DTS_0612	ITA_19_PGP_0006
	HRV_17_DTS_0612	ITA_18_DTS_1218	ITA_19_PGP_0612
	HRV_17_DTS_1218	ITA_18_DTS_1840	ITA_19_PGP_1218
	HRV_17_DTS_1840	ITA_18_HOK_1218	ITA_19_DTS_1218
	ITA_17_DTS_0612	ITA_18_PGP_0012	ITA_19_DTS_1824
	ITA_17_DTS_1218	MNE_18_DTS_0624	
	ITA_17_DTS_1840		
	ITA_17_TBB_VL1218		
	ITA_17_TBB_VL1840		
	SVN_17_DTS_1218		

The model simulates explicitly seven stocks: the five included in the multiannual management plan (MAP) in the Adriatic Sea (Recommendation GFCM/45/2022/8, stemming from Recommendation GFCM/43/2019/5) and two key stocks of GSA 19. In the GSA19 a MAP for demersal stocks is not yet in place. However, considering the possible connectivity of the populations in the whole area (Spedicato et al. 2022) European hake (HKE) and red mullet (MUT) in GSA19 were also included in this analysis. The BEMTOOL model was expanded to explicitly model also common Sole and Norway lobster in GSA 17.

The stocks included are:

- European hake in GSAs 17-18 (HKE17-18);
- European hake in GSA 19 (HKE19);
- Red mullet in GSAs 17-18 (MUT17-18);
- Red mullet in GSA 19 (MUT19);
- Deep-water rose shrimp in GSAs 17-18-19 (DPS17-18-19);
- Norway lobster in GSA 17 (NEP17);
- Common sole in GSA 17 (SOL17).

Giant red shrimp and blue and red shrimp in GSAs 18-19 will be also included as target stocks of the multiannual management plan for sustainable trawl fisheries targeting giant red shrimp and blue and red shrimp in the Ionian Sea (Recommendation GFCM/45/2022/6).

The considered fleets include both active and passive demersal gears operated by fleet segments that rely on, and influence some or all the stocks mentioned above. These fleets encompass all small and medium scale fisheries in five different Countries (Italy, Croatia, Montenegro, Albania, Slovenia).

The model will be further improved in Deliverable 5.6, including the metier information to simulate possible effort re-allocation between the deep and the demersal fishing activity for trawlers. For this aim the socio-economic parameterization has been enhanced in task 2.2, allowing to assume a different cost structure by métier and applying the methodology in Bitetto et al. (2022).

During the STECF Experts Working Groups for Western Med MAP (e.g. STECF, 2019; 2020; 2021a and 2021b; 2022) scenarios complementing spatial closure with other management measures have been simulated, using implicit assumptions, as regards the spatial dimension in BEMTOOL, i.e. by modifying the fleet selectivity. The model is informed about the stock status through the last stock assessments and about the fleet configuration by the socio-economic and transversal data obtained by the SEAwise data call. Under SEAwise project, the development of the spatial component of BEMTOOL is currently in progress. The spatial BEMTOOL will be applied to contribute to the SEAwise Deliverable 5.6. The new spatial component is aimed at modeling the spatial distribution of the target stocks and of the fishing fleets considered in the model, to evaluate explicitly the impact of spatial management measures through relevant biological and economic indicators.

Methodological elements for the spatial parameterization

The spatial layer utilized to condition the model in the hindcasting phase about the spatial allocation of the effort is derived for all the Demersal Trawlers & Seiners (DTS) fleet segments in Table 5.7 above 12 m of length crossing the Automatic Identifier System (AIS) information (in terms of hours at sea) in Global Fishing Watch with the GFCM Fleet Register, associating to each vessel ID the main gear, the registration port and the vessel length. The effort layer has a 1 km resolution.

The model is informed with the spatial distribution of the target stocks through the species distribution maps from SEAwise D5.2, including, where available, spatial distributions of sensitive life stages (e.g., juvenile distribution of

European hake and deep-water rose shrimp) (Figure 5.51). For the stocks for which distribution modeling is not available, the MEDITS spatial distribution of the abundance indices is used.

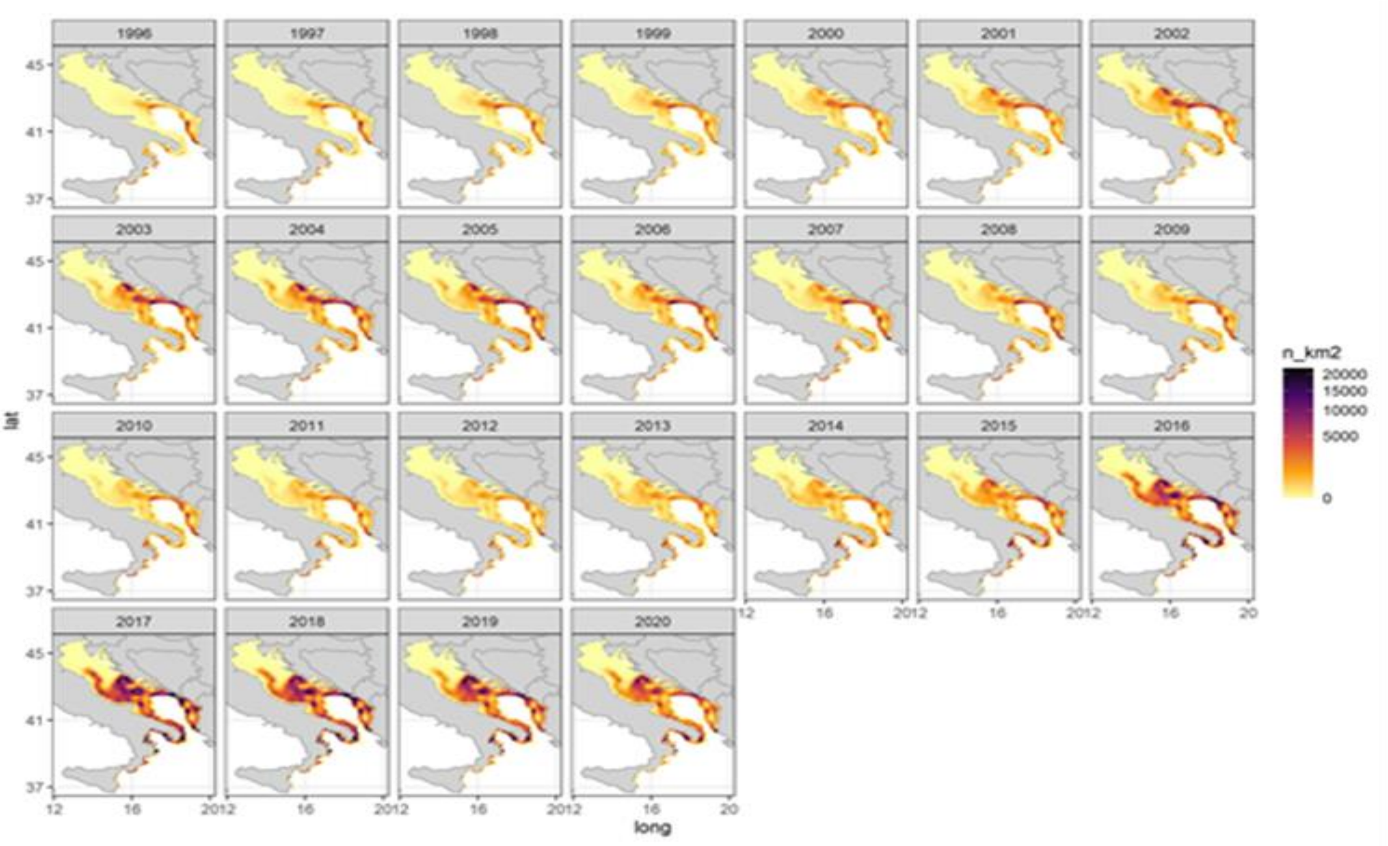


Figure 5.51. Example of species distribution layer (P. longirostris in GSAs 17-18-19) from SEAwise task 5.2.

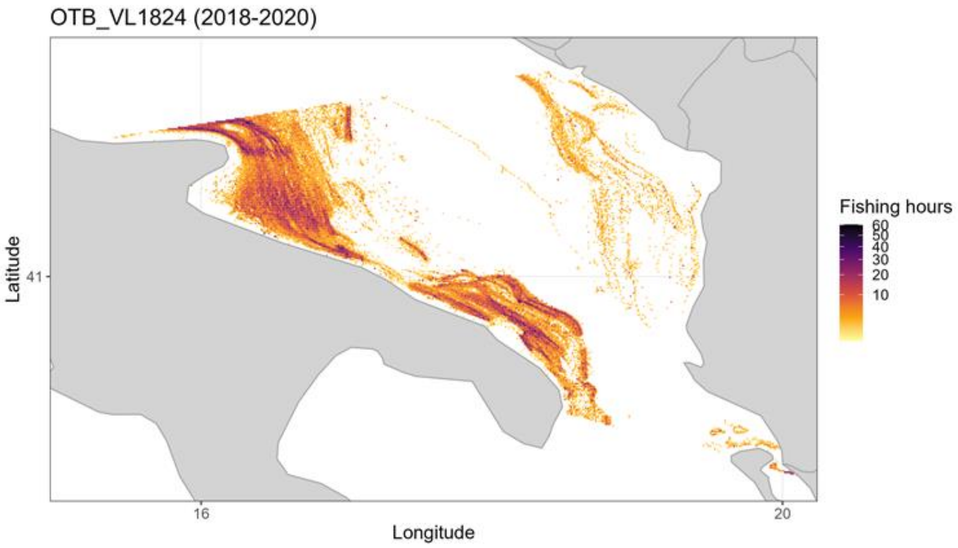


Figure 5.52. Example of effort distribution layer (OTB VL1824 in GSA 18, all ports).

In the upcoming SEAwise D.5.6, the model will be also informed about the position and the extension of existing spatial management areas (e.g. Jabuka/Pomo Pit, other FRAs as Bari Canyon, etc.) and Vulnerable Marine Ecosystems (VMEs) (e.g. in deep waters of GSA18, south Adriatic).

In the present study, an exploration of the effort data for the main ports in the study area has been conducted to identify the fishing grounds more visited by the fishers and get insights on fishing strategies. Specifically, for each registration port, a spatially-constrained clustering technique was applied implementing a regionalization with dynamically constrained agglomerative clustering and partitioning (redcap) by different methods, based on three agglomerative clustering approaches (single linkage, average linkage and the complete linkage, constrained with spatial contiguity in two different ways (i.e. the first-order constraining and the full-order constraining) (Guo et al., 2008). Four methods were explored: full-order constrained single linkage clustering (full single); first-order constrained single linkage clustering (single); first-order constrained average linkage clustering (average); first-order constrained complete linkage clustering (complete) (Guo et al., 2008 for details). The quality and efficiency of the regionalization methods across the number of clusters have been evaluated following Guo et al. (2008), through: 1) the overall heterogeneity, defined as the sum of squared deviations from the mean (Assunçao et al. 2006), 2) the balance of region size (e.g. number of observations in each region) and 3) internal variation within each region (standard deviation).

Once the more visited fishing grounds were identified for each port, a metier group, i.e. (1) coastal, or (2) deep-water trawling, was associated according to the prevalent depth range of the fishing ground. The monitored vessels were classified according to the frequency of visits in each fishing ground, into two groups, following the fishing strategies identified in SEAwise D2.5 for Central Med case study:

- Specialists, characterized by habitual patterns of fishing practices: same target species, one gear and one metier throughout the year, consistent annual fishing pattern from year to year;
- Switcher, prone to modify the fishing strategy: changing the gear, changing métier (from OTB_DWS, deep-water trawling, to OTB_DEM, coastal trawling), changing fishing grounds, moving far from the port.

The results of the spatial cluster analysis, before being consolidated, are compared with two additional sources of information: questionnaires (from Task 2.3) and biological sampling data. In Figure 5.53 there is an example of the results obtained with spatial cluster analysis for trawlers between 18 and 24 m length registered in Molfetta port. In Figure 5.54 the overall heterogeneity and the standard deviation versus the region size are reported, showing agreement among the methods when assuming 2 clusters, corresponding to coastal and deep-water fishing grounds respectively.

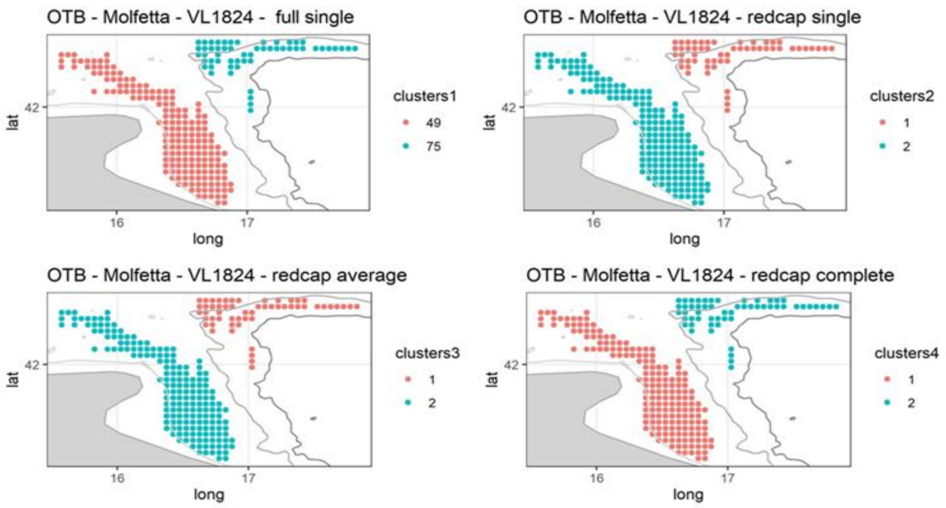


Figure 5.53. Example of spatial cluster analysis for trawlers between 18 and 24 m length registered in Molfetta port. Redcap stands for Regionalization with dynamically constrained agglomerative clustering and partitioning; full single: Full-order constrained single linkage clustering, single: first-order constrained single linkage clustering; average: First-order constrained average linkage clustering; complete: first-order constrained complete linkage clustering.

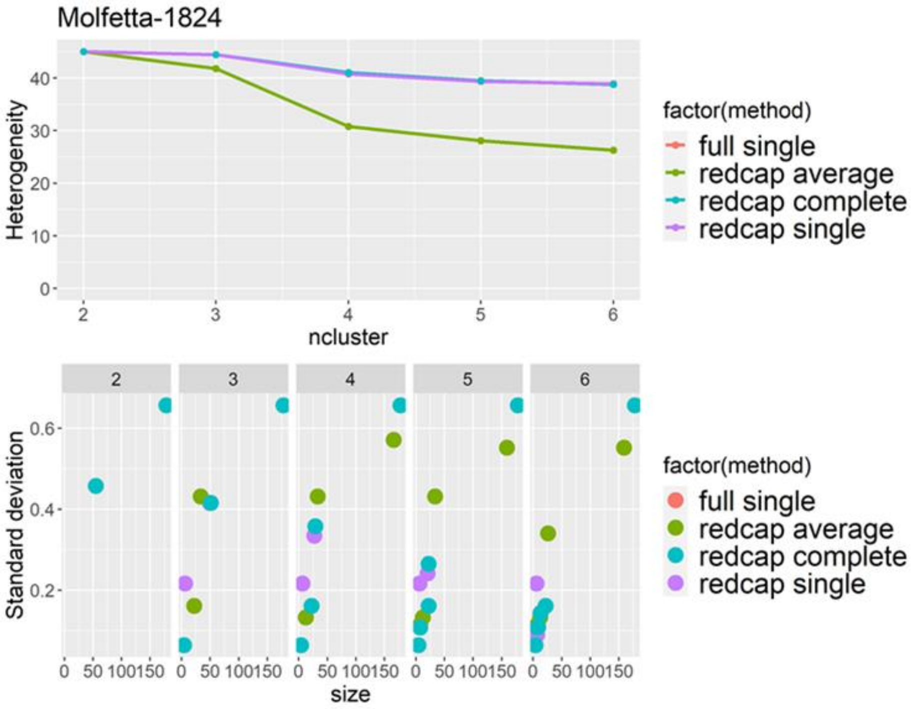


Figure 5.54. Example of spatial cluster analysis for trawlers between 18 and 24 m length registered in Molfetta port. Heterogeneity, size and internal variation of the clusters.

In the example, the vessels registered in Molfetta between 18 and 24 m were split into two quite balanced groups, the first more used to fish on the coastal and closer fishing ground and the second one splitting the fishing activity between both fishing grounds (the coastal and the deep-water one).

When the spatial clustering was applied to all main ports in GSAs 17-18 and 19, the fleet segments modeled in BEMTOOL were further subdivided through the association Registration port-vessel length class-fishing ground - métier (Figure 5.55).

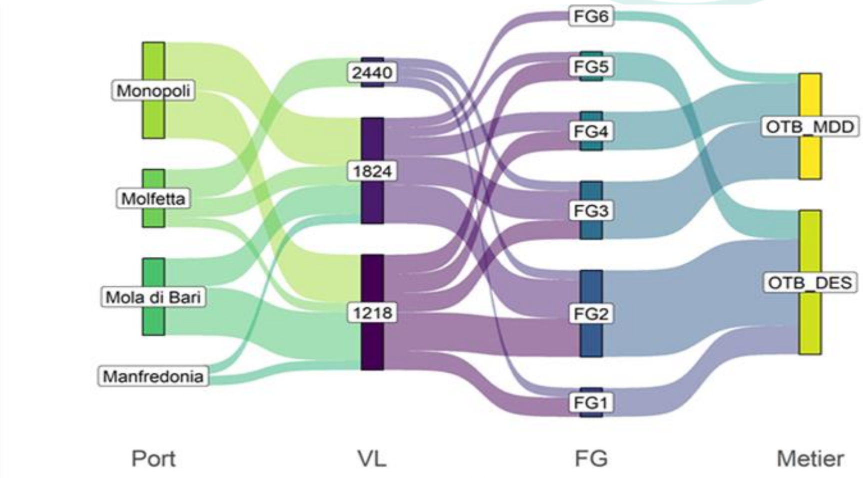


Figure 5.55. Combinations of "port-vessel registration" - "length class" - "fishing ground" – "métier" used to subdivide the fleet segments in BEMTOOL spatial components.

For the forecast phase the fleet will be further segmented by port, preferred fishing ground(s) and fishing strategy. In particular the fishing strategy type will be used to drive the re-allocation of the effort according to management measures (e.g. catch limits on specific target assemblage, as red shrimps in Ionian Sea; FRAs, etc.). Specifically, the specialists’ effort distribution will be based on the minimization of an objective function based on the distance of the cells from the registration port; on the other hand, the switcher effort distribution will be determined by the model maximizing the profit.

BEMTOOL will also integrate the outcomes from SEAwise Task 3.2, simulating changes in stock productivity due to climate change. The new spatial component will be used to run scenarios based on selectivity changes and technical measures or catch limit and effort management, following the key elements of GFCM MAPs in the study areas, under different climate scenarios. This work is ongoing and will be completed for the coming deliverable D5.6.

6. Discussion

6.1 Potential fishable areas

The marine environment and the fisheries that depend on it are facing numerous challenges, as noted by Bastardie et al. (2021). These challenges can potentially limit the space available for fishing. Factors external to fishing, such as habitat degradation (eutrophication, acidification, warming waters, invasive species, etc.), as well as the fishing practices themselves, can impact the suitability for future exploitation. To address the negative impact of fishing, conservation measures have been put in place to limit certain fishing techniques and areas. Our research suggests that while these restrictions may reduce fishing opportunities, it is possible to compensate for some of the missing opportunities by redirecting fishing efforts to adjacent locations in the short term. Redirecting fishing efforts is likely to result in changes to the types of fish caught, catch composition, and the populations harvested, which can impact selectivity. Additionally, there may be changes in operating expenses or an increased fishing effort needed to break even, or on the contrary some gain when less effort is actually needed. It is important to investigate these potential impacts using the best available scientific methods.

It is important to mention that the static approach used has been applied to the entire fleet operating in the Northeast Atlantic and the Adriatic-western Ionian Seas as an example. It would be beneficial to apply the same methodology on a smaller regional scale to more accurately assess the potential for redistributing effort in surrounding areas, and to also apply the analysis at the fisheries scale (which differs from the STECF Annual Economic Report AER fleet-segmentation). Furthermore, a public, standardised and up-to-date database of fisheries restrictions is required for Natura2000 and CDDA areas, and should be made available et EU level. Without such a standardised database, a large effort is put into drafting this database to enable assessments of spatial management measures.

In addition to static modeling, empirical studies are necessary to validate displacement modeling findings. Ongoing projects, such as MAPAFISH-NORTH and MAPAFISH-MED, collect information on the effects of implementing MPAs that can be used to illustrate their impact. Those projects have deployed questionnaire surveys and the analysis of VMS/AIS data. Hence, MAPAFISH-MED identified displacement in 5 selected case studies/MPAs (France-1, Italy-2, Greece-1, Bulgaria-1). On a larger scale, the systematic use of VMS/AIS data and the year of establishment of an MPA is being used to assess fishing effort displacement before and after. Those projects recognize that VMS/AIS data are quite recent (>2012) but year of establishment for most MPAs may have been after 2012 (e.g., in Med and Black Sea 75% of MPAs established > 2011).

In our study, there were three major uncertainties that arose during this preliminary analysis:

- The level aggregation of data utilised, typically by the static reallocation analysis, prevented the study from examining the effects at the individual fisheries level. This could potentially mask undesirable effects for certain fisheries that share the same fishing techniques and areas.
- In the bioeconomic modelling, the variety in fishers decision-making poses a challenge for modellers as empirical data on human decision-making is often scarce. Fisheries dynamics models mostly assume a singular aim of maximizing economic gains, although fishers' behavior is often multifaceted (Andrews et al. 2020, Wijermans et al. 2020). Ignoring these motivations could be misleading when modelling fishing reactions to future scenarios.
- In the longer term, the study would need to include changes in catchability and feedback from population dynamics, a possible change in background economic landscape and fish market dynamics, etc. Some of the bioeconomic models deployed in this study could have captured some of these dynamic effects.

To overcome these shortcomings, bioeconomic models with a more dynamic fleet decision-making are necessary. In the short term, spatial management may increase costs due to longer travel times to reach fishing areas and decrease catches and profits due to the concentration of fishing effort in the remaining open areas. However, this could eventually be balanced out over the long term if the stock recovery is accounted for.

We found that spatial restrictions induce effort displacement and concentration, which can result in mixed outcomes.

Both static and dynamic approaches can be used to anticipate the effects of the EU spatial action plan, which includes more demanding spatial restrictions, calling for phasing out all mobile fishing activities in all MPAs by 2030 at the latest. In our present study only subset of MPAs have been included based on their potential vulnerability to this type of fishing (Figure 6.1).

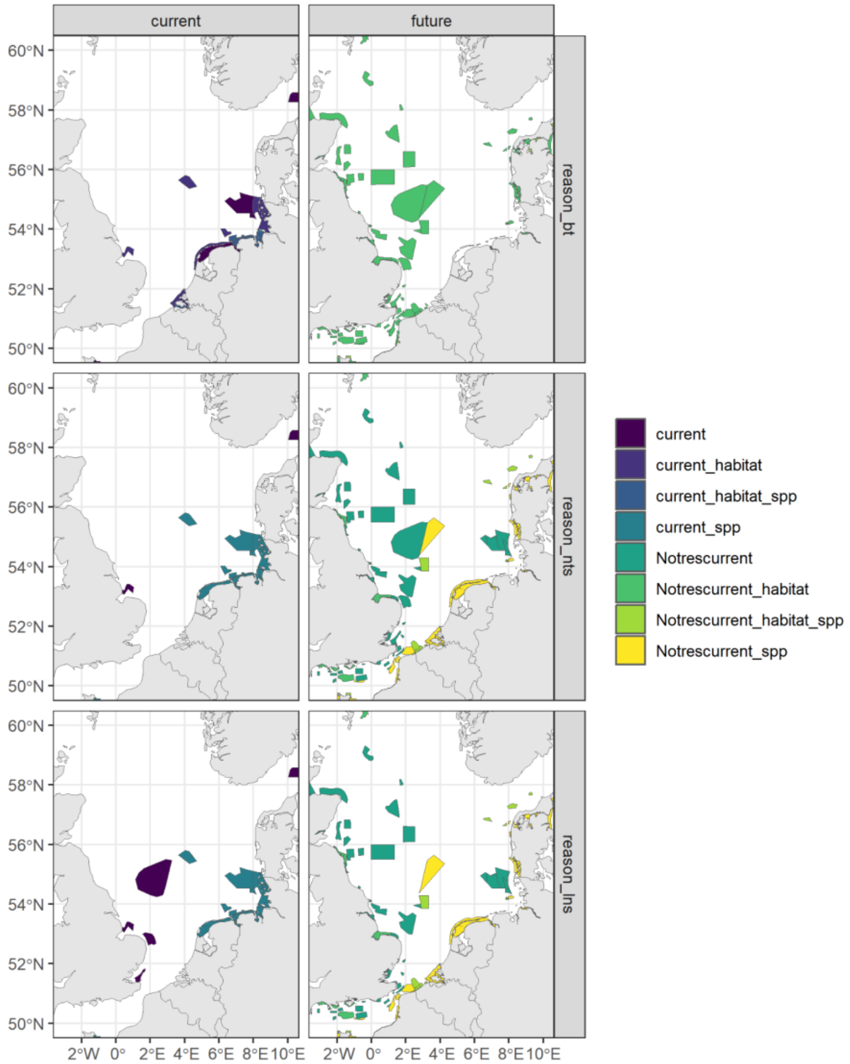


Figure 6.1. Designated conservation areas in the North Sea with restrictions for mobile fishery (bt = bottom trawl, nts = netters, lns = longlines) currently implemented (left) or likely in future (right) given the identified level of vulnerability to this type of fishing technique of the impacted habitat, impacted species or a combination of both.

6.2 Expected Socioeconomic impacts of shrinking fishable areas

Limitations of fishing space may cause a temporary decrease in fishing possibilities, but in the long run, it can result in the restoration of damaged habitats that support ocean production and fish populations. The crucial aspect is determining whether the benefits will remain limited to the local area or spread and extend to a wider region, which would provide access to new fishing opportunities for the fishing fleet. Such benefits may depend on the difference of mobility between species and life stages, where some species are quite sedentary while others are migratory. On less mobile species such as the ones constituting the benthic communities on the seafloor (the "animal forest"), the use of spatio-temporal management measures aiming at mitigating the impact of fishing is a relevant tool. Both economic and ecological impacts also depend on the mobility of the fishing fleet itself which is difficult to anticipate without modelling how fleets would be affected by changing the fishable areas. The effect may differ among small-scale fishing that are more polyvalent in terms of their catch portfolio but less mobile, and large-scale fishing vessels that can steam longer distances but are often more specialised in the species they target (Salas & Gaertner 2004). Moreover, fishing behavior may differ depending on their cultural background and company structure (Schadeberg et al. 2021). On the ecological side, for example, if vessels are very mobile, seasonal closures could increase the homogeneity of overall disturbance or lead to the redistribution of bottom fishing activity to environmentally sensitive or previously unfished areas. Effort reductions or permanent area closures should be considered as a management option to lower cumulative impacts on benthic communities in the long run when fishing effort could displace in reaction to the management (Dinmore et al. 2003). When drafting new measures, heterogeneity of behavioral responses among fishers should also be taken into account. An example from Baltic gillnetters shows that some fishers are more open to transformations, whereas others are more traditional and reluctant to change (Barz et al. 2020).

- In this Task, SEAwise has set the scene for running alternative scenarios of effort spatial allocation when being restricted by other uses of the seas spatially. Running a spatial restriction scenario compared to a baseline scenario for a suite of spatial bioeconomic fisheries models has provided several preliminary findings:

- After using our dynamic modeling method on the North Sea case study with DISPLACE, we discovered that excluding certain fishing techniques from the MPAs network in EU-UK waters, as proposed for conservation areas, could slightly reduce the impact of fishing and affect the fleet economics and fuel use. No striking change in selectivity has been found. This is because these areas are not currently the most heavily exploited, and have also not been initially designated to affect spatial selectivity. However, this observation does not indicate that restricting access to the most heavily fished areas might be a viable solution. Such limitations might only result in the displacement of fishing efforts towards less frequented areas, without actually benefiting the restricted zones. To demonstrate this, such a scenario could be included as a potential consideration in the future (i.e. D5.6).
- In the eastern Ionian Sea, different spatial restrictions for fishing techniques were experimented with using the DISPLACE model, which is a dynamic spatially explicit model. Even though there may have been some advantages to the fishing restrictions, there has been an increase in both unwanted catch and fishing effort, and no significant enhancements were observed in the harvesting of adult fish. Our findings revealed that the alternative scenarios tested are insufficient to make fishing fleets more selective. Additionally, certain fishing fleets were economically affected adversely. The DISPLACE project's eastern Ionian Sea application has produced preliminary results for a brief period that will be further examined in the D5.6 report, along with other potential scenarios, to enhance the fleets' selectivity (such as promoting spatial selectivity) and safeguard vulnerable habitats.
- ECOSPACE in the Adriatic Sea can predict how changes in fleet catch affect total revenue and cost, including fuel expenses. East Adriatic trawlers may benefit from being forced closer to shore after the closure of their traditional fishing grounds. On the other hand, the Italian trawling fleet experiences higher steaming costs, likely due to the closure of nursery grounds and FRAs and redistribution to other areas. ECOSPACE predicts that the mean trophic level of fish caught in deeper waters, closed to bottom trawlers but still accessible to pelagic fisheries, will increase. ECOSPACE indicates a marked rise in biodiversity in the central Adriatic area under the closures scenario. The reported outcome for ECOSPACE should be considered preliminary as it may have been influenced by the assumptions used to build and parameterize the model. The model will be reviewed and refined for the next Deliverable (5.6) to ensure it can be used for additional spatial scenarios.

- ECOSPACE predicts a significant rise in biomass for the southern North Sea, particularly in scenarios where habitat protection closures are implemented. Fish biomass could increase by up to 15%. However, this increase may not be sufficient to compensate for the decline in biomass outside the MPA from more pressure on specific fish species. This, in turn, caused a decrease in overall catches. Within the MPAs, all fishing fleets experienced losses of up to 50%, while outside the MPAs, there was an increase of up to 13% in catches. Nonetheless, the gains outside the MPAs did not compensate for the losses incurred due to the closures.
- The ECOSPACE evaluation on how spatial fisheries management affects the food web and fisheries in the eastern Ionian Sea predicted the spatial distribution of fishing effort for two scenarios - one with existing closed areas and another with possible future closed areas. Preliminary findings indicated that if all fishing activities were restricted inside MPAs (as in the second scenario), there was an increase in fishing effort throughout the study area, rather than just around the MPAs. The application is still under development and refined outcomes will be provided in D5.6.
- Using an agent-based model applied to the southern North Sea and the German fisheries the spatial restrictions may result in reduction in fishing effort, concentration of fishing effort in the remaining open areas, longer steaming times, and lower profits. The spatial scenarios suggested in this deliverable heavily affect the German shrimp fishery due to large overlaps with coastal shrimp fishing grounds, while flatfish and Nephrops fisheries are affected to a lesser degree. Scenarios reduced the fishing effort of all métiers suggesting that adaptations of switching métiers and relocating fishing effort could not negate the impact of spatial fishing closures. The current model version is constrained to simplistic assumptions about resource recovery and does not capture potential spill-over effects.
- In the North Sea, the OSMOSE model was used to test scenarios of effort redistribution and effort reduction. The results indicated a slight increase in the biomass of demersal species, but a significant decrease in the biomass of pelagic species. Both scenarios showed an increase in the relative biomass of protected, endangered, and threatened (PET) species, particularly when effort was reduced. Additionally, changes in the food web led to an increase in the catch of commercial species above legal landing size for both netters and trawlers.
- A spatial BEMTOOL is being developed for the Adriatic and western Ionian Seas to handle fishing activities operated by both active and passive demersal gears fleet segments. The effort data for the main ports in the study area has been explored in this study to identify the fishing grounds that are more frequently visited by fishers and to gain insights into their fishing strategies. This model will be used in the D.5.6 deliverable to investigate the impact of spatial closure on fish and fisheries.

There are inherent challenges in assessing the effect of Marine Protected Areas. It is necessary to compare ecosystem structure and function between long-standing non-fished (e.g. MPA or *de facto* MPA) areas and fished adjacent waters but these studies are rare and seldom incorporate temporal environmental change in the comparisons (e.g., see the meta-analysis in Sciberras et al. 2018 on macrobenthos). Ideally, the studies should consider counterfactuals by applying B(efore) A(fter) C(ontrol) I(mpact) design to provide evidence of the effect of any new implemented management measures on the ecosystem. Most of the studies that compare relationships between different ecosystem components rely on experimental designs that confound pre-existing differences with a significant effect (i.e. only applying Control-Impact). The effectiveness of closed areas should not be evaluated by comparing to open areas alone, because open areas are not valid experimental controls. Experimental controls should not be affected by the treatment, but fishing effort is usually displaced from the closure to adjacent open areas. A more rigorous approach should account for possible effects of the ecosystem aside from the impacts of implemented management measures. Additionally, the use of appropriate metrics is crucial as some indicators could be unresponsive to fishing impact just by construction (e.g. McLaverty et al 2023). For all these reasons, there have been some concerns expressed regarding the assessment of areas that are designated as protected. These criticisms pertain to the methods and criteria used to evaluate the effectiveness of such areas in preserving natural habitats and biodiversity (e.g. Caveen et al. 2015). It is important to address these issues to ensure that efforts to protect the environment are as effective as possible.

Currently, spatial bioeconomic fisheries models used in fisheries science are more able to capture the cost of management on fisheries and largely ignore the benefits and maintenance of supportive and regulating ecosystem services (Liquete et al. 2016), as well as spatial connectivity effects that could arise from a network of protected areas (Carr et al. 2017). Only extensive end-to-end models may have the ability to capture the effects of protecting habitats and scale it up to the whole ecosystem from the phytoplankton to the human dimension (e.g. see Bossier et al. 2021). However, these models are already comprehensive and therefore have difficulties to capture spatial effects, and are not considered truly spatially explicit. A new generation of spatial models needs to be developed so that realistic bioeconomic fisheries models can be coupled with fine spatial modeling of underlying environmental conditions and food-webs to make sure the benefit and costs that would arise from area restrictions are accurately captured and reported.

7. Conclusion

In this task, SEAwise has assessed the potential and existing fishable areas across EU Waters by collating fish and fisheries distribution areas. This task has initiated assessing the future fishable areas regarding scenarios, e.g. to exclude specific fishing activities from MPAs, exclude all types of fishing techniques from OWFs concessions, exclude fishing from Essential Fish Habitats, etc., preserve some areas for space occupation by other marine sectors. It is at present date unsure if and how the newest EU commitment with 30x30 scenarios will be implemented. Not substituting with official site designation and impact assessment channels, SEAwise has suggested an approach to evaluate the socioeconomic consequences of such environmental targets. Hence, the effect of spatial restrictions can be assessed either with a static approach with expert-based rules of thumb for anticipating the fishing effort displacement, or by deploying a more advanced approach using bio-economic fisheries dynamic and spatial models (DISPLACE North Sea, DISPLACE Ionian Sea, BEMTOOL in Adriatic Sea) or marine ecosystem models with some coarser economic components (ECOSPACE in the Med and OSMOSE in the North Sea).

SEAwise has identified that a suite of accurate and geospatial data is first required to conduct the analysis and has gathered them in this task from public sources. By overlaying them, the task has assessed the possible immediate effect of redirecting the fishing effort toward the surrounding or other areas on the likely change induced on socioeconomics of the impacted fleets. To assess the effect on fish species and ultimately on other components of the ecosystem (benthos, bycatch; in cooperation with WP4) and the likely change induced by such a spatial displacement on fishing selectivity and fuel use, SEAwise identified that there is a need for running scenarios capturing the medium to long term effects of ecological and fisheries uncertainties with dynamic full-feedback models, with a baseline scenario further aligned with the WP6 specifications so that to run and present the outcomes in a second deliverable of alternative scenarios for marine spatial plans. If in the short term, spatial management may increase operating costs, this may eventually be balanced out over the long term if the stock recovery is accounted for.

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