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Exploring the viability of innovative fishing technologies as an alternative to bottom trawling in European marine protected areas

An environmental and socioeconomic analysis

STUDY

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Exploring the viability of innovative fishing technologies as an alternative to bottom trawling in European marine protected areas

An environmental and socioeconomic analysis

Fisheries in Europe's marine environment use different types of mobile and static fishing gears that come into contact with the seabed, including mobile bottom-contacting gears (MBCGs) towed through the water and across the seabed. This study explores: the innovative gears that could be deployed as an alternative to the exclusion of bottom trawling in EU marine protected areas (MPAs); the efficacy and feasibility of implementing such innovations; and the environmental and socioeconomic effects on maintaining and restoring biodiversity.

The study shows that mitigating the impact on the seabed with innovations will likely not suffice to reach the conservation objectives. Given the lack of voluntary uptake, the most promising innovations would have to be made mandatory. It recommends that MBCGs be excluded from the designated MPAs deemed vulnerable to bottom fishing. So far, innovations for lighter-impacting gears or solutions not affecting catch rates are lacking. This induces a net increase in impact when fishers increase effort to compensate for loss in catch efficiency.

Excluding MBCGs likely comes with only a limited displacement effect, which might be larger if future MPA designation were to better match sensitive features needing protection. For now, discontinuing the use of other fishing techniques such as passive gears is not required, as they do not impact MPAs where vulnerable seabeds are found. However, some MPAs will be sensitive to passive gears, and these techniques should be limited there if innovations do not reduce the bycatch of vulnerable species to levels deemed acceptable under the EU common fisheries policy and Marine Strategy Framework Directive.

AUTHORS

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Executive summary

Fisheries in Europe's marine environment use different types of mobile and static fishing gears that come into contact with the seabed. These include mobile bottom-contacting gears (MBCGs) towed through the water and across the seabed. This study explores the innovative gears that could be deployed as an alternative to excluding bottom trawling in EU marine protected areas (MPAs). It then looks at the efficacy and feasibility of implementing such innovations. Finally, it analyses the possible environmental and socioeconomic effects on maintaining and restoring biodiversity, including changes in economic return, bycatch of unwanted species, coastal habitat degradation, and fuel use, contrasted with the effects of excluding all MBCGs from MPAs.

Many research studies to support fisheries have focused on developing more selective fishing with bycatch reduction devices. Much less research in recent years has been dedicated specifically to reducing the impact on the seabed, despite the fact that several options for minimising the effects of trawl gear on the seabed were identified a long time ago. The most promising gear modification is replacing otterboards with (semi-)pelagic ones in order to reduce bottom contact with the seabed and, subsequently, the benthic impact. Reduced seabed drag may also result in reduced fuel consumption. Unfortunately, the use of lighter gear would affect catch rates, which can be economically damaging to some fisheries, whenever the herding effects on animals induced by the gear components touching the seabed explain the catching performance, and the saving on fuel expense does not compensate for a performance loss. In parallel, innovations in passive gears have been developed over time, to reduce the risk of bycatch, which is the main criticism that prevents some actors from shifting to specific fishing techniques. Some innovations to limit the effect on the seabed (e.g. raising bottom-set trammel nets off the bottom) can also be identified; however, the passive gear effect on the seabed is much smaller than that for MBCGs.

The policy options explored in this study with a view to reducing the impact of MBCGs show that excluding MBCGs from MPAs effectively improves the benthic biotope in those MPAs without affecting the surrounding habitats, and that the fishing effort displacement effect is minimal. Implementing innovation that would reduce the contact of the fishing gear with the seabed can benefit the living communities on the seabed within the MPAs. However, reducing the contact with the seabed will likely come with a reduced catch rate for most fisheries. There, it will likely not improve the status of the living communities on the seabed at the regional scale, whenever effort is increased to break even and compensate for the potential loss of revenue. To what extent such an effort displacement and increase will occur depends on the degree to which less contact of the fishing gear with the seabed reduces fuel use and expense. An uptake of innovations to reduce fuel use in fisheries is expected shortly to make mitigating the contact of the gear with the seabed a relevant policy. Moreover, the mitigation of the contact to the seabed increases the risk for vulnerable species, as it comes with a net increase in effort to compensate for the assumed 20 % loss in catch rate induced by modifying gear selectivity. Therefore, the challenge in reducing the impact of fishing without excluding those fishing techniques from the MPAs is to innovate mobile fishing gears that have less contact, without affecting the catch rate, while none have so far been identified. Excluding MBCGs as an alternative would also best be accompanied by reducing overall effort alongside fishing restrictions in MPAs, to avoid inducing effort displacement and increase. Such a decrease in effort will, however, likely come with a short-term decrease in economic return before the marine ecosystem can recover and be more productive.

The most effective policy option that could be used as an alternative in order to minimise the negative impact of fishing on the seabed is mandating the use of passive gears to replace all MBCG activities, both within MPAs and at the regional scale. This will significantly improve the benthic biotope within a year, allowing it to recover to levels consistent with natural disturbances after several years. However, shifting EU MBCG fisheries towards using passive gears may increase the risk of bycatch of vulnerable species. Before transitioning, a feasibility study is recommended,

considering the current fleet structure and value chain, upfront conversion costs, and required payback time. The payback time for such a transition could be short, as seen in polyvalent small-scale fisheries that switch gears seasonally alongside fish stock seasonal fluctuations.

The experts consulted (marine scientists, MPA practitioners, non-governmental organisations (NGOs) and some fisheries representatives) share the view that there is a need to define control measures for fishing techniques used in MPAs in order to balance conservation and sustainable exploitation. Only small-scale fishing techniques should be used in MPAs, and bottom-impacting techniques should be excluded in areas with sensitive seabed features (those that are not naturally disturbed, being already adapted to disturbance). Large MPAs require spatial planning of fishing techniques and effort in order to find a trade-off between conservation and sustainable exploitation. However, most think the precautionary principle should be followed, and impactful fishing techniques should no longer be allowed in MPAs. In general terms, eliminating MBCGs and replacing passive high selective gears is believed to improve the protection of sensitive benthic habitats and species. In this respect, case studies (e.g. Jakuba Pomo Pit in the Adriatic Sea, Gulf of Lion in the West Med) show that constant compliance monitoring is critical when implementing spatial restrictions, as poaching from transient vessels is a significant risk and disincentive for fishers who suffer the greatest displacement and will, therefore, not derive the maximum benefits from protection. Case studies highlighted that bottom trawling may, in some occurrences, redistribute towards ecologically essential areas that should first be anticipated with impact assessment studies.

In analysing the coherence of the tested policy options with other policies, it is acknowledged that most marine parks and MPAs designated in EU waters still allow bottom fishing within the protected areas. Fisheries management measures, if they exist, are often linked to collecting data that would contribute to preserving fish but do not cover the effects of fishing on the benthic habitats as such. A policy gap is likely to arise whenever the EU environmental policy for protecting marine habitats (Habitat and Birds Directives, Water Framework Directive, Marine Strategy Framework Directive) is in place, but is not sufficiently related to the common fisheries policy (CFP). Current implementation of the CFP objectives are likely not complete enough to ensure future fishing opportunities that also rely on preserving essential seabed habitats and hotspots of biodiversity, such as estuaries and nursery areas for commercial fish and dependent communities. This protection will only be adequate when the impacting MBCGs are excluded from the MPAs. Consistencies between environmental and fisheries policies have been increased in the most recent Marine Strategy Framework Directive (MSFD) and CFP revisions, which refer to each other, and Member State transposition of the MSFD does not appear to conflict with CFP objectives, as long as it is recognised that healthy marine habitats and an ecosystem approach (as defined in the United Nations Convention on Biological Diversity – UN CBD, 1992) is a pre-requisite to ensure future fishing opportunities in a changing ocean.

This study primarily shows that mitigating the impact on the seabed with innovations will likely not be sufficient to reach the conservation objectives, and would also need making their use mandatory, given the lack of voluntary uptake of the most promising innovations. Based on this, it is recommended that the MBCGs should be excluded from the currently designated MPAs deemed vulnerable to bottom fishing. So far, no innovation or solution exists for lighter, less impacting mobile bottom-fishing gears that, for now, do not affect catch rates, which induces a net increase in the impact when fishers attempt to compensate for their loss in catch efficiency. Excluding MBCGs likely comes with only a limited displacement effect in changing the ecological seascape and socioeconomics of the affected fisheries, which might be larger if future MPA designation were to better match higher productivity areas or sensitive features that require protection. In the meantime, it is not necessary to discontinue using other fishing techniques such as passive gears, since they do not impact MPAs where vulnerable seabeds are found. Among all currently designated MPAs, some will be sensitive to passive gears, and these techniques should be limited there as long as innovations do not reduce the bycatch of vulnerable species to levels deemed acceptable under the EU common fisheries policy and Marine Strategy Framework Directive.

Table of contents

List of figures

Annex – List of figures

List of tables

1. Why has a ban on bottom trawling in MPAs been suggested?

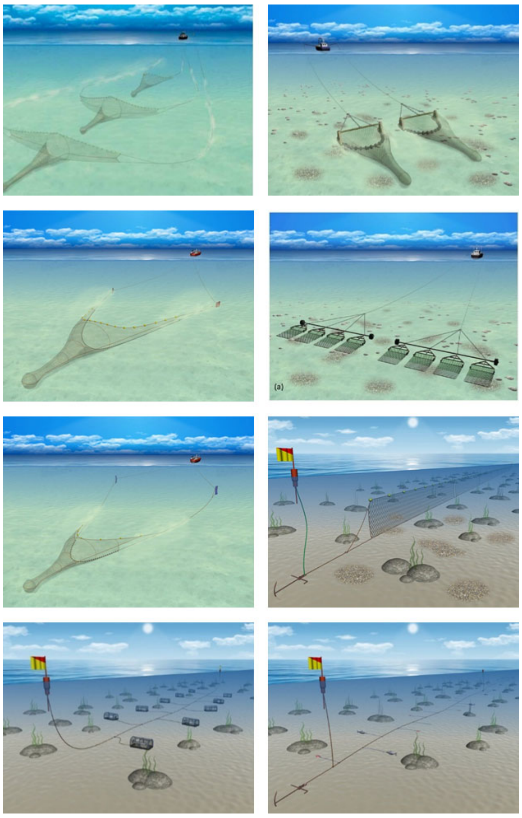
1.1. The issue with bottom trawling

The ocean is a key issue addressed in the European Green Deal and the EU is working for a safe, secure, clean, healthy and sustainably managed ocean – as in the Joint Communication on International Ocean Governance. Rules for sustainably managing European fishing fleets and fish stocks are set in the EU's Common Fisheries Policy. In March 2023, the European Commission suggested actions to be taken to phase out the use of bottom mobile contacting gears within fisheries. If this vision is followed, bottom trawling will be banned in Marine Protected Areas (MPAs) by 2030, but it will still be allowed outside those protected areas. Such a measure recognises that **bottom trawls have large footprints and physical seabed impact when sweeping the seafloor, with additional issues concerning species- and size-selectivity (bycatch and undersize target species discarding)**. Such fishing practices are accused of altering the functioning of the benthic community ecosystems (Rinjsdorp et al. 2020), damaging and degrading the biogenic habitats, and, by reworking and resuspending seafloor sediments, inducing significant physical impact on soft bottoms and possibly mineralisation of carbon from disturbed sediments to CO2 (Epstein et al. 2022; Black et al., 2022; Bradshaw et al. 2021, Diesing et al. 2021).

Compared to other fishing techniques (such as the ones used by artisanal fisheries, or pelagic trawl and purse seine or pelagic longline fisheries, Figure 1), towed mobile bottom contacting fishing gears have the most extensive environmental footprint. In the North Sea flatfish beam and otter trawl fisheries back in the 2000s, the by-catch by weight of invertebrates such as crabs, starfish, Ophiura spp., bivalves, gastropods, and many other benthic species was estimated at several times the number of marketable fish (Fonteneye and Polet 2002). Nowadays, mobile bottom contacting gears in the EU are often fished in areas resilient to fishing disturbance. However, much better resilience is most likely obtained after some time as the result of repeated trawling affecting the structure of the benthic communities, leading to a replacement of sensitive, slow-growing and slow-reproducing species by opportunistic, fast-growing, and fast-reproducing species (Fonteneye and Polet 2002). **The repeated disturbance caused by bottom trawling activity can lead to a shift in the baseline by creating areas that are favourable for future bottom trawling**. This 'farming the sea' hypothesis has long been disputed in the North Sea but was not confirmed by observations (Jenning et al., 2001). On the contrary, an increased gradient of fishing pressure is most likely to lead to reduced biomass, production and species richness (Hiddink et al., 2007). In a few cases, low trawling disturbance might, however, promote the development of fish species, such as flatfish that feed on small invertebrates, the ones left by such disturbance (Hiddink et al., 2008). While such trawled 'monoculture' areas can be highly productive, also driven by other environmental factors such as a change in temperature regime, they are also poor in biodiversity and associated functions, with negative long-term impacts on the marine ecosystem (Beauchard et al. 2023), such as the disappearance of tube dwellers in trawled areas that ensure critical ecosystem functions (Beauchard et al. 2023). According to some authors, bottom trawling and the depletion of fish stocks may be linked in a vicious circle, as the practice may have developed as a way to make catching remaining fish easier while also contributing to the depletion of fish stocks.

Because of such change, alternative fishing techniques may no longer be as effective as they used to be and are likely not economically viable anymore in such a shifted environment. It may take some time for society to see the benefits of using these new techniques as we wait for the habitats to recover. Unfortunately, **in some cases even relatively low bottom trawling frequencies can prevent the recovery** of short-lived species, even truer for long-lived species (see Beauchard et al. 2023 for a review). Because of this filtering on seabed arising from the chronic disturbance with mobile bottom contacting gears, more pressure might not be a concern. Also, **because of natural disturbances in naturally turbulent areas (wave and tidal currents), natural disturbances may sometimes override the effect of trawling disturbance on the benthic community composition** (Nielsen et al., 2023; Van Denderen et al., 2015). In such areas where the seabed has been disturbed for so many years, any changes would have occurred long ago, and what can be seen today is most likely the animals that can survive this disturbance. For example, sandbank habitats like the Dogger Bank in the North Sea are more naturally disturbed than deeper areas with muddy sediments (Bricheno et al. 2015). The shallowness of the sandbank areas causes frequent disturbance of the sandy sediments due to waves (Aldridge et al. 2015). Therefore, the local benthic community is likely adapted to physical disturbances that are like those caused by demersal fishing, as reported by van Denderen et al. (2015) and Eigaard et al. (2022).

Figure 1: a) Scottish seine (fly dragging or fly shooting) as a type of boat seine, showing successive shapes during operation, b) Two beam trawls are towed behind a boat on its outriggers, c) A single boat otter trawl in operation. The trawl is towed behind one boat and is expanded horizontally by a pair of otter boards, d) Eight dredges on two beams towed behind a boat, e) One type of semipelagic trawl with the otter board off the seabed while the trawl groundgear is on the seabed, f) A fleet of set gillnets set on the bottom with anchors at each end, and buoys and highflyers on the surface, g) A fleet of pots set on the seabed, h) A fleet of set longlines deployed on the bottom for catching demersal fish



Source: Montgomerie M. 2022 (Basic fishing methods. A comprehensive guide to commercial fishing methods).

On the other hand, the more stable the habitat, the longer it will take for habitat recovery followed by benthic community recovery. **Protecting some specific marine space is required as soon as these areas constitute stable hotspots for marine life, supportive habitats, and dependent species, including species with a commercial interest in fishing.** Because of such economic value, it is not obvious that the fishing sector understands the concerns raised by environmental scientists calling for more sustainable practices and area protection, a discourse further relayed by environmental NGOs. Most individual trawlers see the MSFD and the Natura 2000 as a threat to their economic activity (Frandsen et al 2015). Individual trawlers can indeed **fail to encompass the complete picture, which leads them to underestimate the detrimental effects exerted by unsustainable practices at the entire marine ecosystem scale** (see, e.g. Dean et al. 2022). Mobile bottom contacting gears tend to homogenise the sediment and simplify the three-dimensional structure both above and below the sediment-water interface (Gray et al. 2006).

This debate is common to the terrestrial ecology facing agricultural productions where two options have been advanced ('land sparing' vs 'land sharing', sensu e.g. Bateman and Balmford 2023). Some authors think intensive fishing combined with strictly protected areas has the best potential to preserve net biodiversity (Erm et al. 2023). In fisheries, recent advances in the assessment have been produced that could help close this debate (e.g. ICES 2024), offering a way to separate areas where bottom trawling matters and where it does not because the natural disturbance is high and the community has adapted. **The impact mainly depends on the fishing gear used, habitat type, and fishing intensity. These impacts also depend on the level of natural disturbance and the degree of species sensitivity**; however, because the pressure and extent of bottom trawling compared to the trawlable area are currently high, bottom trawling, in the long run, is most likely to adversely affect the recovery time of production or biomass of benthic habitat. Hence, Sala et al. (2023) remarked that bottom trawling produces a clearly defined footprint identified by the spatial extent of trawling and the width of the trawl gear that is in contact with the sea floor. Otter-board trawls working in soft sediment habitats have relatively large impacts due to the high sensitivity of the habitats and high trawling. The impact of dredges and beam trawls is lower because of their smaller gear weight, although the local impact is comparable or higher to that of the otter trawls. The impact of seines is relatively low despite high local fishing intensities.

The current perception among EU citizens and eNGOs is that there is **a contradiction between protection in theory and protection in practice**. They are concerned about the lack of implementation plans to exclude certain fishing practices in MPAs (see, e.g. CINEA study MAPAFISH). At the EU policy level, the EU EP PECH Committee members have voted in favour of an extension of MPAs and an improvement of their monitoring and urged the Commission to adopt guidelines for the MPA targets to be implemented in each EU maritime region[1]. Hence, the European Commission has recently consulted the public[2] about actions required to protect the seabed from bottom trawling by fishing vessels in specific areas to judge the effectiveness of prohibiting bottom fishing gear in unassessed areas, besides other consultations required by Article 6 of the CFP Regulation. All five evaluation criteria of impact assessment should be addressed (effectiveness, efficiency, relevance, 'coherence' (consistency) and 'EU added value' (a value that is additional to what would otherwise have been created by EU countries acting alone)). The analysis of the consultation outcomes has pushed the DG MARE to develop a vision and proposal for MS to exclude bottom fishing contacting gear from the designated MPAs and any future MPAs (see the 'Fisheries package'[3]).

The question is asked about continuing fishing in MPAs with mobile bottom contacting gears as soon as those activities could demonstrate fewer impacts compared to baseline bottom trawling. The present study aims to identify such recent developments leading to innovative fisheries management, fishing gear, and other equipment that would reduce the impact of such fishing practices.

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1 More fish in the seas? Measures to promote stock recovery above the maximum sustainable yield (MSY), including fish recovery areas and marine protected areas, INI Report 2019/2162(INI) A9-0264/2020 T9-0017/2021 voted as reported at https://www.europarl.europa.eu/doceo/document/A-9-2020-0264_EN.html

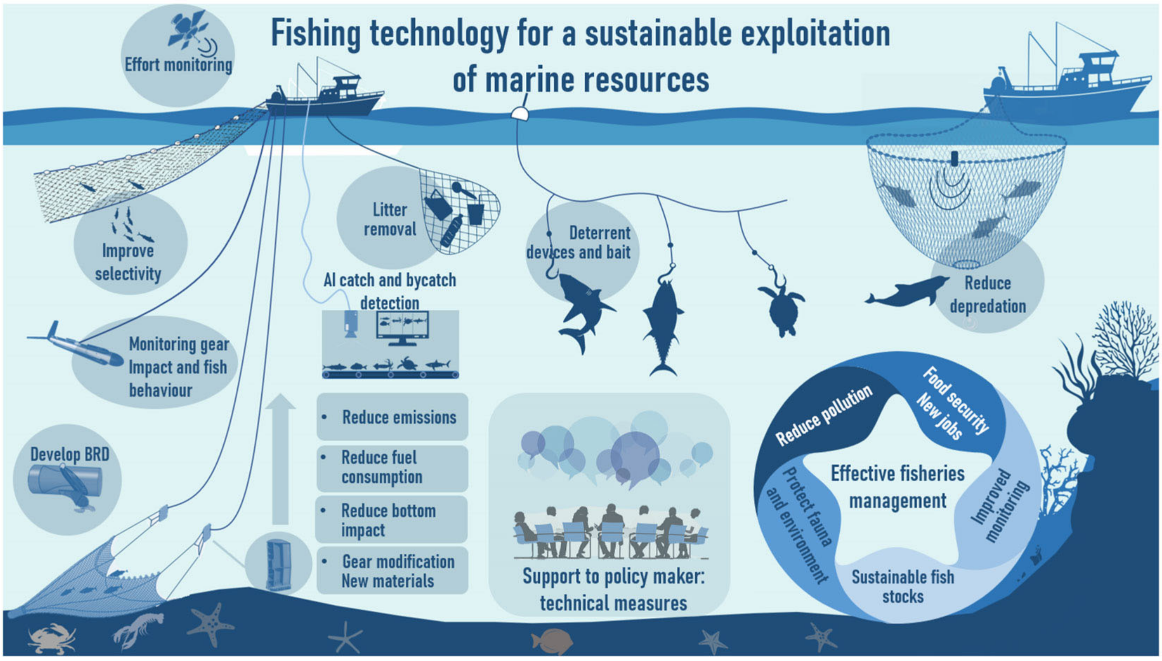
2 https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12953-Action-plan-to-conserve-fisheries-resources-and-protect-marine-ecosystems_en

3 https://ec.europa.eu/commission/presscorner/detail/en/ip_23_828

1.2. Considerations for developing innovative gears

The considerations about protecting habitats and vulnerable species with spatial restrictions to certain types of fishing and the aim of **implementing an ecosystem approach to fisheries management lead to re-evaluating the current fishing practices and their innovation potential that would reduce their impact** as a basis for management actions. The Common Fisheries Policy (CFP), through Article 15 of the EU CFP, calls for developing more selective technical solutions to avoid catching unwanted species and sizes. Innovation in fisheries is seen as improving the status quo, regardless of whether the improvement is incremental, transformative, or disruptive (WKING; ICES, 2020).

Figure 2: Developing fishing technologies for sustainable fishing: A multi-dimensional issue



Source: Lucchetti, et al (2023).

However, the ecosystem approach and effective management should be cautious with developing innovative gears in a multidimensional setting (Figure 2) where fisheries management would:

- *Fully Implement Ecosystem-Area-based Management for fisheries and aquaculture (EBM in a Maritime Spatial Planning context);*
- *Develop a climate-aware fisheries management (given climate change may reduce or displace ocean productivity), and coherence across fisheries and environmental policies (to limit externalities such as pollution and coastal development on fishing opportunities)*
- *Use Incentive-based co-management (eco-labelling etc.);*
- *Eliminate fuel tax exemptions or harmful subsidies and finance the transition;*
- *Minimise waste with more selective fishing and promote innovations across the seafood value chain*
- *Use fishers as data providers on experiential knowledge on how to operate fisheries;*
- *Run impact assessment and deal with uncertain science with risk-based approaches*

In this line, the development and innovation in fisheries should intend to:

- a reduction in bycatch of particular species or undersized specimens, which will also reduce unnecessary sorting time.
- a reduction of the costs of fishing operations by improving catch performance (catch less but catch better), i.e., ensuring the highest quality and value of the catch.
- a reduction in benthic impact
- a reduction in fuel use (that also comes along with less benthic impact)

Such an improvement will also strengthen the fleets' financial situation as soon as energy efficiency raises the fishing productivity per litre of fuel consumed. Such management will also promote more efficiency. However, such benefits on the fisheries side should be further monitored to avoid overfishing, which is likely if more efficient techniques for catching species are not regulated, for example, with quotas (e.g., Dutch seiners in the North Sea targeting squid, or most fish stocks in the Med, etc.). Hence, in areas where catch limits are not yet implemented, as for most fished species in the Med, **any new gear improvement would best require to be accompanied by a regulation implementing a decrease in effective effort to maintain or reduce the prior level of impact**.

Unfortunately, ecosystem-based management innovations are more likely to affect the catch rates, at least in the short term. Sometimes, the unwished impact may directly contribute to the catch rate. For example, fishers had concluded that the catch rates of targeted cod and flatfish were much lower when the trawl doors did not have seabed contact and accordingly generated visible sediment plumes behind the doors (Figure 3) compared to the pelagic trawl door set-up (given fish showing herding effects ahead of the trawl, see BENTHIS deliverable[4]). Hence, pelagic trawl doors are only an option for targeting species that cannot be herded by doors and sweeps/bridles along the bottom, such as shrimp and Nephrops. However, for species like cod and plaice herded by the sweeps/bridles, an off-bottom door rigging where these other gear components are on the bottom can be a helpful solution. This approach can help maintain catchability while eliminating the seabed impact of the doors.

A voluntary uptake of new measures by the industry would be preferable; however, restrictions on fishing opportunities have been necessary to introduce innovative gear designs (Catchpole and Revill, 2008). **A loss in catch efficiency or fear of it is likely not an incentive to use innovations, which might imply the policy-makers would force the uptake of such solutions**. Policy-makers should also be cautious in pushing toward alternative gears, as these gears could come with different challenges impacting the biodiversity present in the MPAs. A precedent was the prohibition of drift

[4] D7.7_Report_on_Options_for_mitigation_fishing_impacts_in_regional_seas_resubm_date_20-10-2014_PUBLIC.pdf

nets in EU waters, which occurred after evaluating this practice as not sustainable in some cases (see FAO[5]). Hence, the substitutions of one gear technique with others should be carefully evaluated.

Spatial management can be used whenever innovations are not deemed sufficient to reduce impact. Here also, possible unwished effects from spatial restriction should be carefully examined as fishing efforts can displace the surrounding or more remote habitats. Moreover, if other gears have too many side effects (e.g. bycatch), or are deemed, not feasible, then displacing or reducing absolute effort should be checked alongside local circumstances. **Case studies** are used to assess the past performance of spatial management without bottom fishing. This is done to contribute to anticipating the outcomes of applying MPAs in the future, as well as in the projection of possible alternative futures.

Figure 3: A visual on the impact of a commercial trawled groundgear on the seabed from cameras mounted on the bottom trawling nets during a trial of Precision Seafood Harvesting in 2015

Source: Seafood New Zealand.

The **effectiveness of allowing or excluding certain fishing techniques** with spatial restriction lies in knowing very well the impact that each type of gear has on the habitat (Figures 3 and 4), in order to establish its selectivity both against non-commercial species and against different types of habitats and vulnerable species. In this way, in large MPAs that cover a large area and in which there may be a great diversity of habitats, **spatial zoning** can be made of the fishing activities that can be carried out with the different types of gear **depending on their degree of selectivity and impact on the marine habitats**. In any case, excluding MBCGs from certain habitats (e.g., rocky, coralline and maërl habitats) might be required.

[5] La pêche aux filets dérivants et son impact sur les espèces non visées: étude mondiale (fao.org)

Hence, **different fishing gears are expected to impact the Natura 2000 sites differently**, as reported on a qualitative scale (Figure 5 below). Such a matrix crossing pressure intensity to the vulnerability of the habitats (Patrinat) can support mandatory analysis of the risk of a given fishing practice not meeting Natura 2000 conservation objectives. If a risk of undermining the conservation objectives of the Natura 2000 protection is identified at the end of such analysis, the legislation says that the fishing activities concerned must be subject to regulatory measures to reduce the pressure of the activity on the habitat or the species concerned. However, the level of risk triggering such mitigation measures is still being determined at this stage [see section 5.1 on GES].

Figure 4: A visual on a bottom set longline

Source: Snapshot of a MyFISH youtube video.

The risk matrix (Figure 5) also accounts for innovations. It shows a **possible large gain in mitigating the impact of the mobile bottom-contacting gears**, as they are the most impacting fishing techniques on the seabed. Innovations for mitigation include making the bottom otter trawl lighter so that the contact with the seabed is reduced and possibly totally removing the contact for some heavily impacting subcomponents of the gear, which are the doors used to open the mouth of the gear when trawling. In practice, such a setting limiting direct impact might be used only to gain access to some restricted areas requiring it, given the possible loss in catch efficiency or safety concerns using them as shown with trials at sea on commercial fishing vessels (see, for example, the numerous French Ifremer's projects such as JUMPER[6], REVERSE[7], CONNECT[8], CONTRAST[9]). Hence, **most gear technologist scientific efforts and innovations to use simple solutions for lighter fishing gears or gear control sensors to limit contact with the seabed have not been followed up with uptake from the industry so far** (see section 2.4), even if available in the market (e.g. via the Morgère company[10]).

6 https://peche.ifremer.fr/Le-role-de-l-Ifremer/Recherche/Projets/Description-projets/Jumper

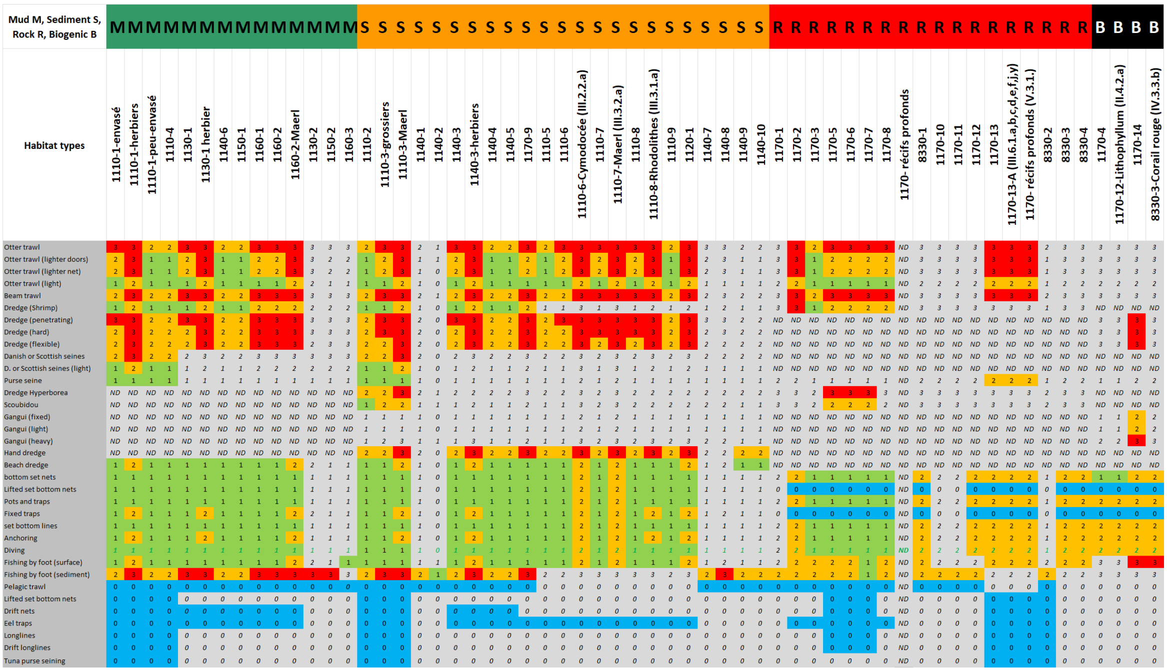
7 https://peche.ifremer.fr/en/Le-role-de-l-Ifremer/Recherche/Projets/Description-projets/Reverse

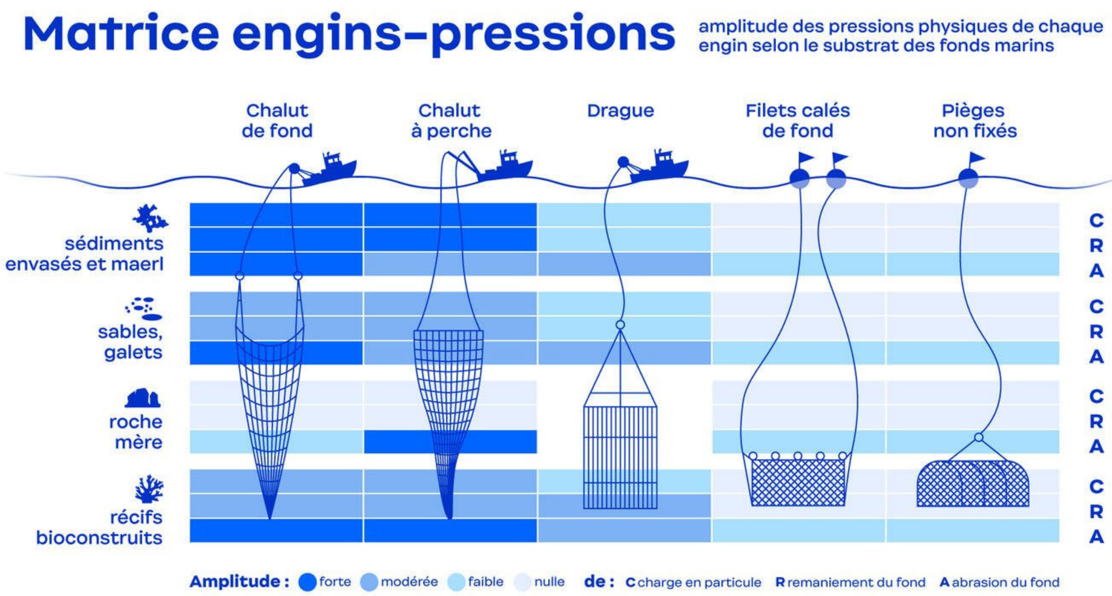
8 https://www.cooperationmaritime.com/projets/connect/

9 https://www.wikimer.org/projets/contrast/

10 https://www.morgere.com/en/

Figure 5: A risk matrix with combinations of Gear x Seabed habitats built in 2019 for Natura 2000 sites in France, with a risk scaled on a 0 to 3 scale from no- to high-risk, as a concrete French transposition of the EU Habitats and Birds directives. (ND: no possible interaction, 0: no risk, 1: low risk, 2: medium risk, 3: High risk), M: muddy habitats, S: mixed sediments habitats, R: rocky bottom, B: biogenic habitats





Source: Modified from https://www.natura2000.fr/outils-et-methodes/guides-et-ouvrages/arp-n2000 Annexe 4 of the methodological report, and Source Ifremer.

When policy-makers use a **risk matrix to assess the impact of fishing techniques on the environment**, it is important to ensure that the matrix is disaggregated enough to distinguish between different fishing methods. For instance, not all bottom fishing involves bottom trawling or seines. Therefore, it is crucial to define fishing techniques clearly to differentiate between those that significantly impact the seabed and those that have minimal impact (such as bottom set longlines, pots, and traps). By doing so, policy-makers can make more informed decisions promoting sustainable fishing practices while minimising environmental harm.

1.3. Proposed approach, scope and methodology

The European Commission 2022 Action Plan ('Protecting and restoring marine ecosystems for sustainable and resilient fisheries') is part of the EU's efforts to restore and protect marine ecosystems and apply an ecosystem-based management approach, including regulating the activity of mobile bottom-contact fishing gears (MBCG) in Europe's marine protected areas (MPAs) to reduce impacts on the seafloor. How to reduce incidental bycatch with more selective fishing is also on the agenda. The present study reports on restricting access to certain fishing techniques in the EU network of MPAs which investigates the (opportunity) costs and (environmental) benefits of different policy options, including possible risks, such as measuring the implications of displacing the existing fishing effort on surrounding habitats and other possibly sensitive species. To guide policy decisions on MBCG, the proposed work is done step-by-step to compare the potential outcomes of various mitigation measures:

(i) The study reviews the scientific literature to provide a list of innovative (regarding catch efficiency, selectivity, and environmental impacts), bottom-friendly, and close-to-market fishing gears, practical solutions to reduce effects in MPAs, and progress in their adoption.
(ii) Based on such solutions, the study develops a quantitative analysis of the economic costs and environmental benefits. It assesses the effectiveness of restrictions in reducing the impact on the seafloor while minimising possible side effects such as bycatch and sustainability. The quantitative analysis focuses on a data-rich ecoregion, the EU water in the North East Atlantic area, based on publicly available fisheries-related data at the regional scale.
(iii) The study discusses case studies in which spatial restrictions on bottom fishing have been implemented to observe their effects on fishing communities and the protected environmental components.
(iv) Finally, fisheries experts, fishers' representatives and operators, as well as possibly upstream businesses (e.g. gear makers), are consulted through a questionnaire survey to verify the technical, economic, social, and ecological feasibility and cost-effectiveness of implementing the proposed solutions, and risks and uncertainties in doing so. This also helps identify technical, social and regulatory barriers or reasons for low uptake.

The study provides options for policy-makers to differentiate between them based on their performance against similar criteria by investigating cost and benefits, feasibility and effectiveness of options, sustainability, risks and uncertainties, coherence with EU objectives, and potential ethical, social, and regulatory impacts.

2. Innovations to reduce physical contact with the seabed

2.1. Innovative management avoiding a full exclusion from protected areas

2.1.1. Zonation and control of fishing effort

In some areas of the world, a specific spatial restriction already applies to bottom-contacting gears due to concerns about benthic habitat impact (for example, the George Bank and NOAA areas; see Chosid and Pol 2023) and to limit conflict with mutually exclusive fishing techniques such as passive gears, a sector currently more active closer to the coast.

In Europe, the zonation depends on various regulations. It is subject to local and national regulations if within the 12 nm coastal strip (inshore waters) or to EU regulation if within the 0 to 200 nm strip, the 12 to 200 nm area defining EEZs (offshore waters). In the EU, bottom trawling is prohibited in the 3nm coastal strip unless in the Med, where areas deeper than 50m can be trawled (the Med plan). However, specific to some national laws, more exclusion distance is implemented in inshore waters and MS EEZ. Some more offshore areas beyond single EEZs are also closed to MBCG by international conventions, such as the NEAFC areas (ICES 2023).

Currently, the EU CFP stipulates that the use of bottom contacting gears is prohibited if they are>800m deep in NEA and >1000m in the Med (Mediterranean Regulation (EU) 1967/2006). In the Med, the GFCM implement protection of specific sensitive seabed habitats (Vulnerable Marine Ecosystems -VMEs) through the establishment of Fisheries Restricted Areas (FRAs) (Recommendation GFCM/29/2005/1). In the NEA, it is the **Deep-sea Access (Regulation (EU) 2016/2336)** that excludes trawling outside the historical fishing footprint between 400m and 800m, beside a list of closed areas protecting detected VMEs (updated list in Regulation (EU) 2022/1614). Finally, EU Technical Measures (Regulation (EU) 2019/1241) also enforce closure to some fishing practices during certain seasons to protect fish aggregations specifically.

Effort reduction can translate into **establishing closed areas that concentrate a fishery in its core fishing grounds**, as the core grounds are already able to withstand repeated disturbance (Bastardie et al. 2020). Avoiding complete closure can be introducing a habitat credit system where fishers are assigned credits to spend according to spatiotemporally varying tariffs (Kraak et al. 2014; Batsleer et al 2017). Such a **habitat credit system** has not yet been introduced in real fisheries anywhere (McConnaughey et al. 2020) and would also require easy-to-use-and-control tool for fishers to get the credits and understand the spatial tariffs. However, ideally, habitat credits may reduce the benthic impacts of the bottom trawl fisheries at a minimal loss of landings and revenue, as vessels are still able to reallocate their effort to less vulnerable fishing grounds while allowing the fishery to catch their catch quota and maintain their revenue. Such a solution is also relevant to optimise catch efficiency by avoiding high probability bycatch areas (Calderwood et al. 2020). However the spatial credits would need to account for both goals: improve the species selectivity and limit the impact on vulnerable seabeds.

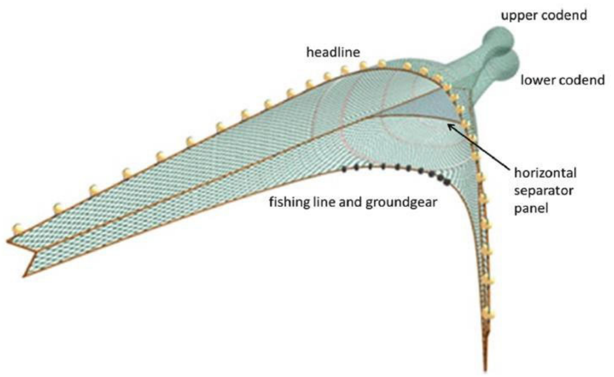
Less radical effort control as alternative management can be proposed to avoid applying such exclusion in all MPAs, and besides mitigating the seabed impact, some with gear modifications. This includes **reducing total fishing effort** by enacting regulations that limit the fishing capacity of individual bottom trawlers as well as the overall capacity of the fleet. Efforts can also be limited by regulating days spent fishing (as in the ongoing West Med multiannual plan), in extreme cases limiting fishing to a few hours 2 days a week during a few months (e.g. scallop fisheries with dredge in the Bay of Saint Brieuc in France).

However, effort reduction may unexpectedly, in some occurrences, limit the capacity to adapt toward less impact. Hence, in Europe, **a cap and reduction on kW engine power** have been implemented in the CFP to decrease historical overcapacity (see, e.g. STECF EWG 23-13). Vessel renewal depends on and cannot exceed such limit. Hence, due to the EU restrictions on public funding for new vessel construction, the opportunities to reduce the fishing impact (seabed, bycatch, fuel consumption) are mainly linked to modifications in vessel operation routines and the development of innovative and fuel-efficient gears rather than commissioning new vessels that would be more energy efficient and operating alternative fishing techniques than bottom trawling [see section on Policy Coherence].

Displacing all kinds of fishing effort away from certain areas might be required by the MSFD when it comes to restoring marine habitats to the **Good Environmental Status** (GES), an objective that can convert into a certain percentage of the surface areal extent that should not be affected in each national waters of the MS. Certain areas of the seabed would be left alone to recover from any damage caused by human activities, such as fishing with gears that comes into contact with the seabed (EU Commission Decision 2017/848) as long as these activities are not compatible with achieving Good Environmental Status. In line with this endeavour, the Biodiversity Strategy for 2030, the **EU Action Plan** (protecting and restoring marine ecosystems for sustainable and resilient fisheries in COM(2023) 102 final) also intends to protect 30% of sea area by 2030, including 10% with strict protection, and phase out all bottom fishing in existing MPAs by 2030 (and prohibit in all future designations). Finally, the proposal for a **Nature Restoration Law** intends to improve degraded habitats (specified list) – proposed targets of 30% by 2030, 60% by 2040; 90% by 2050.

2.1.2. Forcing the use of innovative gears

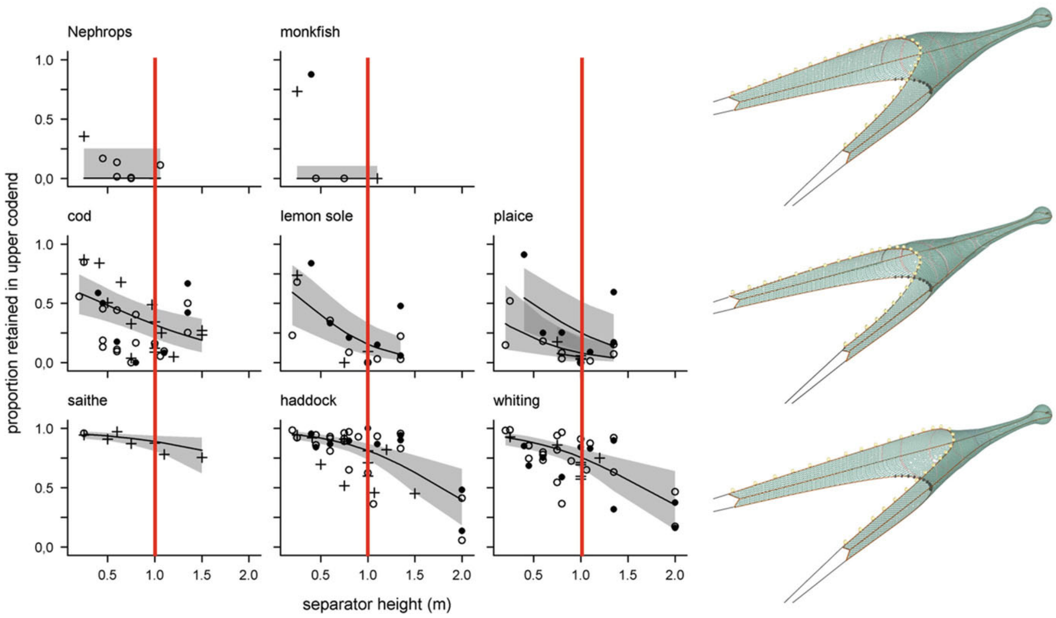
Figure 6: Demersal trawl fitted with a horizontal separator panel that directs fish that go above the panel to the upper codend and fish that go below the panel to the lower codend



Source: Adapted from Fryer et al. (2017).

Innovative management would still allow fishing on demersal species that behave differently facing a trawl by lifting when a trawl pass, contrary to other species that react differently (see O'Neill et al. 2019 giving the proportion of fish that will enter a trawl gear above a given height, see Figures 6 and 7). The proportion of fish that will enter a trawl gear above a given height is important to predict the species selectivity and performance in catch rates of a given trawl that would be lifted from the seabed. Hence, **raised footrope trawls are designed to lift the ground gear or fishing line away from the seabed**. This is achieved by replacing weights on the ground gear with 'drop chains' which allow the net to 'fly' off the seabed (He 2007). This works as a species selective measure, as some species will then go under the fishing line and escape capture, while

Figure 7: The proportion of fish entering a trawl gear above a given height. The vertical red lines indicate the proportion of each species that would enter above a height of 1 m. The trawl gears on the right illustrate how net makers can use this type of information to influence the species profile entering a gear by altering the height and position of the headline. The top net is a standard trawl, the middle one is a low headline trawl and the bottom one is a cutaway trawl



Source: in O'Neil et al 2019 after Fryer et al. (2017) and O'Neill and Mutch 2017.

others will still be caught if they swim higher off the seabed. Hence, innovative gears with raised lines have been developed to separate haddock from cod (Chosid and Pol, 2023). Thus, testing a net to target haddock that fishes entirely off, but close to the seafloor and reduces unwanted catch appeared to be a logical work progression. However, trawl at reducing cod bycatch suggests that raising the mouth of the trawl net even further off-bottom might decrease cod catch even more. Reductions in ground-gear bottom contact between the doors and the net have also significantly reduced cod catches of all lengths (Sistiaga et al., 2015), an **economic loss when marketable fishes escape the trawl**. Avoiding economic loss and engaging fishers for an active participation in developing the innovative solution are important for ensuring compliance and the best innovation would provide this (see section 'Barriers to uptake').

2.1.3. Forcing or incentivising a switch to alternative fishing techniques

One way to avoid the more damaging practices would require fully implementing a **reallocation of quotas among fleet segments** according to the reformed CFP 2013 initial ambition. Such reallocation is, however, possible and would align with the ambition of CFP Art. 17 to allocate more fishing rights to environmentally friendly fishing practices and on social criteria. Several countries (e.g., Spain, Italy, Croatia, Bulgaria) mention support for fishing communities as one of the social criteria justifying the allocation of fishing opportunities (STECF 23-17). Some MS could still argue that they do not use Art. 17 because not distributing any quotas (e.g. MS on the Med side). Ideally, distributing fishing opportunities would also be interpreted as covering distributing fishing efforts and spatial rights.

Innovative fisheries management strategies often incorporate incentive-based approaches. The Common Fisheries Policy (CFP) implemented **incentive-based management** as part of its 2013 reform, known as the Landing Obligation. This policy is designed to encourage the fishing industry to develop selective fishing gear, avoid catching unwanted fish, particularly juvenile fish, and reduce unwanted catch avoiding fishing in the concentration of non-target species in a given area. **However, no such incentive has been implemented yet to avoid damaging seabeds**. Promoting low-impact fishing can, however, be incentivised by developing eco-certification, which would ultimately influence consumer choice when purchasing seafood. There are ongoing efforts to supplement the EU Common Market Organization (CMO) with more knowledge in the perspective of revising it to include more detail about fishing impact on the seabed (STECF EWG-23-18 Fisheries sustainability indicators, or Kinds et al. 2016 and the VALDUVIS tool). To **promote low-impact fishing**, managers could create knowledge-sharing platforms focusing on topics like selective fishing, avoiding bottom impact, and alternative fishing methods (e.g. 'catching the potential' project[11]). Fishers would be informed about these alternative methods and encouraged to adopt them. This can be achieved through increased data collection, such as self-sampling programs, and by establishing appropriate frameworks to support the transition to these alternative fishing methods. Fishers could be educated about sustainable and energy-efficient fishing practices to promote responsible fishing. It is also essential to explore new markets for fish products, particularly by focusing on marketing lesser-known species and sustainably caught fish. To ensure sustainability in the market, a framework for fish processing could be established, along with **eco-certification**, to demonstrate sustainability. This could be accompanied by a thorough analysis of price formation mechanisms and the development of a marketing plan to coordinate supply and demand.

2.2. A review of gear modifications and innovative gears

Pelagic or mid-water gears or purse seine are designed to target fish in the mid- and surface-water (herring, mackerel, sardine, etc.) and do not usually touch the seabed. On the contrary, mobile

[11] https://catchingthepotential.eu/

bottom contacting gears (MBCG) include a suite of towed gears with seabed contact: the demersal (otter and beam) trawls, dredges and bottom seines.

Those gears differ in their level of contact with the seabed depending on the gear components and technical specifications, adapted to target species living close to or on the seabed (Kaiser 2014; Eigaard et al. 2016; Figure 1). By contrast, passive gears such as pots/traps, set gillnets, and longlines also have contact with the seabed but are not towed (Figure 1). Hence, **it is possible to rank towed mobile bottom fishing gear based on their impacts** (Eigaard et al 2016). Going beyond the initial differences among these gears, developing innovative, refined fishing gears is a complex process involving the expertise of researchers from multiple disciplines and several steps. Engineers, applied mathematicians, marine ecologists, and fisheries scientists all play crucial roles in developing fishing gear systems that can reduce the impact of fishing on marine ecosystems. The engineers use their scientific knowledge to predict the hydrodynamic and geometrical performance of the gear, while marine ecologists evaluate the overall impact of the gear on the ecosystem. Finally, fisheries scientists evaluate the effectiveness of the new gear in reducing the negative impact of fishing on the environment while affecting the operating costs.

Hence, the first step is to support research work to study the hydrodynamics of the MBCG gear and its contact with the seabed to **identify the best-performing gears**. This is done through scale modelling in flume tanks, towing tanks, or sand channels. The second step involves using numerical and computational methods to circumvent the difficulty of measuring the parameters that affect the gear's performance. Finally, full-scale trials with experimental fishing are conducted at sea using commercial fishing vessels under controlled conditions, ideally comparing the new fishing impact affecting one area against another comparable area fished with the baseline gear. This stepwise approach ensures that the fishing gears developed are efficient and sustainable, leading to better yields for fishermen and a healthier marine environment. The industry mediated by the political process (i.e. a formal authorisation) can then take up the innovation as soon as the study is proven more efficient than the baseline conventional gear used so far. **The procedure would allow some flexibility to revise the gear specifications back to the scientific evaluation in case the industry experiences practical problems** that would require slightly adjusting the agreed gear. To help this process, several research works have contributed to the evaluation of the added value of the gear innovation including: The VALDUVIS tool to track gear sustainability (Kinds et al. 2016), the SeaFish best practice guidance assessing the financial effectiveness of fishing gear[12], the gear selectivity change assessment (Brooks et al. 2022) and other innovation examples[13].

It has been argued that the consideration of closure strategies instead of technological solutions should first investigate whether technological solutions exist to reduce the impact of MBCG on seabed. Suggesting a ban on certain fishing techniques may repeat the pattern that characterised early strategies on ways to deal with by-catch issues before advances in fishing technologies for more selective fishing were developed (Kennelly and Broadhurst 2002). Hence, a short review is done for this study to identify what gear configurations exist to mitigate habitat impacts and how these benefits can be quantified. To achieve this, **a thorough literature review has been conducted, collating the existing innovations at different stages of readiness for phasing them into the existing fisheries**. The focus is largely on the utilisation of mobile bottom contacting gears. In practice, works referenced in the Scopus database have been extracted the 15th of December 2023 with a query.

[12] Best Practice Guidance for Assessing the Financial Effectiveness of Fishing Gear Scientist-led Trials-1.pdf by Seafish

[13] E.g., https://www.erhvervshusnord.dk/fileadmin/Filliste/Om_os/Fremtidens_Modulaere_Fiskefartoej_FINAL.pdf

Box 1: The code to query the Scopus database

TITLE-ABS-KEY ("fishing gear*" OR "trawl*") AND TITLE-ABS-KEY ("innovative" AND "catch*") AND TITLE-ABS-KEY ("fishing gear*" OR "trawl*") AND TITLE-ABS-KEY ("reduction" AND "invertebrate*" AND "device*")

After sifting through approximately 40 references, valuable information has been gathered on the latest innovation in fishing technology. This includes its effectiveness in reducing the impact on seabed, minimizing the risk of bycatch, cutting fuel consumption, and potentially improving profitability. This list of references has then been completed with a list of gear innovations recently collated by ICES in the **Working Group on Innovative Gears** (ICES WGING 2023), which aimed at ranking them alongside performance in reducing the impact on ecosystems while maintaining the same catch rates, also accounting for capital costs and return on investment in taking up the innovation.

All in all, **the review shows that most innovations identified have been developed and tested so far to optimise and increase catch rates** (for example with 'precision fishing' developed alongside the introduction of the Landing Obligation in EU), to access more (rocky) grounds, and to offer more size- and species-selective gears, **and very few to reduce the impact on the seabed**. The possible reduction of the seabed effect was also not described in the ICES reporting and it was therefore needed to interpret them (see Table 1). Twenty years ago it was already noted that while it is encouraging that there are a few technological options available for reducing impacts of trawl gears on habitats, it is disappointing that so few have actually been tested (Kennelly and Broadhurst 2002). On the contrary, dealing with by-catch issues in recent years illustrated a successful shift in philosophy and paradigms to meet environmental challenges (Kennelly and Broadhurst 2002).

ICES has recently advised the EC about a repertory of innovative gears developed worldwide to mitigate the fishing impacts and/or gain efficiency and get closer to the 'ideal gear properties' (ICES, 2006). ICES defined 'innovative fishing gear' as a gear or a significant component of a gear that is different from the baseline in the current EU Regulations – or, in the absence of such legislation, different from the gear commonly used in the specific sea basin (area) in EU waters. These gears to be implemented would, therefore, need to be included in the EU legislation. The ranking over different criteria relied on the opinions of individuals involved in the development and/or testing of each innovative gear, as no individual can be found with sufficient knowledge and understanding of all submitted gear innovations to rank them all accurately and consistently. In the following Tables, the ranking scales uses ICES (2023) expert opinions as:

- Catch efficiency improvement (on a scale of 1 to 5; Negative, No Effect, Incremental, Transformative, Disruptive), and Technological readiness level (on a scale of 1 to 3; Low, Moderate, High)
- Selectivity improvement (on a scale of 1 to 5; Negative, No Effect, Incremental, Transformative, Disruptive), and Technological readiness level (on a scale of 1 to 3; Low, Moderate, High)
- Environmental impact improvement (on a scale of 1 to 5; Negative, No Effect, Incremental, Transformative, Disruptive), and Technological readiness level (on a scale of 1 to 3; Low, Moderate, High)
- ICES 2023 Cost matrix. Return on Investment (on a scale of 1 to 5; Negative, Minor, Substantial, Significant), Capital cost (on a scale of 1 to 3; High, Moderate, Low)

Among all 75 innovations, most are to take real-time decisions to improve selectivity, catch efficiency and profitability, but not really to reduce seabed impact. There are only a few innovations that aimed at reduce the impact on the such as groundgear modifications, for example, drop chains, raised footrope trawls, sweep-less trawls, use of rollers (He and Winger, 2010; Polet and Depestele, 2010). The actual reduction in total sediment disturbance obtained by lifting the otter doors is much larger as standard otter boards penetrate deeper (up to 35 cm) than any of the other gear components (Eigaard et al., 2016). In the following section, the gear types that have differential effects on the seabed depending on the target species are described together with the identified innovations proven to have a positive effect in reducing the impact on the seabed.

2.2.1. Beam trawls

Beam trawls are specifically designed to catch benthic target species such as brown shrimp and flatfish (e.g. sole and plaice) that live on or buried in the top few centimetres of the sediment. Various configurations of chains are attached between the beam shoes. These chains, called tickler chains, are designed to disrupt the surface of the seabed, and disturb or dig out the target species (Kaiser 2014). Large beam trawls can be fitted with over 20 tickler chains and can penetrate soft sand to a depth of over 6 cm. Beam trawls can be towed at speeds of up to 7 kt depending on the habitat and target species (Polet and Depestele 2010). The shoes act as skis that glide across the surface of the seabed and spread the load of the gear and prevent it from sinking into a soft substrate. In some cases, these shoes have been replaced by wheels that reduce drag as the gear moves across the seabed.

Early attempts to mitigate the effect of beam trawlers on the benthic community developed **benthos escape devices** (Fonteyne and Polet 2002). Such Bycatch Reduction Devices (BRD) inserted into the belly of the net might reduce bycatching invertebrates (Fonteyne and Polet 2002). However, the position of the selective device in the net is found to be very important for such an effect and is dependent on the skipper's skills, as tested on beam trawlers. The mortality of benthos in the trawl path is also uncertain and attention should also be given to damage inflicted by the trawl on animals of the infauna, that are not often found in the catch, but that do encounter some parts of the fishing gear.

An innovation considered disruptive to reduce the impact on the seabed from beam trawl was the implementation of the Dutch SumWing innovation acting as an aero foil-shaped beam creating lift as it is towed through the water like an aeroplane wing. The SumWing trawl eliminates the need for the heavy shoes or wheels used in traditional beam trawls and is as much as 25% lighter than an equivalent traditional beam trawl (Depestele et al. 2011).

Another disruptive innovation was testing **the electric pulse trawl**, which removed the need for lateral tickler chains that penetrated the seabed. Indeed, the tickler chains greatly improved the beam trawl catch efficiency relative to the otter trawl for sole in the North Sea but came with more seabed impact (Sala et al. 2023). Most beam trawls have chain matrices to allow fishing on rough grounds (Fonteyne and Polet 2002). Pulse trawling has been introduced in an attempt to reduce contact with the seafloor. The demonstration showed that pulse trawling reduces those impacts and further increases the catch rate for beam trawlers (Pulse trawls targeting common sole are towed at a 22% lower speed and have a 28% higher catch efficiency for the common sole and a 40% lower catch efficiency for plaice and benthos (van Marlen et al. 2014, Poos et al 2020). Hence, the reduced swept area per kg caught resulting from the reduced speed at trawling and the lower penetration depth of the pulse trawls are likely to result in a proportional decrease in the seabed impact and sediment resuspension.

Most of the time, the beneficial effects of innovation assume no change in fisheries' distribution, including extension to new areas. For example, pulse trawlers could have new opportunities to visit so far inoperable areas for fishing. Hence, the issue with pulse trawling was the possibility of accessing more fishing grounds, while the number of operators was quickly greater than the number of granted licenses, and the mortality on other ecosystem components was and still is uncertain (Soetaert et al. 2016). In reaction to such development, other fleet segments complained about increased efficiency and lobbied to stop pulse trawling (ICES, 2016). This was concomitant to the observation that the sole resource diminished even if catch limits were respected. In June 2021, the EU prohibited pulse trawls and pushed the trawlers to revert to the traditional gear and fishing grounds.

One of the lessons pulse trawling taught was that the use of lighter gear and subsequent lower fishing speeds resulted in lower fuel consumption. This led to the design of a 'rubberticklers' gear. However, the innovative gear will need to improve the marketable catch efficiency or further reduce fuel consumption to be a potential alternative to chain-beam trawl gear for commercial fisheries (van Mens and van de Pol 2024).

Table 1: Adapted from ICES Special Request Advice of 13 Oct 2013 on a non-exhaustive list of innovative gears developed outside and inside the EU and based on ICES WKING 2020, with a short description of the terms of innovative gears and No of the innovation referring to the factsheet number in ICES 2023. The innovative gears are sorted out from the largest to the lowest score on the possible impact reduction, besides other criteria

Innovation	ROI	Select-ivity	Catch	Eco-system	Sea-bed	Description	References
Pulse trawling	5,1	4,3	5,3	4,3	4,3	Electrodes are used to produce an electric field. The cramp response immobilises the fish for 1-2 seconds during which the fish are scooped up in the net. Combining the SumWing design with the pulse technique has resulted in the combined Pulse Wing with a large reduction in seabed contact.	van Overzee et al. (2023) pulsefishing.eu
Shrimp pulse trawl	5,2	3,3	3,3	4,3	4,3	shrimp pulse trawl using electrodes to produce an electric field.	Verschueren et al. (2019)
Sea stars HydroTrawl or hydrorig	3,3	4,3	4,3	2,3	3,3	The beam is held off the seabed with small shoes and the positioning of the net to the beam is altered. The size and shape of the beam, its height above the seabed and the position of the net will all influence catching efficiency of sea stars and bycatch. This reduces the seabed impact and fuel use.	Burgaard et al. (in press)

2.2.2. Otterboard bottom trawls

Otter trawls are fished on the bottom for various demersal gadoids and crustaceans and derive their name from the two otter boards or doors that are fixed between the sweeps and bridles to keep the net open when towed into the water. Otter trawls are towed more slowly than beam trawls (typically from 2.5 – 3.5 kts) as required by the hydrodynamic of the gear. **The otter doors, the plumes of sediment that they create, and the warps attached to the net also have a herding effect and cause fish to aggregate directly in front of the mouth of the net** (e.g., Eighani et al. 2024 in FAO 2024). If the otter trawl doors affect a small area compared to the groundgear swept over the seabed, the doors penetrate sediment up to 20 cm in soft mud habitats and dig a furrow along their tow path (Kaiser 2014, Eigaard et al. 2016).

Many research works have focused so far on developing more selective fishing with bycatch reduction devices such as sorting grids, mounted inside the net designed to release unwanted species and retain the target species that are adapted to avoid catching unwanted groups of species (turtles in Vasapollo et al., 2019, fish by-catch in shrimp trawls in Madsen et al. 2017, etc.). In parallel, separator panel devices for species separation involve fitting a horizontal panel inside the net, usually in the main body of the net to select fish species, as, depending on the species' behaviour, fish may go above (e.g. haddock or whiting) or below the panel (e.g. cod and anglerfish), and into two different cod ends (Fryer et al 2017; Cosgrove et al 2018). The two cod ends may have different meshes and mesh orientations, or one may be open to allow escapes or improve the quality of the catch whenever not mixed up. Cutaway headline or 'topless' trawl designs work on the same basis as the separator panel design, where the removal of the top panel allows some species to escape (Revill et al 2006; Krag et al 2015). Benthos release panels are a special case of escape window designed to release unwanted benthos and debris (Fonteyne and Polet 2002; Revill and Jennings 2005) but with a small performance proven so far.

Much less research has been dedicated to specifically reducing the impact on the seabed in recent years, while several options for minimising the impacts of trawl gear on the seabed were long time identified (Kennelly and Broadhurst 2002; He 2007). Hence, otter trawl innovations explored in flume tank tests or with sea trials and underwater videos have shown potential, including:

- Replacing groundgear with a series of drop chains and weights, significantly **lightening the trawl** and reducing its footprint on the seabed, while the doors of the system still operate on the seabed (He and Winger 2010). With such modification, catch rates for commercial species were similar compared with traditional demersal trawls, while the catch of non-target species was reduced (He and Winger 2010);
- Using trawls with **raised footrope (sweepless trawls) designed to reduce seabed contact** for example in northern shrimp bottom trawl fisheries. Sometimes quite simple but effective solutions can reduce the seabed impact extensively (ca. 60% impact reduction) such as aligning the trawl and rubber discs in the footgear with the direction of tow to reduce the drag resistance (Winger et al. 2010). Effective reduction can also be obtained by modifying the configuration of sweeps using various types of rollers, 'rock hoppers' and 'street sweepers' to minimise impacts of trawls on benthic assemblages, or decreasing the warp length-to-depth ratio as much as possible to decrease the weight of trawl gear on the bottom, or reducing the lengths of sweeps and bridles as much as possible, or maintaining net spread to reduce the likelihood that the net belly contacts the bottom;
- Using semi-pelagic trawling designed as a hybrid technique that can capture fish distributed on- and off-seabed (Nguyen et al. 2023; He et al., 2021; Montgomerie, 2022). **Semi-pelagic trawling** can be considered when doors are fished off-seabed and the trawl is on-seabed, trawl is off-seabed, and the doors are on-seabed, or in a hybrid fishing situation where either doors or trawl are moved on- or off-seabed as fishing conditions or motivations change. This method maintains the doors on the seabed while raising the trawl net off the seabed by connecting the upper bridles to the warps anterior of the doors adapted to fish as they migrate off the seafloor, and to avoid net damage from a rough seabed. For example, semi-pelagic trawling could be a cost-effective solution for the crustacean fleet when targeting fish off the seabed. This technique only requires a typical groundfish trawl and a relatively simple modification to the upper bridles and warps. There are also ongoing attempts to remove the need to spread the towed trawl net with trawl doors (Winger et al 2024).

Hence, **the most promising gear modification is replacing otterboards with (semi-) pelagic otterboards, to reduce bottom contact and subsequently, the benthic impact**. The reduced seabed drag may also result in reduced fuel consumption (Sala et al., 2023). Some semi-pelagic gears are already used to target demersal fish (Chosid et al., 2023), even if commercial pelagic fishing for groundfish species is rare. It occurs in the Baltic Sea for Atlantic cod (Madsen, 2007), and in the Bering Sea for Alaskan pollock (Erickson et al., 1996). Semi-pelagic trawling has also been researched in Norway in recent years, demonstrating similar haddock catches with different amounts of groundgear seafloor contact (Sistiaga et al., 2016). In other cases, heavy otter doors can be replaced with lighter pelagic doors, and the sweeps and part of the net are replaced with lightweight Dyneema patented material, which reduces the amount of swept seabed area. Such **a combination of innovative settings** could limit the depletion of faunal biomass after trawl paths in the Dogger Bank in the Central North Sea (Eigaard et al., 2022).

Unfortunately, the effect of pelagic doors on catch rates can however be negative for some species as soon as the herding effects induced by the gear components touching the seabed is one cause of the catching performance [This information will be used in the scenario evaluation in section 3]. Controlling the doors' positions and the spread of the mouth of the trawl gear is also made more complicated when the doors are lifted from the seabed, requiring sensors on the doors and enough depth water so that the gear spread is not reduced [Pers. Comm. PI of the REVERSE project]. It also requires active control of the skipper operating the fishing e.g. by controlling the length of the bridles to make sure the doors are lifted. While the expected fuel savings are effective, they do not compensate for the loss of tonnage caught. This **loss of profitability as things stand is not satisfactory for fishers** (France Filiere Pêche's ECOCHALUT project). In some very specific cases, there might, however, be a gain in catch efficiency induced by the fish species' behaviour when facing the trawl mouth (e.g. Haddock, Larsen et al. 2024). Hence, ongoing projects are underway to advance the state of the art in the design of commercial trawl gears (FAO 2024), by, for example, establishing criteria for small-scale modelling that incorporate the contact forces associated with fishing gears being towed over the seabed, developing instruments with automatic image processing and machine learning capabilities to assess catch caught in fishing gear in real-time, etc.

Table 2: Possible innovations in Otterboard bottom trawl gears that would reduce the impact on seabed and vulnerable species. ROI: Return on Investment; Catch: Catch efficiency; Ecosystem: Potential for ecosystem impact reduction; Seabed: Potential for short term seabed impact reduction

Innovation	ROI	Selec-tivity	Catch	Eco-system	Sea-bed	Description	References
Reducing the otterboard impact on the seabed ('Connect' system)	2,2	2,3	2,3	4,3	5,3	Trawl doors (otter boards) are equipped with sensors used to calculate the physical impact of the door on the seabed in terms of shocks and vibrations. The information is transmitted to the wheelhouse and the skipper can adjust the warp length and/or the vessel velocity to lighten the doors and reduce their impact.	Sala et al. (2019) and octech.fr projet-connect
Self-adjusting semi-pelagic otterboards for demersal trawls	3,1	2,2	1,2	4,2	5,2	Self-adjusting otterboards that have altimeters and adjustable flaps to allow the door position in the water column to be modified. This reduces drag, improves spreading forces, reduces fuel use, and comes with less contact with the seabed.	Eighani et al. (2023)

Innovation	ROI	Selec-tivity	Catch	Eco-system	Sea-bed	Description	References
A netting-based alternative to rigid sorting grids	3,2	5,3	2,3	5,3	3,3	A new bycatch reduction device, termed 'Excluder', has been discussed during STECF PLEN 20-03. Reduce bycatch of HER, WHG, MAC and PLA. Lighter gear.	Eigaard et al. (2021)
Lighter trawl gear to reduce environmental impact on the seabed	2,2	3,2	2,2	3,2	3,2	The novel fishing gear is 100 kg lighter (total weight 800 kg). The gear was lighter because of thinner twines, shorter sweeps, and lighter hydrodynamic doors. This reduces seabed impact and the fuel use.	Guijarro et al. (2017)

2.2.3. Dregdes

Dredges are used to capture sedentary species such as scallops, clams and gastropods, that live either on the surface of the seabed or within the sediment. A typical dredge incorporates a heavy-duty bag or net attached to a rigid metal frame to which tooth bars or cutting blades of up to 11 cm long and of various designs are fitted (Kaiser 2014). In some designs the belly of the bag is made of steel rings due to the abrasion incurred as the gear is towed over the seabed. The hydraulic dredge has the largest impact by scraping the surface of the substratum and dig into it by resuspending large amounts of sediment (Luchetti and Sala 2012).

Innovative gear modifications in dredges are rare because the disturbance of the seabed is inherent to the catch rate and performance of the gear. However, innovations have introduced dredge teeth that can bends back, and springs clear of snags (Newhaven spring toothed dredge, or the patented N-Virodredge) to reduce the resistance of the gear to the towing force and increase catch rates and swept area. These modifications have enabled scallop dredgers to access much rougher ground than would otherwise be possible. Besides, hydrodregde is shown to lower the effect of hydraulic dredge in resuspending sediments but at the cost of a lower catch rate (Shephard et al. 2009).

Table 3: Possible innovations in dredge gears that would reduce the impact on seabed and vulnerable species. ROI: Return on Investment; Catch: Catch efficiency; Ecosystem: Potential for ecosystem impact reduction; Seabed: Potential for short term seabed impact reduction

Innovation	ROI	Selec-tivity	Catch	Eco-system	Sea-bed	Description	References
Hydro-dredge, a novel innovation in giant scallop dredging	1,3	3,3	1,3	4,3	5,3	Four precisely oriented 'cups' that deflect water into a downward jet and create large-scale vorticity, a sufficient force on the seabed to lift scallops captured by the trailing net/chain bag. This avoids damaging scallops. This comes with lower catch rates.	Shephard et al. (2009)

2.2.4. Demersal seines

Demersal seines are large nets deployed at sea from a vessel to encircling dense aggregation of demersal fish. Seining is considered as a very efficient way of capturing a large volume of fish, also ensuring better fish quality as soon as the stay of the caught fish in the codend before hauling back is limited. **Although these gears have direct contact with the seabed the seine is retrieved slowly and its footprint on the seabed is small relative to trawls** that are towed for hours at a time.

As discussed by Eigaard et al. (2022) the Danish seine has been considered to be an 'environmentally friendly' fishing method due to its lightweight gear, lack of penetrating gear components (doors, shoes, weights, clumps, and tickler chains), and low fuel consumption and the impact is described as having a 'smoothing effect with no pronounced changes to the seafloor' when fished on sandy sediments (Noack et al., 2019). Likely because of this low impact, no research effort to develop further innovation for reducing the impact of demersal seines on seabed have been identified.

2.2.5. Pots and traps and other passive gears

The success of the passive nets is due to their ease of use, high selectivity, and high capture efficiency for numerous commercial species. Their technical parameters such as mesh size, etc. vary widely in relation to the characteristics of target species and fishing areas (e.g., depth, seabed type), as do their selection properties. Although passive nets are considered selective gears, they nonetheless still produce a significant unwanted catch amount (Petetta et al. 2020).

Innovations in passive gears have developed over time to reduce the risk of bycatch (Table 4), which is the main criticism that prevents some actors to shift to that specific fishing techniques (see section 2.4). A few innovations can be identified to also limit the effect on the seabed (e.g. raising bottom set trammels nets off the bottom), while the passive gears effect is much smaller than the one for MBCGs.

Some research efforts have also focused on examining the viability of pots fisheries. Experimental, **biodegradable and collapsible pots** developed in the past few years in certain areas have ensured catch efficiencies comparable to those of traditional set nets (Königson et al., 2015). Pots are passive gears to which fish, crustaceans and molluscs are attracted by bait or pasture, whereas cephalopods are caught because they use them as a refuge or a site to spawn. In Mediterranean small-scale fishing, traditional pots are used to catch molluscs and crustaceans in the local area (Grati et al., 2010; Amengual-Ramis et al., 2016). This is in line with the high efficiency of the experimental pots reported in the Barents Sea (Furevik et al., 2008) and the Baltic Sea (Königson et al., 2015), where pots showed similar, if not higher, catch rates than those of passive nets. Pots are preferable for catching specimens with higher quality because they don't damage them, and don't require any additional rigging or on-board practices (Suuronen et al., 2012; Olsen, 2014).

Table 4: Possible innovations in passive gears that would reduce the impact on seabed and vulnerable species. ROI: Return on Investment; Catch: Catch efficiency; Ecosystem: Potential for ecosystem impact reduction; Seabed: Potential for short-term seabed impact reduction

Innovation	ROI	Selec-tivity	Catch	Eco-sys-tem	Sea-bed	Description	References
Lobster condos	3,2	3,3	3,3	3,3	3,3	Same idea of a Fish Aggregating Devices (FAD) but stored on the bottom. They are often made of wood and roof tins and cinder blocks and look like pallets. The spiny lobster (Panulirus argus) likes to shelter under them, and divers can easily collect them. The innovation replaces wood with steel to having release of toxic into the water.	FAO
Raised Trammel Net (Aranha)	2,2	4,2	4,2	4,2	3,2	A standardised trammel net that is raised off the bottom to avoid bycatching corals and sponges	redelusa.pt
Biodegradable nets to reduce ALDFG and improve EOL recycling	1,1	1,3	1,3	4,3	2,3	Development of biodegradable gear(parts) in the marine environment and/or the improved recycling of fishing gear at the end of its life. However, some issue with lower catch rates for gillnetters.	INDIGO
Modified gillnet to reduce ghostfishing and to aid recover of lost gear	3,2	3,3	3,3	4,3	2,3	The modified gillnets incorporate biodegradable cotton twines (recommended 2 mm diameter) in the float line attachments. By collapsing the gear when the biodegradable floating line is degraded, this reduces ghost fishing whenever the gear is lost.	depaq.ufrpe.br
Pinger to reduce cetacean-fishery conflicts and mitigate bycatch	3,2	2,3	3,3	4,3	2,3	Interactive pingers application to reduce bottlenose dolphin (Tursiops truncatus) interactions with trammel nets. The performance in reducing bycatch is not high.	Buscaino et al. (2021)

Innovation	ROI	Selec-tivity	Catch	Eco-sys-tem	Sea-bed	Description	References
Circle hooks on a Med.-wide longline swordfish fisheries level	2,3	3,3	1,3	4,3	2,3	Circle hooks on longline fisheries targeting swordfish to reduce bycatch of sensitive species (sharks and sea turtles).	Carbonara et al. (2023)
Modified blue swimming crab pot to reduces ghostfishing	2,3	3,2	3,2	4,2	2,3	The new modified pot employs biodegradable cotton material for fixing the pot's entrance. When the pot is lost or left in the water for a certain amount of time (nine months maximum), the cotton twine that fastens the entrance will degrade and reduce ghostfishing.	FAO
Alternative artificial baits to improve longline efficiency	1,2	3,3	1,3	3,3	2,3	Longline efficiency could be improved by taking the unique properties of a chemical stimulus into account and developing a long-lasting bait that attracts fish from a large area over a long period of time. This would improve species selectivity.	Løkkeborg et al. (2014)
3D machine vision allowing catch analysis (CatchSnap)	-	2,3	2,3	3,3	2,3	3D machine vision unit for inspecting catch samples on small fishing vessels. The CatchSnap- Commercial is a mobile product which will aid in the automatic registration of catch information in commercial fisheries	Calderwood et al. (2023) and everyfish.eu
Black seabream fish pot	2,2	3,3	3,3	3,3	2,3	Floating fish pot, conception based on target species behaviour. High quality catch	Méhault et al. (2022)
Nylon leaders to reduce shark bycatch mortality in longline	3,3	4,3	3,3	3,3	2,3	Nylon leaders can be used to replace wire leaders that are too strong to be cut by sharks	Fauconnet et al. (2023)
Image analysis technology (CatchMonitor) to enable efficiencies in REM	-	2,3	2,3	3,3	2,3	CatchMonitor is a system for automatic monitoring and analysis of a catch using CCTV cameras in Remote Electronic Monitoring system	Birch et al. (2022) or smartfish2020.eu
Waste heat recovery system for increasing	3,1	2,2	2,2	3,2	2,2	A portion of the heat loss can be re-used to supply a Waste heat recovery System (WHRS) to collect the heat waste and	Notti et al. (2016)

Innovation	ROI	Selec-tivity	Catch	Eco-sys-tem	Sea-bed	Description	References
energy efficiency						generate electric energy through a turbine, which can be used to supply electric devices and reduce the energy requested to the internal combustion engine, lowering the amount of fuel used.	
Lobster anti-ghost fishing device (Eco-trap)	2,1	4,2	4,2	3,2	2,2	Eco-traps are built with iron and included cotton yarn and sisal twine as biodegradable materials. This improves reducing the ghostfishing. Eco-traps are collapsible, which facilitates their storage on the deck of fishing vessels.	depaq.ufrpe.br
Visual deterrents to reduce sea turtles' bycatch in set net fisheries	2,2	3,2	3,2	3,2	2,2	the development of visual deterrents such as Light Emitting Diode (LED) lamps and light sticks to be attached to set net float lines	Lucchetti et al. (2019)

2.3. Switching to passive gears targeting demersal species

A significant reduction in seabed impact can be expected when bottom trawls are replaced by passive (static) gears anchored on the seabed until they are retrieved such as traps and gillnets which have a hugely reduced footprint compared to towed gears (Jennings et al., 2001). However, **to be a viable alternative, passive gears' catch and economic efficiency must be sufficient to offset the relatively high catch volumes derived from mobile bottom contacting gears**. Conduct feasibility studies of switching gears are required to compare options based on practicality, cost-effectiveness, efficiency, and enforceability. These studies should aim to quantify how easy it is to use the new gear without significant changes to common fishing practices, its maintenance cost, time-saving benefits, ability to catch a wide range of species, and how easy it is to control and inspect by the authorities. Considering all these factors, we can determine the most suitable gear switch option that benefits the fishermen and the environment.

2.3.1. Efficiency in reducing the environmental impact of passive gears

A potential replacement of bottom trawling would be to use static gear such as traps, creels, or pots, all of which have limited effects on benthic species and habitats (see Sala et al. 2023 and reference herein). The swept area of each pot during retrieval is less than 2 m^2 (Kopp et al. 2020), which is negligible compared with mobile bottom contacting gears. However, very large traps impact the seabed, but such gears are not extensively used in Europe (Kaiser 2014), except for tuna traps in the Med (Tsagarakis et al. 2017). In parallel, **long-lines are highly selective** due to hook size and bycatches of invertebrates are virtually non-existent (Løkkeborg and Bjordal 1992). Hence moving from towed to static gears has co-benefits in reducing gear footprint and impact on the seabed, increasing target species selectivity and decreasing bycatch (Sala et al. 2023 and reference herein).

However, **a major concern against using passive gears widely is the risk of increasing the bycatching of endangered, threatened, and protected species, as well as inducing more ghost**

fishing: i) unselective fishing to non-target species is an issue that is common to trawl and passive gears. In the case of passive gears, if such gears are highly size selective compared to MBCG, marine mammals and birds or reptiles are bycaught in nets (Königson et al. 2009; van Beest et al. 2017; Žydelis et al. 2009) and bycatch reduction devices would consist of visual or acoustic deterrent devices attached to the nets or the traps to avoid catching unwanted species. However, the performance of such devices is still under question (STECF-19-07). ii) Ghost fishing is an issue raised by lost fishing gear (nets and pots or traps) at sea whenever the gear continues to fish without the catch being retrieved (Jennings et al. 2001). The probability of static gear continuing to 'ghost fish' is highly variable, as demonstrated by several observational and experimental studies (Kaiser et al. 2005). Ghost fishing is less prevalent in trawl net fisheries because the lost trawl collapses under its weight in the water if not towed. **Several ways exist to reduce ghostfish, including using biodegradable materials to make nets and traps or rope-free fishing with remote sensing to retrieve gears** (Stevens 2021). Besides, even if pot and trap have the potential to ghost fish for the most prolonged period, they likely cease to fish once all the bait has been consumed (Adey et al., 2008).

2.3.2. Cost-effectiveness of fishing with passive gears

A shift from towed to static gears may also involve radical changes in fleet structure, crews' skills and culture, overall catch sizes, and economic efficiency of the fishery, with different vessel sizes, range and fishery coverage, which require a feasibility study. Economic efficiency might also be lower than that of a sizeable mixed fishery, at least in the short term. Producer Organisations and cooperatives may, however, offer support to mutualise the fishing opportunities and improve the working conditions and profitability of their membership alongside diversified sales opportunities (auction markets, private contracts, or direct sales). **Passive gear users may also experience shorter fishing seasons due to the highly variable catchability of these gears throughout the year**. Organising the co-existence between passive trap fishery and active trawl fishery is also a challenge given the competition for space and fishing grounds, even more so if trawling would increase outside the MPAs.

Static gears require less initial investment and ongoing maintenance and are more easily fished from smaller vessels (Kaiser 2014). Operating passive gear is also often safer and easier to use requiring minimal training and is usable in all aquatic habitats without seasonal and environmental limitations (ICES 2006). For this reason, fisheries using passive gears are often dominated by smaller vessels. Such smaller vessels are therefore visiting more coastal areas given a lower mobility range, while trawling requires vessels with more power to tow heavy nets and haul them with the catch back onboard and is typically more prevalent in sea areas with open soft substrate habitats (Sala et al., 2023). Static gears are used more frequently on marginal grounds, mixed substrates, rocky bottoms, around obstacles such as shipwrecks, or areas specifically closed to trawl fishing (Eigaard et al., 2016).

Sala et al. (2023) notes that to date in Europe, the trap fisheries that catch species traditionally caught by trawl essentially target *Nephrops* in certain fishing areas (e.g., Western Scotland and the Swedish West Coast where the Swedish trap fishery is more profitable than the Swedish trawl fishery targeting *Nephrops*). **Establishing a passive gear fishery in a prior trawl ground, the low catch efficiency could be due to the ground degradation operated by trawling**. Therefore, a recovery plan (e.g. with spatial and/or temporal fishing restrictions) may need to be implemented to recover the target species, before that fishery can be introduced in that restored ecosystem. On the long run, passive gears can obtain higher quality catch that are also priced more because catching lower volume at once compared to large volume caught in demersal trawls and seines, even if seiners catches can also be more valuable given the low residence time of the catch in the seine codend. The catch entangled in the net may however be eaten by large predators before hauling, e.g. by seals (in Sala et al 2023) but seal-safe gear may counteract this.

2.3.3. Practicality of switching to passive gears

Delivering different seafood to the market from one day to the next is a practical issue that may prevent or at least limit the shift to other types of target species. This would require skills to connect with other markets, access quotas for such species, and other practicalities such as e.g. extra harbourside warehouse space to store the other gears when not in use (Schadeberg et al. 2021). Especially quota limitation in the NEA already drive the targeting behaviour and when, where and how to fish to influence the catch composition that would best fit the quotas available. Hence, it is most likely the shift from MBCG to passive gears would be easier only if a similar assemblage of species can be caught with the passive gears.

In practice, **it is actually possible to catch the same type of species using passive gears**. As Kaiser (2014) recalled, beam trawlers catch flatfish, some roundfish, and brown shrimps, while otter trawlers catch primary roundfish, Nephrops, and scallops. Dredges are used to catch scallops, mussels, and clams. Passive gears such as gillnets also catch flatfish and roundfish species, and trammel nets are used to catch flatfish species, rays, and certain crustaceans in all states of the tide, while tangle nets target monkfish, elasmobranchs, lobsters and crabs. Pots and traps are suitable for catching crabs, lobsters, prawns, and some fish. Bottom-set longlines can be used to catch demersal species being hundreds of meters long lying on the seabed and set with hooks. Therefore, catching similar species when switching to passive gears is not a big obstacle.

In local circumstances and specific to some fish stocks, **there may be technical constraints to deploying static gears, for instance due to currents and wave actions** (Sala et al. 2023). Traps require different skills than trawls and crews, which would call for a renewed education of the crews embarking such vessels operating passive gears (Sala et al. 2023). Operating passive gears also come with different trip patterns as there is an optimum soak time after which the catch rate of the gear decreases considerably, requiring consideration that catches are at risk from damage by seals and crustacean scavengers such isopods and amphipods within 24 hours (Kaiser 2014). Hence, the frequency with which the gear is hauled will depend upon the cost of retrieval, catch rate and losses to catch degradation.

Conversely, fishing vessels using passive gears are often polyvalent and already know how to operate different fishing techniques, strategically switching gears and mesh sizes throughout the year to target different species (Schadeberg et al. 2021). By changing fishing techniques, some fishers can monitor the quality, availability, and market value of a particular species alongside determining week to week whether they will target it (Schadeberg et al. 2021).

The physical conversion of bottom trawlers to fish with passive gears would mean phasing out current trawlers by retrofitting them to operate such fishing techniques. This is because passive gears on current vessels may be non-ergonomic compared to vessels specifically designed to fish with traps (Sala et al. 2023). Such adaptation will be **costly**. However, the viability of fishing fleets including many demersal trawl fisheries may only profitable at present because of fuel tax exemptions, while rising fuel costs further threaten them, while operating passive gears is less fuel demanding. Besides, gillnets are cheap to produce and can be deployed by hand from small vessels (Kaiser 2014). Unfortunately, retrofitting is expected to not suit all local circumstances. For example, the project PASAMER[14] investigated the possibility of operating set longlines from a former trawler (33 m, 13 crew members). The project concluded that this technique was unsuitable for capturing the targeted species as the commercial catches appeared insufficient in view of the costs of operating a 33m vessel with 13 crew members. That being said, although the tests have not been conclusive on a specific fishery, the project has noted that it could have an interest in smaller vessels targeting high-added-value species.

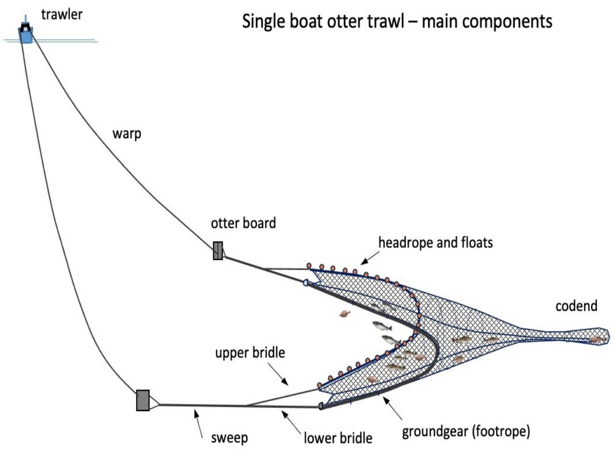
[14] https://www.francefilierepeche.fr/projets/pasamer/ led by Ifremer and France Filiere Peche

The use of passive gears also requires a marine space occupation which is incompatible with the use of trawl requiring large area swept (Kaiser 2014). Areas that are heavily fished with static gear represent a navigation hazard to vessels, especially those using towed bottom fishing gear (MacFayden et al. 2009). Deliberate acts of vandalism of passive gear by trawlers have also been reported (Kaiser 2014). **Fishing gear zoning regimes** have effectively minimised conflict among different sectors in several circumstances. However, such arrangements are not frequently reported. These management systems are most vulnerable to violation by itinerant fishers from distant ports (Kaiser 2014). This adds to the issue of displacing bottom trawling effort out of MPAs (see Annexes) that will likely come with an increase in the competition for access to the same marine space and with conflicts between mutually exclusive gears resulting in damage to the fishing gears (Kaiser 2014). Such conflicts impair the development of new fisheries, and also may be the first cause of fishing gear lost at sea and the subsequent 'ghostfishing', a risk that could be reduced with better communication among skippers in the two sectors (MacFayden et al. 2009), or stricter and enforced zonation (Blyth et al. 2002).

2.4. Barriers to the uptake of innovations in fisheries

Trawling can lead to a high proportion of the catch that is unmarketable because the size of the catch is below the minimum landing size, there is low survival of the non-retained fish, high fuel consumption and a large area impact per kg of fish landed, as well as conflict with other fishing techniques such as passive gears. Nevertheless, a switch to other practices has not happened, also because the use of alternative fishing techniques is perceived less efficient, labour intensive and more costly (provided the fuel tax exoneration is in place for the use of fossil fuels). Hence, **innovations uptake by most fishers often remains low** (Steins *et al.*, 2022; Pol and Maravelias, 2023), and is guided by the interplay between a variety of social, policy, and science-related factors influencing the readiness, willingness, and ability of fishers to adopt proven fishing gear (Steins et al., 2022; Jenkins et al., 2023). Even if a voluntary uptake of new measures by industry is preferable, restrictions on fishing opportunities is often necessary to introduce innovative gear designs (Catchpole and Revill 2008). In absence of restrictions, fishers considering using an innovative gear will first consider the capital cost (i.e. upfront cost) of that gear; if this is deemed attractive, they will then consider the potential Return on Investment (ROI), defined as the profit fishers derive from catch landings and catch quality following investment in an innovative gear minus the costs associated with the operation of that gear (purchase, fuel, ice, bait, boxes, repairs etc.). **The anticipated financial performance affects the potential of these gears to be taken up by commercial fishers**. Some

Figure 8: Components and terms of a typical single boat bottom otter trawl. Different types of otter boards and groundgear (footrope) can be associated to it



Source: Extracted from He et al. 2021.

Initiatives have developed guidance tools to assess such performance in pilot studies[15]. It is usually expected that the ROI and innovation uptake are directly dependent on:

- Change in catch efficiency

For a long time MBCG have been designed to maximise the catch. Accommodating other goals such as minimizing the bycatch of unwanted species and fish size, as well as reducing the impact on seabed is most likely contradicting this optimisation. **There are then concerns about losing catch efficiency when implementing innovations**. For example, using a semi-pelagic trawl with 'flying doors' will remove the sediment plume induced by the doors of a conventional trawl (Figure 8) when penetrating the sediment profile, while this resuspension can be a desired feature to maintain catch rates. Hence, the fish 'herding' properties of the sweeps may be of particular importance when fishing with mid-water doors, as the lack of contact between the doors and the seabed means that no sand cloud is created by the sweep section to contribute to the herding (Guijarro et al., 2017). Bottom sweeps are known to be very effective for herding benthic species such as skates and flatfish (Ryer 2008). Although lifting the doors from the seabed is touted as a positive development for the bottom trawl fleet targeting cod (Gadus morhua) in the Barents Sea, fishing with the lifted sweeps led to 33% of cod catch losses in comparison with the setup that kept the sweeps at the seabed (Sistiaga et al., 2015).

- Upfront costs

It is true that **some innovations have upfront costs that need to be overcome for an uptake to happen**. Hence, albeit efficient to reduce fuel consumption the use of Dyneema net is still very expensive on the world market (Thierry et al., 2019). Fishers are reluctant to change fishing gear primarily because of concerns it will be costly or painful, lacks incentive, results in a loss of control, or comes at a time of uncertainty about the future (Eayrs et al., 2019). None of the hundred innovations these authors listed have been implemented at the time of their study. In EU, some fisheries are already at the edge of profitability and, therefore, not eager to take the risk. Some other fishers would feel unfairly constrained if using selective devices compared to others who would not (Suuronen 2022). **Economic viability studies** are also lacking to support the claim of scientists, leading to some fear of unnecessary economic losses from lower income from missed catches (lower catch rates). Financial benefit is not always sufficient inducement for fishers to change their gear, also because of upfront costs. Often, financial incentives do not produce the desired outcome. For example a $2500 rebate to encourage the purchase of semi-pelagic trawl doors by fishers in New England proved of limited effectiveness at a time when fuel prices were at a historic high (ICES WGFTFB, 2016).

- Prioritisation of short-term over longer-term effects

Improvement of size selectivity or fuel use efficiency in fisheries currently using bottom trawls will only be reached in a long-term horizon impairing the successful uptake of technological solutions in the short term (Guijarro et al. 2017). However, for bottom trawling, fishers and managers lack of a clear vision about what the policy on this activity would look like in 5 to 10 years' time. Hence, the provision of facts alone is inadequate to achieve innovation uptake. There is also a mistrust toward innovation, and scientists and fishers do not believe in accurate scientific data collection (Suuronen 2022). It is also found that fisheries change agents often do not have the proper training to inspire change (Jenkins et al., 2023). Fishers can also question the rationale for implementing selective devices if they do not believe in the survivability of fish going through the mitigation devices. Fishers are also not offered follow-up studies that would prove the performance. If the main motivation behind adopting an innovation is to increase revenue by catching more, **implementing measures to**

[15] E.g. Best Practice Guidance for Assessing the Financial Performance of Fishing Gear: Industry-led gear trials. Prepared for the UK Fisheries Economic Network (UKFEN) by Seafish

sometime catch less may seem counterintuitive. However, it is possible that reducing catch can lead to a net positive economic effect if the decrease in catch efficiency is offset by reduced fuel costs, a gain that is only perceived in the longer-term. Hence, fishers are often hesitant to make changes in their fishing practices, even when presented with evidence that new fishing gear could increase efficiency, selectivity, or reduce costs (Eayrs et al., 2015).

- Safety concerns, difficulties in operating the new gear, and habits

Fishers also express concerns against innovation that seems to work on paper but is unpractical when it comes to operating the fishing (for safety reasons, handling time, etc.). The innovation can be more difficult to operate practically (e.g. when shooting or hauling the gear). It is more likely that increased performance typically requires a more finely tuned system, which might not be the priority or accessible to all operators. For example, the JUMPER doors (see the JUMPER project) have proven to be more efficient at saving fuel with less impact on the seabed require careful monitoring during the trawling, also demand electronic system and instruments to track the position of the gear underwater to maintain optimal catches, by nature making these gears sensitive to such tuning. Hence, in-operation data of door spread, and their vertical position are essential for the vessel captain, to constantly optimise trawling speed and warp length during fishing operations (Sala et al., 2023). Such innovation can lead to the development of new gears or **gear components that may affect the safety and working conditions of the crew** by making fishing operations slightly more challenging. Hence, easing the operation in practice would require the R&D in fisheries technology science to continue to find operatable ways to preserve the seafloor integrity including new technologies and fishing techniques converting to more bottom-friendly gear for relevant/possible target species and technological solutions for species that can only be caught effectively with a certain type of gear. On the other hand, implying all partners in a dialogue between scientists, fishermen and netmakers ease the development of new gears on one hand and leads to a mutual understanding of the challenges and results on the other, limiting the suggestion of unfit solutions (Feekings et al., 2019). Finally, fishing operators are often specialised by having a stable fishing strategy in terms of gear, target species, and location. For those fishers, social scientists observed that tactical behaviour at sea may be more habitual and risk-averse, expecting such practical knowledge to be an investment on future economic return (Schadeberg et al. 2021).

- Regulatory barriers

Fishing in certain areas is limited by law through quotas or fishing effort regulations. This means that **most skippers must explore their catch optimisation with gear modifications or alternative fishing techniques within the available quotas or maximal effort allowed**. However, this reallocation of effort would require some skippers/vessel owners to invest heavily in new gear and quotas to continue targeting specific species with these new techniques. If a gear modification is chosen instead of a shift to some alternative gears, it also requires that the developed and scientifically tested modified gears will first be implemented in legislation. The regulator may consider implementing financial support or a compensation scheme if quotas cannot be transferred. This is because quotas are determined by the biological capacity of renewals of the stocks, not by economic limitations and therefore cannot be increased to content the fishing industry. The regulator would have the possibility to also make financing projects easier to align the fleet with fishing opportunities. Experience showed a lack of loan opportunities to finance the implementation of innovative solutions (Frandsen et al. 2015) or reallocation of effort toward alternative fishing practices. A difficult reallocation of opportunities among fishing agents is likely to lead to a lack of acceptance of a policy promoting a shift. This would require strict enforcement and expensive monitoring, control and surveillance to penalise those who engage in irresponsible fishing, as non-compliance with technical measures is possible and mistrust toward authorities goes high.

- Call for evidence

Impact studies would search to identify uncertainties, barriers, and leverage for the policy-makers to implement and follow up on innovative solutions that could avoid banning the use of conventional MBCG from vulnerable MPAs. The analysis would further deduce the **extra fishing effort required to break even when adopting innovative gears**, the payback time, and economic feasibility. Some solutions may need less payback time than others. For example, even if innovative trawl doors mitigating the contact with the seabed could double the cost of traditional doors, fuel savings may give a payback time of 100 days at sea, i.e. less than one year (Sala et al. 2023). Such studies would need to further discuss the ecological feasibility of a change in target species assemblage, possible implications on the bycatching of sensitive species when converting vessels to operating innovative/passive gears only, and other possible implications (e.g., seafood value chain disruption). Some of the difficult bits related to the socioeconomic impacts or vessel design requirements may require data information retrieval from the stakeholders through questionnaires.

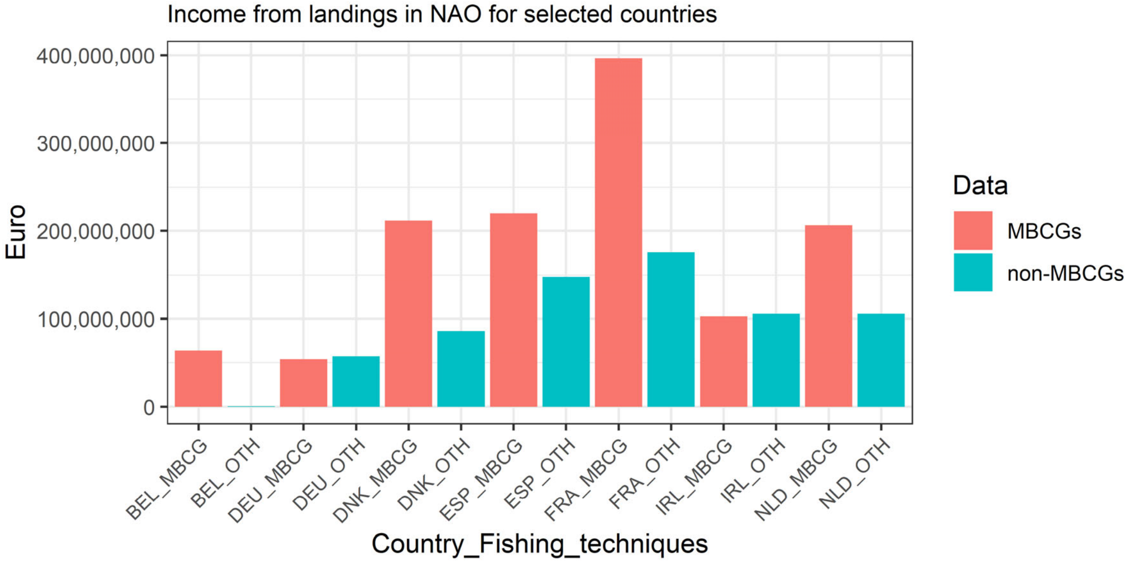
3. Anticipating the socioeconomic and environmental impacts of mitigating the effects of bottom trawling or displacing it away from MPAs

Mobile bottom contacting gears have affected and still affect the benthic habitats by direct mortality on the trawl path, and by causing long-term change to the seabed habitats and their productivity by repeated disturbance (Watling and Norse 1998), even if relative equilibria in the short term can let bottom trawlers and some scientists in the 90s think this activity is like 'farming the sea' (Jennings et al. 2001). The study proposes to measure to which extent displacing this pressure away from the MPAs will improve or at least maintain the current baseline status of the benthic habitats in the short term while affecting the economic revenue that the concerned fisheries used to make going at sea (Figure 9) and related crew members (Figure 10). Note that Figures 9 and 10 include all ongoing activities for selected countries in the NAO without considering MPAs. Displacement in reaction to MPAs could be a spatial reallocation of the fishing effort deployed, or a reallocation to alternative fishing techniques. It should be borne in mind as a disclaimer that the present study does not have the capacity to evaluate the benefits of protecting biodiversity in the longer term (recovery, recolonisation, 'overyielding' hypothesis stipulating that mixtures of species produce more biomass than every one of their constituent species in isolation, etc.).

As anticipated by McConnaughey et al (2020), prohibiting certain gear types spatially will likely reduce the seabed impact of bottom trawling by eliminating high-impact gears in a defined region, at the same time reduce harvest of some target species if high-impact gears were more efficient, also possibly induce more or new bycatch risk when effort displacement occurs. This might increase stability and ecosystem function alongside improved benthic habitats or decrease it elsewhere. The overall environmental effect could be positive if the effort is displaced from vulnerable to more resilient areas. New economic opportunities may develop for alternative fisheries that may compensate for loss in catches. In the long term, this may induce increased costs if less efficient gears are adopted or reduced costs if less efficient gears are replaced, with subsequent socio-economic impacts.

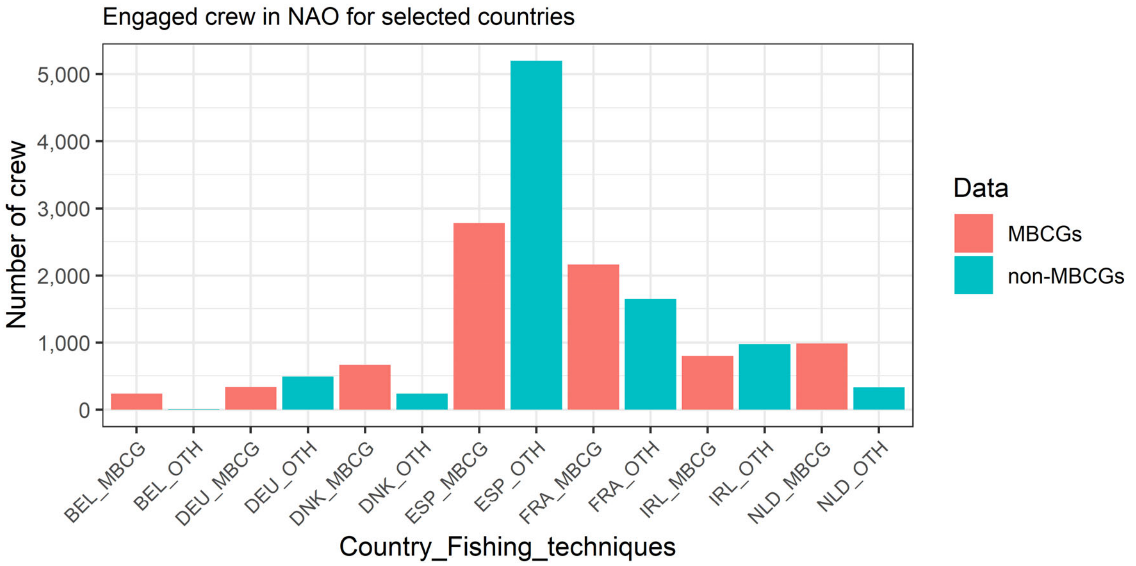
The present evaluation proposes to measure the environmental and socioeconomic effects by looking at a raw of sustainability metrics including i) the opportunity costs ('manque à gagner') if the historical landings made out of MPAs would be missing, ii) the impacted engaged crew on concerned vessels, iii) the change in Relative Benthic Status RBS and impact avoided (for example per euro missed), iv) the change in bycatch risk from different exposure to fishing effort, v) the possible short-term change in fuel use from extra effort to break-even, v) discussing the change in pressure on blue carbon habitats.

Figure 9: The 2021 income from landings for selected country fleets active in the North Atlantic Ocean (NAO) split by MBCGs and alternatives to MBCGs (i.e. pooled in a OTH category)



Source: Own elaboration from STECF AER 2023 database.

Figure 10: Engaged crew in 2021 for selected country fleets active in the North Atlantic Ocean (NAO) split by MBCGs and alternatives to MBCGs



Source: Own elaboration from STECF AER 2023 database.

3.1. Not all MPAs are vulnerable to MBCGs

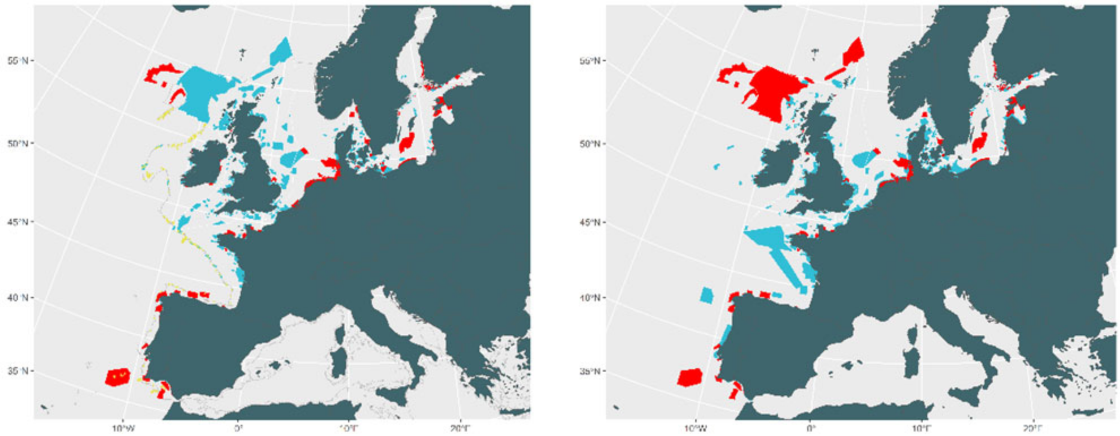
There are different types of marine area protections, from no-take areas to fisheries restricted areas (FRA) and other area-based fisheries management measures typically constituting Essential Fish Habitats (EFH) and in EU embedded into the Common Fisheries Policy and described in the EU Technical Measures Regulation. Such closures are either seasonal closures or spatial closures, or both temporal and spatial closures whenever implemented to protect areas during periods of high species density or during a vulnerable life history stage, for species targeted for their commercial interest or non-target species but vulnerable to fishing while protected, threatened, or endangered (PET species). Complementary to this, safeguarding areas of high biodiversity intends to maintain the integrity of such areas to continue providing ecosystem services (e.g. Thrush and Dayton 2009), including their contribution to fisheries, for example, arising from a spill-over effect of fish biomass in their surroundings (e.g., a meta-analysis in Ohayon et al., 2021) or as a source of larvae for recolonisation of disturbed seabed (Lambert et al. 2014). These hotspots of biodiversity areas and a vivid source for other areas would usually constitute the ideal Marine Protected Areas (MPAs).

In the EU, the designation of these MPAs has been a long process after carefully evaluating the Habitats and the Birds EU directives requirements (listing species and habitats to be protected, see Annexes of these directives). Hence, the designation of specific species and habitats to be protected has led Europe to build the so-called NATURA 2000 network, both on marine and land ecosystems. In the marine context, enforcing such a network of protected areas should ensure coherence and complementarity between the CFP and environmental policies, fully coherent with an ecosystem approach to fisheries. However, to date, if the component to be protected is most of the time well identified (a species, or a specific habitat), the specifications for the human activities that would be mitigated or otherwise excluded from the individual MPAs are still lacking for most of them (e.g. see a review in MAPAFISH, or HELCOM Action).

However, what is the detailed effect of trawling on components that MPAs aim to protect is still an ongoing field of research, even if numerous research works have documented basic evidence of an effect for the most frequent combinations of fishing techniques and habitat/sediment types (e.g., Rinjsdorp et al 2021). What is less known is how ecosystem functions of benthic communities are altered by mobile bottom contacting gears and to what extent these habitats can withstand such pressure, which require an understanding of the function of species and their sensitivity to such pressure (Larsen et al., 2005; Bolam et al., 2017; Beauchard et al., 2023). In the absence of such detailed knowledge in the present study, it is assumed that the vulnerability to certain practices is deduced from the biological components that are to be protected by the legislation designing those areas. However, so far, information on seabed recovery times has rarely been used to define spatial management plans that minimise seabed impacts. Management plans that limit the use of MBCG to more resilient areas and maintain permanently unfished patches within these areas would likely minimise the impacts of a given amount of fishing effort on seabed habitats (Lambert et al. 2017).

Assessing the features that led to the designation of the Natura 2000 sites makes it possible to characterise vulnerable areas to MBCG (Bastardie et al., 2023, Figure 11, Table 5). These features included marine habitats and species that are mentioned in the EU Directives. Hence, nine marine habitat types are defined in the EU Habitats Directive as natural habitats types of community interest whose conservation was classified as vulnerable to MBCG: 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. A list of species that are protected under the Bird's or Habitat's Directive are reported in standard data forms for species under Annex II-IV of the Directives, reclassified here as marine mammals, birds, fish and invertebrates. Sites were considered vulnerable to MBCG when 'Invertebrates' were listed.

Figure 11: Left: Marine areas vulnerable to mobile bottom contacting gears among the designated protection areas in the NEA (in red, exclusion enforced; in blue, not yet enforced in 2023) and 2022 enforced exclusion areas from VMEs (in yellow); right: Areas vulnerable to passive gears (longline and netters) in the NEA (in red, exclusion enforced; in blue, not yet enforced in 2023)



Source: Own elaboration based on Bastardie et al. (2023).

In parallel, there are other types of protected areas that have already implemented a ban on MBCG since 2020, which are the Vulnerable Marine Ecosystems (VMEs). These habitats of the seabed and their associated biology have been considered so sensitive that they most likely should not be fished at all (VMEs are fragile, unique, slow to recover, and habitats with structural complexity). As the trawls sweep over them, they snag the emergent fauna and drag them off the bedrock with no possible recovery before hundreds of years. They have long been passively protected by their remoteness, also explaining why showing pristine communities, but have been made more accessible to MBCG alongside the development of deep-sea fishing in recent decades. The EU Council Regulation 734/2008 was adopted to transpose UN resolution 61/105 on sustainable fisheries related to the impacts of destructive fishing practices, including bottom trawling on VMEs on the high seas. In 2020, the Deep-sea Access Regulation set the scene for banning bottom trawling below 800m in the NAO and in 2022, the EU implementing act closed 87 areas located off the coasts of Spain, France, Ireland and Portugal to protect VMEs from bottom fishing gears (bottom trawls and any other gears with bottom contact).

Table 5: Surface area in km-squared and percentage of the surface area of currently designated MPAs (2023 status) deemed vulnerable to MBCGs occupying the trawlable area in each EEZ of European countries in the NAO. Note that even if deemed vulnerable to MBCGs (following criteria identified in Bastardie et al. 2023), it does not mean the MBCGs are currently excluded from such MPAs. Source: Own calculation

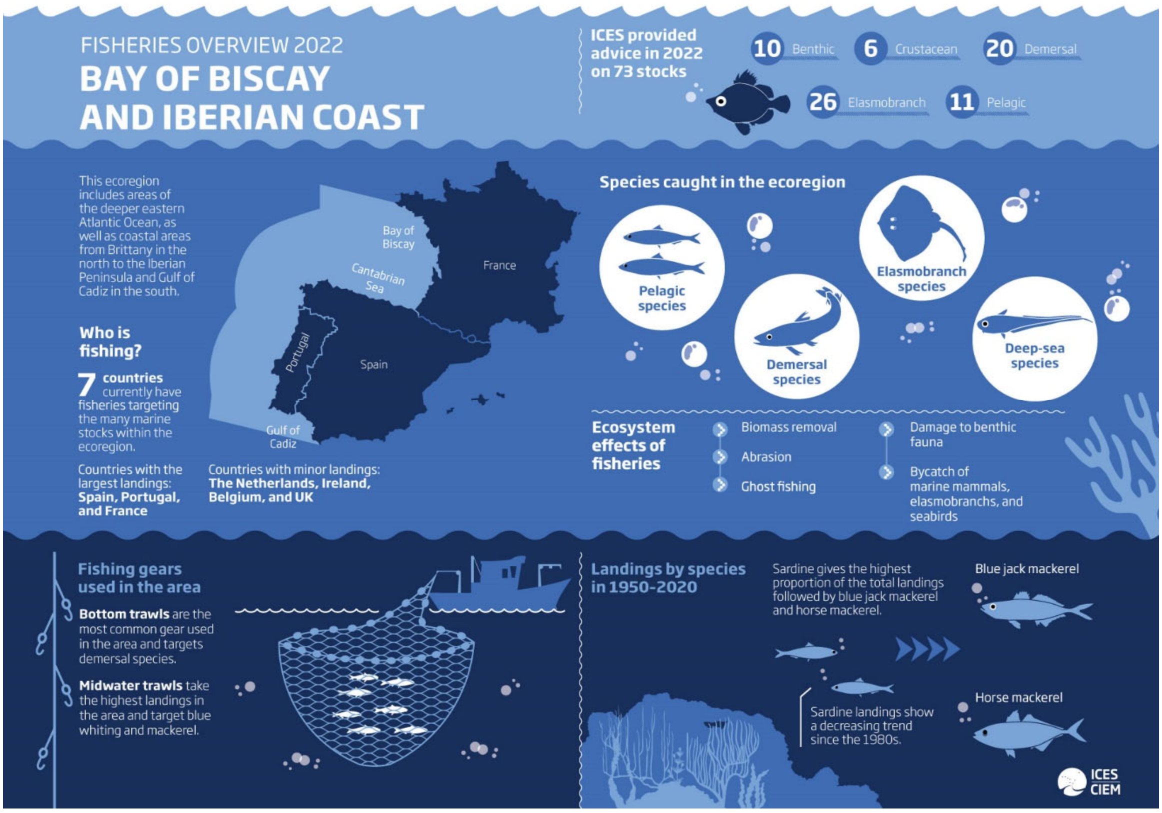
	BE	DE	DK	EE	ES	FI	FR
Km-sq of MPAs vulnerable to MBCG in EEZ	1480	31415	10415	10261	20834	4740	29318
Km-sq of MPAs vulnerable to MBCG in fishable area (i.e. <800m)	1466	28859	8039	8029	13012	4156	21944
Km-sq of fishable area per EEZ	3444	54936	99717	35922	44569	75851	153932
Percent of MPAs vulnerable to MBCG in the fishable area (i.e. <800m)	43%	53%	8%	22%	29%	5%	14%
	IE	LT	LV	NL	PL	PT	SE
Km-sq of MPAs vulnerable to MBCG in EEZ	6944	1146	732	15421	7026	28979	18356
Km-sq of MPAs vulnerable to MBCG in fishable area (i.e. <800m)	2779	1028	691	14117	5601	4091	17646
Km-sq of fishable area per EEZ	216880	5886	28765	61795	31311	36210	152769
Percent of MPAs vulnerable to MBCG in the fishable area (i.e. <800m)	1%	17%	2%	23%	18%	11%	12%

3.2. Not all fishing techniques are active in MPAs

A spatial overlay analysis between currently designated MPAs and fishing activities in the NAO region as a case study where fisheries are challenged (e.g. in the Bay of Biscay, Figure 12, or other areas described in ICES Ecosystem Overviews[16]) demonstrates that the degree of overlap is less than 10% in effort for most of the analysed fleet segments (Figures 13 and 14), demonstrating that the spatial dependency on the MPAs is limited. Such estimates of overlap confirm that a large fraction of the currently designated MPAs and vulnerable to bottom trawling have been designated to protect mainly rocky habitats, which does not affect the fishing grounds of most demersal trawling, such as trawling for benthic crustaceans, which live in muddy habitats.

It is anticipated that area closures in areas where existing fishing effort is low (such as in the currently designated network of Natura 2000 sites[17]) will lead to less effort displacement and are more likely to benefit benthic communities than closures in areas where fishing effort was high. This is a win-win as the socioeconomic impact would be minimal for the fisheries while the benefit would be maximal (see Bastardie et al. 2020 about concentrating the effort on core areas). However, such displacement requires caution as it is unknown to what extent the receiving habitat can support extra effort before the chronic effort disturbance reduces affected habitat resilience. Hence, heavily trawled areas in the North Sea have still been proven sensitive to extra pressure (see Reiss et al. 2009). Therefore, it is best to instore an effort regime and cut effort so as to reduce it by the fraction currently lying within the MPAs.

Figure 12: Bay of Biscay and challenges to fisheries



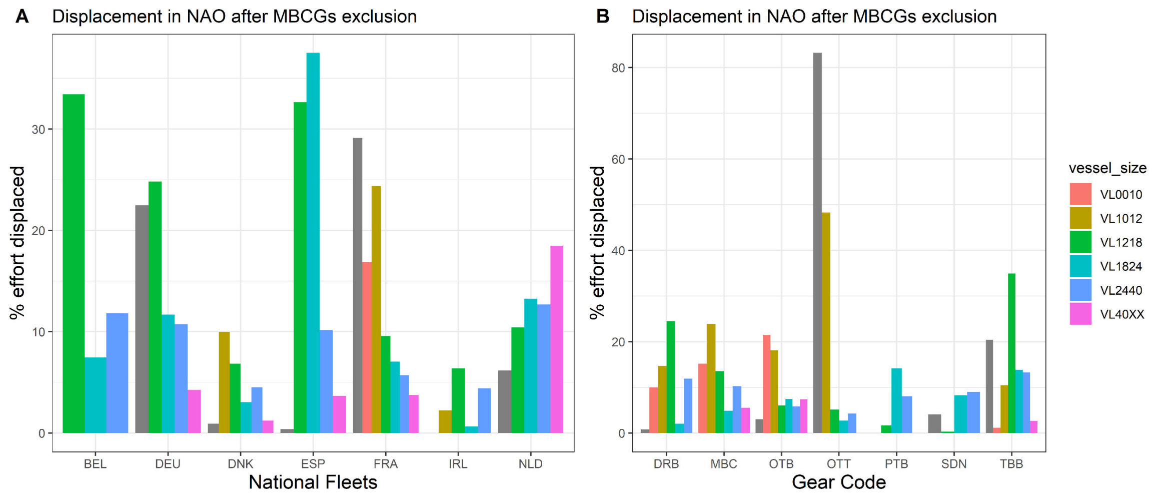
Source: ICES fisheries overviews 2022.

16 https://www.ices.dk/advice/ESD/Pages/Ecosystem-overviews.aspx

17 https://hub.arcgis.com/maps/eea::protected-sites-in-europe-natura-2000/about

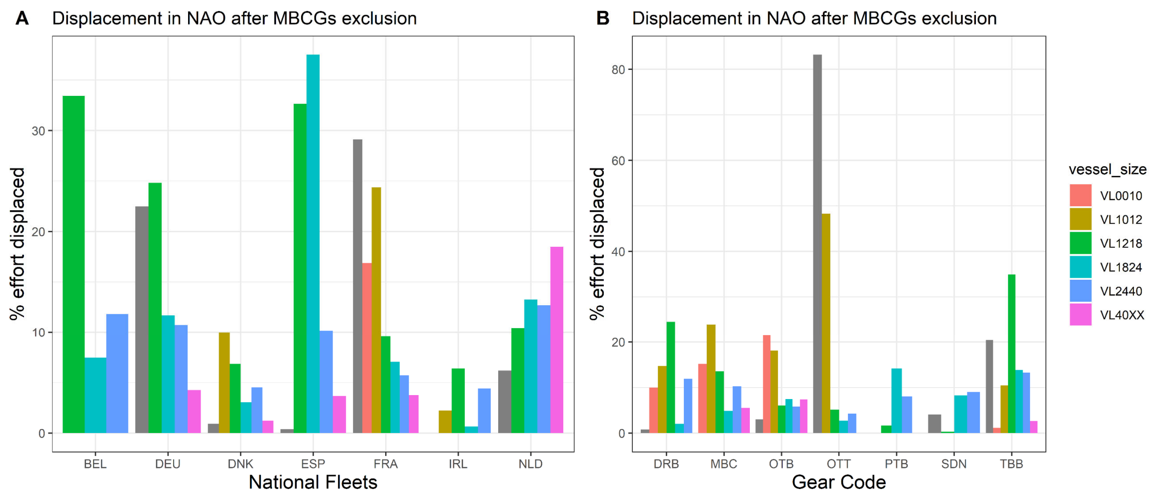
Areas identified as lightly fished are often those with high recovery potential (especially of the benthic community) and could be protected with both minimal harm to current fishing activities (Figure 15) and the maximum effect on ecosystem function (see section 3.3). To ensure an acceptable trade-off with the economic return, some management plans should aim at displacing the fishing effort from marginal (typically low catch rates) fishing grounds to core fishing grounds (high catch rate areas) (Bastardie et al., 2020).

Figure 13: Percentage of the historical fishing effort that would be affected by the closure if the MBCGs were to be excluded from the currently designated MPAs vulnerable to MBCGs for fleet-segments aggregated in a selection of countries, vessel size categories or gear types, and in terms of effort deployed in the NAO



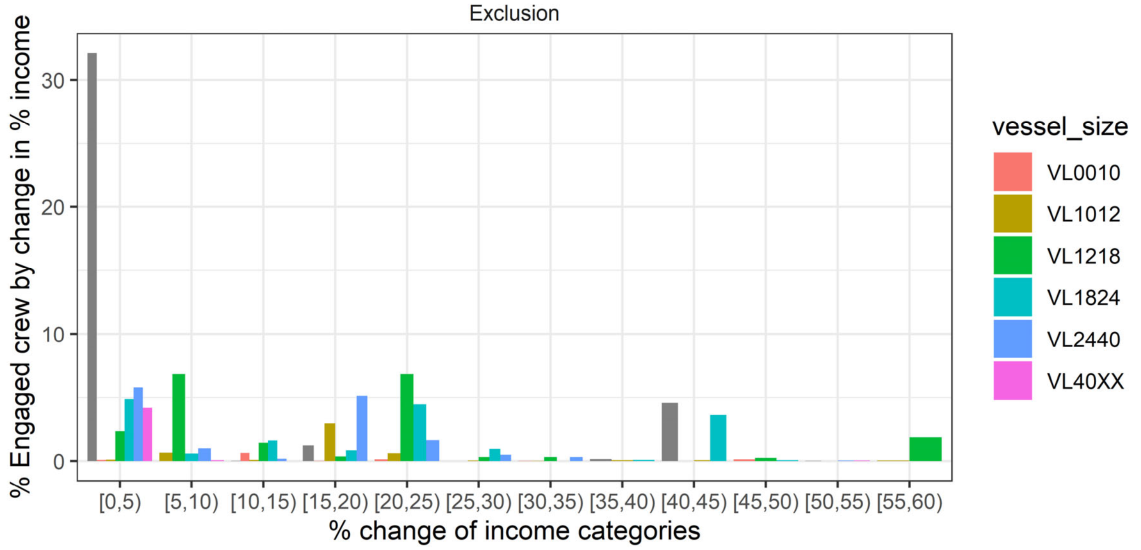
Source: Own elaboration from a spatial overlay analysis.

Figure 14: Historical landing value impacted by policy that would exclude MBCG



Source: Own elaboration.

Figure 15: Engaged crew impacted by an exclusion policy that would exclude MBCG per category of impact. The grey colour displays non-informed vessel category data



Source: Own elaboration.

3.3. Mitigation and/or effort displacement from vulnerable MPAs to MBCGs

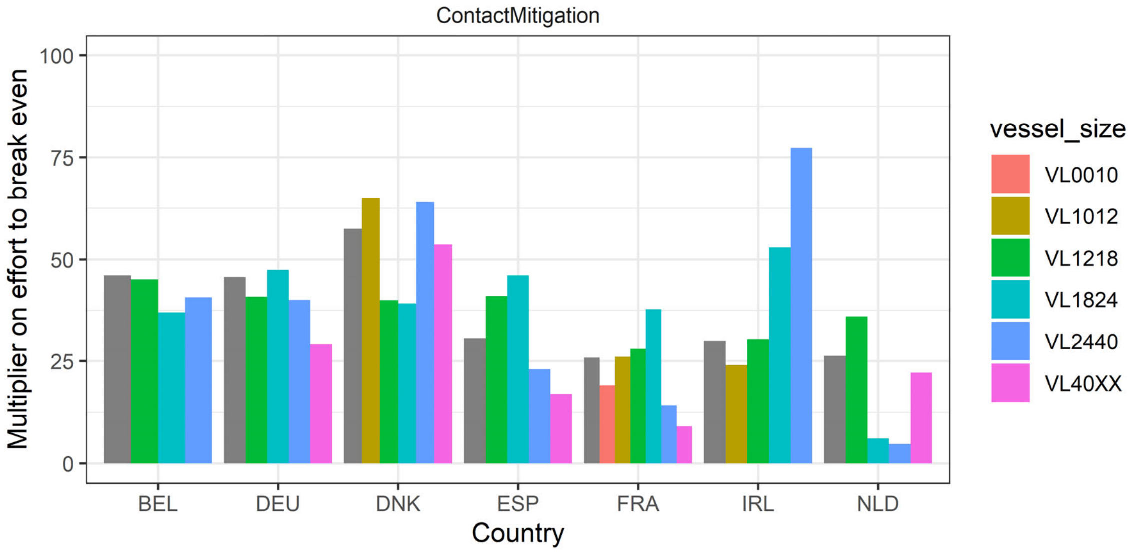
There are many points of uncertainty about the economic consequences of various types of management measures. A socioeconomic impact evaluation would ideally enable the impact assessment of changes in fishing pressure on the biological and ecosystem components with effects propagating to the economics of the fishery. Such assessment would include what would be the impact of policies on changing the pressure on the marine habitats on the seabed, as well as changing the risk of unwished, incidental catches of vulnerable species. If MBCG is likely to put some risk on the seabed integrity, there are ecological risks on components of the marine biodiversity induced by shifting toward alternative, passive gears.

To address some of those possible mitigation measures and risks, the present study has used fisheries-related data to map the fishing activities spatially and disaggregate those activities per fleet segment. This has consisted of merging vessel position data (VMS) to the Fisheries Dependent Information[18] (FDI) database to the Annual Economic Report[19] (AER) database to disaggregate EU fishing effort and cost structure spatially and per fleet-segment Data Collection Framework (DCF) Level 6 in the North East Atlantic (NEA) region and selected countries with sufficient data coverage.

[18] FDI database at https://stecf.ec.europa.eu/index_en

[19] AER database at https://stecf.ec.europa.eu/index_en

Figure 16: Extra effort that the fleet would deploy in the short term to break-even and induced by policy that would mitigate MBCG contact to the seabed alongside assuming a 20% loss in catch efficiency

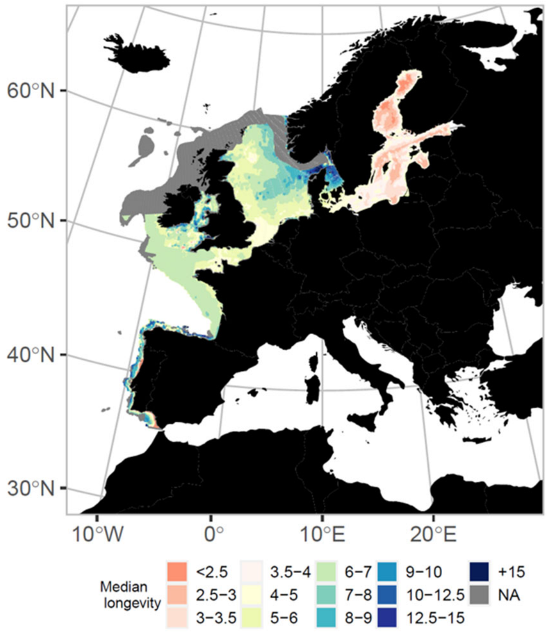


Source: Own elaboration.

The bycatch risk is determined by analysing and overlying the spatial distribution of fishing effort and the abundance of the studied species. The relative abundance were obtained from the SeaWise project (Astarloa et al., 2023) for an emblematic threatened bird species (Balearic shearwater in the Bay of Biscay), most bycaught fish species (skate and rays in OSPAR area) and a representative of marine mammals (short-beaked common dolphin (*Delphinus delphis* in the Bay of Biscay in spring and autumn distribution). The fish group comprised common skate complex (*Dipturus* spp.), blonde ray (*Raja brachyura*), spurdog (*Squalus acanthias*), tope (*Galeorhinus galeus*), spotted ray (*Raja montagui*), undulate ray (*Raja undulata*), starry ray (*Amblyraja radiata*), John dory (*Zeus faber*), Atlantic wolffish (*Anarhichas lupus*) and Atlantic halibut (*Hippoglossus hippoglossus*). Displacement scenarios of effort induced by the scenarios or increase of effort to break even change the overall bycatch risk per species group from a weighted average over grid cells. The attempt to offset negative GVA induced by spatial restrictions or a shift from MBCG toward passive gears may require additional effort. It is noted that the current calculation for bycatch risk has some significant limitations. Firstly, it fails to consider the cumulative effect of already active passive gears. Secondly, it only speculates on the risk based on the spatial overlap between the gear activity and the abundance rather than based on a fleet-specific bycatch rate per species group, which is not available in this study.

The impact of fishing on the seabed is determined by calculating the area of seabed swept, which is then deduced from the gear width being used, the typical fishing speed, and the detection of fishing

Figure 17: Average life expectancy (i.e. longevity in years) of the species making up the benthic community in the NEA, split per class of longevity. In the NEA area shallower than 800 meter deep (part of the Celtic Sea is still missing)



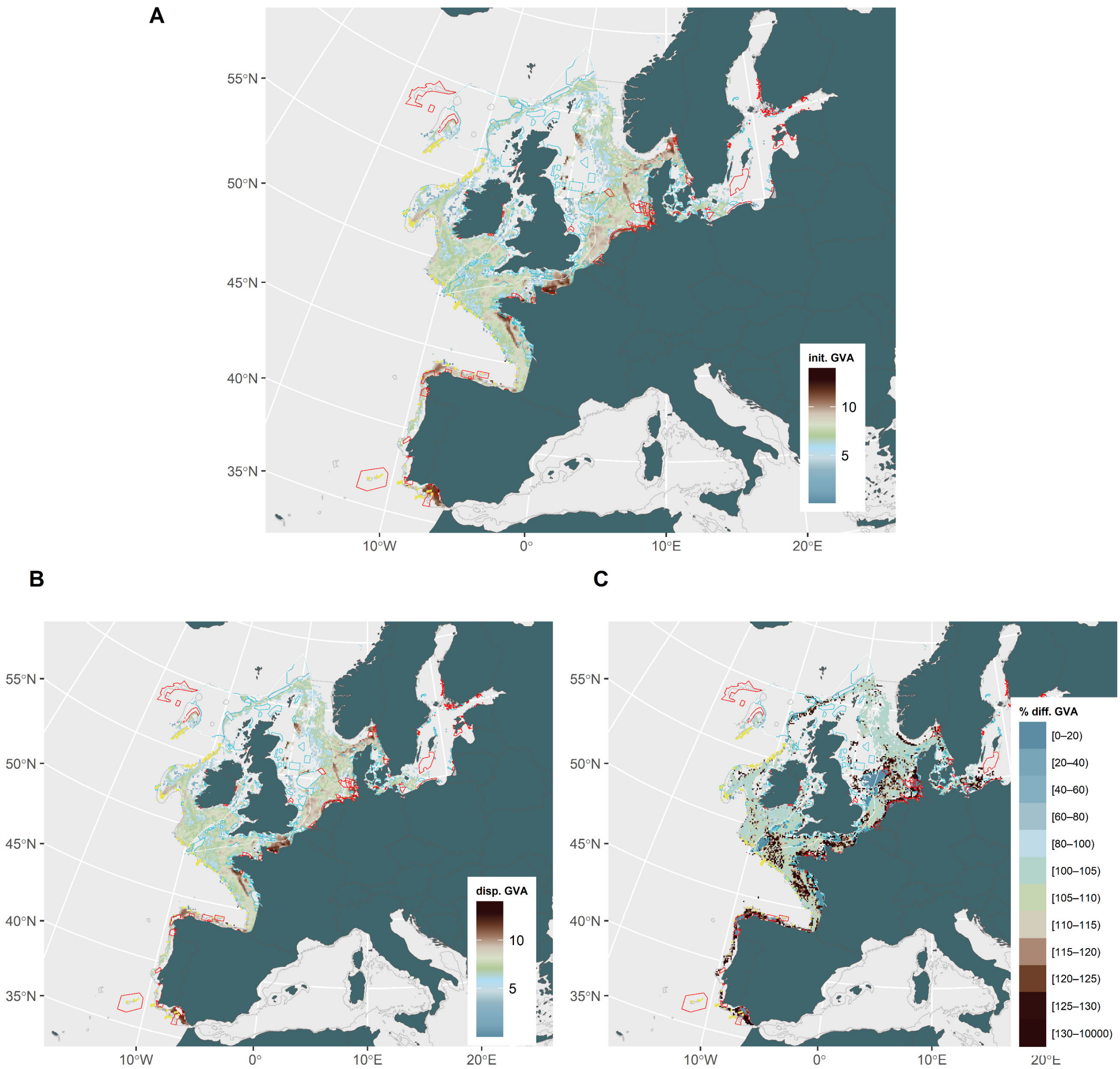
Source: ICES WGFBIT 2023.

sequences using approved assessment methodology (Bastardie et al. 2010; Eigaard et al 2016). The study by Eigaard et al. (2016) decomposed the swept area fraction into surface and subsurface swept area, considering the penetration of gear subcomponents into the seabed. The Swept Area Ratio (SAR) is calculated by dividing the gridded swept area by the surface area of each 0.05-degree grid cell. The longevity approach used in ICES WGFBIT 2023 defines low and intermediate fishing intensity based on benthic community life expectancy in a given area being fished (Figure 17). For example, when it comes to the impact of trawling on vulnerable marine ecosystems (VMEs), a low impact is likely to be less than 0.1 SAR considering the maximum lifespan of emblematic sea pens, which is estimated to be 10 years, meaning that a cell with an SAR value of 0.1 would be completely covered by trawling activities within a decade. An indicator called Relative Benthos Status (RBS) is estimated based on a workflow outlined by ICES WGFBIT 2023. The RBS value ranges from 0 to 1 and is calculated by taking into account depletion rates and fishing intensity SAR across different gear types. The benthic biomasses are then modelled spatially and divided into 5 longevity classes. This approach is also described in Rijndorp et al. (2021). The estimated change in RBS values is a weighted average of RBS longevity classes along with displacement scenarios.

The present quantitative assessment tests a suite of contrasted scenarios as alternative policy options including:

- 'Business as Usual'. No new regulations are implemented. Therefore, there will be no changes to the fleet structure, the spatial distribution of effort, catch rates, operating costs, and CFP fisheries management.
- 'Exclusion'. A policy has been implemented to ban all Mobile Bottom Contact Gears (MBCGs) from currently designated Marine Protected Areas (MPAs) that are deemed vulnerable to MBCGs. This would result in the displacement of fishing efforts to surrounding habitats (i.e. areas already visited specific to each fleet segment), depending on the attractiveness of the habitats in terms of realised spatialised Gross Value Added (GVA) by the fleet segment in the baseline year.
- 'ContactMitigation'. A policy has been implemented which requires all bottom trawling fisheries to use lighter gear components. This would result in less penetration into the seabed per unit of swept area, assuming a 30% reduction in seabed contact. However, this change would also lead to a decrease of 20% in the absolute catch rate (measured in kg caught per unit effort) due to an unfavourable shift in gear selectivity as observed by some trials at sea [see section 2.2.2].
- 'ContactMitigationSavingFuel': The same as previously, but assuming a 20% fuel savings induced by reducing contact with the seabed.
- 'ShiftingToPassiveGears'. A new policy prohibits the use of MBCGs both inside and outside MPAs. All MBCG efforts are now allocated to operating passive gears and displaced to the historical spatial effort distribution of passive gears.

Figure 18: Change in spatial Gross Value Added (GVA) of MBCGs fisheries before/after exclusion of MBCGs from MPAs deemed vulnerable to MBCGs. Data gridded in 0.05-degree grid cells in the NAO area and for described countries only (GVA in million euros given on a logarithm scale). A- Initial GVA, B- Displaced GVA, C- % difference between initial and displaced GVA. Red polygons on map delineate the currently designated MPAs deemed vulnerable to MBCG activities



Source: Own elaboration.

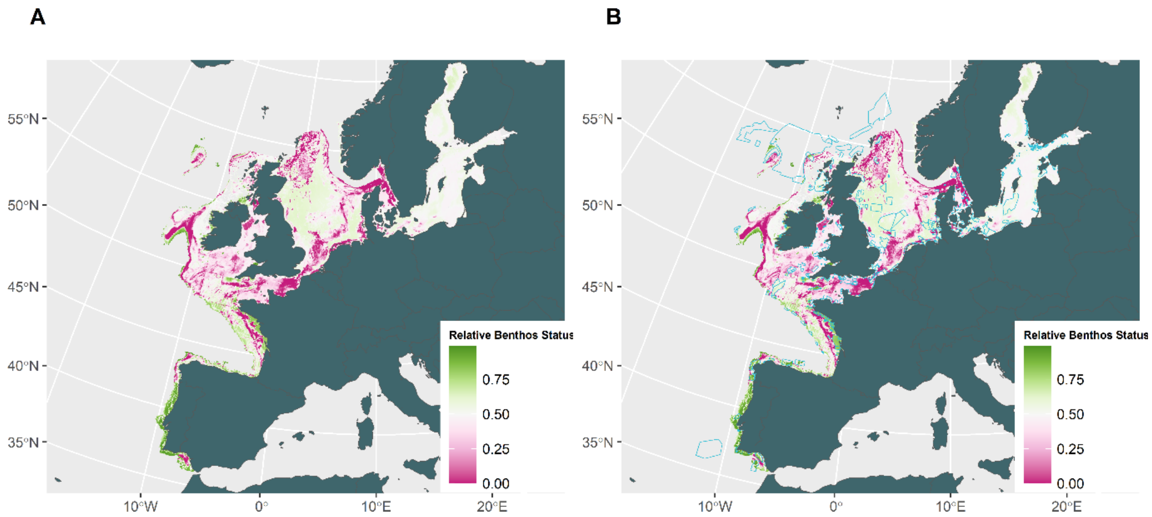
Table 6: Outcomes of the quantitative assessment. RBS indicator from 0 to 1 (with 1 an unaffected benthic community). GVA in millions euros. Bycatch risk from 0 to 1

	Business as Usual	Exclude MBCG	30% Contact Mitigation	Shift To Passive Gears
EEZ	Mean RBS in MPAs	Mean RBS in MPAs	Mean RBS in MPAs	Mean RBS in MPAs
Belgium	0,24	0,57	0,19	0,57
Denmark	0,40	0,49	0,38	0,49
France	0,43	0,68	0,53	0,68
Germany	0,43	0,59	0,41	0,59
Ireland	0,64	0,67	0,63	0,67
Netherlands	0,35	0,57	0,34	0,57
Spain	0,48	0,79	0,39	0,79
EEZ	Mean Regional RBS	Mean Regional RBS	Mean Regional RBS	Mean Regional RBS
Belgium	0,23	0,29	0,19	0,56
Denmark	0,38	0,37	0,35	0,52
France	0,43	0,43	0,36	0,69
Germany	0,44	0,46	0,41	0,59
Ireland	0,40	0,39	0,36	0,56
Netherlands	0,36	0,37	0,33	0,60
Spain	0,53	0,56	0,46	0,78
Fleet	Mean GVA	Mean GVA	Mean GVA	Mean GVA
Belgium	13	13	6	87
Denmark	75	75	49	130
France	133	137	62	310
Germany	35	36	17	7
Ireland	20	19	9	430
Netherlands	47	47	16	82
Spain	83	85	43	257
Fleet	Mean Bycatch Risk	Mean Bycatch Risk	Mean Bycatch Risk	Mean Bycatch Risk
Belgium	0,07	0,08	0,10	0,07
Denmark	0,02	0,02	0,03	0,02
France	0,08	0,10	0,10	0,07
Germany	0,02	0,02	0,03	0,01
Ireland	0,06	0,06	0,08	0,05
Netherlands	0,04	0,05	0,04	0,03
Spain	0,03	0,03	0,03	0,03

The outcome of the present assessment of changing the pressure on the seabed shows that (Table 6):

- The RBS is low on the scale from 0 to 1 for most countries.
- Excluding MBCG from vulnerable MPA only marginally affected most EEZ after one year (Figures 18 and 19), with some EEZ positively affected (e.g., Belgium). Caution: the estimation method is not suitable for capturing small localised and connectivity effects. The effort displacement can sometimes slightly lower the EEZ RBS (e.g., Ireland).
- The most striking outcome is that reducing the contact to the seabed with innovative MBCG by 30%, which assumes a loss of 20% catch rate, does NOT improve the net RBS but would possibly come with a significant economic loss (in GVA), effort displacement, and some extra effort to break even. This outcome holds even if fuel savings occur from less seabed contact.
- Shifting all the MBCG activity toward operating passive gears in passive gears' historical areas, catch rates and cost structure, would both largely improve the RBS and increase the economic return. This, however, assumes that the existing MBCG fleet has been converted entirely and that the fishing opportunities are aligned.

Figure 19: Change in spatial RBS before/after exclusion in the OSPAR area and for described countries only. A: Business as Usual scenario. B. MBCG exclusion scenario. MPAs vulnerable to MBCG are indicated in blue



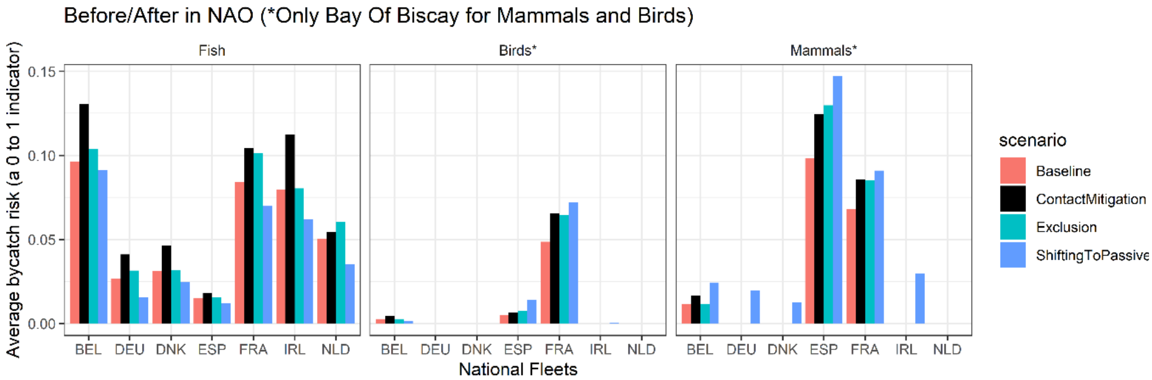
Source: Own elaboration.

The outcome of the present assessment changing the bycatch risk shows that (Figure 20):

- The bycatch risk of vulnerable fish species is not affected by exclusion, but lower if shift to passive gears.
- The bycatch risk of vulnerable birds and marine mammals (estimated here in the BoB only) is increased after effort displacement, due to an increase in absolute effort to compensate for the loss in spatial opportunities. Such an increase is larger if the shifting to passive gear is implemented.

- Mitigation of the contact to the seabed increases the risk on vulnerable species as it came with a net increase of the effort to compensate for the assumed 20% loss in catch rate induced by the gear selectivity modification.

Figure 20: Bycatch risk (i.e. an indicator of exposure to fishing from 0 to 1) estimated as fishing effort crossed with, for mammals, the relative abundance and distribution of common dolphin for May 2016-2019 and September 2013-2019 in the Bay of Biscay (BoB), for birds, the relative abundance of Balearic birds in the BoB, and for fishes, a list of vulnerable fish species in the North Sea, Celtic Seas and BoB



Source: Own elaboration.

An important disclaimer is to recall that static effort displacement, as applied here, ignores by nature the possible negative feedback in the short term. A static reallocation with fixed catch rates may ignore change in catch rates arising from a crowding effect. Quirijns et al. (2008) provided evidence for interference competition in the Dutch beam trawl fleet and estimated that a doubling of the vessel density within an ICES rectangle would reduce the catch-rate by approximately 10%. Hence, the present assessment has made several assumptions, including the change in catch rates induced by the gear modification deduced from gear selectivity studies, the change in depletion rate for a single trawl path (induced by the change in penetration per gear subcomponents) from the existing meta-analysis in the scientific literature. Because of inherent uncertainties, sensitivity to changing parameters would require further exploration with simulations within each policy option (e.g. testing a row of depletion rates, catch rates, and spatial catch rates from crowding effects).

On the economic side, loss of spatial opportunities and lower catches may induce in the short term some market disruptions if a given fishery cannot deliver the required volume to the seafood market anymore because of a spatial restriction. Reducing this risk would require a well-diversified supply chain to deliver to the domestic and international markets (Plagányi et al. 2021). On the contrary, positive feedback from conserving resources can also arise in the long term. At the same time, a change in fishing level combined together with external factors to fishing (such as climate change) is likely to induce trophic cascading (e.g. Kirby et al 2009 in the North Sea).

3.4. Bottom trawling effects on organic carbon remineralisation

Blue carbon marine ecosystems include shallow waters with seagrass meadows, tidal marshes, and mangroves, all of which are among Earth's most efficient absorbers and long-term storers of carbon. There are aquatic plants with rhizomes and roots that can retain carbon in the sediments for centuries, or macroalgae growing in the water column in dense populations (kelp forests or 'blue forests'). This capacity for carbon storage makes them sources of CO_2 emissions when they are degraded or destroyed. The deep ocean also has a vital role in storing carbon in the marine sediments but is hardly explored by bottom fishing in EU waters. Still, blue carbon habitats are found in shallow waters of continental shelves, those habitats includes Maerl beds (620 MgC.ha-1), Lophelia reefs (100 MgC.ha-1), Horse mussel beds (40 MgC.ha-1) seagrass beds (20-50 MgC.ha-1), kelp forests (5-9 MgC.ha-1) (EUNIS, 2020). Maintaining, restoring, and extending blue carbon habitats is recognised as an ecosystem-based solution to remove and sequester excessive carbon currently released into the atmosphere. To the opposite, bottom trawling may in some occurrences remobilise the carbon stored in the seabed while there is a need for protecting irrecoverable carbon in Earth's ecosystems (Goldstein et al. 2020).

While recent studies have alarmed on the substantial potential for seabed carbon disturbance induced by bottom trawling (e.g., Sala et al. 2021), the risk for carbon re-mineralisation of the carbon stored into the seabed is still under appreciation. Trawling carbon impact likely depends on the substrate type, the towing speed, and the gear specifications affecting the seafloor. The net effect (direction and amount of carbon fluxes) is still uncertain given the resuspension of sediments into the water column and carbon remineralisation also being mitigated by the faunal loss induced by the trawling and effect of the natural bioturbation and sediment mixing. Moreover, the fraction of carbon into the sediments vulnerable to re-mineralisation (i.e. the 'labile carbon') is variable and most likely dependent on local environmental conditions while more labile compound classes displayed considerably greater depletions after trawling (Paradis et al. 2021, Epstein et al. 2022).

One of the main uncertainties in bottom fishing effect on carbon is the scaling of the effect. Bottom trawling effect on carbon re-mineralisation will be larger on some habitats (e.g. muddy habitats were there is a large amount stored and the labile C fraction is larger) as organic carbon vulnerability depends on the amount of the fine fraction in the sediment. Oxygen availability also controls such vulnerability as the microbial loop responsible for re-mineralisation is activated depending on. Hence the net effect (i.e. re-mineralisation vs sequestration) at large scale is unclear given muddy areas can also be hypoxic. Even more, the scaling of possible releasing into the atmosphere is very much more uncertain. There is likely no consensus that the resuspended carbon will convert into acidification and a release of CO_2 into the atmosphere, albeit respiration from living organisms might contribute to it. There is a need for more research from local effect to the bigger effects in order to adequately advice policy-makers on such a matter. At the time of writing, there are still some methodological issues that divide the scientific communities about the importance of the fluxes. Reviewing methods to assess carbon lability is required, given a lack of agreement when it comes to describing or quantifying lability making it difficult to compare scientific findings. Scaling the effect adequately is also key to comparing those effects with direct fuel use emissions (or natural disturbance such storm events e.g. Mengual et al 2016). Organic carbon re-mineralisation needs also to be put in the context of other drivers of possible carbon release such as the OWFs, the effect of aquaculture and the climate change.

Acknowledging such uncertainties there are however ongoing effort to model what the effect of displacing the bottom trawling effort would be on changing the re-mineralisation effect at the basin scale. Dedicated carbon protection zones modelled in the North Sea show potential for reduction impact of bottom trawling and can contribute to gain macrobenthos biomass as well (Porz et al. 2024). However displacing bottom trawling put some risk on reaching environmental targets if redirecting the effort toward untrawled areas, also given the effect on the seabed is known to be the largest at the first trawl path (Pitcher et al. 2017). Protecting those carbon-rich habitats is also important not only to avoid releasing carbon from the sediments but to ensure a healthy biodiversity and limit the effect on the seabed. In this respect, reducing the most impacting bottom trawling might also be a win-win when fisheries operate on hotspots of carbon storage such as muddy areas, all other uncertainties being at play. Again the scaling of the effects is an issue, and in some occurrences, displacement of fishing effort itself might also increase emissions from fisheries (e.g. the Norwegian mackerel fleet after Brexit, in Scherrer et al. 2024).

4. Gathering expert opinions on the possibility of continuing MBCG use in MPAs

It appears that **very few initiatives in the EU have sought to evaluate the performance of spatial management measures**. This is true of biological studies (because applying the Before-After-Control-Impact design is challenging due to the lack of accurate temporal baseline and counterfactuals; see Underwood, 1992). However, evaluations of the economic impacts of spatial management options are even sparser, given the relatively recent focus in ICES on collecting and using economic and social data (see ICES WGECON and WGSOCIAL or Thébaud et al. 2023). STECF recalled that conducting static analyses based on snapshots of the historical deployment of fishing activities at sea ignores the dynamics of fleets and stocks by nature. Examples of possible unwished effects of closed areas when changing fisheries spatial allocation previously discussed by STECF include:

- the seasonal closures of bottom trawlers on the part of the fished GSA 7 area, which would displace effort with unassessed consequences (STECF PLEN 19-03, ToR 6.4),
- the adoption of trawl closures in GSAs 9, 10, and 11, which would lead to an increase in fishing pressure on hake sub-adults and adults (STECF 20-01, ToR 3.5),
- the displacement of the gillnet fishery in the Kattegat, where there is a likely increasing incidence of sensitive species bycatch (STECF PLEN 21-01, ToR 6.6),
- the displacement in West Med closed areas toward other gears, species and habitats (STECF PLEN 21-02, ToR 6.2),
- The decrease in the catch rates for the targeted species outside the Celtic Sea Protection Zone (STECF PLEN 21-03, ToR 5.8).

In this context, **for anticipating effort displacement, fishers' perceptions can provide valuable information** to fishery managers when integrated with other types of data (Frezza and Clem, 2015). They can also offer guidance on approaches that would be supported by the local community, leading to increased compliance (Stankey and Shindler, 2006). However, fishers may not always perceive the larger-scale effects of fishing-induced degradation, which may be due to regulations that have altered fishers' behaviour. This misperception likely results from regulations that can cause catch rates to increase while the stock has declined (Dean et al. 2023). Hence, it is relevant for this study to **collect expert opinions and experiential knowledge from the fishers and practitioners** active in the field, as well as the views of marine and fisheries scientists owning data and analysis that can catch the bigger picture and trends (Pinello et al. 2017).

The present study has investigated the possible effects of fishing activities on a range of ongoing spatial restrictions by identifying case studies through the consultation of stakeholders. A survey has been mailed to marine specialists, fisheries representatives and other stakeholders (via the advisory councils[20]) to collect views on the coexistence of fishing activities in MPAs. Such consultation is also deemed important given that access to data on the Med side was limited to the time dedicated to the present study. The issue of excluding MBCGs in the Med (FAO 37) is therefore investigated qualitatively through the case studies.

About 53 **participants from 10 countries** (Italy, France, Greece, Spain, Portugal, Croatia, Bulgaria, Cyprus, Belgium and Sweden) answered the questions. Marine scientists and gear technologists have answered the survey, as well as some fishers' representatives, MPA managers and eNGO campaigners. All in all, the scientists gave the most answers and quite a homogeneous opinion. To avoid the number of respondents to bias the outcome toward science, which would not provide a

[20] https://oceans-and-fisheries.ec.europa.eu/fisheries/scientific-input/advisory-councils_en

representative and quantifiable opinion of society concerning the issue at stake, we treat the answers for fishers' representatives and eNGOs separately given the divergence in views.

4.1. Stakeholders' preferred options for mitigating MBCG fisheries

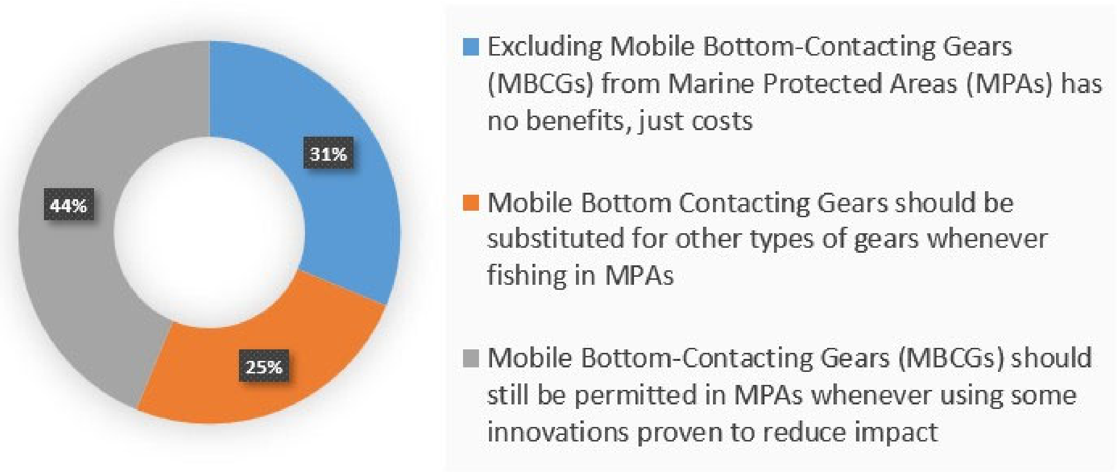
From the consultation, the summary of preferred options per type of stakeholder is below:

Scientists (Figure 22): 'Mobile Bottom Contacting Gears should be substituted for other types of gears whenever fishing in MPAs'

Fisheries representatives (Figure 21): 'Mobile Bottom-Contacting Gears (MBCGs) should still be permitted in MPAs whenever using some innovations proven to reduce the impact'

NGOs and MPA managers (Figure 23): 'Mobile Bottom Contacting Gears should be substituted for other types of gears whenever fishing in MPAs'

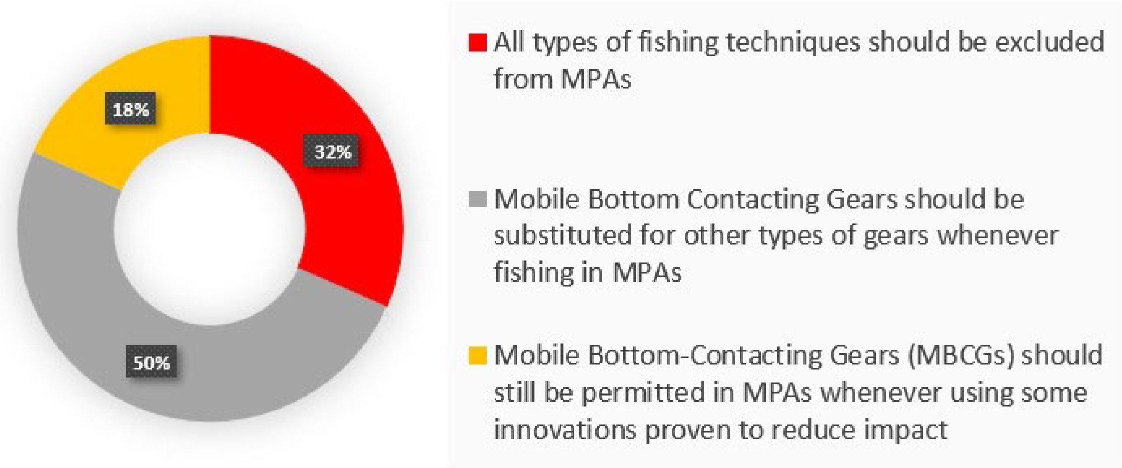
Figure 21: Survey investigation (Question 1: 'Can you specify which among the following options is the most suitable for you?') – Fishers' representatives



Source: Own elaboration.

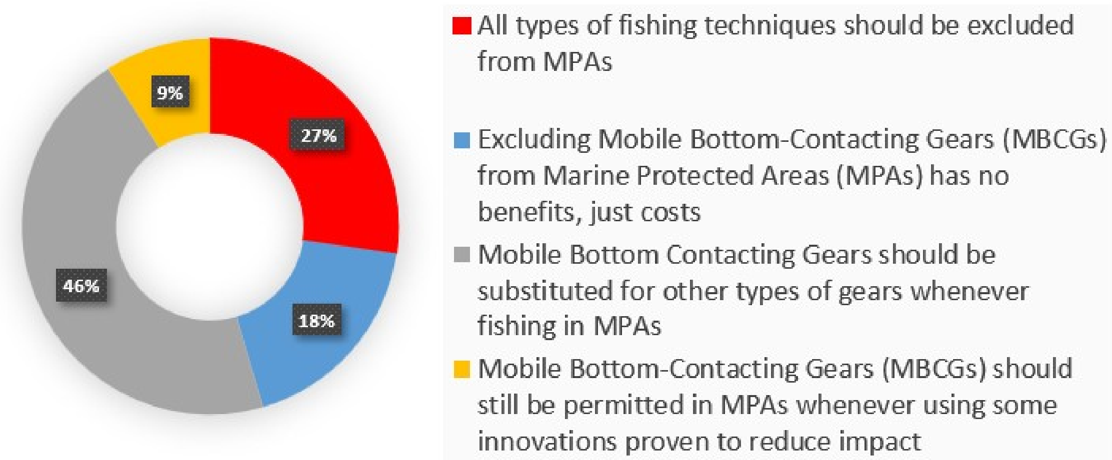
It is possible to get a general view of the expert opinion collected in this study from the 'Question2: What type of innovations might reduce impact? What type of alternative gears might still be operated in MPAs?'. Most experts think the MBCGs should be substituted for other fishing techniques as soon as fishing inside MPAs, or even totally banned. Some experts still think that the impact of fishing on the seafloor can be reduced by limiting contact with the bottom and improving the selectivity of fishing gear. Mobile bottom-contacting gears require innovations to reduce their impact on the ocean floor. Regulations are needed to control the use of small-scale fishing gears, including the mesh size and duration of sets, and prohibit fishing in certain areas. Small marine protected areas and limiting fishing in sensitive habitats are recommended. Only fishing gear targeting specific species should be used with controls and quotas. Artisanal gears and highly selective passive gears are alternative options.

Figure 22. Survey investigation (Question 1: 'Can you specify which among the following options is the most suitable for you?') – Scientists' views



Source: Own elaboration.

Figure 23. Survey investigation (Question 1: 'Can you specify which among the following options is the most suitable for you?') – Park managers and eNGOs

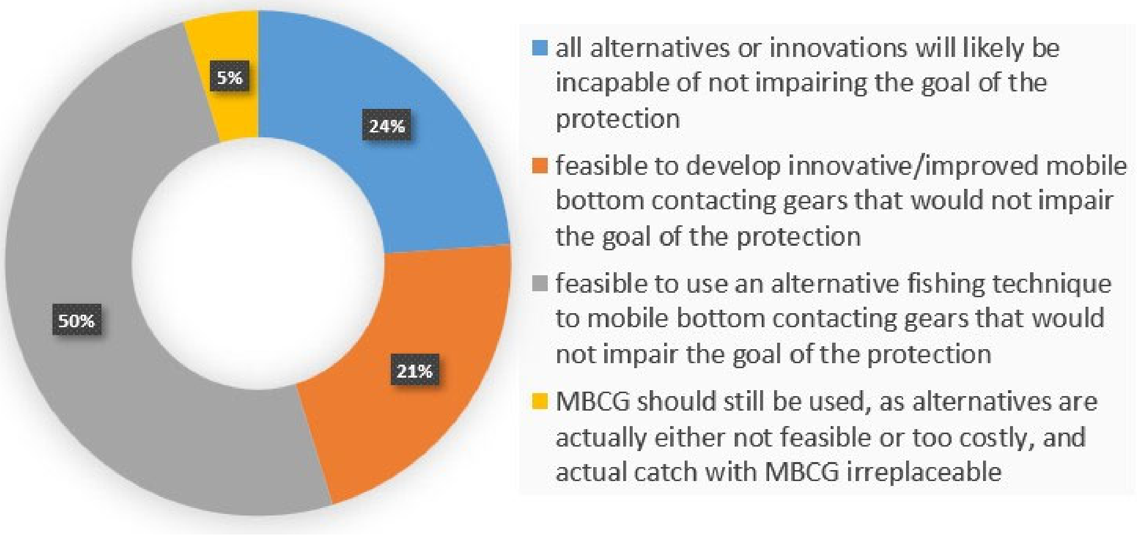


Source: Own elaboration.

4.2. Feasible options according to stakeholders

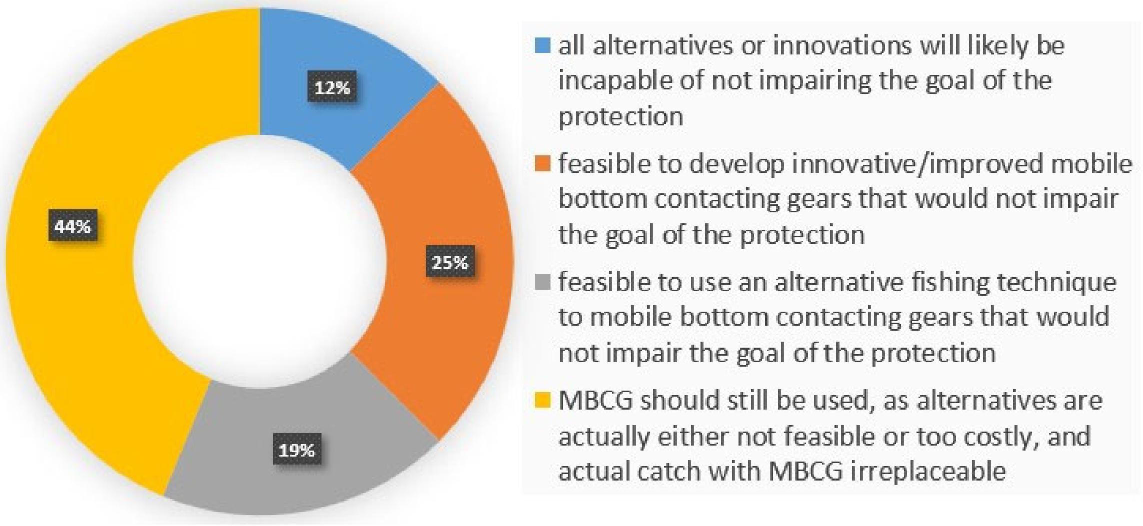
Most scientists agree that the best policy would be to use alternative fishing techniques to MBCGs in MPAs (Figure 24), while gear innovation is not seen as sufficient to compensate for the fishing impact on the seabed by the panel of experts who participated in the survey.

Figure 24: Questionnaire survey (Question 4 : 'In continuing fishing within an MPA, ...') – Scientists' opinion



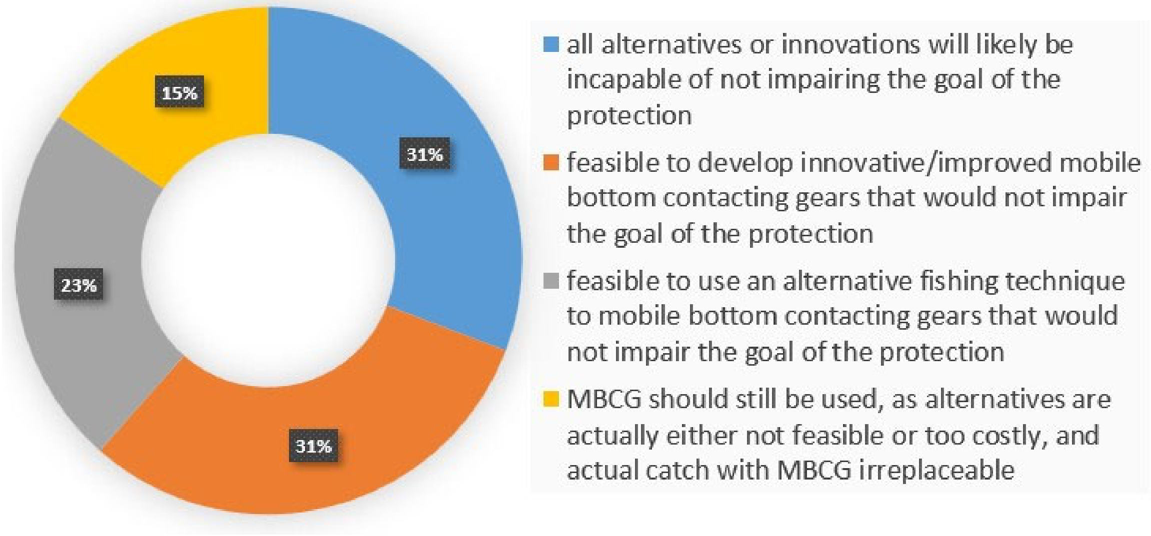
Source: Own elaboration.

Figure 25: Questionnaire survey (Question 4 : 'In continuing fishing within an MPA, ...') – Fishers' opinion



Source: Own elaboration.

Figure 26: Questionnaire survey (Question 4 : 'In continuing fishing within an MPA, ...') – Marine park managers and eNGOs' opinion



Source: Own elaboration.

In answering Question 5, 'Can you explain how allowing only certain or excluding fishing techniques in MPAs can be effective/ineffective?', the shared view acknowledges a need to define control measures for fishing techniques used in MPAs to balance conservation and sustainable exploitation. Only small-scale fishing techniques should be used in MPAs, and bottom-impacting techniques should be excluded in areas with sensitive seabed features (the ones that are not naturally disturbed, which are already adapted to disturbance). Large MPAs require spatial planning of fishing techniques and effort to find a trade-off between conservation and sustainable exploitation. However, some think the precautionary principle should also be followed for large areas. No more impactful fishing techniques should be allowed in MPAs all year around, even to the point that all fishing techniques should be excluded to preserve the pristine area and its structural complexity and connectivity (with Posidonia beds, etc.). By contrast, some views express their concern about applying the same recipe without considering the case-by-case situation. For those, risk analyses must be carried out by area, and bans must take into consideration the degree of risk.

However, eliminating MBCG and replacing it with passive high selective gears is thought to improve the protection of sensitive benthic habitats and species, as MBGCs would always touch fragile seabeds and are relatively unselective. Fishers operating passive gears can continue fishing activities targeting adult fish with higher market value and valorised on the market with quality labels. Making some fisheries part of the solution would likely reduce social tensions and facilitate reaching the protection goals, including recreational fishers and developing tourism opportunities. However, using gillnets within an MPA is a matter of concern due to the possible capture of turtles and sharks and the depredation and capture of marine mammals.

Surveyed opinions recall that attention should also be paid to avoid excessive exploitation of the spill-over effects in the buffer areas around MPAs, as socioeconomic impact, lack of enforcement, and stakeholder engagement may likely induce such an increase in effort. Analysing such effects requires extra studies as very few respondents could identify socioeconomic impact studies besides assuming short-term losses but positive economic returns from ecological effects in the longer term (see, for example, Table 7, about bigger fishes, spill-over of biomasses and protected ecosystem services).

Fishers' representatives are especially concerned that short-term loss of local value may also result in fewer spatial opportunities when renewable energy facilities also develop at sea alongside other anthropogenic threats to marine ecosystems, such as pollution, climate change, and habitat degradation, and add to a lack of alternative livelihood options. These effects would be less likely whenever coastal artisanal fishers by nature using alternative gears are maintained and included in the management plans of the protected areas, as well as land-water interactions are better addressed.

One fisher opinion states that [translated from Greek] 'All fishing gears must still be allowed in MPAs, as long as it does not target a sensitive - protected species, endemic to the area, or poses a risk to a particular ecosystem'. The risks MBCGs pose to the seabed in MPAs are documented in the present study in sections 1 and 2.

We **complete the collected opinions with real-life case studies** (see Annexe), to document possible side effects induced by displacing the fishing effort of MBCG from the MPAs. Based on the consultation outcomes and because the Med lacks a quantitative assessment in the present study, the following case studies in the Med. have especially been selected. Effort displacement effects and long-term dynamics are highly likely to arise along with stock and habitat recovery. Examples of effects have been previously discussed in the literature (e.g., Table 7), including seasonal closures in some Med GSAs, leading to an increase in fishing pressure on hake, the displacement of the gillnet fishery in the Kattegat and increasing incidence of sensitive species bycatch, the displacement in West Med closed areas toward other gears, species and habitats, the decrease of the catch rates for the targeted species outside the Celtic Sea Protection Zone, etc. There are also recent examples of banning bottom trawling, such as in the UK EEZ, now likely affecting the EU fleet[21].

[21] For example, the UK Dogger Bank is closed to bottom trawls (https://kingfisherrestrictions.org/fishing-restriction-map)

Table 7: Some ecosystem services for case studies of MPAs in the West Med. Adapted from Marcos et al. 2021 - Table 2. See other references in this article. The original table contains many more ecosystem services

	Cerbère-Banyuls-sur-Mer MPA	Cap de Creus MPA	Levant de Mallorca-Cala-Rajada MPA	Islas Columbretes MPA	Nord de Menorca MPA	Tabarca MPA	Cabo de Gata-Níjar MPA
Year of creation	1974	1998	2007	1990	1999	1986	1995
Objective	Protect Marine Biodiversity	Protect fish stocks for small-scale fisheries	Protect fish stocks for small-scale fisheries	Protect fish stocks for small-scale fisheries	Protect fish stocks for small-scale fisheries	Protect Marine Biodiversity	Protect fish stocks for small-scale fisheries
No-take surface	10%	0.69%	11%	33.67%	21.70%	4.45%	6.55%
Surface	650 ha	3056 ha	11286 ha	5543 ha	5119 ha	1754 ha	4653 ha
Increase in fish biomass outside the MPA as a direct effect of spill-over	Not validated	Not evaluated	Not evaluated	Yes (Goni et al 2008; Stobart et al. 2009)	Not evaluated	Yes (Goni et al 2008; Forcada et al 2009)	Not evaluated
Restore the population of native species to desired reference points	Yes (Lenfant et al 2003)	Not evaluated	Not evaluated	Yes (Díaz et al 2016)	Not evaluated	Not evaluated	Not evaluated
Favor the survival of vulnerable, endangered, and focal species	Yes, (Posidonia meadow, red coral)	Not evaluated	Yes (Seagrass meadows, Groupers, and Slipper lobster)	Yes (Groupers and spiny lobsters)	Yes (Seagrass meadows)	Yes (Coral species Rubio-Portillo et al. 2016, Posidonia meadow González-Correa et al. 2007, Groupers Forcada et al. 2008)	Yes (Marine mammals)
Protection of traditional fishing and traditional food	Yes	No (Gómez et al 2006)	Yes	Yes	Yes	Yes (Forcada et al. 2010)	Not evaluated

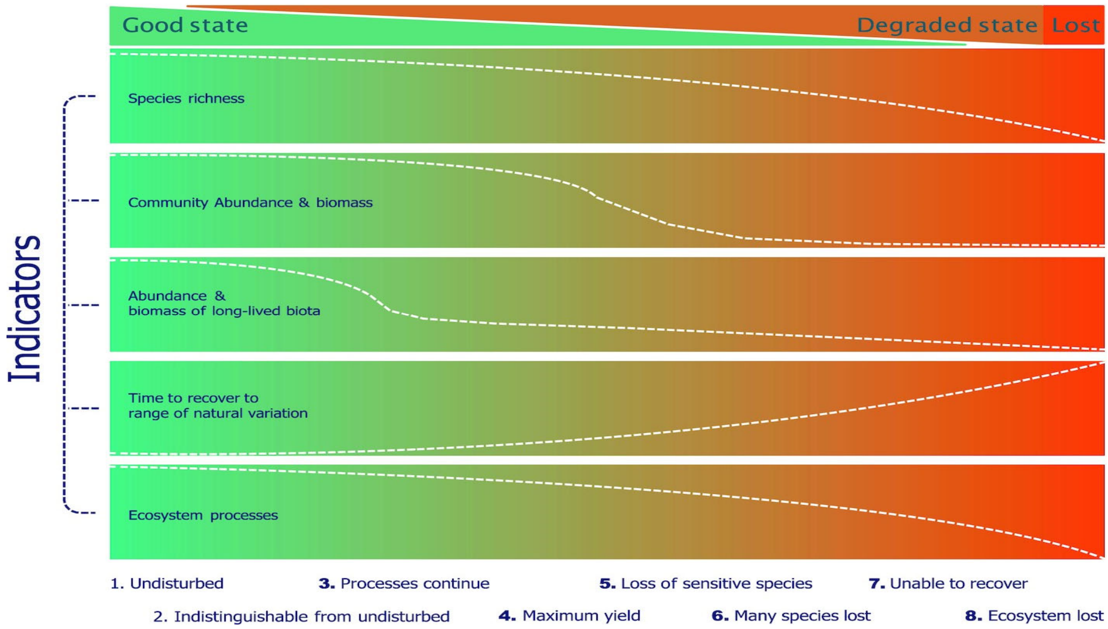
5. Goal of environmental protection in EU waters and policy coherence

5.1. Good Environmental Status and restoration of the EU seabed to GES

The European Union's Marine Strategy Framework Directive (MSFD) has established environmental goals to **attain a good environmental status for all European waters**. A set of operational indicators must be monitored to achieve this objective, and the MSFD policy is re-evaluated every six years. However, it is still uncertain what level of pressure is required to restore a poor environmental status to a good one and what measures can maintain the good environmental status.

Regarding the seabed impact, as discussed by Hiddink et al 2023 (Figure 27), an undisturbed ecosystem is expected to have many species present, with each species having a natural distribution of abundance and biomass over the different age and size classes, with ecosystem processes at high rates. The challenge is to manage the ecosystem so that ecosystems/communities/habitats are at a sufficiently 'good' state to ensure we sustain overall ecological integrity. Stage 1 and 2 (see Figure 27) both ensure biodiversity, structure, and function and can be considered 'good'. It is expected that stages 7 and 8 are degraded or even lost. Sustainable human exploitation that maximises the yield of targeted species can involve intense activities and is likely to result in widespread changes in size, age, and species composition, with values generally outside the range of natural variation. Progressing pressure may result in the loss of the largest and most-long-lived species, resulting in large drops in the total biomass of the community and large drops in the rates at which ecosystem processes occur. However, most people agree that any changes from stage 3 to 6 may be considered as 'good enough' when part of a socio-economic trade-off and where a prioritisation of the management actions is needed.

Figure 27: Conceptual view on the continuum between good and bad states alongside habitat degradation induced by a pressure on marine ecosystems



Source: Extracted from Hiddink et al. 2023.

5.2. Coherence with EU objectives and potential ethical, social and regulatory impact on policy proposals

High-level strategies developed by the EU Green Deal to indicate the direction and priorities of the EU include preserving and restoring ecosystems and biodiversity as described in the EU Biodiversity strategy for 2030 (COM 2020 380). Restoring and maintaining biodiversity is seen as crucial for safeguarding EU and global food security, while the costs of inaction are high and are anticipated to increase[22].

The study's findings indicate that for such objective **the best policy option is to exclude the MBCG from the current and future MPAs that contain benthic communities sensitive to mobile bottom fishing. Passive gears would best be the only ones allowed to operate within these areas**, as long as using passive gear in the same area does not raise a sustainability issue. The use of innovative gears in the market is not deemed sufficient to achieve the goal of protection, and likely, barriers are preventing their uptake by the fisheries.

This outcome partly aligns with the European Commission's proposal and vision described in the 'Fisheries package' in early 2023, which is to exclude all mobile bottom-fishing contacting gears from the designated MPAs and any future MPAs. **Such a policy that would exclude damaging fishing practices from MPAs in EU is coherent with the ecosystem approach to fisheries management and the Common Fisheries Policy (CFP), which encourages the transition towards more responsible fishing practices (Article 7 of CFP basic regulation).** However, the present study recalls that excluding mobile bottom fishing from all MPAs is unnecessary as recent assessments show that some of these MPAs have not been designated to protect the seabed but for another purpose (i.e., bycatch risk or species aggregation). In this logic, **future MPAs will also have to consider if protecting the seabed is one of their objectives before restricting access to such fishing techniques**.

On the contrary, a recent report[23] approved by the EP in early 2024 has argued that the Commission's action plan would lack coherence with other priorities and complains that recent rising commodities prices or strengthening economic growth and employment have not been adequately considered. Accounting for 25% of catches, the report argued that a ban on mobile bottom fishing would have an economic impact in many regions from the coast. The report also anticipates that closing zones to this practice can lead to conflicts and put pressure on other fishing areas. Indeed, policy-makers need to bear in mind that if MPAs are an effective tool to ensure the protection of habitat for healthy ecosystems with the possibility of catching more, larger fish with less fuel use and less effort, which results in more abundant species and a better outcome for certain fishing activities, **the implementation of MPAs might cause some costs for the fishing communities in the short-term**. Some fishing activities may be preserved by financial aid (e.g. payment in support of the fleet during the COVID-19 pandemic, in support of temporary cessation induced by emergency measures on declining stocks[24] etc.), while others may not, leading to equity issues. Restricting fishing in MPAs may pose some challenges for some fishing communities in terms of short-term costs compared to long-term benefits.

In the long term, excluding MBCG from MPAs and only permitting passive gears can lead to preserving seabed integrity, as evaluated in this study. It may also follow with improved productivity of the exploited ecosystem. Excluding bottom trawling in biodiversity hotspots can bring **co-benefits** in energy transition and efficient management of fisheries resources. Ultimately, phasing

[22] Biodiversity Strategy for 2030 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52020DC0380

[23] EU Action Plan: protecting and restoring marine ecosystems for sustainable and resilient fisheries, rapporteur Niclas Herbst

[24] https://ec.europa.eu/commission/presscorner/detail/en/MEMO_04_181

out bottom trawling can result in co-benefits for protecting biodiversity. As shown in this study [see section 3], the area-based conservation proposed in the EU can impact certain existing fisheries, especially more inshore fisheries. However, **the overlap with fishing grounds of offshore fisheries was found to be minimal given that MPAs are not designated to protect species of commercial interest but hotspots of biodiversity**. The potential for inshore fisheries using MBCGs to consider less-than-ideal locations in reaction to spatial restrictions thus depends on the inherent flexibility of their operations and the necessary financial and technological means of occupying a less-than-ideal site. Besides, **integrating social and cultural dimensions may require additional criteria for defining valuable areas**. Valued areas could, for instance, result from the information on those areas to which fishers are most attached, which might be of low value at the scale of the whole fisheries (Janssen et al. 2018). Other occupations of space from other sectors are active at sea besides fisheries, including offshore wind, aquaculture, coastal and maritime tourism, maritime transport, area-based conservation, and defence. Cumulative impact can further reduce the available space for fishing, knowing that not all marine space is suitable for fishing activities, with further crowding effects. 'Hard' sectors require fixed infrastructure in the sea; they tend to be in place for a long time, expensive to install and difficult to move. Spatial conflict prevention is crucial in the case of 'hard' use, as changing a situation after the fact is usually tricky (EASME, 2019).

Restricting access of bottom trawling to MPAs is coherent with the CFP at large. Indeed, the CFP intends to 'promote fishing methods that contribute to more selective fishing, to the avoidance and reduction, as far as possible, of unwanted catches, and to fishing with low impact on the marine ecosystem and fishery resources;' and 'specifications on the construction of fishing gear, including: (i) modifications or additional devices to improve selectivity or to minimise the negative impact on the ecosystem; (ii) modifications or additional devices to reduce the incidental capture of endangered, threatened and protected species, as well as to reduce other unwanted catches; (c) limitations or prohibitions on the use of certain fishing gears, and on fishing activities, in certain areas or periods; (d) requirements for fishing vessels to cease operating in a defined area for a defined minimum period in order to protect temporary aggregations of endangered species, spawning fish, fish below minimum conservation reference size, and other vulnerable marine resources; (e) specific measures to minimise the negative impact of fishing activities on marine biodiversity and marine ecosystems, including measures to avoid and reduce, as far as possible, unwanted catches.'

Currently, the CFP controls for overexploitation, which is understood as avoiding excessive exploitation that leads to reduced productivity and possibly irreversible damage. In an ecosystem approach, the supportive habitats, not only fish stock abundances, need to be considered. Pressured habitats need to be maintained within ecologically safe limits so as to have a good level of certainty that the affected benthic communities can stand future pressure without changing. The present study identifies that **full implementation of the existing policies (CFP, MSFD, etc.) needs to happen, closing the implementation gap for the EU seas to remain productive enough to ensure future fishing opportunities**, and the recommendation is to address the implementation gap. Consistencies between environmental and fisheries policies have been increased in the last MSFD and CFP revision referring to each other and the MS transposition of the MSFD does not appear to conflict with CFP objectives, as long as it is recognised that healthy marine habitats and an ecosystem approach (as defined in Convention on Biological Diversity UN CBD, 1992) is a pre-requisite to ensure future fishing opportunities in a changing ocean. Individual EU member states in charge of implementing the MSFD in their waters still needed to **transpose the MSFD objectives into restricting access to fishing in the designated MPAs**. It has been observed that many marine parks in the EU still permit bottom fishing within protected areas. In some cases, such as the 'Reserve de la Mer d'Iroise' in France, fishers must sign a stewardship agreement to continue fishing in the MPAs. This agreement allows park managers to collect data while fishing operations occur. However, more than simply acquiring this data is needed to protect benthic habitats. Efforts to improve monitoring or meet the MSY objective of the CFP are insufficient to ensure future fishing opportunities if habitat degradation resulting from chronic fishing disturbances is not considered.

Member states are given the chance to propose vulnerable areas that need to be protected jointly. These proposals are submitted to the European Commission, which then examines their validity with the help of the EU Scientific Committee (STECF)[25]. After the proposals have been deemed valid, the European Commission can create delegated acts to achieve the goals of the proposals.

On the cost side, several challenges are associated with establishing, monitoring and assessing MPAs. One of the main issues is the high administration costs involved in ensuring proper **monitoring and surveillance** given that 'The coastal Member State shall have a system to detect and record the fishing vessels' entry into, transit through and exit from fishing restricted areas under its sovereignty or jurisdiction' (Art. 50 of the Control EU Regulation). Both satellite and in situ Earth Observatory products are required to gather the necessary data (Camia et al., 2023). Still, these can be complex to integrate to obtain a comprehensive picture of the state and evolution of the sites (Corrales et al., 2020). To ensure effective surveillance, real-time alerts are necessary to prevent illegal fishing and to alert authorities when vessels enter these zones. Several tools can be employed for this, such as AIS, VMS, GPS, Copernicus Maritime Surveillance, Remote Electronic Monitoring, and Fishery and Oceanography Observing System (FOOS). These measures can help to prevent illegal fishing and alert authorities when vessels are approaching or transiting across regulated MPAs. The recently revised EU fisheries control regulation (Regulation (EU) 2023/2842) will strengthen those aspects by now including mandatory equipment onboard for tracking activities of smaller vessels.

By enhancing future fishing opportunities with stringent rules, such endeavour is also working toward preserving jobs in fisheries, which represented roughly 82000 full-time equivalents for the EU-27 in 2020 (STECF AER 2022). However, implementing conservation areas, such as the MPAs (e.g., Natura 2000 designated areas) in the EU and including strictly protected areas, may require costly adaptations to fishing strategies in the short term. From the research side, **evaluating the socioeconomic impacts** comes with the need for feasibility studies. Ensuring a robust and sustainable fishing fleet in the EU will require planning for the transition to alternative practices, including estimating the upfront costs fishers can face and the investment payback time alongside the transition. Funding possibilities (such as the European Maritime Fisheries and Aquaculture Fund) would also be offered to support the transition to more selective and less damaging fishing techniques. This will involve addressing potential issues related to social training, certification, and standards, such as social security and minimum wage. We would also benefit from prioritising and promoting the renewal of crew and skippers, focusing on encouraging women and artisanal fisheries. This is particularly important as younger generations are more open to new practices and innovations. To support this promotion, we need to identify relevant indicators that can be used for future fisheries management, such as Social Indicators for fisheries (as per STECF Nov 2023).

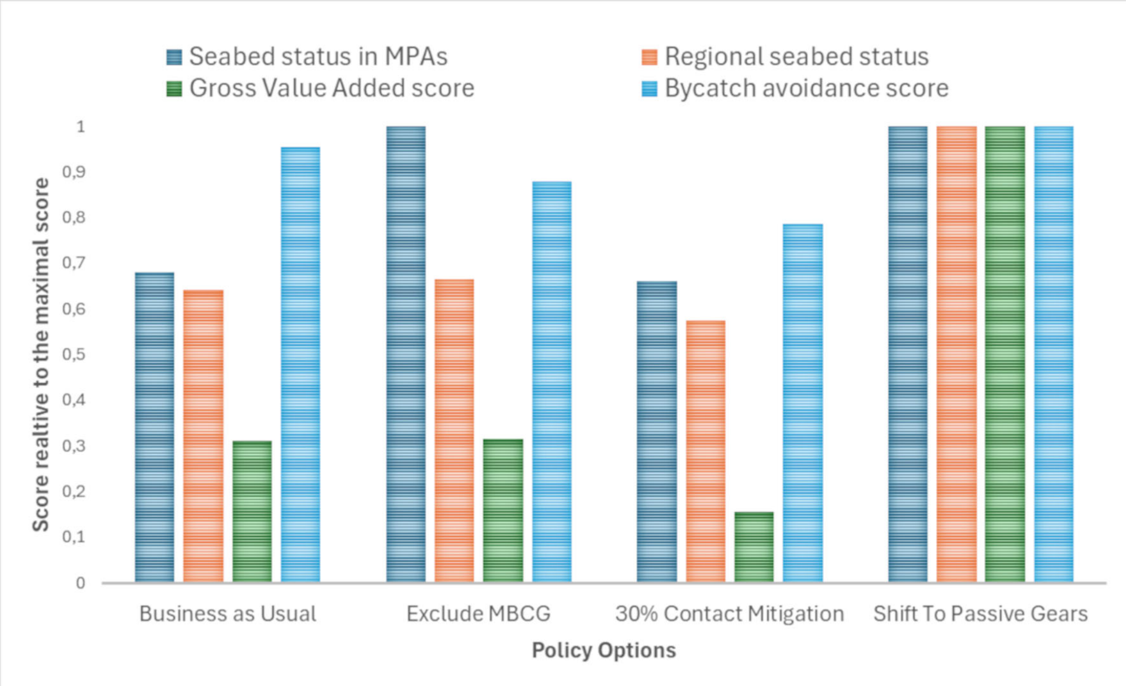
[25] Example of a Joint Recommendation to exclude MBCG: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R0340&from=EN

6. Lessons learnt and policy recommendations

This study aims to inform the political discussion around MPAs by providing scientific evidence regarding the most effective policy options to mitigate the fishing impacts in the MPAs. **Policy options** investigated are:

- Continue fishing within MPAs without restriction;
- Exclude the use of all MBCGs from the MPAs deemed vulnerable to mobile bottom fishing;
- Force the use of innovative MBCG with reduced seabed contact, within and outside of the MPAs, even if it would result in a 20 % decrease in catch efficiency, but also a 20 % fuel saving induced by less contact with the seabed;
- Force a switch towards using alternative, passive gears.

Figure 28: Relative scoring of policy options ('1' gives maximal score) against four indicators including the seabed status (Relative Benthos Status, RBS) inside the MPAs, or regional RBS averaged over EEZs (including inside the MPAs), the gross value added score averaged over fleet segments, and the incidental bycatch avoidance score. Note that a maximal score of 1 does not mean the bycatch effect is null or the seabed status is at best, as only relative scores are given here



Source: Own elaboration built upon section 3 outcomes.

The study did not find bottom trawl innovations that will not affect the catch rate and, therefore, the profitability of fisheries using bottom trawling. Currently, 'precision fishing' alone does not seem enough to reduce contact with the seabed, and may further face resistance to implementing any beneficial gear modification, given the potential loss in catch rates. If bottom trawling continues, it may be worthwhile to consider **excluding bottom trawling from marine protected areas to improve the ecological status within those protected areas and, at the same time, continuing research efforts on trawling-related technologies** to determine the maximum acceptable loss of catch rate, balanced against the savings on fuel expense. This research should be conducted locally, as the optimal strategy will depend on the target species, local economic conditions and vulnerabilities. For now, any existing solutions reducing the contact of the trawl gear with the seabed would likely result in counterproductive outcomes whenever more effort is needed to compensate for the loss in gear efficiency.

Consequently, the study has identified likely innovations to mitigate certain types of bottom trawling, even if those **innovations are still found insufficient to continue fishing in MPAs without their effect**. Developing such innovations further and implementing them requires the active support of the fisheries sector. So far, there is **low uptake** of current solutions, also because the fishing sector has yet to be forced to take action and use those solutions. The main reason for the currently low uptake of innovation outcomes is likely the loss in catch rates induced by the modifications aimed at mitigating the bottom impact. However, if implementing innovations may be expensive, with upfront costs and possible loss in catch rates in the short term, long-term solutions exist. If the policy goal is to reduce the seabed impact of bottom trawling into the MPAs, the legislation should oblige the operator to only use in the regulated areas any proven gears that greatly reduce the contact of the gear with the seabed, including sleepless trawl, raised footrope, or semi-pelagic 'flying' otterboard doors. Again, **such impact reductions within MPAs may overlook the risk posed by deploying more bottom-fishing efforts in other areas to compensate for the loss in catch efficiency. The key improvement would come from the fishing industry's encouraging partnerships with science and taking up innovations that would reduce the impact, while not affecting catch efficiency, and/or saving enough in fuel use and expenses to compensate for such a decrease in catch efficiency**.

Mobile bottom contacting gears have an unwanted impact on stock development (demersal species fished with these techniques are not in good shape in the EU[26]) and areas of high biodiversity, which should be limited to maintain future fishing opportunities and resilient seas. Continuing to preserve such areas with more stringent regulations is of value for biodiversity; this is desirable, given that a highly diverse marine environment will be more stable and resilient to change and disturbance (for example, induced by climate change, invasive species, or a combination of pressures) and a source for recolonisation for surrounding habitats. Even if limiting the possible economic consequences of excluding certain fishing practices from MPAs would gain at being implemented in periods when the stocks are increasing, and the habitats are in good health, if marine ecosystems are already degraded, the consequences of excluding certain fishing practices are inevitable.

On the other hand, there is no need to innovate in order to continue fishing within the MPAs without impacting the seabeds whenever passive gears can still be used in MPAs. In the meantime, effort research could continue to help the sector reduce bycatch risk induced by those gears. **Shifting all MBCG activities to passive gears will give the best local and regional anticipated outcomes** as soon as access to fishing opportunities is reallocated to this type of fishing. **However, the resistance to such a transition will likely be high**, given the low mobility of the invested capital in fisheries-related assets and upfront costs for the conversion.

In such a perspective, it appears urgent to take immediate policy actions to address the following issues relating to marine habitats deemed vulnerable to bottom fishing.

1) MBCG use should be excluded from MPAs deemed vulnerable to physical abrasion, even with innovative gears. Current innovations only have a marginal effect on reducing the seabed impact, and come with extra costs and loss of catch efficiency, making the net effect at the regional scale counterproductive. Displacement effects have been estimated as minimal as long as the MPAs are sizeable enough to cover the vulnerable habitats in their entirety.

26 See e.g. ICES stock assessment https://ices-taf.shinyapps.io/advicexplorer/

2) Allowing only passive gears and switching from mobile bottom-contacting gears to other fishing techniques would cancel out the impact on the seabed in MPAs. Maintaining thriving local and coastal fishers' communities in regulated areas (aka the 'land sharing' concept in terrestrial ecology) is also important to facilitate social acceptance and equity while preserving the resource, making the habitat recover, and exploiting it sustainably. In the long run, falling costs will make the transition/conversion more affordable and exploitation more profitable.

3) Introduce better fit-for-purpose MPAs and continue supporting the research effort to understand whether a new designation of MPAs can encompass several goals, i.e. protecting the seabed, limiting bycatch, and protecting fish and carbon-rich and vulnerable habitats, or whether insolvable trade-offs exist.

There are likely **upfront costs associated with converting the existing fleet structure to such techniques**, making it difficult for trawlers to switch to passive gears, along with other barriers, especially if only a part of their fishing grounds is to be closed. Trawlers can, however, continue fishing outside MPAs, as it is likely that the socioeconomic effects of a spatial ban for MBCG in operating in MPAs will be low, given that the designated areas are not areas of currently high productivity on target stocks. It is also likely that the current trawling activities will redirect their effort to surrounding areas. Such **effort displacement should be carefully examined in order to avoid putting more pressure on vulnerable areas or, in case of protection, mismatching the ecosystem features to be protected**. Such displacement may increase local conflicts between mutually exclusive gears (trawlers vs passive gears), and may also come with a decrease in catch efficiency in the remaining, still open areas (10 % loss has been reported in the North Sea) following effort concentration. However, such displacement will be minimal if restrictions are implemented in the currently designated MPAs (among those deemed vulnerable to MBCGs only).

Although it is commonly believed that many trawl paths are causing habitat degradation, the study recalled that **the most damaging trawl paths occur in less visited areas, which are also rich in biodiversity**. Therefore, it is crucial to protect these areas, typically designated as MPAs, from the effects of MBCGs, and to focus the fishing pressure on already well-fished areas. Therefore, a lot **more than just innovation for better bottom trawls that aims to minimise the contact of such fishing gears with the seabed may be needed to reduce the impact of fishing in certain areas where a small number of trawl paths can significantly harm the vulnerable benthic marine life**.

On the methodological side, the present study circumvented some common pitfalls assumed by other evaluations[27]:

- Passive gears touching the seabed are often confused with mobile bottom contacting gears (MBCGs). The scientific literature provides evidence that the effect of passive gears is not comparable with, and much less than, that of towed gears on the seabed. Policy-making should avoid confounding these different techniques, especially when excluding damaging fishing practices from the MPAs as the most effective policy.
- The study has considered marine habitats' varying levels of vulnerability. Some habitats, and the associated benthic biotopes are naturally prone to disturbance and have adapted to such perturbation. On the other hand, designated areas for MPAs are most often not such habitats, and must be protected because of their vulnerability to MBCGs. Careful reviews of MPAs identifying their vulnerability to MBCGs should be done ahead of restrictions.
- The study has looked into how fishing activity and pressure can be affected by spatial restrictions, particularly in areas surrounding habitats. After careful evaluation, it was found that this displacement is not significant for most fleet segments but may impact

[27] (e.g. https://www.senat.fr/rap/l22-633/l22-633.html)

inshore fisheries in the short term. Policy-makers would need to be aware that this effect should not be exaggerated, and that it needs to be weighed against the benefits of protection.

- The study has predicted that switching to passive fishing gears could increase the unwanted catches of sensitive species other than seabed species. However, a balance between preserving seabed habitats and protecting vulnerable species such as birds, sharks, rays, turtles or marine mammals can likely be achieved on a case-by-case basis, considering each MPA's specific spatial context and goal.

The research reviewed by this study has shown that **bottom trawling is an unselective fishing method** that results in many discards[28]. These discards (i.e. undersized, unwanted or damaged catches returned to the sea) are unintentional, but the European Union has imposed landing size limits to prevent a market for small, juvenile fish or shellfish from developing and overfishing the seas. However, some fishers blame these limits and the Landing Obligation (LO) of all catches (of marketable size or not) for causing waste and economic loss. The real issue is that the EU introduced the Landing Obligation in the 2013 fisheries policy CFP reform to avoid wasting living marine resources. Still, **trawlers are not taking steps to develop more selective gears** (see numerous derogations to the LO as listed in STECF 2023) to avoid catching unmarketable, undersized fish, for example with nets of larger mesh sizes, or adopting and shifting toward more responsible and sustainable fishing practices.

Table 8: Comparing four policy options to manage the activity of mobile bottom contacting gears (MBCGs) in European MPAs alongside anticipation of the short-term and long-term performances, the feasibility of the transition, including the fisheries sector's resistance to the change, and a description of possible ecological, economic and social consequences

Policy options	Effective-ness in reducing seabed impact in the short term	Effective-ness in the long term	Feasibility/ resistance	Ecological consequences	Economic consequences	Social consequences
Continued MBCGs fishing within MPAs	None	None	No change	Resource scarcity, habitat degradation and lower stock productivity	Lower incomes, lower resilience to environmental changes	Cross-sector conflicts induced by externalities
Exclude the use of all MBCGs from the MPAs deemed vulnerable to mobile bottom fishing	Medium	High	High	Habitat recovery within MPAs, extra pressure displaced outside but on already fished habitats	Lower income in the short term from loss of spatial opportunities, long-term benefits	Incentive toward shifting to alternative fishing techniques to access the MPAs. Possible equity issues

28 https://www.europarl.europa.eu/RegData/etudes/STUD/2024/752438/IPOL_STU(2024)752438_EN.pdf

Policy options	Effective-ness in reducing seabed impact in the short term	Effective-ness in the long term	Feasibility/ resistance	Ecological consequences	Economic consequences	Social consequences
Force the use of innovative MBCG with reduced seabed contact	Low	Medium	Low (medium resistance)	A few improvements are depending on the skipper's ability, but mitigation technologies are not ready, and low uptake will likely persist	Degraded revenue in the short term from lower catch rates	Upskills needed for operating the innovations
Force a local or regional switch toward using alternative, passive gears	High	High	Medium (high resistance)	Increase of incidental catches if innovations are not used	Market disruption. Upfront costs. Higher revenue for the fishing sectors from co-benefits	Uncertain changes in the labour force. Stock recovery is taking time

As demonstrated by the case studies and the questionnaire survey, the effect of excluding trawlers from MPAs on these areas and, more broadly, on the marine environment is challenging to measure, and **time is needed before benefits can be seen**. More evidence on spill-over effects should be provided, which requires advancing tools for marine reserve research, including predicting biological spatial connectivity and different species dispersal traits (Palumbi et al., 2003). **The general opinion is to promote the use of passive gears instead of bottom trawl gears for fishing in MPAs that have unique or potentially unique seabed conditions**. Passive gear will also bring co-benefits at the regional level as there are usually more selective fishing practices. However, due to the higher risk of bycatching vulnerable species for certain species groups, it is obvious that **passive gears should not be promoted in MPAs that are, on the contrary, designated to protect remarkable marine bird species, marine mammals, reptiles or protected elasmobranchs**. Policy-making still needs to support further research to mitigate the possible bycatch of protected or sensitive species such gear could induce.

Hence, Madsen (2007) and other gear technologists discussing the degree of gear selectivity recalled that **gillnets are more selective than trawls for commercial target species**. This is because small fish can swim through the mesh unharmed, while larger fish are trapped. Increasing the mesh sizes can further improve size selectivity since the technical parameters do not have much influence on selectivity, unlike trawls. Another advantage of passive gears such as set longlines is that they are more selective and use less fuel during operation. Using larger mesh sizes in fishing nets results in better quality fish, which are cleaner and less damaged. This leads to higher product value. Additionally, the crew's workload is reduced as less sorting on the vessel deck is required for unwanted species and invertebrates. This allows the crew to work more efficiently, with more time to prepare the fish, rest, and increase safety (most fatal accidents in fishing arise from human error, as noted by the PECH report on STCW-F[29]).

Policy-makers could look at deploying governance framing support tools to promote the use of low-impact and responsible fishing techniques. The regulators identify co-benefits and compensate for short-term trade-offs and upfront costs during the transition. Without adequate alternative livelihood options or compensation measures to bear the transition costs, impacted fishing communities may resist or circumvent MPA regulations. Policy-makers would build on stakeholder engagement to reduce such effects, including strengthening the community approach. One example, among other 'fishing styles', would be adopting a 'cooperative' model to ensure the future of sustainable fishing. In the past, with the introduction of Individual Transferable Quotas (ITQ) in the last two decades, larger fishing agents bought smaller ones in some areas whenever quotas were attached to vessels. This has resulted in a general trend where trawlers got much bigger, with larger engines and fishing capacity (Hegland and Raakjaer 2020). On the contrary, fishers' cooperatives could balance this tendency by ensuring a future for local coastal fishing communities using passive gears and less fishing capacity (Dinesen et al., 2022), which can currently struggle with individual profitability alongside marine habitat degradation induced by bottom trawling and other external factors (pollution, etc.). In such models, the costs and value chain can be mutualised by sharing a quota pool, resulting in economies of scale that give more access to funding and bank loans and lift the barriers for younger fishers. The entrance of younger fishers is then facilitated without forcing them into debt.

To encourage more low-impact fishing methods, **directing consumer choice towards healthy and high-quality fish through campaigns or eco-labelling can help offset the initial costs of implementing more labour-intensive, low-impact fisheries with higher-value fishing products**. Promoting the development of tools which objectively measure and score sustainability efforts in the fishing sector will empower stakeholders to track and improve their sustainability practices, promote transparency in the supply chain, and guide consumers toward sustainable choices. Sustainable fishing practices supporting healthy ecosystems are necessary for EU citizens to reap the benefits of replenishing fish stocks in EU waters, ensuring economically viable fisheries, long-term food self-sufficiency in the EU, and competitiveness of EU fisheries and aquaculture products on the global market (Aranda et al. 2024). Ensuring long-term fishing opportunities is the result of maintaining the **resilience** of the exploited seas, which equals maintaining 'the extent to which ecosystems can absorb recurrent natural and human perturbations and continue to regenerate without slowly degrading or unexpectedly flipping into alternate states' (Hughes et al. 2005).

[29] https://www.europarl.europa.eu/RegData/etudes/STUD/2024/747290/IPOL_STU(2024)747290_EN.pdf

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8. Annex – Questionnaire survey

Questionnaire survey sent by email to stakeholders

1. Can you specify which among the following options is the most suitable for you?

   Excluding Mobile Bottom-Contacting Gears (MBCGs) from Marine Protected Areas (MPAs) has no benefits, just costs

   Mobile Bottom-Contacting Gears (MBCGs) should still be permitted in MPAs whenever using some innovations proven to reduce impact

   Mobile Bottom Contacting Gears should be substituted for other types of gears whenever fishing in MPAs

   All types of fishing techniques should be excluded from MPAs

2. What type of innovations might reduce impact? What type of alternative gears might still be operated in MPAs?
3. Can you please clarify why you think it's worth/not worth excluding Mobile Bottom Contacting Gears (MBCGs)?
4. In continuing fishing within a MPA, ... *

   ...would it be feasible to use an alternative fishing technique to mobile bottom contacting gears that would not impair the goal of the protection

   ...would it be feasible to develop innovative/improved mobile bottom contacting gears that would not impair the goal of the protection

   ...all alternatives or innovations will likely be incapable of not impairing the goal of the protection

   ---MBCG should still be used as alternatives are actually either not feasible or too costly, and actual catch with MBCG irreplaceable

5. Can you explain how allowing only certain or excluding fishing techniques in MPAs can be effective/ineffective? *
6. Do you know about a specific Marine Protected Area (MPA)? *
7. Please provide the usual name of the MPA you know and explicitly mention the fishing techniques that have been excluded.
8. Can you explain the reason behind the designation, implementation, or enforcement of certain exclusions in this specific MPA?
9. Can you explain how allowing only certain or excluding fishing techniques in this MPA has been effective/ineffective?
10. Please provide information on the effectiveness of the surveillance measures in place and the (perceived) level of compliance.
11. Please provide a brief description of the metrics used to measure the performance of the exclusion, including environmental factors.
12. Please provide a brief explanation of the socioeconomic consequences and their potential contribution to the effectiveness/ineffectiveness of the referred MPA.
13. Would you prefer to remain anonymous and have your answers combined with those of others?
14. To avoid duplicate answers, please enter your email address.
15. Please provide us with your job title.

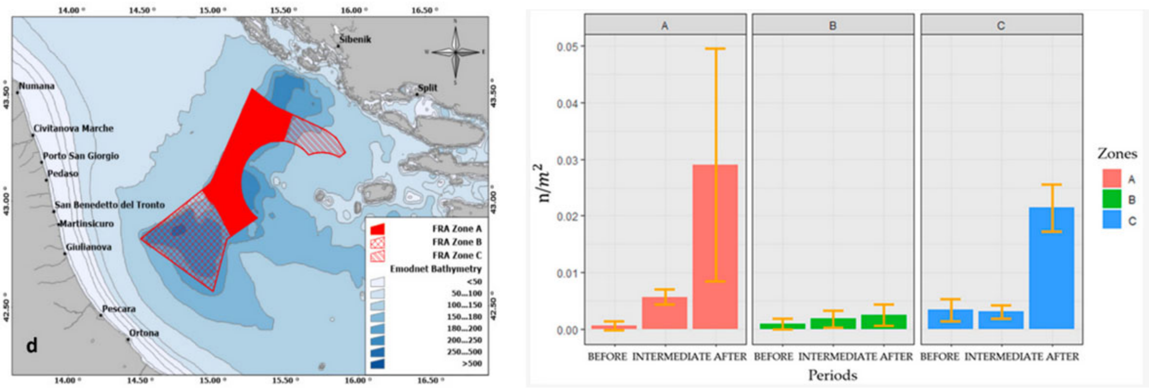
9. Annex – Case studies

9.1. Italian/Croatian Jabuka Pomopit (GFCM/41/2017/3)

Due to its natural characteristics, the Jabuka/Pomo Pit area is a critical habitat for demersal species, particularly hake and Norway lobster. However, these species have commercial value and are subject to persistent overfishing. The negative trends in demersal stock biomass over the past twenty years show that the resource is exploited at unsustainable levels.

Such declining biomasses of marine stocks with commercial interest has pushed both Italian and Croatian side to agree on implementing a closure of the Jabuka Pomo Pit area, including a strict exclusion zone of fishing since 2015. Post hoc evaluation has shown positive closure effects on the target species with a significant increase in biomass and density following the establishment the no-take zone. A combined effect of the spillover of European hake and the displacement of the fishing effort around the closure has possibly led to a balance on the average catch rate on hake that kept the same outside the closed areas (Chiarini et al., 2022).

Figure A.1: Average densities (n/m^2) of F. quadrangularis colonies recorded in the three FRA zones ('A', 'B', 'C') for the three considered periods ('BEFORE', 'INTERMEDIATE', 'AFTER')



Source: Extracted from Chiarini et al. 2022 and Martinelli et al. 2023.

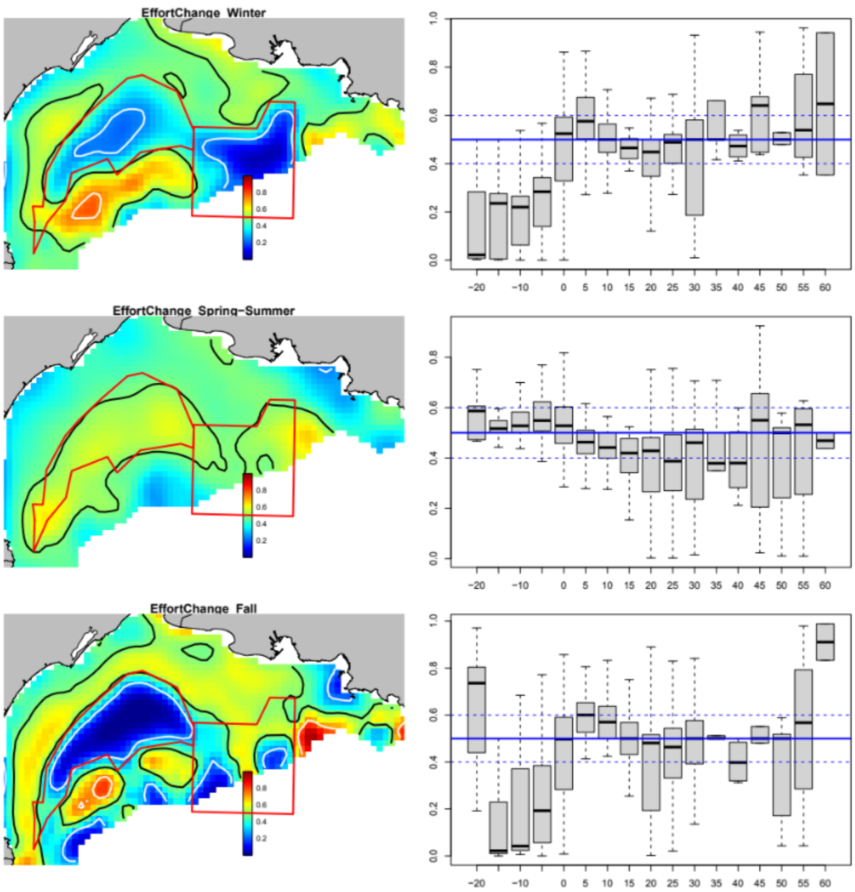
The exclusion of bottom trawling was beneficial for the benthic communities making the management measures effective from a positive influence on epibenthic communities (Martinelli et al. 2023), the study using sea pens as indicators of impact on and/or recovery of exploited habitats.

Nevertheless, fishers maintained similar overall levels of fishing effort by trawling elsewhere, likely to mitigate the short-term economic consequences. A constant monitoring of compliance is key when implementing spatial restrictions as poaching from transient vessels is a major risk and disincentive for fishers who suffer the greatest displacement who will therefore not take the maximal benefits from the protection. Unexpectedly, some trawling redistributed into other persistent fishing grounds for several species of commercial interest in the Adriatic Sea (Elahi et al. 2018).

9.2. Gulf of Lion seasonal closure in French and Spanish EEZs

In the Gulf of Lion, a seasonal closure was established in 2020, excluding the use of bottom trawling (OTB and OTT) in GSA07 over a 5000km² area, consisting of two boxes; the east box closing six months from Nov to April and the west box closing eight months from Sept to April within the 90-100m isobath strip. The objective of such closure is to reduce catches of juvenile hake by 20%, which will add to a reduction in the fishing effort cap by 10% annually as stipulated by the WestMed plan (Regulation (EU) 2019/1022). The closure was assessed as successful in reducing juvenile hake catches.

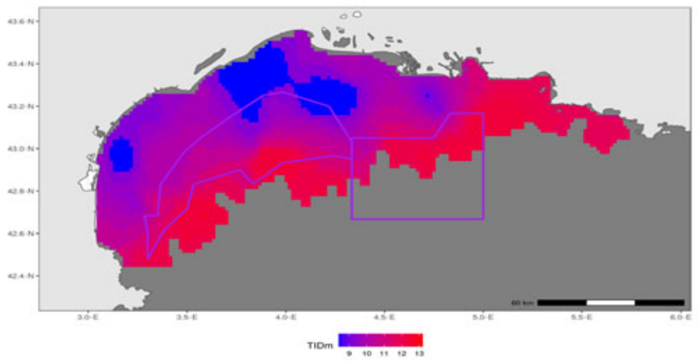
Figure A.2: Left: Maps of the relative change in effort distribution by season (ratio of effort after over effort before per grid cell with black isolines marking 0.5 values, and white isolines marking 0.25 and 0.75. Right: boxplots showing how the same values evolve with distance to the closure border (in km). The shape of the closure are clearly visible in all seasons, associated to a strong effort reduction in winter and fall, and to a slight effort augmentation in spring-summer



Source: Extracted from STECF 23-01 page 65.

Even if not the primary goal of the closure, the closure area also includes sensitive areas from the point of view of benthic populations. An assessment of the vulnerability to the fishing disturbance has been done, accounting for natural disturbance and the potential for a rapid growth (Jac et al 2020, see Figure A.3). Based on the assessment, it was found that the entire continental shelf is not equally at risk due to repeated historical disturbances that have already affected the benthic communities. The only area containing sensitive benthic communities is the slope zone. Therefore, protecting the south of the Western closure zone and the north of the Eastern closure zone could be beneficial for these sensitive biotopes. However, it is challenging to preserve these areas due to the effort displacement that results from seasonal closures. This displacement may cause extra pressure to be reallocated on the sensitive benthic communities unless the fishing operators are discouraged from visiting these areas due to the reduction in overall fishing effort due to the loss of spatial opportunity for fishing, leading to effort displacement (see STECF 23-01 page 65) and a decreased overlap with the unwished fishes.

Figure A.3: Maps of the closure areas of the management plan and the distribution of the species sensitivity indicator (TDIm indicator proposed by Foveau et al. (2017)) defined on the basis of the benthic communities observed between 2012 and 2018 and their biological trait

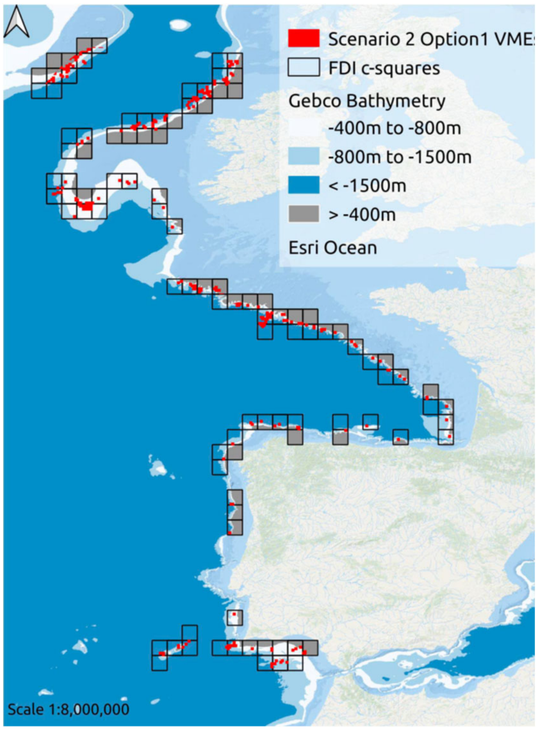


Source: Extracted from https://archimer.ifremer.fr/doc/00740/85189/90189.pdf.

9.3. Vulnerable Marine Ecosystems (VMEs)

Vulnerable marine ecosystems (VMEs) are a type of marine habitat defined as particularly vulnerable to fishing activities (FAO) made of habitat-forming animals such as deep-sea sponges, stony corals, sea pens, sea fans, lace corals and black corals form three-dimensional underwater forests. VMEs are particularly susceptible to bottom-fishing activity as they are easily disturbed at low levels of fishing effort while slow to recover. EU Deep-sea Access (Regulation (EU) 2016/2336) has limited the bottom trawling to areas shallower than 800m in the North East Atlantic area and 1000m in the Med where VMEs are likely to occur. One step further was to implement the Deep-sea fishing areas & VMEs (Commission Implementing Regulation (EU) 2022/1614) to protect VMEs in the region with 87 closed boxes enclosed between 400m and 800 m depth.

Figure A.4: Map of the list of 87 areas from Regulation (EU) 2022/1614 with c-squares



Source: Extracted from STECF PLEN 23-02.

In 2023, the EU STECF has been requested to evaluate the socioeconomic impact of protecting VMEs in the North East Atlantic area alongside different scenarios provided by ICES. The report revised by the STECF indicates that for all scenarios combined (current and future closures), the impact would not exceed 10% of the GVA. Spain appears to be the most affected MS with up to -7.20% change in average GVA for the Spanish fleet operating MBCGs (ESP_DTS_VL1218 in Closure2022 or -10.8% for ESP_DTS_VL1824 in Closure2022). French vessels using hooks would also suffer a GVA loss of up to -12.34% if Scenario C is adopted. The direct impact on the engaged crew would be the most significant in Scenario C for vessels 24 to 40 meters long with more than 1000 engaged crew members, which could be impacted by a -6 % GVA change in this kind of vessel.

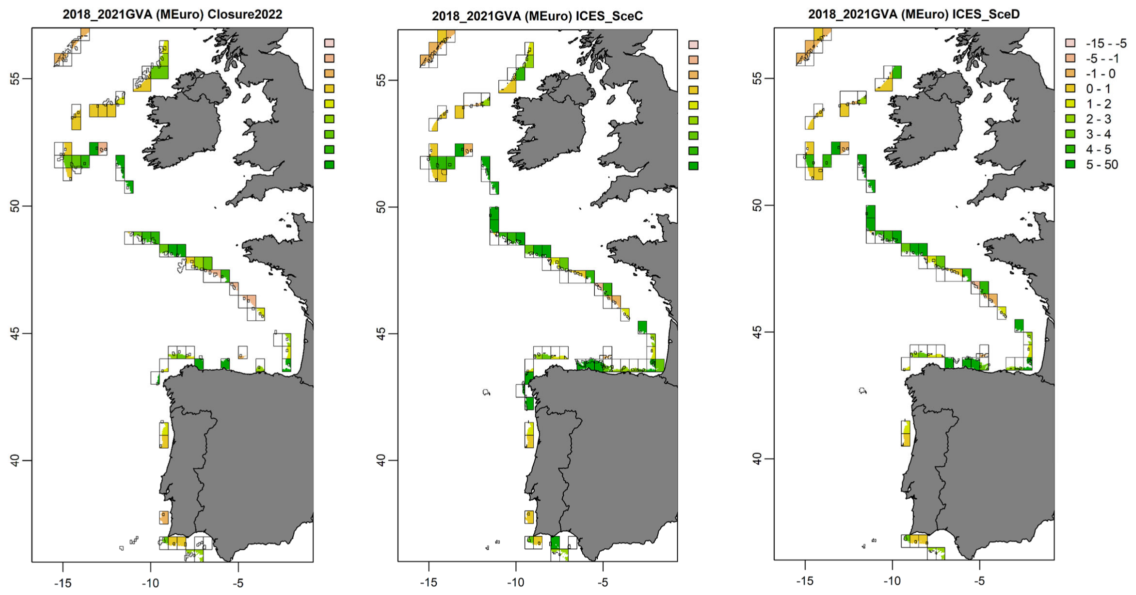
The socio-economic impact varies according to the scenarios, where most of the GVA lost comes from a few VME locations.

The evaluation made in 2023 has indicated a possibility of offsetting the loss of spatial fishing opportunities within the VME closures by displacing fishing efforts to surrounding areas in the proximity of the VMEs. However, further analyses and discussions with stakeholders on fishing patterns would help in assessing the impacts expected of effort displacement on surrounding areas. In deep-sea fisheries, due to the species' slow growth and sedentary nature, many areas are not fished every year, or there are gaps of many years between fishing activities in an area. Deep-sea species have a lower biological productivity (Vieira et al., 2019), which makes assessing their status difficult by nature, besides the past overfishing in the 80s and 90s having made their overall abundance decline to low levels (ICES WGDEEP).

A slight change affecting the economic return (GVA) may lead to a large change in profitability, given some large-scale fishing vessels with extensive fixed capital assets are engaged in deep-sea fisheries. Important drivers in fleet dynamics could also be addressed, especially when protected areas may improve catch possibilities around with a 'spillover effect' (Clark et al. 2016), potentially leading to increasing fishing efforts in surrounding areas. However, no-take zones cannot be expected to increase fish biomass in places that historically have low fishing pressure, and no overly optimistic gain for the fisheries should be expected from these protections. VMEs should likely be protected per se, given their rich biodiversity, without expecting a monetary gain for fisheries, but expecting not degrading natural capital that supports ongoing and future fishing opportunities. On the economic cost side, as noted in STECF-PLEN 23-02, what is considered so far is potential short-term effects and does not assess any long-term dynamics or changes in labour costs and employment in the medium term. This would require additional analyses.

It was the first time this analysis was conducted for the VMEs. STECF is aware that Article 9(6) of Regulation (EU) 2016/2336 requires a yearly review by the Commission based on STECF advice, with a first revision of the list of VMEs in early 2025, depending on this advice. Therefore, STECF assumes similar analyses will likely be requested in the future. It has been observed that there has been a decline in the number of continental-shelf fisheries (Viera et al. 2019, and references herein). As a result, there has been an increase in deep-water fisheries that operate beyond 400m, near the lower limits of the upper continental slope. To address this issue, it is recommended to focus on restoring conventional fish stocks that are fished by the EU fleet rather than expanding the exploitation to deep-sea fishing.

Figure A.5: Gross value added potentially affected in areas (c-square) containing the 87 VMEs protected by the EU Regulation 2022/1614 (left), and two alternative scenarios for VMEs protection placements provided by ICES (center and right)

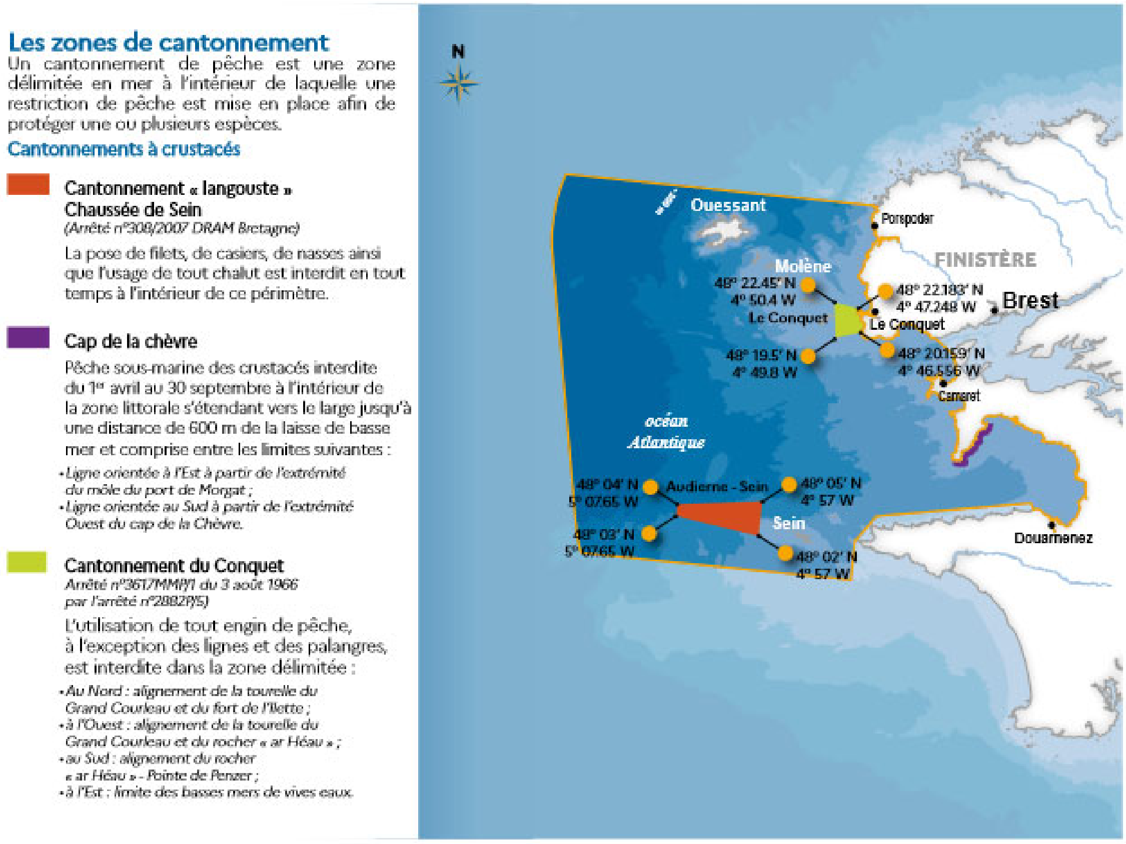


Source: Extracted from STECF PLEN 23-02.

9.4. Marine park of Mer d'Iroise in French Brittany

French national strategy for biodiversity led to the creation of the status of Marine Natural Park to have a tool which allows an integrated approach to the objectives of nature protection and sustainable development of human activities managed by a public body (Office Français de la Biodiversité (OFB))[30]. The Mer d'Iroise is one of the marine parks in France[31]. The marine park of Mer d'Iroise argues that, since its creation, the park has worked with professional fishers to understand and protect marine resource changes. Since 2017, he has led a network of volunteer professional fishers committed to the 'Partner Fishers' charter[32]. Commercial fishers have to sign this agreement whenever they want to fish inside. Hence, besides other fishing techniques, bottom fishing is still allowed in the marine park, and a zonation is in place (Figure A.6).

Figure A.6: Zonation for spatial restriction to certain fishing practices in the French marine park of Mer d'Iroise (ca. 3500 km^2). The red area is closed to all fishing types. The green area is set to exclude bottom trawling



Source: Office Français de la Biodiversité (OFB).

30 https://www.legifrance.gouv.fr/loda/id/JORFTEXT000000609487/

31 See also a catalogue of MPAs in France from Office Francais de la Biodiversité (OFB) at https://www.maia-network.org/homepage/marine_protected_areas/mpa_data_sheets/an_mpa_datasheet?wdpaid=388659&gid=178

32 https://parc-marin-iroise.fr/editorial/la-charte-pecheurs-partenaires

The park managers promote cohabitation among different sectors in the park despite rising concerns about the park's ability to meet its conservation goals while allowing fishing[33]. The park managers may use dashboards built upon scientific knowledge to overlay local vulnerabilities and potential pressure effects before allowing human activities.

Oral history 'Pêcheurs d'Iroise'[34] collected some views of local fishers : 'Il y a pire que de scier la branche sur laquelle on est assis, c 'est de scier la branche sur laquelle nos enfants sont assis' [EN : « There is worse than sawing the branch we are sitting on, it is sawing the branch our children are sitting on »], 'Il fut un temps où, sur la mer, c'était un peu le no man's land. Chacun faisait ce quíl voulait. Il n'y avait pas de réglementation. C'était «en avant toute ! », le premier arrivé, le premier servi, et tant pis pour demain. On n'est plus dans cette logique là aujourd'hui. La mer n'est plus un espace de liberté. Il faut que les gens s'enlève ça de la tête' [EN : 'There was a time when, on the sea, it was a bit like no man's land. Everyone did what they wanted. There were no regulations. It was 'all ahead!' », first come, first served, and too bad for tomorrow. We are no longer in this logic today. The sea is no longer a space of freedom. People need to get this out of their minds.'].

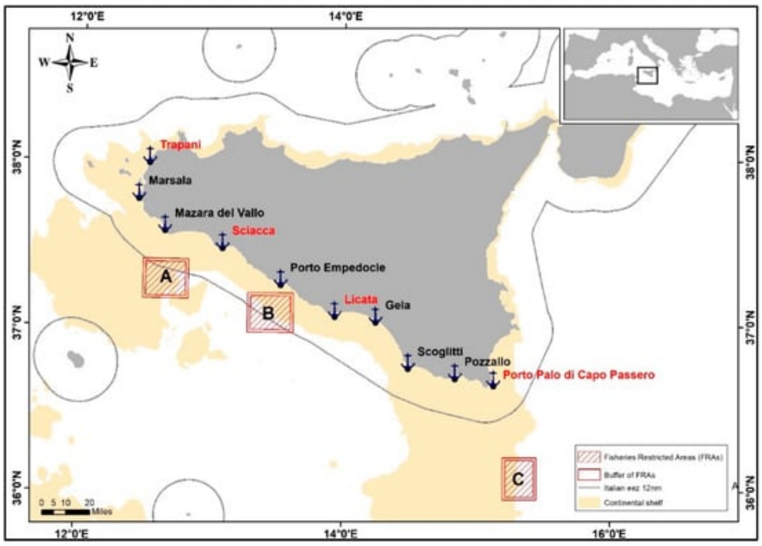
33 https://www.debatpublic.fr/la-mer-en-debat/peches-et-enjeux-environnementaux-quel-avenir-de-la-filiere-dans-la-transition-ecologique-et-5615

34 https://www.port-musee.org/wp-content/uploads/2018/03/DpPecheurs-d-IroiseA4_web.pdf

9.5. Fishing Restricted Area (FRA) in West of Gela Basin, East of Adventure Bank, East of Malta Bank (GFCM/42/2018/5)

The three reserves were established in 2016 by the General Fisheries Commission for the Mediterranean (GFCM), which is responsible for the sustainable use of marine resources as a means to protect essential fish habitats. Hence, such a case does not aim to protect the seabed as such but demonstrates the challenges in implementation beyond EU jurisdiction.

Figure A.7: A: the FRA situated to the east of Adventure Bank; B: the FRA situated to the west of Gela Basin; C: the FRA situated to the east of Malta Bank



Source: Extracted from Di Maio et al. 2022.

All the countries on the northern and southern Mediterranean shores are member countries of the GFCM, including Italy, Tunisia and Malta. Consulted fishers consider MPAs to be a useful tool to protect biodiversity and fish stocks, but they can attract illegal fishing. Hence, the European Fisheries Control Agency has confirmed illegal incursions in the restricted areas. EFCA has continued cooperating with third countries in the Mediterranean to promote an adequate level playing field in the area (see 2017 and 2018 reports from the annual inspections performed by the EFCA), further pointed out by an OCEANA study[35]. The general perception is also that MPAs don't help reduce conflicts among users since they cause overcrowding from fishers' displacement toward the surrounding areas, another incentive for non-compliance to the spatial restriction. However, simulations with a bioeconomic model have estimated that the reduction in earnings induced by the loss in spatial opportunities and increased fuel and salary costs, would be compensated by an increase in fish stocks and thus daily catches, even just a year after the closures (see MANTIS project[36]). Such an increase would result from the connectivity due to larval dispersal from spawning to nursery areas, as well as from reproductive migration from nursery/feeding grounds to spawning areas.

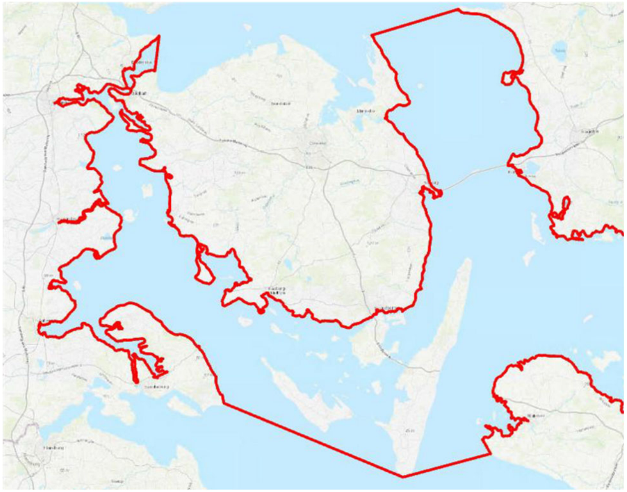
[35] https://europe.oceana.org/wp-content/uploads/sites/26/d_files/oceana_transparency_and_compliance_weaknesses_in_gfcm_fisheries_restricted_areas.pdf

[36] MANTIS, 2019, MARINE PROTECTED AREAS NETWORK TOWARDS SUSTAINABLE FISHERIES IN THE CENTRAL MEDITERRANEAN, Final Report http://jadran.izor.hr/mantis/scidiss.html

9.6. Trawl-free zone in Danish EEZ (Belt Sea, ICES subdivision 22)

The poor environmental condition in the Belt Sea (a subcomponent of the west Baltic Sea) is primarily due to frequent, widespread oxygen depletion caused by nutrient discharge from agriculture and river runoffs[37]. A trawl-free zone in the Belt Sea should, therefore, support the objectives of Baltic cod population recovery and maintaining social life in the coastal communities in the area while doing so with the least possible impact on the marine environment. The Danish Fisheries Commission supports a trawl-free zone in the Baltic Sea but recommends that fishing with bottom trawling gear still be allowed in some core fishing areas. The Danish Fisheries Commission argues that the location of the core areas (i.e. where fishing is most efficient and profitable) must be designated in collaboration with the fishers after advice on the environmental effects. By maintaining fishing in limited core areas, the objective of supporting life in the coastal communities around the Belt Sea can also be supported with the least possible impact on the marine environment alongside the MSFD's objective of restoring and maintaining GES. The Danish Fisheries Commission recommends maintaining fishing in core areas to prevent increased adverse effects from effort displacement in less affected areas. The Danish Fisheries Commission also recommends, in relation to the concrete design of a Trawl Free Zone in the Belt Sea [Translated from DK:] 'that all fishing in the Belt Sea must be fully documented; specific requirements be introduced for the use of bottom trawling gear with minimal impact on the seabed and risk of bycatch; some consideration given whether fishing should be limited to vessels native to the area to support the local communities, the introduction of these restrictions simultaneously supports fishing that needs to be converted to low impact fishing gear; some regulation of area impacted by mussel dredging, which at all times follows the strictest regulation in the Natura 2000 areas and with a focus on reducing the area impact, especially in the areas where the right growth conditions for eelgrass and macroalgae respectively are present; the inclusion of some management measures to reduce the adverse effects of oxygen depletion in the water column and on the seabed'. The Danish Fisheries Commission, in its deliberations on a trawl-free zone, has also formulated two alternative models (i.e. a 100% closure and a 0% closure for bottom trawl fishing) but has concluded that 100% closure should be preferred. However, the Danish Fisheries Commission has finally concluded that the introduction of trawl-free zones will likely have a significant positive impact on the marine environment's ecosystems and commercial stocks in some other Danish sea areas.

Figure A.8: Area to be banned to bottom trawling from 1st Jan. 2023 onwards in the Belt Sea. The trawl-free zone creates a continuous protected area of approx. 6,000 km2, corresponding to 5.7% of Denmark's total sea area



Source: Danish Ministry of Food, Agriculture and Fisheries.

[37] Extracted from Recommendations on Trawl-Free Zone in the Belt Sea by The Danish Fisheries Commission https://static-curis.ku.dk/portal/files/383784372/Fremtidens_Fiskeri.pdf

In European marine environments, various fishing gears contact the seabed, including mobile bottom-contacting gears (MBCGs) towed across the seabed. This study evaluates innovative alternatives to bottom trawling in EU marine protected areas (MPAs), examining their effectiveness, feasibility, and environmental and socioeconomic impacts. The findings indicate that innovations in gear technology are insufficient to meet conservation goals. Voluntary adoption of these innovations is low, suggesting the need for mandatory regulations. Consequently, the study recommends excluding MBCGs from MPAs vulnerable to bottom fishing. No current innovations achieve lighter impacts without affecting catch rates, potentially increasing the overall environmental footprint as fishers increase effort to compensate for reduced efficiency.

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