Deliverable 7.7

Report on options for mitigation fishing impacts in regional seas

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SUMMARY

INTRODUCTION

Impacts on the ecosystem through trawling are a complex issue and involve mostly negative impacts (reduction in diversity and habitat damage). Direct impacts are mediated through removal of organisms, damage to organisms, modifications to the environment and many complex secondary impacts through ecosystem functioning (e.g. changes to sedimentary processes, loss of habitat heterogeneity, changes to predator/prey relationships). Positive impacts may be in the addition of discards (organic carbon/feed inputs to the seabed) or increased productivity.

In the present deliverable a review of existing knowledge on technical innovations, fishing gears and alternative management scenarios is reported based on the literature and fishermen interviews. A list of the most promising alternatives has been investigated based on potential reduction of impact, economic performance and operational characteristics. Description of options of mitigation and how they interact are schematic presented for each case study.

Options for mitigating trawling impacts are primarily through input controls to the existing trawling industry. Input controls can be divided into three major categories: reducing effort, reducing contact and increasing selectivity. As Discards Bans are becoming important policy tools they are also included in having implications for trawling impacts. There is a huge variety of options. Each option has its own likelihood of being taken up in a particular area, depending on social, economic, and political reasons. Figure 1 shows how the major categories relate to impact reduction.

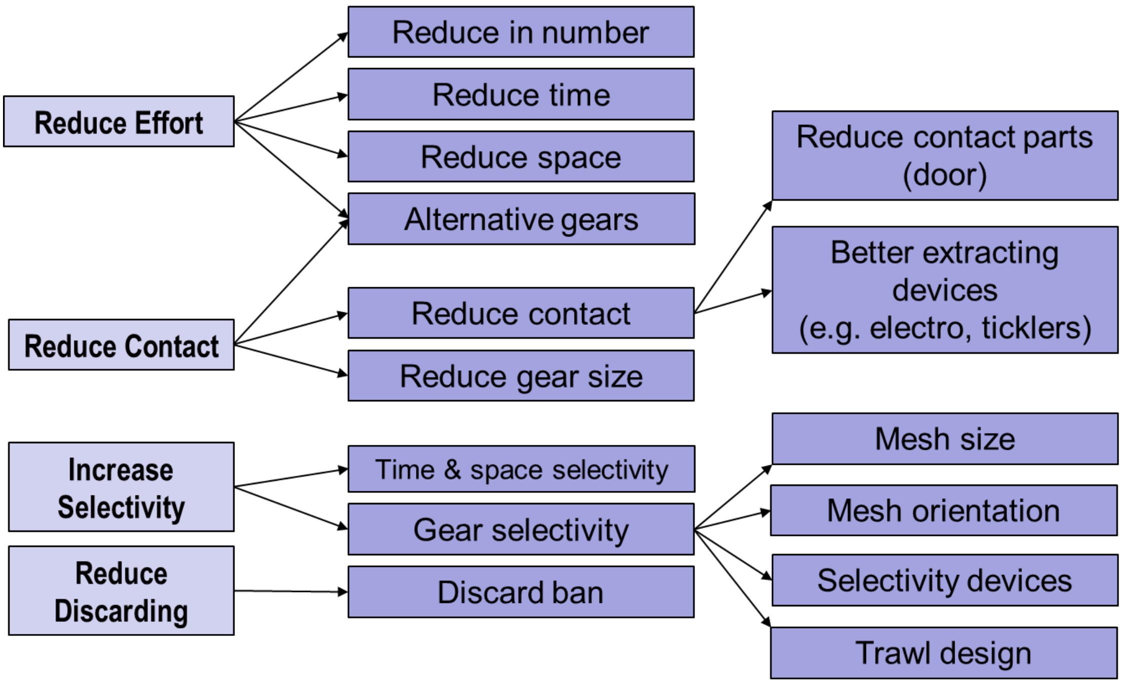


Figure 1. Potential input control options for mitigating the fishing impacts on the seabed.

Reduction of Effort

Reduction in Number

Within the last decades there has been a gradual reduction in the number of licences. This has either been in the form of buy-back, voluntary removal (removal or switching licence) or from the reduction in the issuing of new licences. Further reduction in licensing is a contentious issue due to the political interest, continued employment in the fishing sector, the need to replace older vessels, and maintenance of supply of fresh fish in the market place.

Possible option:

Option: To reduce the number of trawling licences.

Likelihood: Unlikely as there would be strong political objections, with vessel numbers already quite low. Strong incentives would be required for example buy-back schemes.

Reduction in Time

Since many decades annual closed season have been implemented in all bottom trawling fisheries (during summer months in Mediterranean countries). The primary reason for the ban is to protect reproductive stocks. The closed season also has allowed an annual maintenance period without pressure of losing fishing days. This ban will stand for the foreseeable future and is unlikely to be changed.
Possible options:

Option 1: To extend the closed period to allow a higher level of ecosystem protection
Likelihood: Likely, but fishermen will except incentives during the closed season.

Option 2: To close specific geographical areas over specific time frames to allow a specific ecosystem protection (including individual, periodic or rotational harvesting).
Likelihood: Likely, but requires strong reasoning and legislation at the local level (e.g. specific problems with local stocks or essential areas).

Option 3: To impose limitations on fishing outside of the 6 mile limit during the closed season.
Likelihood: Likely, but requires strong reasoning and legislation (e.g. specific problems with local stocks or essential areas). But further bans could be applied to geographical areas.

Reduction in Space

Other closed areas have been introduced in legislation either on a permanent basis or temporary basis. Permanent closures include a number of enclosed bays controlled as protection of nursery grounds. Marine parks is a more recent type of protection measure and new MPAs and VMEs are coming into force.
Possible options:

Option: To close specific geographical areas to allow a specific ecosystem protection
Likelihood: Likely, but requires strong reasoning and legislation at the local level (e.g. specific problems with local stocks or essential areas).

Alternative Gears

Whilst there is certainly space for the introduction of alternative gears to the trawler fleet there has been no new introductions. Modifications to existing trawling gears are dealt are discussed in the next paragraphs.
Possible options:

Option: To switch activities from otter trawling to other less impacting methods.
Likelihood: Possible, but requires incentives and examples (gear studies, including economic aspects).

Reduce Contact

Several parts of bottom gears are in contact and impacting the seabed. These may include tow warps in front of the door, the trawl doors, the door to net warps, the ground rope or parts of the ground rope and the belly of the net. The warp contact is incidental if towing is not optimum, there is too much wire deployed, the gear is not well rigged or the seafloor has a high level of topography. More continuously in contact and more impacting to the seafloor are the trawl doors and the ground rope. The trawl doors contribute to fishing in a number of ways; keeping the net open, cause optical and acoustic disturbance to the fish in order to herd them towards the centre of the tow line and the net opening. In spreading the net and keeping the trawl down the design has been towards a high-contact device that drags along the seabed digging a furrow. The high contact device also creates high-drag which maintains a high level of fuel consumption. Recognising that fuel consumption can be decreased with lower drag boards the fishermen are more open to innovation and this would also fulfil the conservation target of reduced bottom contact and consequent impact. The traditional basic design has remained unchanged for decades. Only in the last years local door manufactures have started to collaborate with scientists to develop new prototypes. New door technologies for low-weight, low drag, off-bottom designs that can

still maintain the trawl opening at typical trawl speed would be a good mitigating option. Option: To change from traditional otter doors to new low impacting doors.
Likelihood: Likely, but requires good examples (gear studies including economic aspects) and availability of new doors. Ground ropes are typically fitted with chain and some form of bobbin. More recently some trawl ground ropes have been fitted with some form of roller. This has allowed the trawlers to operate on harder grounds where there is more danger for catching and ripping the net. Unfortunately this has been applied to maerl grounds and has undoubtedly led to a high level of damage to these fragile ecosystems. Rollers are probably not of interest in other grounds as these fisheries are not highly targeted and they may lead to loss of normal catch.

Reduce Gear Size

The impact footprint of a trawl is defined by the sweep distance set between the doors being a function of rigging, warp length width of trawl and tow speed. In some Mediterranean countries like Greece there is no legislation to control the width of the gear.
Possible options:

> *Option*: To fix the size of gear to decrease impact.
> *Likelihood*: Unlikely as there is no current restriction on gear size. A size would have to be set (how?) and then legislation brought in, which would not be popular.

Increase Selectivity

Selectivity issues include targeting specific groups of fish, populations or parts of the populations by changes in fishing methods. This can include fishing at particular times or in particular places when those target groups are available or modifying the gear so that only those specific targets are caught/retained. Although selectivity measures have been introduced, there are local issues that make this more difficult; this mostly concerns the single type of bottom trawl used in multispecies-targeted bottom trawl fisheries. In some cases a selectivity measure may be beneficial for one species, but not for another within the same fishery.

Time & Space Selectivity

Time and space selectivity could be noted as Smart fishing and requires some knowledge about fish behaviour and movement patterns. Some species have regular movements such as diurnal or seasonal patterns in migration over short distances (up and down in the water column) or over greater distances (feeding or spawning movement). These movements can be targeted to primarily catch that species or a specific part of the population that takes part in the movement. An example of this is Nephrops where the burrowing species tends to forage on the sediment surface at dawn and dusk and is therefore more available to trawling. Care must be taken in using these strategies to separate selective fishing from decreased impacts and just increasing catch.

> *Option*: To promote smart fishing.
> *Likelihood*: Possible, but requires provision of advice on specific movement patterns, showing advantage to the fishermen. May require legislation related to time and area to allow specific fishing at forbidden times/areas or ban specific fishing at specific times/areas.

Gear Selectivity

A number of different selectivity studies have been undertaken and some measures have been taken up with corresponding legislation. The primary selectivity measures concern mesh size, orientation or pattern and use of special devices (sorting grid, TEDs, square panel, separators, etc.)

BALTIC SEA

General introduction to Baltic case study

Fishing activities with towed bottom gears are an important anthropogenic pressure that affects marine ecosystems worldwide (Dayton et al., 1995; Jennings and Kaiser, 1998; Collie et al., 2000; Kaiser et al., 2006; He and Winger 2010). Conservation of marine ecosystems may be achieved by reduction of fishery impact through limiting fishing pressure or banning fishing activities or by introducing gear types with reduced impact on the ecosystem. Ecosystem impacts of fisheries cover among other the impacts on the stocks from landings and discard, physical impacts on the seabed and on the benthic ecosystems (benthic community functioning) from fishing gears, and emissions of greenhouse gasses from fuel consumption in the fishery.

Benthic ecosystem impacts from demersal fishery in the western Baltic is assumed to come mainly from Nephrops trawling in the central and southern Kattegat, mussel dredging in the Belt Sea, and mixed cod trawling in the western Baltic Sea. The Baltic case study has focus on gear technological innovations to reduce effort, benthic contact of fishing gears, and discarding. There are conducted experimental fisheries in relation to evaluation and comparison of ecosystem and habitat impacts, catch efficiency (target/by-catch/discard/invertebrates), selectivity, energy efficiency, and economic efficiency (vessel specific cost-efficiency/cost-benefit analyses) of different gear modifications compared to standard gears. Furthermore, the case study evaluates potential fishing closures directed towards sensitive benthic habitats and communities. The case study explore in cooperation with the industry a number of possible innovations, gears and their modifications to reduce fuel consumption, maintain catch efficiency towards target and by-catch species, reduction of discard, and to reduce direct benthic impacts by the gears in order to reduce ecosystem impacts compared to standard gears.

With respect to mitigation in relation to plausible technological innovations and efficient management measures to reduce benthic impacts there is through stakeholder workshops under the Baltic case study obtained input and feedback from around 30 stakeholders including the involved fishing industry SMEs based on *i)* questionnaires and *ii)* specific suggestions from the different stakeholder groups for 3-5 issues/initiatives to be further investigated in the project under the Baltic case study. This has covered:

1) A review in collaboration with broad stakeholder groups including the fishing industry, on technological and management alternatives to mitigate fisheries impacts on the benthic ecosystem in the Baltic;
2) Presentation of relevant new technologies to be tested in experimental fishery in the Baltic case study and possible management measures to a large group of Baltic stakeholders (30 representatives);
3) Obtained Stakeholder feed-back with a) questionnaires and b) specific suggestions for 3-5 mitigations (alternative gears, technological developments, fishing methods) to be further investigated to reduce benthic impacts and discard as suggested by the stakeholders;
4) Cooperation with stakeholders on advice on development of the innovative fishing gears, technologies and methods for mitigation;
5) Planned of sea trials during several case study meetings.

Sub-case study 1: Mussel dredging in the Belt Sea, Western Baltic

General introduction to sub-case study

Sub-tidal beds of blue mussels (*Mytilus edulis*) are fished with dredges in several countries including UK, Ireland, and Denmark (Dolmer and Frandsen, 2002; Smaal, 2002). Blue mussels form beds that support high densities of associated fauna and, compared with the surrounding sediment, the mussel beds can be regarded as islands of high biodiversity (Norling and Kautsky, 2008; Ysebaert et al., 2009). Subtidal dredging is reported to affect the benthic fauna (Eleftheriou and Robertson, 1992; Dolmer et al., 2001; Dolmer, 2002) and flora (Neckles et al., 2005) and to change the structure of the sea bed (Dolmer, 2002; Dolmer and Frandsen, 2002). Dredging may also reduce substrate complexity owing to by-catch of shells and stones and this has been demonstrated to locally reduce survival of juvenile blue mussels (Dolmer and Frandsen, 2002; Frandsen and Dolmer, 2002) as well as the population structure of sessile epibenthic organisms such as *Metridium senile* (Riis and Dolmer, 2003). Furthermore, dredging is reported to affect higher trophic levels such as birds through competition for resources (Atkinson et al., 2010). Apart from the potential impact on transparency as a result of a reduction in the filtering biomass (Møhlenberg, 1995; Dolmer, 2000), dredging may also reduce transparency locally owing to resuspension of sediment. Resuspension is induced at the bottom during dredging and at the surface when by-catch of sediment is released when washing the catch (Riemann and Hoffmann, 1991; Dyekjær et al., 1995). Besides reducing transparency, resuspension of sediment has been found to increase levels of ammonia and silicate in the water column and to reduce the oxygen content (Riemann and Hoffmann, 1991).

In Denmark, 30000–40000 tons of blue mussels are harvested annually by dredging in coastal areas (Frandsen et al. 2014). The fishing grounds include NATURA 2000 sites designated for a number of marine habitat types including 1110 Sandbanks, 1160 Large shallow inlets and bays, 1170 Reefs, marine mammals, and a number of birds including mussel-eating birds. In 2013 a new Mussel Fishery Management plan was decided in Denmark in order to regulate the fishery in Natura 2000 areas. The mussel fishery was banned in habitats that are vulnerable to dredging, e.g. Zostera beds and geogenic reefs, while restricted fishing effort with low impact gear was permitted in the remaining NATURA 2000 area. The management plan allows for a cumulative impact by area of 15% on 'Large shallow inlets and Bays' and 'Sandbanks' in 2013, reducing to 13% in 2017. The management plan is an adaptation of the Irish management of aquaculture (Anonymous, 2013), and the Dutch management of the fishery for seed blue mussels used for bottom culturing (Nehls et al., 2009).

Presentation of some realistic options for the Case Study Region

With respect mitigation in relation to plausible technological innovations and efficient management measures to reduce benthic impacts from mussel dredging the different options presented during the stakeholder workshop RSE1 involved different solutions with a lighter mussel dredging gear according to gear width compared to a standard mussel dredger. This was based on some previous experiments involving pilot investigations under among other the BENTHIS project as described below.

Option 1. Reduce contact

The pilot investigations in Frandsen et al. (2014) focused on developing a mussel dredge with reduced ecosystem impact, which can be implemented without compromising commercial viability of the fishery. The aims of the gear development are to: (1) reduce resuspension of sediment in order to reduce impact on water transparency; (2) increase catch efficiency in order to reduce the affected area; and (3) reduce the force needed to tow in order to improve energy efficiency and potentially reduce energy transfer to the sediment. The implementation of the dredge in conservation areas is discussed in relation to reduced impact on the ecosystem and the economic efficiency of the fishery. The results of the pilot investigations of dredging blue mussels, *Mytilus edulis* are the following:

i. With respect to ecosystem impacts of mussel dredging: a) removing structural seabed elements, b) inducing re-suspension of sediment, c) reducing filtration capacity;
ii. Reducing fishing impacts: development of new Light Dredge with stakeholders;
iii. Tested against a standard dredge on commercial vessels using different experimental setups;
iv. Results from use of light dredge: a) the weight of sediment retained and re-suspension of sediment at the surface were lower, b) the drag resistance was significantly lower indicating a

reduction in energy transfer to the sediment, c) catch efficiency increased – reducing area of impact and reducing fuel consumption - and accordingly increasing economic efficiency;

v. Sea floor tracks made by the two dredges could not be distinguished by use of a side-scan sonar and the tracks were still detectable two months after fishing.

Option 2. Reduction of effort

Smart fishing, included video monitoring in advance of fishing to identify and monitor optimal fishing areas with respect to identification of areas with optimal underlying resources to fish upon:

a) higher density areas

b) higher value mussels (larger and better quality mussels of relatively higher density).

This will enable reduction in effort with impact on the benthic community and discards as searching for good fishing areas through trial fishery will be reduced because of the alternative video monitoring and because potential un-wanted catch from the trial fishery and searching will be reduced.

Selection of specific options for future work

Based on the above description of innovative measures the options have been selected for further testing. This selection is based on the stakeholder feedback and input obtained from RSE1 from questionnaires and focus group discussions, which have been followed up during the RSE2 in relation to mussel dredging. The two options of mitigations in mussel dredging have been suggested and selected during the RSE1 workshop in Copenhagen (DK) the 24th May 2013 and followed upon with planning of sea trials during the case study meetings in Haarlem (NL) June 2013 and in Göteborg (S) in September 2013 as well as in Rome (I) in April 2014. Blue mussel (*Mytilus edulis*) dredging trials with light twin mussel dredge in the Belt Sea (western Baltic), summer-autumn 2014 (Figure 2): Light /Heavy mussel dredge to reduce effort and bottom/benthic contact as described under the pilot investigations.

Figure 2. Different types of mussel dredges – light at the left and standard heavy at the right hand side.

The experimental fishery and survey design has been developed for testing the alternative fishing methods, and the main experimental fishery trials will be conducted in 3rd to 4th Quarter 2014. There will furthermore be conducted follow up investigations in 2015.

Comparison with existing, standard fishery and fishing methods will be done for selected mitigations. Data for the following parameters will be sampled, analysed and evaluated: i) Improved catch efficiency? ii) Reduced benthic impact? iii) Increased energy efficiency? and iv) Management measures based on maximum width of the gear in relation to efficiency?

Sub-case study 2: Cod trawling in the Western Baltic Sea

General introduction to sub-case study

The main fishery (main catches) of western Baltic cod is by trawlers, gillnetters and to a small degree by Danish Seines in the ICES subdivisions (SD) 22-24, i.e. in the Belt Sea and the western part of the western Baltic Sea (ICES 2013a). There is a trawling ban in place in subdivision 23 (the Sound). This implies that at present gillnetters are taking the major part of the commercial cod catches in the Sound. In SD22 and 24 the main part of the catches are taken by trawlers. The cod trawl fishery in the western Baltic Sea is mainly conducted with demersal otter board trawlers. In 2012, most of cod landings in SD22-24 were taken in SD24. The importance of SD24 for cod fisheries in the Western Baltic has substantially increased in recent years. Presently, around one third of the cod catches is taken in SD22, where fishery mainly takes place in the first quarter of a year. Catches are predominantly Danish, German and Swedish, with smaller amounts occasionally reported by other Baltic coastal states (ICES 2013a).

In the Baltic cod fishery, different cod-end mesh sizes and panels have been implemented as technical management measures to increase targeting and avoid un-intended by-catch and discard. The Baltic Sea trawl fishery that targets cod has traditionally been with two different cod-end types. The first is a BACOMA cod-end with 105- or 110-mm mesh-size (depending on period) with diamond mesh netting in the normal T0 orientation, and with a 120-mm square mesh netting in the upper panel (Madsen et al., 2002); the second is a 120-mm T90 cod-end, in which the mesh orientation is turned by 908 (Wienbeck et al., 2011). The BACOMA cod-end was in 2010 increased from 110 mm to 120 mm to minimize the discard of cod in the western Baltic. The purpose of mounting different selection panels in the cod-end of the Baltic cod trawls has been to target certain species and size groups and accordingly to reduce discard. Management measures according to ecosystem impacts of the Baltic cod fisheries have so far focused on by-catch and discard reduction. No measures exist at present for reduction of benthic impacts of the Baltic cod fisheries.

Presentation of some realistic options for the Case Study Region

With respect to mitigation in relation to plausible technological innovations and efficient management measures to reduce benthic impacts from Baltic cod fishery the different options presented during the stakeholder workshop RSE1 involved different solutions with use of pelagic trawl doors instead of standard demersal trawl doors to reduce benthic impacts from the trawl doors, as well as different options for fishing closures to reduce effort and fishing pressure on certain benthic habitats and sensitive benthic communities from the trawl fishery. The suggestions for the innovations were based on some previous experiments and results among other involving pilot investigations under the BENTHIS project and other projects using pelagic doors as described below, as well as based on results on management strategy evaluation of management options for certain fishing closures in the Baltic sea in relation to large marine constructions and NATURA 2000 sites (see below). The former is among other in relation to establishment of the Fehmarn Belt fixed link between Denmark and Sweden.

Option 1. Reduce contact - Pelagic trawl doors

The most effective method to reduce trawl door impact on the seafloor is to lift the doors off the bottom. This measure, however, has a technical as well as a catchability disadvantage and will therefore not work in all fishing situations. Pelagic trawl doors are mainly an option for target species that are not herded by doors and sweeps/bridles along the bottom, such as shrimp and Nephrops. For such target species the mouth area of the trawl itself is the key parameter for the catching efficiency (Eigaard et al., 2011). For species such as cod and plaice, which are herded by the sweeps/bridles, an off-bottom door rigging where these other gear components are on the bottom, may be a solution to maintain catchability and eliminate the seabed impact of the doors. The technical challenge with such rigging is to keep the trawl door distance above bottom nearly constant. He et al. (2006) reported on the development and testing of such semi-pelagic rigging in the shrimp fishery in the Gulf of Maine (United States of America). In these experiments the door height was set above the seabed by adjusting the length of the warps when the distance of the doors to the bottom was monitored with acoustic instruments. Similar catch rates were obtained with this semi-pelagic trawl door rigging as with traditional trawl doors. Monitoring the height of the trawl doors above the bottom requires appropriate instruments which can be used to adjust the door height by altering trawl warp length or, alternatively, the towing speed. An active control of the trawl door depth can also be achieved technically by adjusting the towing point and back strops of the doors while towing (FAO Technical Report 2007).

Some initial trials with pelagic doors (Figure 3) and alternative gear riggings have already been conducted in the western Baltic. The initial results indicate that there seems to be area differences in the catch efficiency of the gear when using pelagic doors, possibly due to substrate or seasonal related behavioural differences of cod in reaction to the gears. In a national development project (Gemba, 2011), results from test trials with the same trawl rigged with pelagic or bottom doors, respectively, demonstrated similar catch rates (Figure 4), However, the gears were tested using alternate gear configurations shifting on a trip basis, and the temporal and spatial variation is not accounted for in the comparison, so the values in the figure should be treated with caution. Further testing is needed.

Figure 3. Pelagic trawl doors compared to standard trawl doors in demersal cod trawl fishery.

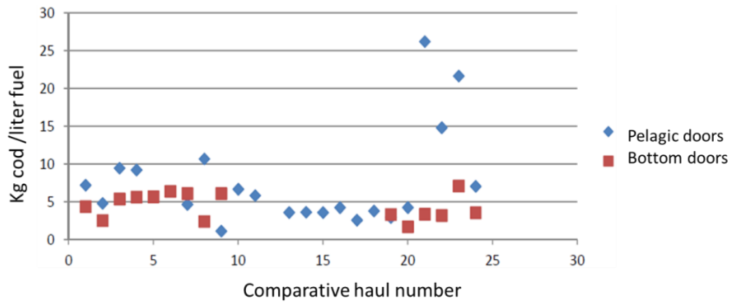


Figure 4. Cod catch weight (kg) per liter fuel consumption for the same trawl and sweep lengths fished with pelagic doors (blue diamonds) and bottom doors (red squares) from the same vessel, but on different trips (Gemba, 2011).

Option 2. Reduce in Space and Time - Fishing closures

A major scientific approach has been to develop bio-economic and spatial and seasonal explicit fisheries management evaluation methods and models which take into account and integrate fisheries dynamics and behavior, maritime cross sector spatial planning, fish population dynamics, and marine ecosystem dynamics, as well as fisheries energy efficiency. These innovative methods and simulation tools cover different marine seas and areas, several fish stocks and international fisheries, and operate on a spatio-temporal highly explicit scale enabling quantitative effect evaluation of fisheries management measures and broader marine management to reduce impacts on the marine ecosystem and environment and to optimize fisheries performance both with respect to ecological sustainability, economic sustainability and energy efficiency. The Baltic FLR model (Kell et al., 2007), which is a multi-stock and multi-fleet bio-economic model that is seasonal and spatial explicit, has been developed to evaluate effort regulation and quota based regulation systems and management scenarios for the Baltic cod fishery on a fleet specific basis (Bastardie et al. 2010a; Bastardie et al. 2010d; Bastardie et al. 2009). The Baltic FLR model has furthermore been dynamically coupled with the multi-species model SMS to take into account biological interactions between cod, herring and sprat in the management evaluation (e.g. Bastardie et al. (2012); Nielsen et al. (2011)). The DISPLACE model is an individual vessel based bio-economic multi-stock and multi-fleet model (Bastardie et al. 2010c; Bastardie et al. 2013; Bastardie et al. 2014; Bastardie et al. (submitted); Bastardie et al. (In advanced prep.)) which is highly spatial explicit using satellite track data of individual vessels and their fishing trip based catch information (coupling of Logbook-VMS data; e.g. Bastardie et al. 2010b) and using individual fishermen behavior information (e.g. Bastardie et al. 2013). This model has been developed to perform spatial fisheries management evaluation also in context of broader marine management and cross sector maritime spatial planning. A major facet of the model is to evaluate energy efficiency of the fishery in terms of individual vessel fuel consumption in relation to effort allocation (Bastardie et al. 2013; 2014), impacts of large marine constructions (e.g. Miethe et al. 2014), as well as evaluation of overall fishing pressure by type of vessel and gear in relation to fishery impacts on benthic sensitive habitats according to effort allocation in different habitat areas (Bastardie et al. (submitted)).

Selection of specific options for future work

Based on the above description of innovative measures the following options have been selected for further testing. This selection is based on the stakeholder feedback and input obtained from RSE1 from questionnaires and focus group discussions, which have been followed up during the RSE2 in relation western Baltic cod trawling. This has involved the two below mitigations in relation to western Baltic cod trawl fishery as suggested and selected during the RSE1 workshop in Copenhagen (DK) the 24th May 2013 and followed upon with planning of sea trials during the case study meetings in Haarlem (NL) June 2013 and in Göteborg (S) in Sept. 2013 as well as in Rome (I) in April 2014.

Baltic cod trawling mitigations will involve experimental sea trials with testing of pelagic trawl doors in the Western Baltic compared to standard demersal trawl doors during late summer-autumn 2014:

i. Sea trials with testing of pelagic doors with demersal trawl doors with overlap in time and space to reduce bottom/benthic contact as described under the pilot investigations; Evaluation of efficiency of the different doors in different fishing areas;

   a. The experimental fishery and survey design has been developed for testing the alternative fishing methods, and the main experimental fishery trials will be conducted in 3rd to 4th Quarter 2014. There will furthermore be conducted follow up investigations in 2015.

   b. Data for the following parameters will be sampled, analysed and evaluated: Change in catch rates and discard? Reduced fuel consumption (energy efficiency)? Economic efficient/sustainable (CBA)? Reduced bottom contact (doors, sweeps, foot rope) and Benthic impacts?

   c. Physical impacts from desk-studies of standard trawls given gear specifications; Changed physical impacts with pelagic doors with respect to doors, sweeps and footrope? Benthic physical impacts will be monitored as a desk study using results from measurements with laser analyses of footprint from similar gears and with specific information about gear properties.

ii. Smart fishing with re-allocation of effort away from certain areas with sensitive habitats and benthic communities;

   a. This will enable reduction in effort with impact on the benthic community and discards through searching for good fishing areas according to habitat type through trial fishery also with focus on avoiding un-wanted by-catch.

   b. Another focus in the sub-case-study is scenario evaluation of different effort allocation schemes with respect to benthic impacts and catch efficiency of Western Baltic trawl fishery evaluated through effects of potential fishing closures. The western Baltic waters offer a unique opportunity to evaluate the benthic impacts of fishing closures (both acute and chronic impacts) from comparative studies of habitats and catches inside and outside potential closures. Bastardie et al. (2013; 2014) has developed the DISPLACE mode to be used for this (see model description above). Certain fishing closures in the Western Baltic Sea has already been evaluated according to large marine constructions (fixed Fehmarn Belt link between Denmark and Germany) in Miethe et al. (2014), and in relation to NATURA 2000 conservation areas and windmill farm sites (Bastardie et al. (submitted)). In relation to the BENTHIS project (Baltic case study) initial investigations with evaluation of trawl fishery impacts on sensitive habitats with respect to effort pressure is performed in Bastardie et al. (In advanced prep). These simulation studies will be followed up upon when the actual impact of the specific gear is known which among other will be obtained from a desk study using comparable results from BENTHIS.

Sub-case study 3: Nephrops trawling in the Kattegat area

General introduction to sub-case study

Both Denmark and Sweden have *Nephrops* fisheries in the FU4 (Kattegat). In 2012, Denmark accounted for about 77% of the total landings in FU4 on ca. 1900 tons, while Sweden took 23 %. Minor landings have been taken by Germany (1%), however, no landings were recorded in 2012 (ICES 2013b). The Danish landings exclusively originate from demersal trawl fishery directed for *Nephrops* but with by-catches of cod and flatfish. Also, the major part of the Swedish landings originates from demersal trawl fisheries, but by-catches and landings of other species are minor due to the use of sorting grid in this trawl fishery (Frandsen et al. 2013a). About 20% of the total Swedish landings of *Nephrops* were from creel fishery with minor by-catches (Jansson 2008; ICES 2013b).

Cod and sole are significant by-catch species in the mixed fisheries in Kattegat-Skagerrak, and even if data on catches, including discards, of the by-catch gradually become available, they have not yet been used in the management. The ICES WGNSSK (ICES 2013b) has for many years recommended the use of species selective grids in the fisheries targeting *Nephrops* as legislated for Swedish national waters. New technical measures (Swedish grid and SELTRA trawl) to reduce by-catch have recently been agreed upon for the *Nephrops* directed fishery and have been implemented since the 1st February 2013. The European Union and Norway have also agreed that a discard ban should be implemented in the Skagerrak (Division IIIa N) (ICES 2013b).

The mixed *Nephrops*-fish fishery is characterized by a relatively high by-catch of juvenile fish species and high discard rates. In the Kattegat, the cod stock is at a critically low level (ICES 2013a), and measures have been taken to rebuild it, including designating seasonally, year round protected areas where only selective fishing gears are allowed, and a fully closed area (ICES 2013a; Madsen and Valentinsson 2010; Sköld et al. 2012; Vinther and Eero 2013). The use of a sorting grid is an option in the Norway lobster fishery under current legislation in Skagerrak and Kattegat (Valentinson and Ulmestrand 2008; Frandsen et al. 2009; Madsen and Valentinson 2010) and has also been tested recently in other Norway lobster fisheries (Loaec et al. 2006; Catchpole et al. 2006; Graham and Fryer 2006; Drewery et al. 2010). While sorting grids are very effective at allowing cod to escape and to reduce discard (Valentinson and Ulmestrand 2008; Frandsen et al. 2009; Madsen and Valentinson 2010), they are more difficult to handle onboard the small vessels that typically operate in this area, and fish and debris can block the grid. Furthermore, losses of Norway lobster, particularly the larger and more valuable individuals, have been observed (Frandsen et al. 2009). In general, Danish vessels in Kattegat and Skagerrak have not used the Norway lobster grids that have been permitted by the legislation since 2005, even though the use of these grids allows unlimited days at sea, whereas there have been severe restrictions on using less selective gear. The square-mesh escape window (henceforth window) is one of the most widely used selective devices in European fisheries. A 120 mm window was implemented in the Kattegat and Skagerrak fisheries beginning in 2005 (Krag et al. 2008), but it did not produce a marked improvement in selectivity for cod (Frandsen et al. 2009).

Conventional escape windows are not adequate to properly release cod and other by-catch species caught in the trawls. To address this issue Madsen et al. (2012) developed a novel sorting box concept consisting of a four-panel section with a window on the top in order to improve the escape of cod and other by-catch species through an escape window while retaining the target catch of Norway lobster. The concept was tested on a commercial trawler in Kattegat and Skagerrak. Two different window mesh sizes and two different sorting box heights were tested using a traditional codend cover and a dual cod-end cover. Here there were observed greatly reduced by-catches of both cod and other fish species compared to a standard cod-end.

On the contrary, the major part of the Swedish fishers have adapted to the use of sorting grid since it was introduced in national waters in 2004. The incremental use is likely due to the incentives by the management, i.e. access to *Nephrops*-fishing grounds along the coast, derogation from effort limitation (article 11) and dedicated quotas (Sköld et al. 2011). Currently the Swedish *Nephrops* quota is allocated to different gear categories (20% to creels, 50% to grid trawls, and the remaining 30% to other trawls, ICES 2013b).

In summary, management measures according to ecosystem impacts of the Kattegat Nephrops fisheries have so far focused mainly on by-catch and discard reduction. The exception is the trawl boundary along the Swedish coast. The trawl boundary was furthered out in 2004 with aim of avoiding trawling on reefs according to the habitats directive (Sköld et al. 2011). However, no measures exist aimed at reducing benthic impacts in the open Kattegat.

Presentation of some realistic options for the Case Study Region

With respect mitigations in relation to plausible technological innovations and efficient management measures to reduce benthic impacts in Kattegat *Nephrops* trawl fishery different options were presented during the stakeholder workshop RSE1.

Option 1. Reduce contact and gear size

The gear innovations presented involved four-codend-trawls (Figure 5a) with lighter bottom gear, different types of selection devices such as SELTRA trawls and TOPLESS trawls, changes in trawl gap, and standard trawls rigged with shorter bridle length than standard rigging bridle lengths, i.e. gears with shorter sweep lengths (Figure 5b).

Option 2. Reduce in space (fishing closures)

Other measures presented and discussed was closures of certain fishing areas in relation to distribution of sensitive habitats and benthic communities. It was discussed to make comparative analyses of multiple data time series of catch rates and benthic sampling according to the different types of fishing areas, i.e. the long term closure of the Sound to towed gears since the 1920s and the short term closed area from the Kattegat MPAs introduced in 2008 compared to (nearby or surrounding) otherwise heavily exploited fishing regions in Kattegat (open fishing grounds) in relation to the potential effects of *Nephrops* trawl fishery but also in context of a broad variety of mixed demersal trawl (and seine) fisheries (Figure 6a and Figure 6b).

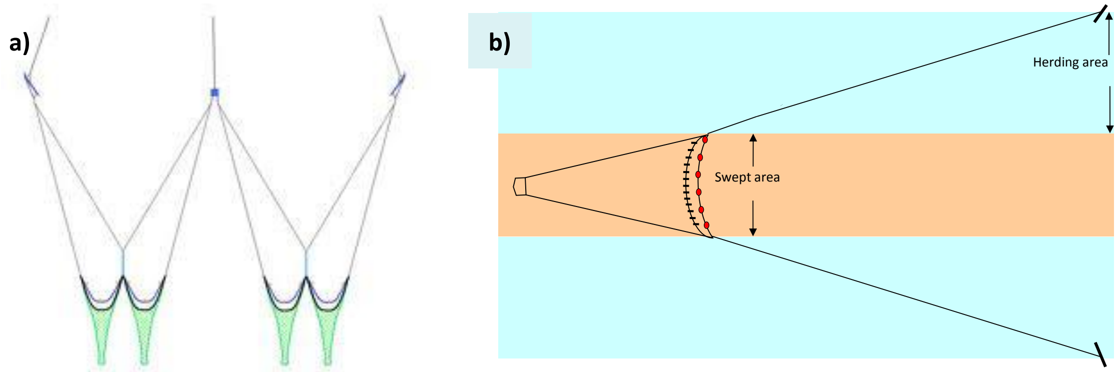


Figure 5. A) Four trawl (codend) system and B) scheme of bridles or sweeps shortening in Nephrops Fishery in Kattegat.

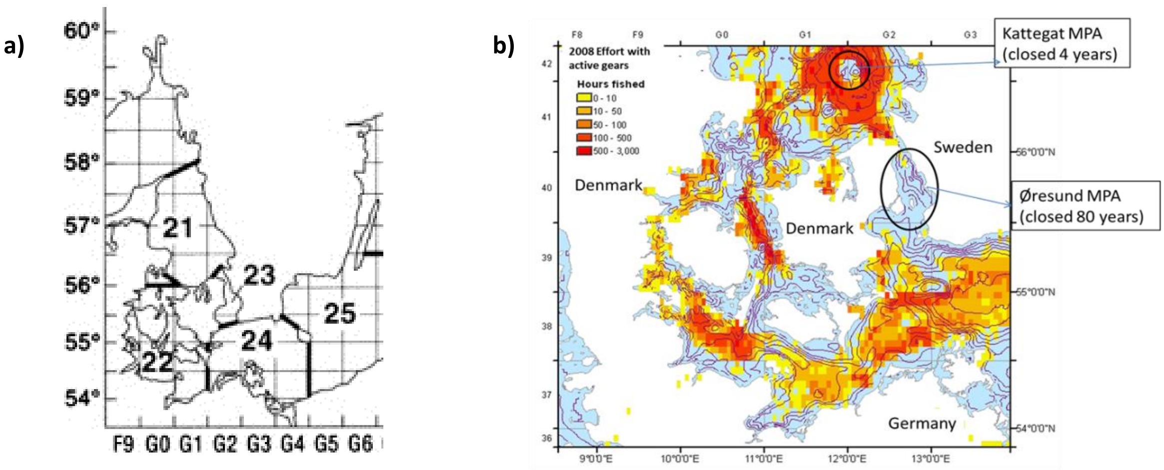


Figure 6. A) Fishing areas and B) fishing closures in Kattegat and the Sound.

Based on the evaluation and discussion of the presented options for innovations to reduce benthic impacts of the Kattegat Nephrops trawl fishery during the stakeholder events it was considered most efficient to test different sweep lengths. This is because shorter sweeps are considered to have less benthic contact and cause less benthic and impact, and they will avoid herding of fish by-catch which is un-wanted either because of overall TAC- and/or effort- restrictions (especially according to cod), or because of lack of individual quotas for fish species for the *Nephrops* fishermen. Accordingly, discard will also be reduced, and the innovation will meet a coming discard ban in the fishery.

Selection of specific options for future work

Based on the presentation of potential innovative measures at the RSE1 the two below mitigations and options were selected for further investigation in the Kattegat *Nephrops* trawl fishery. This selection is based on the stakeholder feed-back and input obtained from focus group discussions and questionnaires in relation to the Nephrops trawl fishery in Kattegat during the RSE1 workshop in Copenhagen (DK) the 24th May 2013 and followed upon with planning of sea trials during the case study meetings in Haarlem (NL) June 2013 and in Göteborg (S) in September 2013 as well as in Rome (I) in April 2014.

The main experimental fishery trials will be conducted in second half year of 2014: Nephrops trawl fishery trials, Kattegat, August 2014;

(i) Traditional Nephrops twin-trawl with benthic doors and 2 different sweep lengths: Aalbæk Bay, Northern Kattegat - standard Nephrops trawl fishery area (open); Sweep lengths – Standard (74 m), Short (10 m);

The hypothesis is that the shorter sweeps will not change the selectivity and catch of nephrops, because Nephrops are not herded by the fishing gear, while the un-wanted by-catch of fish (especially roundfish like cod) will be reduced because there will not be as much herding of these fish from the shorter sweeps compared to the longer standard sweeps. Sweeps are known to herd most fish, especially roundfish. Fish by-catch is often un-wanted in the Nephrops fishery because it may restrict the fishery either because of overall TAC- and/or effort- restrictions according to a fish catch (especially according to cod), or because of lack of individual quotas for fish species for the *Nephrops* fishermen because these quotas are very expensive. Accordingly, discard will be reduced, and the innovation will meet a coming discard ban in the fishery. The hypothesis is furthermore that shorter sweeps are considered to have less benthic contact and cause less benthic and impact.

Evaluation of:

Physical and biological benthic impacts of different sweep lengths (standard fishery compared to gear technological innovations)?
Lighter bottom impact because of smaller gears and lighter bottom gear door-seabed-contact to be considered?
Higher catch efficiency / Cost Benefit Analyses (CBA) / energy efficiency?
Less by-catch and discard of fish because of changed herding?

(ii) Trial fishery in different types of fishing areas with different fishing pressure in Kattegat

(iii) Monitoring of benthic communities in different types of fishing areas with different fishing pressure in Kattegat and surrounding areas

With respect to (ii) and (iii) the purpose is to investigate differences in benthic impact of the Nephrops trawl fishery (and other trawl fishery) in the Kattegat area: a) Open fishing area Northern Kattegat; b) Short term closed area Southern Kattegat; c) Long term closed area, The Sound (ICES SD23) with respect to longer term biological benthic impacts of fisheries and short term differences in catch rates from the different areas.

The sea trials will be carried out in August–September 2014 in Kattegat in three areas subject to different fishing intensity (Aalbaek Bay, S. Kattegat, and Øresund) at depth of 25-30 m (16-18 m). Vessels involved are one Nephrops OTT (FN370), and one Danish Naval Home Guard Vessel. A twin-rigged Nephrops trawl with shortened sweeps will be deployed to reduce swept area and minimize seafloor impact from these. Benthic impacts is planned to be tested in a BACI design using sediment profile imaging (SPI) and core samples (haps corer) for measures of sediment grain size composition, SPI index values, pigment profiles (HPLC), depth of H_2S free zone, and species abundance, biomass and diversity and biological traits composition. Depending of the weather conditions side scan sonar & UW video recording may be used. If possibly, laser profiling will be carried out to evaluate the physical impact of different trawl elements.

Sub-case study 4: Nephrops creel fishery in the Kattegat area

General introduction to sub-case study

In the Skagerrak, approximately 25% of the Swedish Nephrops quota is taken by the creel fishery, while the creel fishery in the Kattegat is limited. Most creel vessels are less than 12 meters and fish in coastal areas, where it is often combined with gillnetting, trawling or creeling for other species (e.g. crabs and black lobster). The Swedish creel fishery for Nephrops occurs primarily north of Varberg, largely due to the absence of the archipelago, which is why the use of trawls further south is favoured (ICES 2013a). It is also impossible to deploy creels in trawled areas and since the fishing grounds for Nephrops in the central and southern Kattegat are intensively trawled there is no space for the creel fishery to develop.

Presentation of some realistic options for the Case Study Region

Option 1. Alternative gears

Fishermen's understanding on the benthic impact of creeling is that there is very limited impact, whereby creels are directly lifted off the bottom. During a creel trail in autumn 2013 cameras were used to obtain a preliminary understanding around this issue. The footage obtained revealed that creels were not directly lifted off the bottom but were dragged for several minutes (http://www.youtube.com/watch?v=EL2G1sMXZUo). Quantification of the physical disturbance which occurs from the creel fishery was not possible from the footage obtained and therefore needs to be measured. However, it should be noted that dragging of creels over the seabed during a relatively limited time interval of heaving is physically impacting a smaller area than a trawl haul with impact from doors, sweeps and footrope over long time span covering a larger area.

During commercial creel fishing, catches are sorted immediately, where Nephrops are retained and the rest thrown overboard. Previously, it was estimated that by-catch was thrown back in the water within 20 seconds (Jansson, 2008), which was also the case in the DTU Aqua trial in spring 2013. All catch immediately went to the bottom, and no predation from sea birds was observed. By-catch of round fish is considered most vulnerable to this type of fishing as their swim bladder inflates when they pulled up quickly through the water column. We observed no visible deviations in the cod's behaviour when they swam to the bottom. However, previous studies have shown that cod can swim far down (> 10 m) with distended swim bladders until they become exhausted and float back to the surface where they become available to sea bird predation (pers. Comm. J. Karlsen, DTU Aqua, http://www.dtu.dk/Service/Telefonbog/Person?id=39844&tab=2&qt=dtupublicationquery).

With respect to mitigation in relation to plausible technological innovations and efficient management measures to reduce benthic impacts by using Nephrops creels different options were presented during the stakeholder workshop RSE1. This involved first of all creels as an alternative fishing method to trawling and discussion of this, but also different types of creels and different settings of the creels were presented and discussed. These discussions were based on preliminary results from pilot investigations among other under the BENTHIS project as described below.

The pilot investigations (Figure 7) with creels on soft (muddy) bottom are reported in (Frandsen et al. 2013b). Camera monitoring indicated that the creels sank very much down into the sediment;

(i) The bait attracted Hagfish (*Myxine spp.*) which scared the Nephrops in the creels => some escapement;

(ii) Catch rates about 180 g/creel per day;

(iii) CBA: Daily profit about 3800 DKK per day;

(iv) CBA: Comparable trawl fishery for trawlers < 12 m about 3050 DKK per day, i.e. comparable; Larger trawlers have higher profit;

Figure 7. Creel fishery as an alternative to trawl fishery as well as different options for the creel settings and parameters.

Selection of specific options for future work

Based on the above description of innovative measures and pilot investigations the below options have been selected for further testing. The overall aim of the sub-case study is to provide information on benthic impacts of creels to be compared to benthic impacts of the Nephrops-fish mixed trawl fishery

(Figure 8) and at the same time compare the catch efficiency and the economic efficiency in these fisheries, as well as discard levels, given different fishing conditions. Aspects of this purpose are already covered in the pilot studies described above. The selection is based on this purpose and the stakeholder feed-back and input obtained from RSE1 from questionnaires and focus group discussions, which have been followed up upon during the RSE2 in relation to Nephrops creeling.

Nephrops creel fishery trials in Kattegat late 2014 – early 2015 with different modifications of creel set-up (only to be performed in fishery areas open for trawl fishery):

(i) Overlapping fishery between Swedish commercial Nephrops trawl fishery with standard trawl and Swedish creel fishery in northern Kattegat;

(ii) Experimental fishery to follow up on pilot investigation results on fishery at soft bottom in standard Nephrops trawl areas compared to usual creel fishery at harder sediment types;

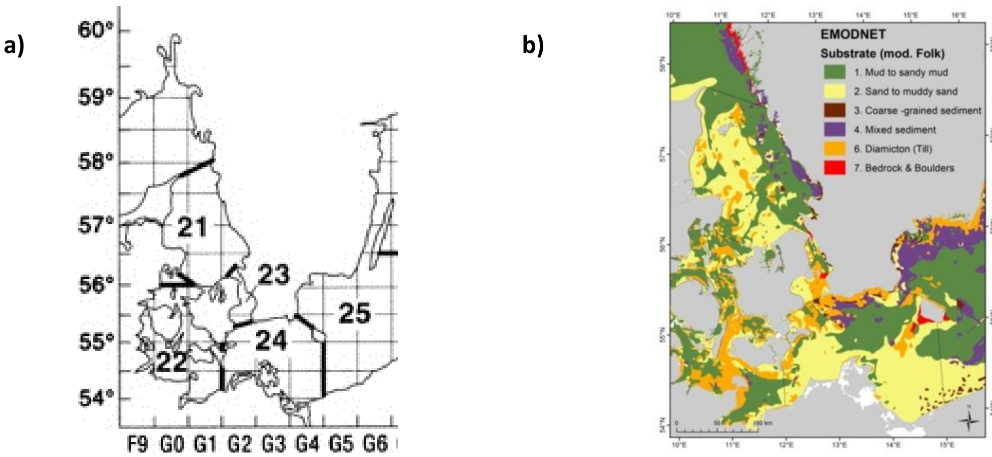


Figure 8. A) Fishing areas and B) seabed types.

(iii) Attachment points of the creels (top instead of center point), shelters in the creels;

(iv) Evaluation of: Change in Catch rates (Catch per Unit of Effort, CPUE)? Discard reduction? Economic efficient/sustainable (CBA)? Reduced bottom impact (also when heaving 40 creels)?

NORTH SEA

General introduction to case study

Beam trawl fisheries

Beam trawling is an efficient method for catching demersal flatfish species (mainly sole (Solea vulgaris L. and plaice (*Pleuronectes platessa* L.)), and brown shrimps (*Crangon crangon* L.). The fishing vessel operates two steel spars or beams from two derricks simultaneously (Figure 9). A beam trawl gear consists of the beam with two trawl shoes on each side to which a net is attached and an array of chains, called 'tickler chains'. Often at the footrope inside the net additional chains are placed, called 'net ticklers'. The number of these chains can vary, but values of 8-10 ticklers and 8-10 net ticklers are commonly used. By EU Regulation No 850/98 the width of the gear or beam length is limited to 12 m, and the power of the installed main engine to 2000 hp for flatfish beam trawling. There are two types of beam trawl in use in the flatfish fishery, one with tickler chains for flat sandy fishing grounds, called the 'V'-net, and one with a chain mat for rough grounds, called the 'R'-net. A 'flip-up' rope system can be used to enable passage over stones and boulders. The mesh size used in the cod-ends for flatfish is usually 80 mm for sole fishery and 100 mm or 120 mm for plaice fishery. Cod-ends are restricted in circumference to 100 meshes round, and the twine thickness to 6 mm double braided.

The beam trawl for brown shrimps (*Crangon crangon* L.) is a much lighter version. A typical beam length used is 9 m. The mesh size in the cod end is usually much smaller, ~20 mm inside knots. The conventional gear is fished with a bobbin ground rope. Although this gear is primarily designed to catch shrimps, in most areas fish bycatches also occur. Some fishermen aim at these bycatches as share of their income, mostly in the southern areas of the North Sea. Sieve nets are developed to filter larger specimen out, and turned out to be effective from lengths greater than 10 cm (van Marlen et al., 2001c; van Marlen et al., 2001b). Recent attempts were made to lower the drag of this beam trawl. A new wing-shaped beam design called "Dolphine" enabled the skipper of MFV WR124 to drop his weekly fuel consumption from 12 to 8 tons (Anonymous, 2010).

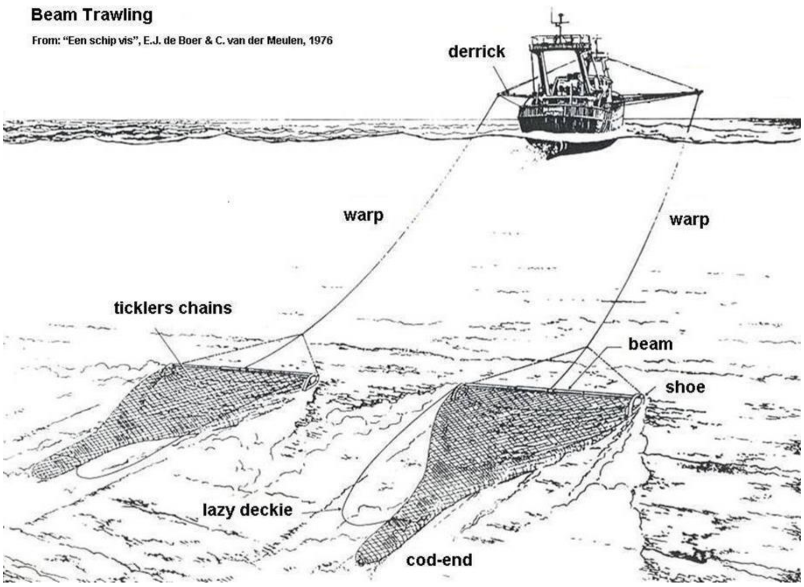


Figure 9. Beam trawling (From: E.J. de Boer en C. Vermeulen, 1976)

Table 1 below lists the mean vessel and gear characteristics of the main beam trawling segments for The Netherlands, the United Kingdom, and Belgium. Data covers: country, a segment description, Loa range, power range, gear type, main target species, gear dimensions, e.g. beam width, net circumference, headline length, footrope length, siderope length, codend mesh size, average fishing speed, average yearly fishing effort, average yearly landings, average LPUE, average fuel consumption per year, and average LPUE per unit of energy used.

Presentation of some realistic options for the Case Study Region

Option 1. Reducing contact and drag

Practical trials with alternative beam and trawl shoe shapes driven by the sharp rise in fuel prices in 2006-2007 were carried out in the Netherlands instigated by the "Task Force Sustainable North Sea Fisheries" on four vessels, ranging in installed engine powers of around 2000 hp (Bult, 2007).

Four different variations were studied (Figure 10):

1. Wheels replacing the conventional trawl shoe construction
2. Spoilers attached to the beam with additional changes
3. "Fly-Beam": a replacement of the circular pipe with a fixed hydrofoil construction
4. "Sum-wing": a replacement of the circular pipe and trawl shoes with a fixed hydrofoil construction that could run off-bottom with only a front runner touching the bottom

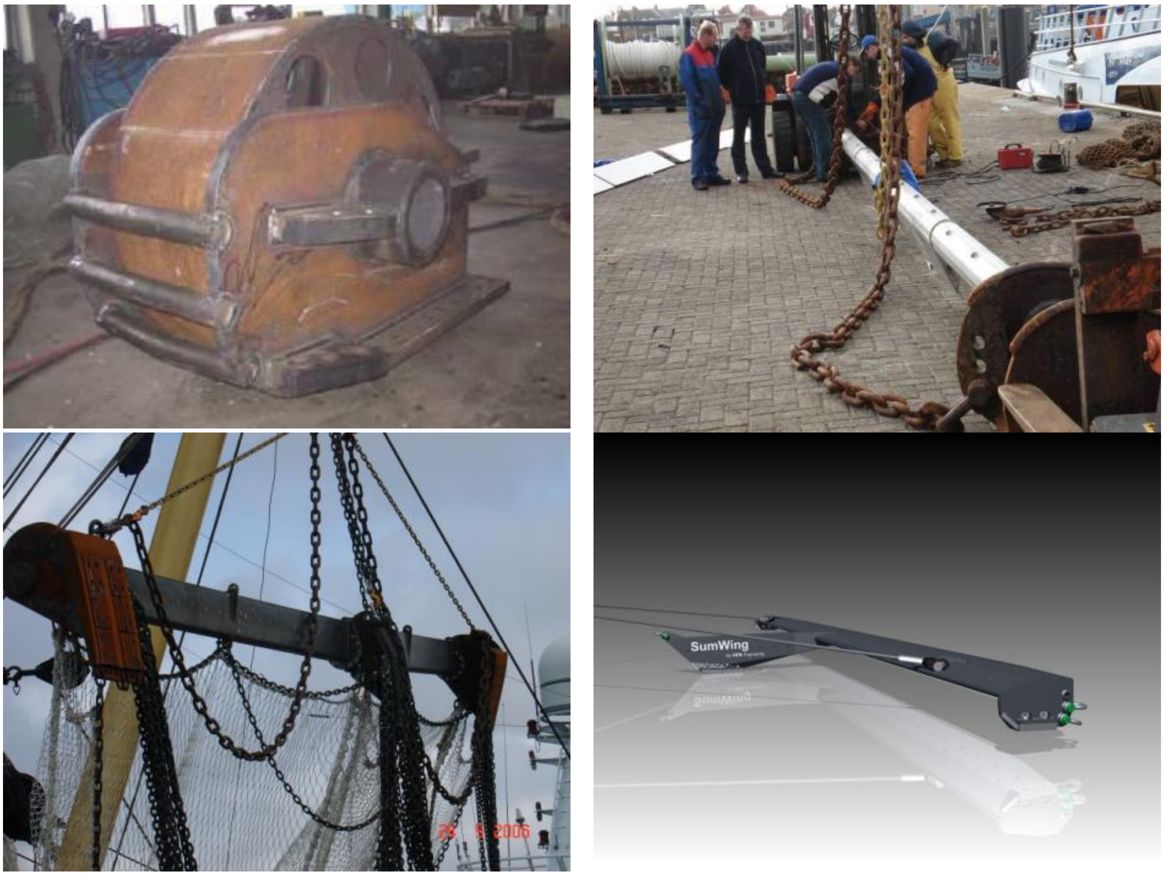


Figure 10. (A) Wheel to replace beam trawl shoe; (B) Spoiler; (C) Fly-beam and (D) SumWing with front runner.

Table 1. Catalogue of fishing vessel and gear characteristics – beam trawl(er) NL, UK and BE.

Country	Segment description	Loa range (m)	Power range (kW)	Gear type	Main target species	Gear code	Beam width (m)	Net Circumference	Headline length (m)	Footrope length (m)	Side rope length (m)	Cod-end mesh size (mm)	Average fishing speed (kts)	Average yearly fishing effort per vessel (1000 kW*days or days)	Average yearly landings (tonnes) per vessel	Average LPUE (tonnes/ 1000 kW-day; kg/day)	Average fuel consumption per year (*1000 ltr) per vessel	Average LPUE per unit energy (kg/ltr)
NL	Beam trawlers 12-24m	12-24	211	Beam trawl	brown shrimps	TBB	9	n/a	8.5	25			2.5	21.7	97	4.47	162	0.60
NL	Beam trawlers 24-40m	24-40	1471	Beam trawl	sole, plaice, other	TBB	12	n/a	11.5	30			6.5	144.87	242	1.67	1045	0.23
NL	Beam trawlers >40m	>40	1471	Beam trawl	sole, plaice, other	TBB	12	n/a	11.5	30			7	304.63	465	1.53	1570	0.30
UK	Beam trawlers 24-40m	24-40	778	Beam trawl	sole, plaice, monkfish	TBB	10	21	10	18	0.5	80	5	159	247	1.56 tonnes/ 1000 kW-day	744	0.33
BE	Beam trawlers 12-24m	12-24	221	Beam trawl	Brown shrimps	TBB	8	n/a						34	83	2.44	246	0.34
BE	Beam trawlers 24-40m	24-40	883	Beam trawl	sole, plaice, other	TBB	12	n/a						216	293	1.36	1045	0.28

Option 2. Pulse Trawl

The development of electric fishing or 'pulse' trawling in The Netherlands has a long history dating back from the 1950s(van Marlen, 1985; van Marlen and de Haan, 1988; van Marlen et al., 1997). The idea was raised to scare brown shrimps (*Crangon crangon* L.) off the sea bed by applying pulsating electric fields, and later this technology was also applied for sole (*Solea vulgaris* L.). The research was affected by the fuel crises in the middle and late 1970s and aimed at saving fuel costs and energy, later in the late 1980s due to critique on the ecosystem effects of trawling and beam trawling also on reducing adverse impacts (Lindeboom and de Groot, 1998; Kaiser and de Groot, 2000; Piet et al., 2000; Fonteyne and Polet, 2002).

Wageningen IMARES (former RIVO) became again involved in 1998 in a research and development programme in cooperation with a private company (Verburg-Holland Ltd.), the Dutch Fishermen's Federation and the Ministry of Agriculture, Nature and Food Quality leading to a second decade of research and development.

A comparison of landings was done on various trips for the 12m variant. The CPUEs found during experiments onboard FRV "Tridens" in 2004 and 2005 were compared to those found during discard monitoring trips made on commercial fishing boats. The experiments resulted in 26 kg/hr for sole and 52 kg/hr for plaice for the pulse trawl, and 21 kg/hr (sole) and 62 (plaice) for the conventional gear. Values between 12-25 kg/hr for sole and 40-60 for plaice were found for a range of vessels (Quirijns et al., 2004). This shows that the catch rates obtained with the gears tested were in the same order of magnitude of those of commercial boats. It should be noted that in case of comparing two gear types on the same boat the conventional gear is usually towed at a speed lower than in commercial practice, *i.e.* around 5.5 kts (van Marlen et al., 2005b).

The pulse trawl system as developed to-date for commercial application consists of a complete system of two winches with feeding cables, connected to pulse trawls. These trawls feature a container with underwater electronics, an array of electrodes in the belly of the net in front of the footrope, and an adjusted net behind it.

The performance of 12 m pulse trawls in terms of catches (landings and discards) between a commercial vessel fishing with two pulse beam trawls, and commercial vessels fishing with the conventional beam trawls was compared in 2005 and 2006. The main findings of the comparison were that landings of plaice and sole were significantly lower, *i.e.* about 68% (

Table 2). There was no significant difference in the catch rates of undersized (discard) plaice between the pulse trawl and the conventional trawl. In the pulse trawl, the catch rates of undersized (discard) sole were significantly lower than in the conventional beam trawl. The catch rates of benthic fauna (nrs/hr of *Astropecten irregularis*, *Asterias rubens,* and *Liocarcinus holsatus*) were significantly lower in the pulse trawl. Also, as found before, there were indications that undersized plaice is damaged to a lesser degree and have better survival chances in the pulse trawl (van Marlen et al., 2006).

Table 2. Overall landings LpUE comparison found from catch compari¬sons between a vessel fishing with two pulse trawls and a vessel fishing with two conventional tickler chain beam trawls in 2005 and 2006 (van Marlen et al., 2006)

Trip	Pulse kg/hr	Conv kg/hr	Ratio
1	65.7	69.3	94.8%
2	57.8	87.8	65.8%
3	86.2	145.7	59.2%
4	50.2	75.5	66.5%
5	61.2	87.4	70.0%
1 to 5	**64.6**	**95.4**	**67.7%**

Meanwhile questions concerning ecosystem effects on other species encountering the beam trawl were raised by the European Commission and ICES in November 2005. Discussions in working groups of experts and advisory committees in 2006 led to the conclusion worded by ICES that the pulse trawl gear could cause a reduction in catch rate (kg/hr) of undersized sole, compared to standard beam trawls. Catch rates of sole above the minimum landing size from research vessel trials were higher but the commercial feasibility study suggested lower catch rates. Plaice catch rates decreased for all size classes. No firm conclusions could be drawn at the time for dab, turbot, cod and whiting but there was a tendency for lower catch rates. The gear seemed to reduce catches of benthic invertebrates and lower trawl path mortality of some in-fauna species. Because of the lighter gear and the lower towing speed, there was a considerable reduction in fuel consumption and the swept area per hour was lower. Nevertheless, there were indications that the gear could inflict increased mortality on target and non-target species that contact the gear but are not retained.

ICES recommended additional experiments to be undertaken on a range of target and non-target fish species that are typically encountered by the beam trawl gear and with different length classes and with an exposure matching the situation in situ during a passage of the pulse beam trawl before final conclusions to be drawn on the likely overall ecosystem effects of this gear. Additionally ICES gave a plea for closely monitoring the fishery with a focus on the technological development and by-catch properties once the pulse trawls were introduced into the commercial fishery (ICES, 2006b; ICES, 2006a). Additional tank experiments were carried out in 2009, but the debate on the ecosystem effects of pulse trawling is still carrying on (ICES, 2006b; ICES, 2006a; van Marlen et al., 2007; de Haan et al., 2008; de Haan et al., 2009; ICES, 2009; van Marlen et al., 2009a).

The performance of 12 m pulse trawls over the year 2006 in terms of catches and earnings between the vessel fishing with two pulse beam trawls (denoted PT1), and four vessels fishing with the conventional beam trawls (BT1, …, BT4) were analysed. Later a new vessel started using pulse trawls (denoted PT2). The economic performance was measured in 2009 and compared to average values for beam trawlers (BT) over the year 2007 (Table 3).

Table 3. Comparison of economic performance of pulse trawlers (PT) with conventional tickler chain beam trawlers (BT) , figures derived from (Hoefnagel and Taal, 2009).

Vessel	Year	Gross Revenue (GR)	Fuel Cost (FC)	Nett Rev. (GR-FC)	**Ratio Nett Rev. PT/BT**	Fuel Cons.	**Ratio Fuel Cons. PT/BT**
Unit		€/wk	€/wk	€/wk	%	litre/wk	%
BT1...4	2006	29789	14381	15408		34277	
PT1	2006	23087	8004	15083	**97.9**	18885	**55.1**
BTx	2007	31945	12730	19215		32932	
PT2	2009	34972	5993	28979	**150.8**	17122	**52.0**

The average fuel consumption for the pulse trawler PT1 in 2004-2006 could be decreased with a ratio of 0.551, and even better results were found with the pulse trawler PT2 in 2009 with a ratio ranging between 0.520 (Hoefnagel and Taal, 2009; van Marlen et al., 2010). Thus the value of 0.50 can be used as a proxy for the energy saving potential of the 12 m pulse trawl, mainly caused by its lower drag and towing speed. If the gear is replaced by a pulse trawl configuration than a reduction in fuel consumption of 35% was predicted using the GES-model, which is lower than these figures reported here. The investment in a complete system for pulse trawling, including winches and feeding cables, with installation and system tests is estimated at 440000 €, with an estimated yearly costs of 150000 € in depreciation, interest and maintenance and repair, minus a saving in existing gear costs of about 20% due to the lower towing speed. Catches and bycatches of vessel PT2 fishing with the pulse trawl (2000 hp (1471 kW), Loa = 41.15 m, B = 8.50 m, H = 5.30 m) were monitored during four week trips in 2009 (Steenbergen and van Marlen, 2009).

The average number of plaice landed per hour was 58 or, in weight 19 kg plaice per hour. The average number of plaice discarded per hour was 164 or, in weight 18 kg plaice per hour. This resulted in an average discard percentage for plaice of 74% in numbers and 49% in weight. The average number of sole landed per hour was 208 or, in weight 53 kg sole per hour. The average number of sole discarded per hour was 54 or, in weight 5 kg sole per hour. This resulted in an average discard percentage for sole of 21% in numbers and 9% in weight.

The comparative study performed (van Marlen et al., 2006) showed that with the pulse trawl fished on PT1 less sole was landed in kg per hour, i.e. 12.87 vs. 16.45 (ratio 78.2%), and fewer plaice, i.e. 29.76 vs. 46.13 kg per hour (ratio 64.5%).

Comparing the data of the pulse beam trawl with the data from conventional beam trawl discard surveys in 2007 (van Helmond and van Overzee, 2008) leads to the general im¬pression that less plaice and more sole was caught with the pulse trawl. The range of individuals of plaice landed per hour was 101 - 561 on the conventional beam trawls monitored in 2007, whereas during this study between 14 - 106 individuals of plaice were landed per hour with the pulse trawl. The range of individuals of sole landed per hour was 45 - 149 on the conventional beam trawls that were monitored in 2007, whereas during this study between 142 - 259 individuals of sole were landed per hour with the pulse trawl. The discard rates for plaice and sole were compared with conventional beam trawls over the years 2005, 2006 and 2007, and these were in the same order of magnitude, but in the lower end of the scale (Table 4).

Table 4. Comparison of discard percentages of plaice and sole with those of conventional beam trawls in the years 2005, 2006, and 2007 (van Keeken, 2006; van Helmond and van Overzee, 2007, 2008).

	% D Plaice		% D Sole	
	n	w	n	w
BT 2005	83	52	23	11
BT 2006	86	54	29	13
BT 2007	77	46	23	10
PT2	**74**	**49**	**21**	**9**

Recent developments in pulse trawling are the production of a Pulse SumWing by HFK Engineering, and improvements in the design by Verburg-Holland Ltd. with the Delmeco Group Ltd. Model tests were recently (26/03/2010) carried out in the flume tank of Boulogne-sur-Mer with new designs of wing shaped beams (Figure 11). These designs will enable a further drop in fuel consumption with the pulse trawl, as the beam shape of the earlier versions was not optimal in hydro-dynamical sense.

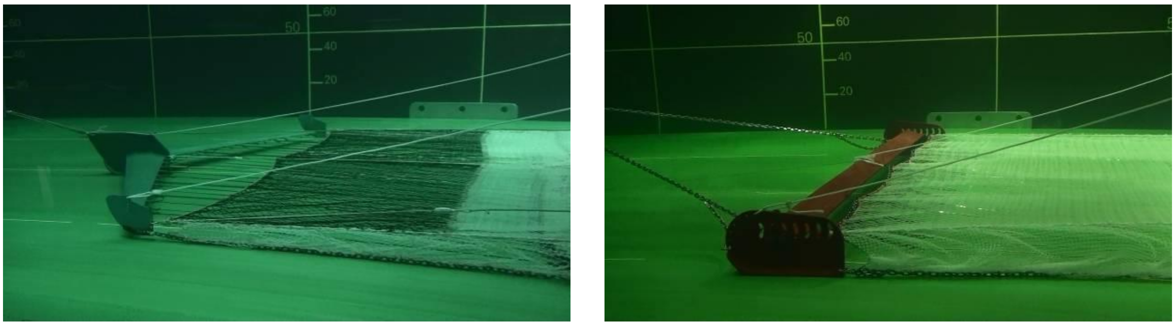


Figure 11. (A) Model of a “Jack Wing” in the flume tank of IFREMER in Boulogne-sur-Mer; (B) Model of a “Delmeco Wing” in the flume tank of IFREMER in Boulogne-sur-Mer.

Option 3. Alternative gear

Instead of using towed gear to catch plaice and sole, static gear such as gill nets can be considered. Selection factors (L50/mesh size) ranged from 3.28 for sole, 2.60 for plaice and 4.56 for cod, and it was found that a bi-normal form for the selection curve gave the best fits (Madsen et al., 1999). The Scientific, Technical and Economic Committee for Fisheries of the European Commission summarized data on discarding in the European fishing fleets, and made a list of mitigation methods that might be considered, although not specifically aimed at gear to catch plaice and sole (STECF, 2008). An extended review of physical and biological effects of bottom trawling and potential gear modifications to mitigate such effects was done in EU-project REDUCE (contract FAIR C&-97-3809), (Linnane et al., 2000). We summarize these views in Table 5 14 and have added some new entries in Table 5 below.

Table 5. Gear-based mitigation measures that might be considered.

TECHNOLOGY, PRINCIPLES AND COMMENTS	NOTES	EXAMPLE REFERENCES
Large Mesh Toppanels in beam trawls (TBB) **Proven effective to release about 30-40% of round fish without much affecting flatfish catches.**	Reduces capture of undersized fish of species including WHG, HAD, COD	Van Marlen, B., 2003. Improving the selectivity of beam trawls in The Netherlands. The effect of large mesh top panels on the catch rates of sole, plaice, cod and whiting. Fisheries Research, 63: 155-168, 2003
Benthic Release Holes in beam trawls (TBB) **Under development, research shown it to have potential. Need to be fine-tuned.**	Reduces capture of benthic invertebrates	Van Marlen, B., M.J.N. Bergman, S. Groenewold, M. Fonds, 2005. New approaches to the reduction of non-target mortality in beam trawling. Fisheries Research, 72: 333-345, 2005 van Marlen, B., van Helmond, A.T.M., Buyvoets, E., 2009. Reduction of discards by technical modifications of beam trawls. IMARES Report C003/09, pp. 69.
Sieve net in brown shrimp (*Crangon*) beam trawls (TBB) **Proven effective to release non-target fish > 10 cm length.**	Reduces capture of undersized fish of species (> 10 cm in length) including WHG, HAD, COD	Polet, H., Coenjaerts, J., Verschoore, R., 2004. Evaluation of the sieve net as a selectivity-improving device in the Belgian brown shrimp (*Crangon crangon*) fishery. Fisheries Research 69 (1), 35-48. van Marlen, B., de Haan, D., Revill, A.S., Dahm, K.E., Wienbeck, H., Purps, M., Coenjaerts, J., Polet, H., 2001. Reduction of discards in crangon trawls (DISCRAN): final report for the period 01-03-1999 / 28-02-2001. RIVO Report C012/01. van Marlen, B., de Haan, D., Revill, A.S., Dahm, K.E., Wienbeck, H., Purps, M., Coenjaerts, J., Polet, H., 2001. By-catch reduction devices in the European Crangon fisheries. ICES CM 2001/R:10, Theme Session R.
Alternative stimulation in beam trawls - Pulse beam trawl (TBB) **Proven technology to save fuel and catch sole and plaice in flatfish fisheries, and to catch brown shrimp (*Crangon crangon* L.) in shrimp fisheries. Need for lift of EU-ban. Currently under review by ICES.**	Reduces capture of benthic invertebrates by ~50% (flatfish trawl) to ~75% (shrimp trawl)	Hoefnagel, E., Taal, K., 2009. The economic performance and the environmental impact of the Pulse trawl in comparison to the conventional Beam trawl (WP 5.1 and WP 5.2.). Report EU-project DEGREE, Sept 2009. ICES, 2006. Report of the Ad-hoc Group on Pulse trawl evaluation. Polet, H., Delanghe, F., Verschoore, R., 2005. On electrical fishing for brown shrimp (*Crangon crangon*): I. Laboratory experiments. Fisheries Research 72 (1), 1-12. Polet, H., Delanghe, F., Verschoore, R., 2005. On electrical fishing for brown shrimp (*Crangon crangon*): II. Sea trials. Fisheries Research 72 (1), 13-27. Steenbergen, J., van Marlen, B., 2009. Landings and discards on the pulse trawler MFV “Vertrouwen” TX68 in 2009. IMARES Report C111/09, pp. 20.

TECHNOLOGY, PRINCIPLES AND COMMENTS	NOTES	EXAMPLE REFERENCES
		van Marlen, B., Grift, R., van Keeken, O., Ybema, M.S., van Hal, R., 2006. Performance of pulse trawling compared to conventional beam trawling. RIVO Report C014/06, pp. 60. van Marlen, B., Piet, G.J., Hoefnagel, E., Taal, K., Revill, A.S., O'Neill, F.G., Vincent, B., Vold, A., Rihan, D., Polet, H., Stouten, H., Depestele, J., Eigaard, O.R., Dolmer, P., Frandsen, R.P., Zachariassen, K., Innes, J., Ivanovic, A., Neilson, R.D., Sala, A., Lucchetti, A., De Carlo, F., Canduci, G., Robinson, L., 2010. Development of fishing Gears with Reduced Effects on the Environment (DEGREE). Final Publishable Activity Report - EU Contract SSP8-CT-2004-022576, pp. 239.
Alternative stimulation in beam trawls - HydroRig (TBB) **Under development, has shown potential to reduce fuel consumption and bycatches.**	Reduces capture of benthic invertebrates by ~50%	Not published yet.
Outriggers replacing tickler chain beam trawls	Reduces capture of benthic invertebrates by ~80%, mainly good for catching plaice (150%), less efficient on sole (20%).	Bult, T.P., Schelvis-Smit, A.A.M., 2007. Een verkenning van de mogelijkheden van outriggen door vissers, uitgevoerd in het kader van het advies van de "Task Force Duurzame Noordzeevisserij" (Dutch). IMARES Report C02207, pp. 33. Vanderperren, E., 2008. Projectrapport Outrigger II - Introductie van de bordenvisserij in de boomkorvloot met het oog op brandstofbesparing (Flemish). ILVO Report VIS/06/C/02/DIV, pp. 106. van Marlen, B., vanden Berghe, C., van Craeynest, K., 2009. Onderzoek naar de verbetering van tongvangsten in de outrigvisserij (Dutch). IMARES Report C117/09, pp. 46.

WESTERN WATER

Sub-Case study 1: Hake-Nephrops mixed fisheries in the bay of Biscay

General introduction to case study

Background data and descriptions for the case study are in the deliverable D7.6. The case study will evaluate some possibilities for the mitigation of the mixed nephrops-hake fishing pressures in the "Grande Vasière" area (GV) of the Bay of Biscay. The mixed nephrops-hake fishery counts around 160 vessels catching more than 2 tons of Nephrops in the Bay of Biscay and employs around 500 fishermen with a mean crew number on board of 3.2. They generated 70 million euros to 80 million euros turn-over between 2010 and 2012. The Nephrops bottom trawler fleet counts vessels of 14.7 meters length, 238 kW and 45 gross Tonnage on average. The fleet depends on average at 40% on Nephrops in terms of % of gross revenue on this species. The Nephrops fishery is a mixed fishery characterized by highlevels of bycatches (of monkfish, hake, sole or cephalopods that represented 38% of the landings in value in 2012) and discards (mainly of smaller individuals under the Minimum Landing Size).

Trawling is not far from being the only fishing method occurring in the bay of Biscay Nephrops fishery. That fishery is mainly performed by trawlers utilizing twin trawls with bottom otter boards. Main specifications of traditionally utilized trawling gears in the GV area, as collected from netmaker and fishermen interviews for Benthis project, are given into Table 6. Nephrops and crustaceans traps fishery is very limited and performed by less than 10 vessels along the French Atlantic coast (Figarede & Bigot 2011). There is no exclusive Nephrops traps vessels ; that metier is operated by vessels mixing nets, traps for others crustaceans and even trawls. Conflicts for space with exclusive trawlers are one of the main reasons for the low occurrence of vessels operating traps in the GV area. The metier of traps for Nephrops is therefore restricted to non-trawled area in very coastal zone or in the vicinity of rocks. Main gear utilized is Scottish trap.

Impact of trawls over Nephrops grounds in the GV area has been stressed in previous studies. Trawling effects in the GV can be summarized by the following points:

- significant modifications of resuspension and transportation sediment processes as compared to natural processes (Bourillet et al. 2006)
- modifications of habitats by sediment reworking (Bourillet et al. 2006)
- short term modifications on macro and mega-epifauna and infauna (Blanchard et al. 2004, Rémi & Fabian 2006)
- long term benthic community structure modifications (Hily et al. 2008)

More details about trawling impacts in the Nephrops fishery are given into the deliverable D7.6.

Table 6 - Main gear traditionally utilised by the French vessels in the GV area operating Fish and Nephrops trawling activity on muddy grounds.

Trawl type and name (production year)		Twin trawl for Nephrops (Chaluts jumeaux à langoustine)	Single trawl for various fish (Chalut simple à divers poissons)				4 sided trawl (Chalut 4 faces)	Pair trawl (Chalut traîné en bœuf)
Trawling mode		single	single		single	single	single	pair
Rigging		twin	single		single	single	single	single
Codend: mesh opening, inside knots (mm)		70mm gauge if combine with a square mesh panel if not 80mm gauge	70		70	70	70	70 or 100
Targeted species		1) Nephrops 2) Monkfish 3) Flat fish	1) Sole, flat fis 2) Monkfish, cuttlefish, squid		1) Sole, flat fis 2) Monkfish, cuttlefish, squid	1) Sole, flat fis 2) Monkfish, cuttlefish, squid	Makerel, sea bream, other demersal & pelagic fish	1) Squid 2) other
Vessel specificities	Trawling speed (knots)	3 to 3.5	2.5 to 3		3 to 3.5	3 to 3.5	3 to 3.5 sometimes more	3 to 3.5
	engine power (kW)	350-450 CV	200 CV max		200 - 450	max 600	max 600	550-800max
	overall length (m)	15 to 18m	10 to 12		12 to15m	15 to 18m	12 to 18m	18-24m
Codend - Trawl circumference (number of meshes)		120	120		120	120	120	120 if 70mm codend and 110 if 100mm codend mesh size
Trawl	trawl height (m)	1.20m max	1.5 to 2m		2-3m	2-4m	minimum = 3m maximum = 7m, and generally 5m	10m max
	wing spread (m)	10-12m for one trawl	< 12m		10.20m	20-30m	12-15m	35-40m
Doors	Type	bottom	bottom		bottom	bottom	bottom	-
	number	2	2		2	2	2	-
	producer, and model	Traditional wooden or iron rectangle doors	Doors with "Foils" (usually from Morgères or thyboron)	Thyboron Type 2, 50 inch	Thyboron Type 2, 60-66 inch	Thyboron Type 11, without foil	Type 2 (or type 11 for the larger vessels)	Same weight as the chains
	length (m)	1.50 to 1.70m	1.2m	1.3	1.6 to 1.75	1.6	1.6 to 1.75	-
	height (m)	0.90 to 1.10m	1m	0.85	1 - 1.1m	1.3	1 - 1.1m	-
	weight (kg)	250 to 300kg	250 to 300kg	150kg	300 - 450KG	450-600kg	300 - 450KG	Weigts instead of doors : 500kg each side of the trawl
	spread (m)	45 to 50m	60m	20 to 25m	25 to 50m	65m max	25 to 50m	Distance between trawlers depends on the trawl size and the warp length (usually, distance between trawlers = horizontal opening + 0.6 x (warp + sweeps))
sweep length (m)		40m ("bras") *(+ 60m "fourche" in case of Nephrops Twin trawl, cf drawing below)*	no sweep		from 25 to 60m, tend to be short if hard bottom, and long if plane bottom	60 to 85m	no sweep	100 minimum and 300m max
Bridles (number)	number	2 per wing, 4 per trawl, 8 in total for twin trawl	2 per wing, 4 per trawl		2 per wing, 4 per trawl	2 per wing, 4 per trawl	2 per wing, 4 per trawl	2 per wing, 4 per trawl
	Length (m)	10m each	10 to 15m		10 to 15m	10 to15m	50m	30m

Tickler chains or lines	**number**	max 2 per trawl	max 2 per trawl	max 2 per trawl	max 2 per trawl	No	No general use of tickler chain
	total weight of each chain or line (kg)	Depending on the length of the chain	Depending on length of the chain, but usually heavier than for Nephrops trawl	Depending on length of the chain	Depending on length of the chain	-	?
Groundgear	**Length (m)**	13 to 22m	15m	20 to 28m	max 40m	26m min	70m
	type	Simple footrope ("*bourrelet franc*", Footrope bosom with chain or footrop bosom with bobin or rockhopper (max 6m) if rocky grounds	Simple footrope ("*bourrelet franc*"), with footrope bosom with chain and/or small bobin ("*rondelles moulées*")	Simple footrope ("*bourrelet franc*"), with footrope bosom with chain and/or small bobin ("*rondelles moulées*")	Simple footrope ("*bourrelet franc*"), with footrope bosom with chain and/or small bobin ("*rondelles moulées*")	Rockhopper for larger vessels only	Simple footrope ("bourrelet franc"), with footrope bosom with chain and/or small bobin ("*rondelles moulées*")
	Diameter (mm)	Rockhopper = 250mm diameter, bobin = 200mm diameter in the footrope bosom, and 80mm diameter bobin ("*rondelles moulées*") in the wings	80mm diameter bobin ("rondelles moulées")	80mm diameter bobin ("rondelles moulées")	80mm diameter bobin ("rondelles moulées")		80mm diameter bobin ("rondelles moulées")
	Wheight (kg)	Simple footrope ("*Bourrelet franc*") : 5kg/m	5kg/m	5kg/m	5kg/m		5kg/m
Clump	**Type**	Chain are generally used in the case of "fourche" rigging, roller are much less used	-	-	-	-	
	Wheight (gk	Weight of chain is usually simalr to the doors weight	-	-	-	-	

Already existing management and technical measures includes harvest control rules and gears specifications. Nephrops fishery is managed through a TAC (around 95% of the TAC is caught by French vessels) and a licence system with a *numerus clausus*. In order to reduce discards, especially for juvenile hake, several programs of improvement of selectivity of this fishery have been conducted these last 20 years. They resulted in a number of selective devices existing and to be adopted by licence owners since 2008.

We will test three options for mitigations strategies (summarized into Figure 12):

1) trawling gear modification by replacing traditionally utilized bottom doors by doors having reduced contact with the bottom ("jumper board"). Evaluation of nephrops traps feasibility and efficiency in the bay of Biscay.
2) Evaluation of new spatial management rules balancing the reduction of the fishing footprint while optimizing the production level to ensure viability of the Nephrops fishery
3) Alternative gear utilization and technical interactions of metiers mixing trawling and traps

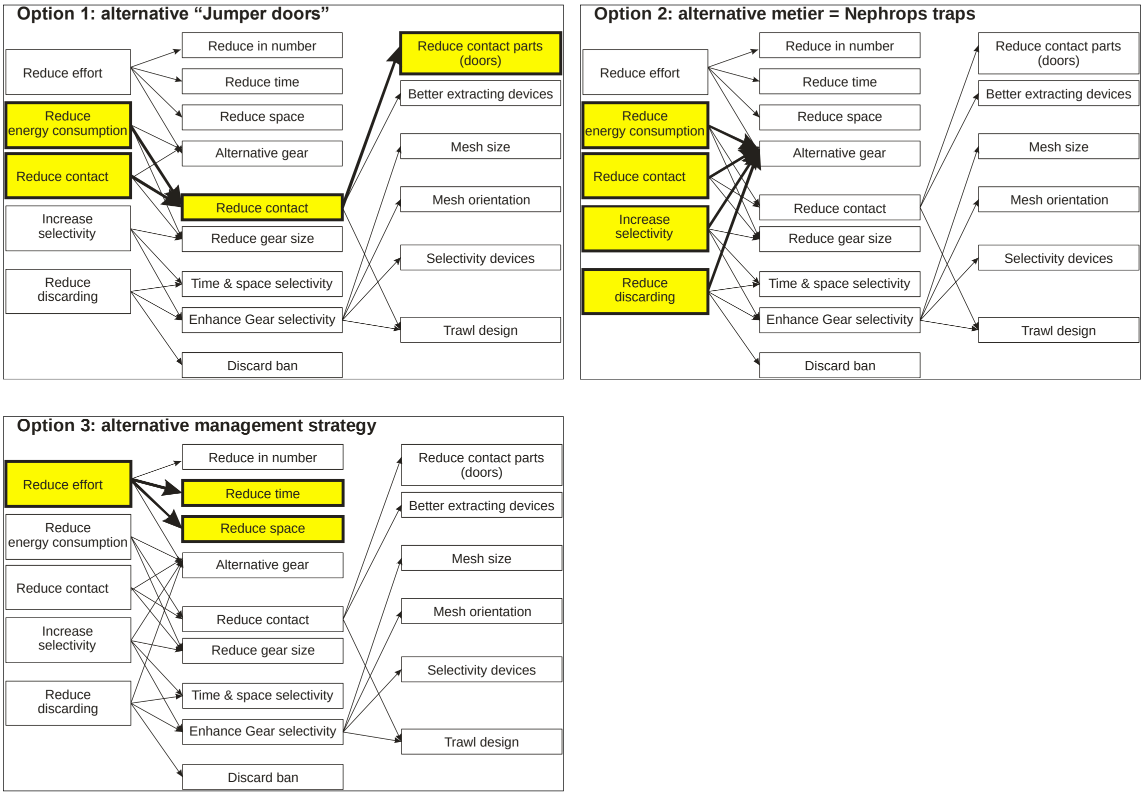


Figure 12. Diagrams summarizing specificities of the 3 options to be tested in the sub-case study dealing with the Nephrops fishery of the bay of Biscay.

Presentation of some realistic options for the Case Study Region

Option 1. Jumper board

The strategy of trawling gear modification is based on the replacement of traditionally utilized bottom doors of the Nephrops twin trawls by less impacting gears with doors having reduced contact with the bottom ("jumper" board, Figure 13). Those doors are being developed since few years through different national and european project: EU FP7 DEGREE (2008), OPTIPECHE (2010, Vincent et al. 2010) and JUMPER (2013-2014, http://wwz.ifremer.fr/peche/Projets/Jumper2). That new trawling board has been developed with two main objectives: to reduce forces exerted on the bottom and to reduce sediment re-suspension processes. By testing utilization of those doors in the Nephrops fishery, we aim at reducing the contact with the sediment and so mitigate the impact on benthic habitats (sediment re-suspension, penetration depth into the bottom) and improving energetic efficiency of trawlers by reducing fuel consumption (boards are responsible of 20 to 25% of fuel consumption and even more for the most basic/planed-shaped one).

Figure 13. Illustrations of A) traditionally utilized otter board for twin trawls, submarine view of plan-shaped board (left picture) and more recent otter board onboard partner fishing vessel (picture on the right) and B) prototype of the jumper board tested during Optipeche project (Vincent et al. 2010) and that will be tested in the Nephrops fishery during Benthis project.

Tests of that new gear includes an analysis of:

- the reduction of impact by utilizing data collected during dedicated surveys on the sediment resuspension processes and seafloor impact.
- the fishing efficiency and economic viability issues

Fishing efficiency and economic viability the new gear will be tested through mid-term data acquisition involving the professional fisherman partner of Benthis (SME09). Data acquisition will be based on already designed specific questionnaire (Figure 14) to be implemented during regular fishing trips all the yearlong and alternatively utilizing classical vs new trawling gear (SME09). Economic survey will be performed through analysis of mid-term consumption data and production efficiency collected during the Benthis project.

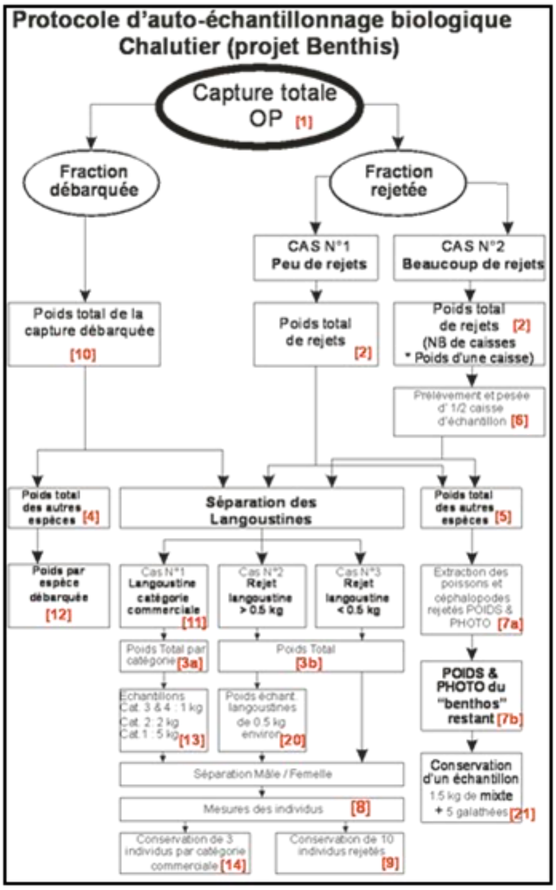


Figure 14. Summary of auto-sampling protocol to be utilized on-board the fishing vessels partners of Benthis.

Option 2. Traps

The second option is to test for partial replacement of trawling activity by an alternative metier mixing trawling and traps for Nephrops. Expected benefits are to enhance selectivity that will reduce impact on both exploited populations and by-catches. Traps should also help to lower impact on sediment especially in reducing sediment re-suspension and penetration depth of the gear. As for the new trawling gear, fishing efficiency and economic viability of that new gear is tested through mid-term data acquisition involving the professional fisherman partner of Benthis (SME10). Data acquisition is based on already designed specific questionnaire (Figure 4) to be implemented during regular fishing trips all the yearlong and utilizing Nephrops traps.

Option 3. Protected areas

The third option to be tested for the Bay of Biscay Nephrops fishery aimed at developing protected areas design including spatial and/or temporal rules. Performed analysis should help us to evaluate the potentiality of reducing fishing footprint while keeping a viable fishery. Spatial rules will permit to extract some area from fishing and allow the protection of vulnerable habitats and species occurring in the GV (*e.g.* pennatulacean species). By developing population recovery areas, it should also help to get a better sized structure of the exploited population and especially for the Nephrops stock. Moreover, mixing spatial and temporal rules will help to better take into account seasonal specificities. The main issue to deal with is the fishery viability/efficiency depending on exploited populations dynamics and available fishing grounds. A specific option coming from stakeholder discussions is to test for the possibility of developing a spatial and/or temporal management strategy that could help to maximize size structure of the Nephrops population. Socio-Ecosystem spatially explicit modelling framework (ISIS fish combined with IAM models from WP5, Figure 15) will be use to evaluate effects of gear changes and/or new spatial rules on fishing effort re-allocation. The ISIS-Fish modelling framework is spatially explicit and will be used to simulate the impact of management strategies to assess the risk and the vulnerability for the benthic community. ISIS-Fish enables quantitative bioeconomic assessment of management scenarios (Mahévas & Pelletier 2004, Pelletier et al. 2009) and the proposed management measures will include innovative spatial Harvest Control Rules where management action depends both on the biomass levels of commercial species and on constraints relating to habitat protection, essential habitat and the role of habitats in protecting biodiversity. The prognostic will be formulated on quantitative indicators of changes including both biological and socioeconomic descriptors. Using sensitivity analysis methods (based on the selection of an appropriate experimental design and statistical model) management strategies robust to uncertainties can be identified (Drouineau et al. 2006, Lehuta et al. 2010).

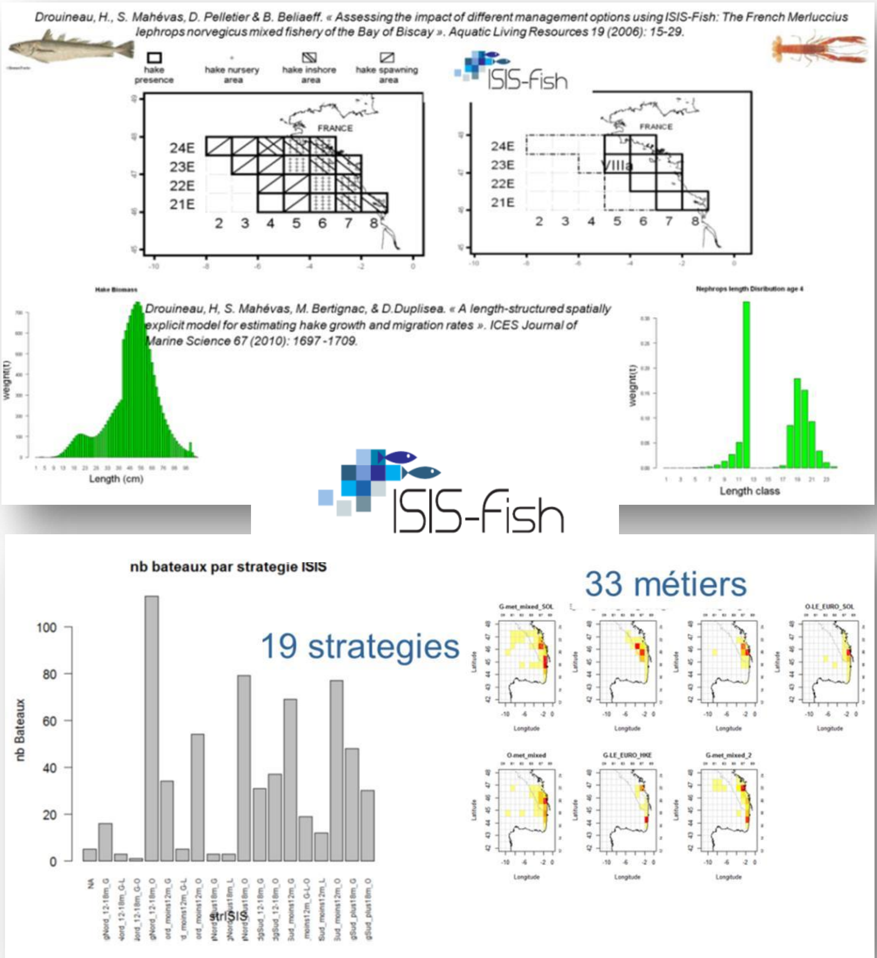


Figure 15. Illustration of Isis fish parameterization processes for exploited populations (Nephrops and Hake) and fishing fleet and metiers.

Sub-Case study 2: Scallop dredge in the Celtic Sea (south-eastern Irish coast)

General introduction to case study

Background data and descriptions for the case study is in section D7.6. The case study will evaluate some possibilities for the mitigation of scallop fishing pressures in the north east Celtic Sea. Scallop fishing is a common and important fishery in offshore waters in Celtic sea, Irish Sea, English Channel and Bay of Biscay and also in inshore waters on north European coasts.

Presentation of some realistic options for the Case Study Region

Option 1. Reduction of fishing effort

In the north east Celtic Sea vessels >15m fish for scallops with dredges on sedimentary habitats. A proportion of these areas have been mapped acoustically and high resolution bathymetry and multibeam backscatter information is available. Previous survey work showed that scallop catch rates were significantly correlated with acoustic backscatter; essentially suggesting that scallop abundance was much higher on gravel than on sand (Figure 16). However, sediments in the area are mixed and patchy and fishermen’s knowledge of this fine scale distribution of sediments is insufficient for them to target areas of high scallop abundance only. High resolution backscatter maps provide these data. The potential benefits of providing high resolution information on seabed substrates to scallop fishermen are increased efficiency; a higher volume of catch can potentially be caught with lower dredging effort and a lower fishing pressure footprint. If fishing effort per unit of catch is reduced fishing costs and fishing time per unit of catch is also lower. There are, therefore, potential gains from reduced environmental impact, reduced fuel consumption, lower carbon emissions per unit of catch, reduced labour costs and reduced time at sea. This of course would need to be developed in parallel with management measures that limited the total outtake. Otherwise the provision of the maps to the fleet simply represents effort creep. The trial will investigate, under commercial fishing conditions, whether the gains described above can be realised. The intention is that vessel performance indicators will be collected during one fishing week when the skippers are not using the fine resolution map and then during a second week in the same area with the maps. The fishing pattern in the second week will need to be optimised according to the distribution of favourable or ‘best’ habitat areas for scallop and will therefore represent a change in fishing behaviour in terms of number of operations per day, length of the operation, handling time on board etc. Scallop vessels in the Celtic Sea and elsewhere are increasingly using seabed discrimination data to direct their fishing operations. A number of vessels now use the Olex system which also provides an index of seabed hardness derived from single beam acoustic data. The multibeam data represents a further advancement on this. In any case significant effort creep may be occurring in the fleet. This case study will facilitate increased efficiency of vessels but will also use this to drive the development of a management plan for scallop fisheries in the Celtic Sea. The option of mitigation described above represents an attempt to reduced fishing effort and contact as outlined in the schema presented in (Figure 16) in the introduction to this document.

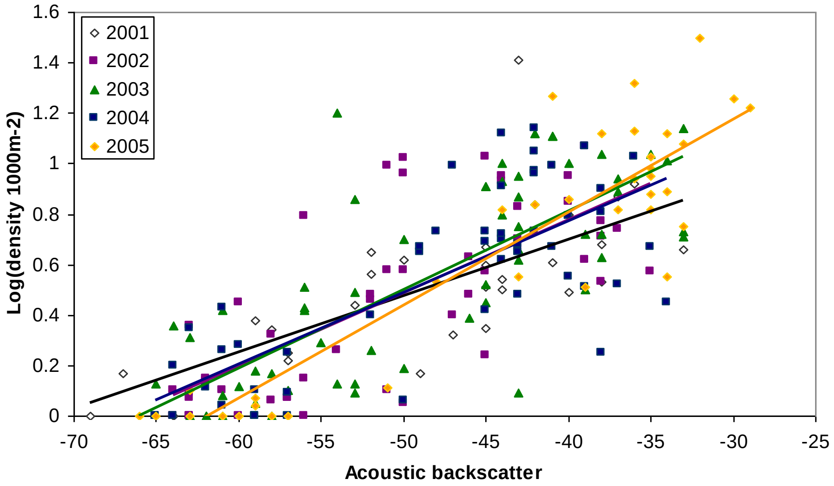


Figure 16. Relationships between multibeam acoustic backscatter and catch rates of scallop in annual surveys, 2001-2005, in the Celtic Sea. Higher catches occur on harder ground (gravels).

Option 2. Enviro Dredge

The spring loaded toothed dredges currently used by the fleet cause both surface and deep disturbance to benthic communities. The target species (*Pecten maximus*) however is not recessed to any significant degree into the sediment and surface disturbance should be sufficient to capture this species. The Enviro dredge, which is currently undergoing trials in various countries (Figure 17) does not penetrate the sediment although shallow disturbance to a few centimetres may occur due to the dredge tracks. However the teeth are individually sprung and 'touch' the sediment surface to disturb scallops rather than digging into the sediment. As a result the dredges cause less drag and reduce fuel consumption by 20-30%. In addition there is a reduced catch of stones. The potential benefits, if the catching efficiency is comparable to dredges currently used in the fishery, is reduced deep disturbance of sediments and reduced impact on infauna. The fuel savings reduces costs and carbon emissions per unit of catch. The case study will undertake a comparative trial of standard and Enviro dredges and collect information on catch composition, catch volume, by-catch and fuel consumption in controlled trials. Benthic epifauna will be monitored in a BACI design.

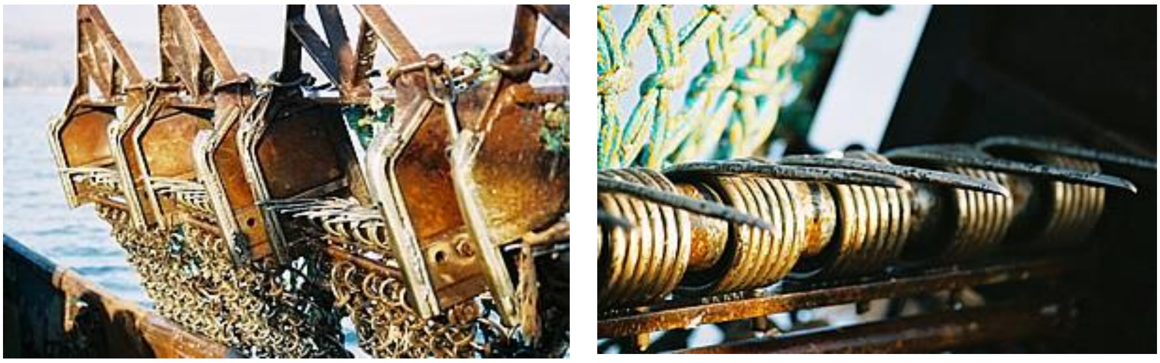


Figure 17. Enviro dredge showing detail of individually sprung teeth (tines).

Option 1+2: description, impacts, benefits.

There is an in-combination add on benefit to be gained by adopting both options 1 and 2 above. Option 1 reduces footprint and contact and Option 2 reduces the impact in the footprint area. Both options provide for fuel savings per unit of catch.

Sub-Case study 4: VME's interacting fisheries from the bay of Biscay to the Norwegian Sea

General introduction to case study

Over the past few decades, the development of deep-water fishing worldwide has caused an extension of fishing grounds over previously unexploited areas and unimpacted benthic communities (Koslow et al. 2000, Koslow et al. 2001, Fosså et al. 2002, Hall-Spencer et al. 2002, Clarke 2005, Morato et al. 2006). More fishing effort is actually expanded on the shelf break (200-400m) and upper slope (400-750m) by several types of fisheries targeting primarily hake (*Merluccius merluccius*), anglerfish (*Lophius* spp.) and megrims (*Lepidorhombus* spp.) with bycath of ling (*Molva molva*) greater forkbeard (*Phycis blennoides*), Blackbelly rosefish (*Helicolenus dactylopterus*), conger (*Conger conger*) and other species. These shelf break and upper slope fisheries did not undergo such strong regulation as fisheries for deep-water stocks and might have been mostly stable for the past two decades. Nowadays, the presence of corals is well known to the fishermen who often experience gear damage and losses, but they often fish close to these areas (e.g. D'Onghia et al. 2010).
Fishing methods depend on different local socio-economical factors, resources and regulations, but primarily consist of long-lining, gillnets and trawling from large and small vessels depending on the geographic area (Holley & Marchal 2004). One of the main threats to cold-water coral (CWC) habitats is the physical damage caused by fishing gears, mainly by bottom trawlers (Fosså et al. 2002, Hall-Spencer et al. 2002) but by passive gears too (e.g. longlines *in* Freiwald et al. 2004). Specificities of impact on CWC and others vulnerable habitats is that they represent immediate and long lasting impacts. Some quantitative estimates of the proportion of impacted CWC communities have been conducted off the Norwegian coast (Fosså et al. 2002). Many coral-areas have been destroyed by fishing in Icelandic waters (Steingrimsson et al. 2006). Evidence of trawling impacts from recent ROV surveys and fishermen testimonies state that Western Irish continental shelf and bay of Biscay slope have been submitted to heavy fishing impact during the 20th century.

Already existing management and technical measures for deepwater fisheries and CWC habitats protection

Considering the impact of trawling and, to a lesser extent, of other fishing gears on the CWC ecosystem (Koslow et al. 2001, Fosså et al. 2002, Hall-Spencer et al. 2002, Reed 2002, Roberts 2002), measures for protection have been promoted for some of them. Norway was the first country to implement protection measures with the ban of all bottom trawling activities (trawls, dredge) and bottom-tending gear in the Sula reefs area in 1999 (Table 7) and followed by others closures in the following years. In the North East Atlantic in recent years, the Northeast Atlantic Fisheries Organization (NEAFC) implemented protection of Vulnerable Marine Ecosystems (VMEs) in international waters by defining large areas where fishing gears in contact with the bottom is banned. This provides protection to a significant proportion of VMEs (mainly CWC reefs and communities). In March 2004 the European Council agreed to give permanent protection to Scotland's unique cold water coral reefs, Darwin mounds ('Special Area for Conservation'), by banning deep-water bottom trawling in the area. Some extension of protected areas was recommended in 2010. With regard to the Mediterranean Sea, in January 2006 the General Fisheries Commission for the Mediterranean (GFCM) decided on recommendations concerning the prohibition of towed gears (dredges and trawl nets) in the deep-water coral banks of Santa Maria di Leuca (Ionian Sea). Moreover, for conservation objectives two other deep-sea sites in the Mediterranean High Seas were selected: the chemosynthesis-based cold seep ecosystem near the Nile Delta and the Eratosthene seamount, offshore from Cyprus. In order to protect all these sites the GFCM has created the new legal category of "Deep-sea fisheries restricted area". The GFCM recommends members to notify the appropriate authorities in order to protect these ecosystems from the impact of any other activities jeopardizing conservation of the features that characterize these particular habitats. The protection measures for coral habitats could combine biodiversity conservation and fisheries management objectives (Reed 2002). Measures implemented for fisheries management (i.e. not aiming at habitat conservation per se) such as the ban of orange roughy (*Hoplostethus atlanticus*) fishing in large areas to the west of Ireland since 2005 have *de facto* protected CWC occurring in these areas in the depth range of this species.

For the Benthis project, we will focus on a restricted list of sensitive habitats (Table 8). Description and maps of those habitats are given into the deliverable D7.6. In the Bay of Biscay we will exclusively analyse fisheries interacting with soft bottom CWC habitats as well as those interacting with seapen and burrowing megafauna habitat (linkage with sub-case study 1).

Table 7 - Spatial management rules of fishing activity in Mediterranean and North-East Atlantic for deep-waters and CWC reefs habitats and resources (table from EU CORALFISH report, Laffargue et al. 2011). NEAFC (North-East Atlantic Fisheries Commission); SAC and SCI (Special Area of Conservation and Site of Community Importance, Natura 2000 network).

Region	Area name and size	Protection objective (Habitat, Fisheries or both)	Type / Status and Reference	Main rules Gear Regulation / Fishing rules	Implementation date
Northern Norway (1)	Sula Reef (EEZ+territorial waters, 973.4+11.6km^2)	FISHERIES and HABITAT (CWC)	Norwegian regulation number 1878, 22.12.2004 OSPAR MPA network	Ban of all bottom trawling activities (trawls, dredge) and closures to bottom-tending gear (for the first five areas)	1999-Present
	Iverryggen (620.9 km^2)				2000-Present
	Røst ,Tisler and Fiellknausene reefs				2003-Present
	Selligrunnen (territorial waters, 0.6 km^2)	HABITAT (CWC, 39m deep)	Natural Reserve, Norwegian Nature Conservation Act (Norwegian regulation number 605, 08.06.2000)		2000-Present
Iceland (2)	Reynisdjup Reef Coral Reef (coastal waters, 9.45km2)	HABITAT (CWC)	OSPAR MPA network		2006-Present
	Hornafjarðardjúp Coral reef (EEZ, 31.27 km^2)				2006-Present
	Skaftárdjúp Coral Reef (EEZ, 7.36 km^2)				2006-Present
	ALL	FISHERIES, Area of spawning locations for blue ling.		closed to fishing fleet	2003-Present
UK / Irish shelf (3)	Darwin Mounds (UK / UK0030317, EEZ, 1380.1 km^2)	HABITAT (CWC/Seamount) and Ressources	SCI / Council Regulation (CE) 602/2004, OSPAR MPA network	Ban of bottom fishing (all trawls and gillnets in contact with the bottom)	23/08/2004-Present
	SW & NW Porcupine Bank (Ireland, EEZ, 1045.7km^2)		OSPAR MPA network		
	NW Rockall Bank (UK/UK0030363)	HABITAT and Ressources	SCI		CANDIDATE
	W Rockall Mounds	HABITAT and Ressources	Council Regulation (EC) n° 40/2008	Closed to all fishing activities	16/01/2008-Present
	Wyville Thomson Ridge (UK0030355)	HABITAT and Ressources	SCI		CANDIDATE
	Staton Bank (UK0030359, EEZ, 817.9 km^2)	HABITAT and Ressources	SCI, OSPAR MPA network		DONE
	ICES sub areas VIa, b and VIIb, c, j, k.	FISHERIES	Council Regulation (EC) N°51/2006	Use of gillnets by community vessels banned at depths greater than 200 m. Derogation in 2006 allowing gillnets with mesh sizes between 120 and 150 mm down to depths of 600m.	20?? - 2006
	ICES sub area Via : edge of the Scottish continental shelf and Rosemary Bank	FISHERIES		Protection of spawning aggregations by limitation of the amount of captures for blue ling (<6 tonnes) from 1st March to May 31.	2009-present
	Haddok Box	FISHERIES	Council Regulation (EC) 41/2007	Closed to all fishing activities	21/12/2006-Present
	Rockall and Hatton banks (97300 km^2)				
Bay of Biscay (4)	NONE in French EEZ or territorial waters	NONE	NONE	NONE	NONE-Present
	El Cachucho (also known as Le Danois Bank; Spain, 2398.5 km^2)	HABITAT (CWC) and ressources	OSPAR MPA network, SCI proposal	Establishment of fishing management plans in progress	2007-Present
The Azores (5)	ALL	FISHERIES	(EC Reg.) N°1954/2003	100 miles box limited to deep-water fishing vessels registred in Azores	2003-Present
	ALL	HABITAT (CWC/Seamounts)	Council Regulation (EC) N°1568/2005	Bottom trawling and dredging forbidden (Council of 20 September 2005) and all fishing nets from 200m deep.	20/09/2005-Present
	Condor Seamount	FIHERIES & HABITAT		Closed to all fishing activities	2010-2011
Mediterranean (6&7)	Capo Santa Maria di Leuca	HABITAT (CWC)	General Fisheries Commission for the Mediterranean (GFCM)	Deep-sea fisheries restricted area	2006-Present
	All Mediterranean	HABITAT and resources	General Fisheries Commission for the Mediterranean (GFCM)	All Mediterranean and Black Sea areas deeper than 1000 m closed to bottom trawling.	2005-Present
Others *	Mingulay (UK)			Regulation (Ban in progress	In Progress
	Madeira and Canary Islands	HABITAT (CWC/Seamounts)	Council Regulation (EC) N°1568/2005	Bottom trawling and dredging forbidden (Council of 20 September 2005) and all fishing nets from 200m deep.	20/09/2005-Present
	Logachev Mounds	HABITAT (CWC/Seamounts)	Council Regulation (EC) n° 40/2008	Closed to all fishing activities	16/01/2008-Present
	Trænarevene, Breisunddjupet and an area northwest of Sørøya in Finnmark (2009)				
	Altair (4400 km^2) and Antialtair (2200 km^2)	HABITAT (Seamounts)	NEAFC (interim basis) Council Regulation (EC) N°27/2005	Ban of all deep bottom fishing activities (trawls and static gears)	22/12/2004-present
AR (Mid-Atlantic-Ridge)	Hecate and Faraday	HABITAT			
	Reykjanes Ridge (50900 km^2)				

Table 8. List of vulnerable marine ecosystems (VME) that will be considered for the Western waters sub-case study 4 of Benthis.

Sensitive habitats types		Norwegian waters	Bay of Biscay
Sponge community	Soft bottom	X	
	Hard bottom	X	
Coral gardens	Soft bottom	X	X
	Hard bottom	X	
Seapen and burrowing megafauna		X	X[1]
Umbrella stands		X	
Glass sponge community		X	

1. Linked to the first Western waters sub-case study

Presentation of some realistic options for the Case Study Region

Option 1. Reduction of fishing effort

The bathymetric distribution of the density of fishing operations (expressed in hours/km^2, Figure 18) shows that fishing effort is at least equivalent in the deepest than in shallower areas for trawlers (OTB) and even more important for longliners whose activity is closely related to the 200-800m area. Those high effort values in the deepest areas of the bay of Biscay reflect concentration of fishing activity in rather small depth-related habitats. Moreover, analysis based on fisheries distribution from VMS data aggregated at 3' by 3' squares (Laffargue et al. 2011) have shown that:

1) for longliners (LLS), the vicinity (in a 3'/3' square) of 70% of recorded CWC locations of the bay of Biscay were submitted to some fishing activity in 2010 but 90% of LLS total activity occur in a maximum of 27% of recorded CWC locations.
2) for trawlers (OTB), the vicinity (in a 3'/3' square) of 90% of recorded CWC locations of the bay of Biscay were submitted to some fishing activity in 2010 but 90% of OTB total activity occur in a maximum of 56% of recorded CWC locations.

Those results confirm a high dispersion feature of the fishing activity over the fishing grounds of the shelf break. It indicates that spatial management rules should greatly help to optimize utilization of those fishing grounds to reduce bottom impacts and, very probably, without deeply impairing the viability of those fisheries.

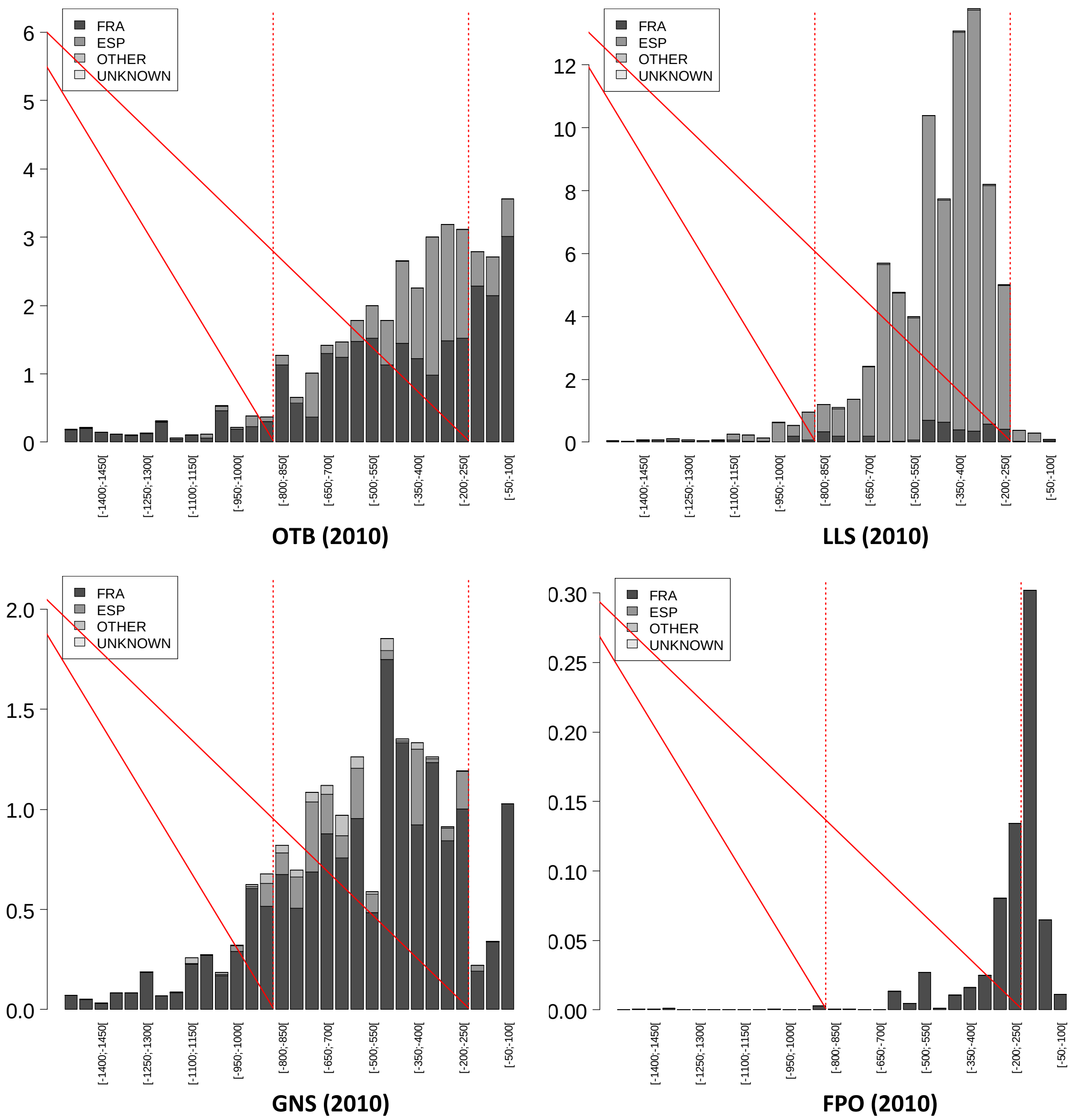


Figure 18. Bathymetric distribution of fishing activity (yearly total duration of fishing operations expressed in hours by km2) in the bay of Biscay for main active (OTB) and passive demersal gears (LLS, GNS and FPO) potentially operating in the CWC area of the Bay of Biscay in 2010. Data are derived from VMS 3'/3' aggregated dataset. Fishing effort is aggregated depending on depth ranges (each 50 m depth band, from 50 m, right side of barplot, to 1500 m deep at the left side of barplot). Main countries operating in the area are also indicated (France, Spain and others). Dotted lines show bathymetric limits of main theoretical CWC distribution in the BoB.

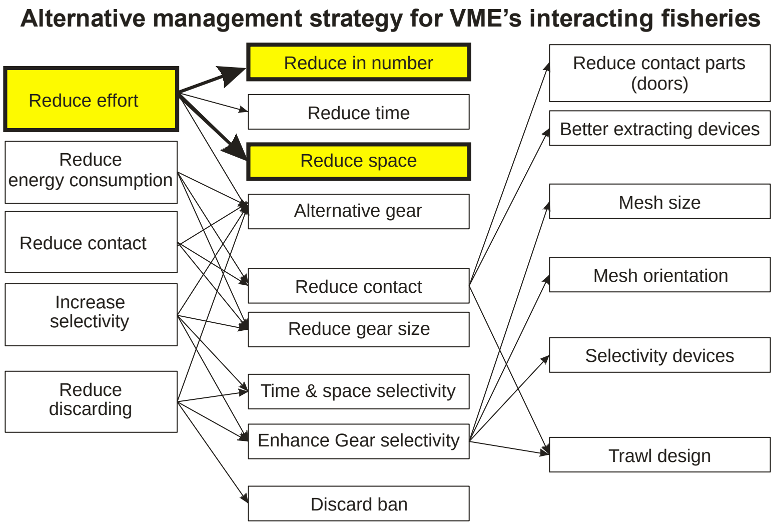


Figure 19. Diagrams of the option to be tested in the sub-case study: fisheries interacting with VME's in French and Norwegian waters.

To complete previously realised work, high resolution VMS data will be utilized to derive distribution of fishing events on VME's and/or CWC locations of the bay of Biscay and Norwegian waters. CWC habitat distribution is still not well defined for the bay of Biscay. Bottom characteristics and hydrological processes that favour coral garden development in that shelf break area are not well understood. However, as far as cold water coral habitats (i.e. *Lophelia* and/or *Madrepora* gardens or reefs) distribution is restricted to a reduced depth range and mainly on the slope (almost from depth of 200 to 800m), focusing only on those specific bathymetric ranges should allow us to define fishing pressure over existing or potential CWC areas. An estimation of catches relative to fishing effort distribution will help us to better define how much those fishing grounds benefit to the fisheries. Such an analysis will allow us to evaluate the consequences of the implementation of new spatial management rules (e.g. implementation of closed MPAs).

MEDITERRANEAN SEA

Bottom trawl fisheries

General introduction to case study

Mediterranean studies on otter trawling impact (Lucchetti et al., 2011) showed that trawling implied functional change on the megafaunal community structure, where sessile or discretely mobile filter-feeding organisms are replaced by mobile scavengers and opportunists. The ecosystem effects related to the use of bottom gear may extend far beyond the direct impacts discussed above. For example, eutrophic processes in closed basins and low depth (as in the northern Adriatic) may be enhanced by trawling, leading to hypoxia in sensitive soft bottom areas and an increase in the quantity of hydrogen sulphide released from sediments (Lucchetti et al., 2011).

Commercial fisheries utilize a wide variety of fishing gears ranging from passive gears such as pots and trammel nets, to bottom trawl that are towed over the sea bed. Passive gears may damage benthos, for instance when a long line deployed on a reef may tear off branches of the reef, but it is generally assumed that bottom trawls will have a much larger impact on benthic ecosystems than passive gear because a) they cause higher mortality rates of benthos and higher habitat modification rates and b) because the footprint of towed gears will be many orders of magnitudes larger than those of passive gears (Jennings and Kaiser 1998).

Bottom trawling has a long history that goes back for many decades and even centuries (Smith, 1994; Engelhard 2008) and has affected large areas of the continental shelf seabed in Europe and elsewhere around the world (Rijnsdorp et al., 1998; Pitcher et al 2000; Roberts, 2007).

The impact of a bottom trawl will depend on the size of the gear components, their penetration depth as well as the speed and distance over which the gear is towed. In an otter trawl, the sweeps only touch the surface of the sea bed, whereas the otterboards dig a furrow into the sediment. Modern door designs are more advanced and sophisticated as a result of increasing fuel costs and the necessity to minimize impact on the environment. Meeting these challenges has led to significant improvements in the way new otterboards are designed and tested (Sala et al., 2009).

In the Mediterranean sea, bottom trawling fleets predominate in many fisheries and are responsible for a high share of total catches and, in many cases, yielding the highest earnings among all the fishing sub-sectors (Lucchetti and Sala, 2009). These bottom trawl fleets are unselective with multiple target species, leading to problems related to the capture of undersized individuals, by-catch (and subsequent discards) of particularly vulnerable species or groups. There is also compelling evidence that the physical impact of Mediterranean bottom trawling on soft bottoms is significant: trawl doors penetrate more deeply than other sediments, with potentially greater effects on infaunal species. The ecosystem effects of trawling on deep muddy bottoms, i.e. in red shrimp or Norway lobster fisheries, also deserves special attention given the high vulnerability of deep muddy bottom communities to external perturbations and long recovery times.

Presentation of some realistic options

Option 1. Implementation of pelagic otterboards in bottom trawl fisheries

Trawl gear without any bottom contact during fishing is certainly not harmful to the bottom habitat. Potential technical innovations for reducing benthic impact in the Mediterranean Sea have been discussed during the Regional Stakeholder Event, held in Ancona (Italy) March the 22nd, 2013. During the meeting, a list of relevant factors and possible mitigation actions were proposed to stakeholders who were invited to choose the most relevant action. Otterboards were considered the most relevant action, followed by modifications to the trawl net and in particular with respect to the ground gear. Shifting from active to passive gears was also considered as a viable solution for reducing benthic impact (see Table 9).

The majority of impact in bottom trawl fisheries is due to otterboards. As the otterboards can dig into the sea bed, additional ground contact forces apply to the otterboard and, particularly on soft ground and at low towing speeds, the spread of the doors could be higher due to the extra spreading force produced by the ground shear. As a result, there is significantly more damage to benthic ecosystems, increased

bycatch of sedentary benthic animals, and higher fuel consumption (Sala et al., 2010). The otterboard is a key component for effective and efficient use of an otter trawl. Many modern otterboards are the result of initial designs, improved through practical trials until they work well enough to be used commercially.
The viability to reduce the benthic impact of the otterboards have been evaluated in Sala et al., 2010, by means of the implementation of pelagic otterboards in bottom trawl fisheries. The idea is that the traditional demersal otterboards are replaced with two chains that keep the bridle ends down, while a pair of pelagic otterboards are towed ahead of the chains and clear of the ground to provide spread. This approach to bottom trawling relies entirely on hydrodynamic force to open the gear, eliminating ground shearing forces and seabed impact.
The VF15 pelagic doors tested (Figure 20) have been developed by the door manufacturer Thyboron (Denmark). By lifting the doors off the bottom, the capture efficiency of the gear is guaranteed by two additional chains inserted just behind the backstrops (see Figure 21). In order to compare performances of the new otterboard, a traditional Vee type (termed VEE door) was selected as reference door. The two otterboards were alternated on the same trawl, commonly adopted in commercial practice in Mediterranean demersal trawl fisheries.
The VF15 otterboard produced horizontal openings greater than VEE otterboard, with less fuel demands. The VF15 was demonstrated to be more stable at lower towing speeds than the VEE otterboard and the explored area (EA) by the trawl in a 1-hour-haul shows a significant increase due to the higher horizontal net opening achieved (see Table 10). Therefore the use of the VF 15 produced a further higher fuel saving in respect to the explored area.

Table 9. Scoring of the most relevant technical innovation aimed at reducing benthic impact.

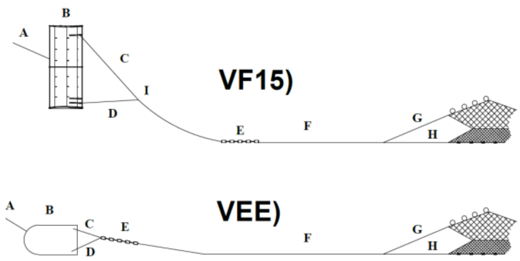
		1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27	Subtotal	%
1	Otterboards		26	19.8
2	Twine/Materials/trawl design		25	19.1
3	Shifting from trawl to seine		19	14.5
4	Corrent/coppers		19	14.5
5	Groundgear modification		22	16.8
6	Shifting to static gears		20	15.3
		Total	**131**	**100.0**

Option 2. Fishing gears modifications to reduce seabed impact and fuel consumption of bottom trawls.

There are many techniques and operational adaptations available to reduce the drag and weight of the bottom trawl gear and thereby reduce fuel consumption and seabed impacts. Some of these techniques have been reported to reduce environmental impacts and gear drag without marked decrease of the catch of the target species (Glass et al., 1999; HE, 2007; Valdemarsen et al., 2007; Queirolo et al., 2009; Van Marlen, 2009). As an example of fishing gear modification He and Winger (2010) demonstrated how seabed contact can been reduced while catching efficiency is maintained through the use of ballast elements or dropper chains to hold the footrope near, but not contacting, the bottom. In

Table 11, Suuronen et al. (2012) summarized a list of potential options to mitigate the seabed impact of bottom trawl fisheries. Many of these can be considered as viable solutions both for benthic impact and fuel consumption reduction.

Figure 20. VF15 pelagic otterboard from Thyboron (Denmark).



	Configuration	VF15	VEE
A	Wire ø 16 mm	150 m	150 m
B	Doors	Thyboron VF15 195x78 cm 290 kg	Traditional VEE 163x100 cm 300 kg
C	Combination rope ø 22mm	5 m	1.85 m
D	Combination rope ø 22mm	5 m	1.90 m
E	Chain	7.5 m	4 m
F	Combination rope ø 36mm	110 m	110 m
G	Combination rope	8 m	8 m
H	Combination rope	8.5 m	8.5 m
I	Combination rope	39 m	-

Figure 21. Main details of the gear rigging adopted during the sea trials. Configurations with the Thyboron type VF15 (VF15) and with the traditional VEE door (VEE).

Table 10. Comparison between the traditional VEE (VEE) and the Thyboron type VF15 (VF15) otterboard. Mean value of horizontal door spread (HDS); horizontal net opening (HNO); fuel consumption rate (FCR); vertical net opening (VNO); towing speed (TS); explored area in 1-hour-haul (EA); fuel consumption per explored area (FCEA).

Parameter		VEE	VF15	Diff.	Diff%
TS	[kn]	3.85	3.25	-0.60	-15.6%
HDS	[m]	61.13	86.57	25.45	41.6%
HNO	[m]	19.88	24.61	4.74	23.8%
VNO	[m]	1.67	1.70	0.03	1.6%
FCR	[kg/h]	58.74	48.16	-10.59	-18.0%
EA	[1000m^2]	141.72	148.15	6.43	4.5%
FCEA	[kg/1000m^2]	0.41	0.33	-0.09	-21.6%

Table 11. Examples of potential energy saving techniques and operational adaptations to reduce fuel consumption and environmental impacts of demersal trawling (Suuronen et al., 2012).

Technique/measure	Effect	Constraints–barriers
Use of thinner and stronger twines, super fibres, knotless netting, square mesh netting, T90net, less netting, larger mesh size.	Reduces the amount, weight and surface area of netting and increases water flow through the net, thereby reducing the overall drag.	High price and availability of materials; the use of larger meshes can reduce the catch of marketable species and sizes; cost benefit analyses not carried out formost fisheries.
Use of smaller and/or multiple nets forspecies that exhibit poor avoidance behaviour to the presence of the fishing gear (e.g. shrimp, flatfish).	Reduces the overall netting surface area and thereby the weight and the drag without reduction in catch.	Policy, complexity of rigging, resistance to change.
Using four-panel design (instead of typical two-panel) in the belly, extension piece and codend, using square mesh netting in the belly	Ensures easier and better geometry and stability forthe back end of the trawl	Cost benefit analyses not carried out formost fisheries
Better rigging of the gear, lighter ground-gear, shorter ground-gear, less discs and better rotation capacity, self-spreading ground gear, composite ropes, lengthened bridles, off-bottom bridles, lightweight warps, and proper matching of trawl net and trawl doors.	Lighter and reduced contact points to seabed, less seabed pressure, smaller impact area, less drag.	Performance monitoring
Converting from single boat trawling to pair trawling	Reduces fuel consumption, less seabed damages	Policy, human behaviour
Improving navigation and fish finding, and improving knowledge on fishing grounds (GPS, electronic charts, sea-bed mapping)	Maximizes catches and minimizes time, energy and collateral impacts	Price, training

Boat seine fisheries

General introduction to case study

Boat seining is generally considered to be a more environmentally friendly and fuel efficient fishing method than bottom trawling (Suuronen et al., 2012; Dickson, 1959; Einarsson, 2008; ICES, 2010). The gear is lighter in construction and the area swept is much smaller than in bottom trawling, and because there are no trawl doors or warps, there is less pressure on the seabed. The light gear and low hauling speed means that fuel usage may be lower than for a comparable trawling operation. Boat seine nets are generally regarded as having low impact on the benthos, although few specific studies have measured this impact (ICES, 2006). Tulp et al. (2005) derived fishing event mortality rates for four main fishing gear categories, including the bottom seine. Two Canadian reviews recently concluded that the main impact of seining is on bycatch of both undersized individuals of the target species and individuals of non-target species (Donaldson et al., 2010; Walsh and Winger, 2011).

Option 1. Modification in fishing techniques

In Italy, in particular in the Ligurian Sea commercial fishery is mainly represented by the small-scale coastal fishery, operated basically with traditional fishing gears as boat seine. Since June 2010, EC Regulation 1967/2006 identified boat seine as a towed gear, leading to this fishing gear the same restrictions applied to bottom trawls. These restrictions have effectively crippled boat seines fishery, as this fishery is operated at short distance from the coast, shallow waters and by very small mesh size net.

Considering the existing difficulties to obtain local management plans for this fishery, alternative fishing gears have been assessed and experimented at sea. An experimental surrounding net without purse line (Figure 22) and particular fish pots (Figure 23) have been compared to the traditional fishing gear in terms of performance and physical seabed impact.

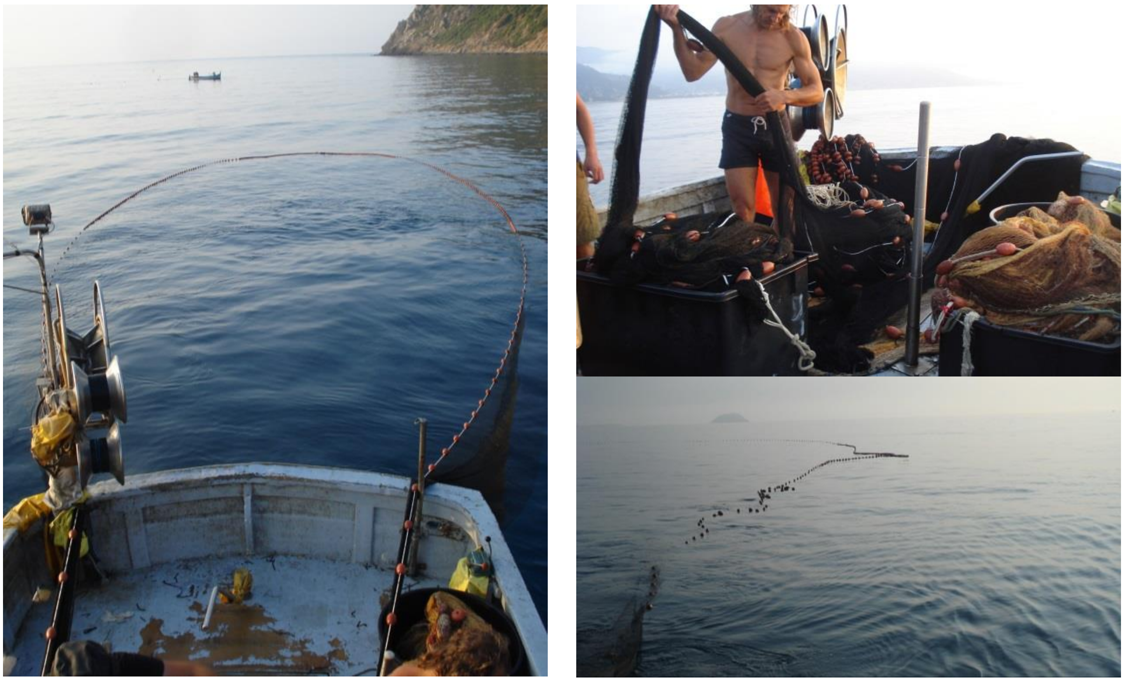


Figure 22. Surrounding net without purse line.

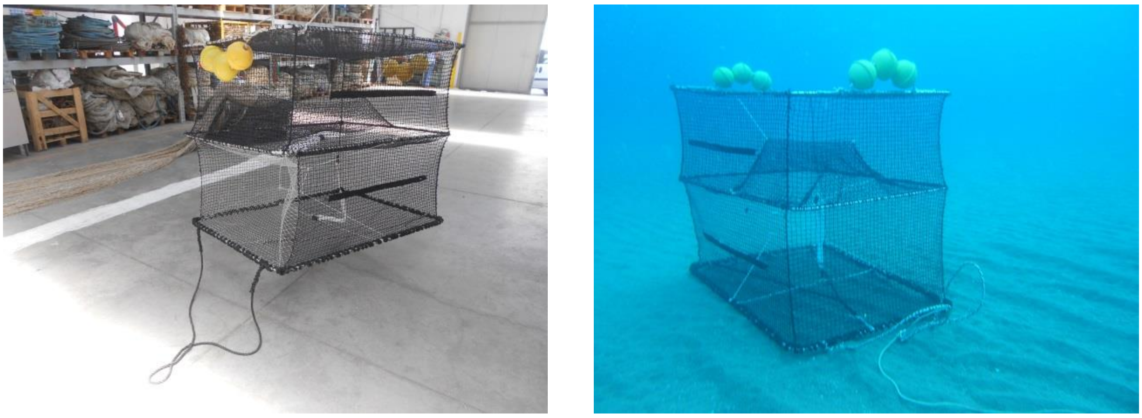


Figure 23. Fish pots (CARAPAX).

Boat seine has been the most efficient fishing gear in catch quantities (estimated in kilograms per hour) with an average of 70 kg/h, significantly higher than that obtained with the experimental gears, ranging from 8 (purse seine) to 18 kg/h (fish pots). Catch Comparison analysis have shown how the traditional fishing gear was also the most efficient gear regardless of species captured, resulting however, less selective. The experimental purse seine was more species-selective and the most abundant catch has been recorded for the saddled seabream (*Oblada melanura*), a mid-water living species (Figure 24). The fish pots were highly selective, mainly targeting eel species with low commercial value (Figure 24) as Mediterranean moray (*Muraena helena*) and the European conger (*Conger conger*).

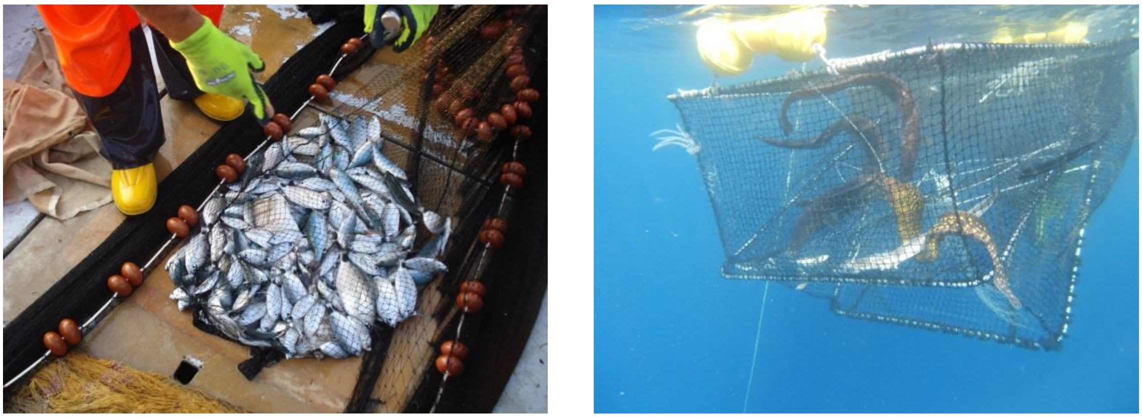


Figure 24. Catches of saddled seabream (*Oblada melanura*), a mid-water living species (on the left) in surrounding net without purse line; catches of Mediterranean moray (*Muraena helena*) and the European conger (*Conger conger*) in pot fisheries.

Physical impact on the seabed has been monitored by underwater video observations which showed furrows left by leadline of boat seine on sandy bottoms (Figure 25). Regarding the impact on Posidonia mats, the boat seine leadline lightly brush meadows, even if seagrass tufts were frequently observed on board after hauling operations. On the other hand, experimental purse seine showed no physical impact on the seabed, because of positive buoyancy of the gear did not allow leadline to touch the bottom (Figure 25). Physical impact of fish pots on the sea bed was also negligible.

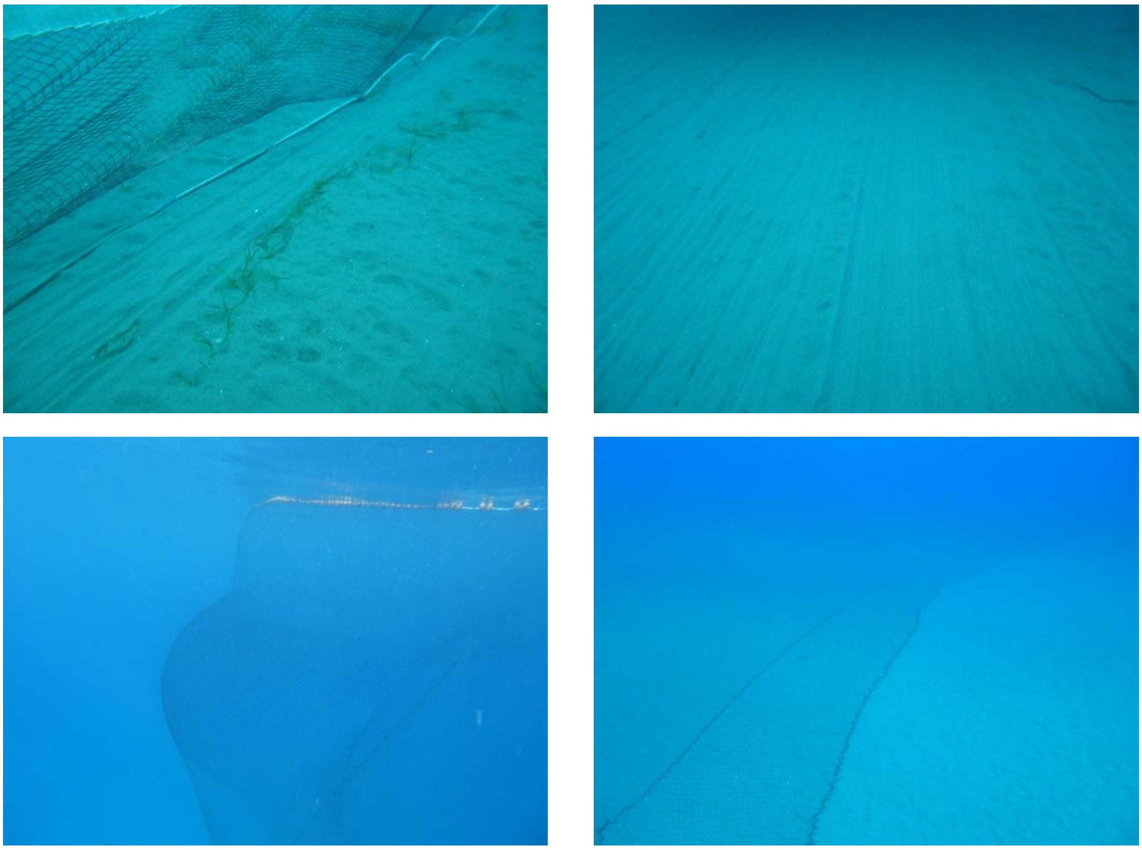


Figure 25. Up: furrows left by boat seine trawling. Down: buoyancy of the surrounding net and no impact recorded on the bottom.

Mitigating trawling Impacts: Greek Waters

Option 1. Alternative Gears

The diversity of fishing gears are relatively low in Greece with the small artisanal fleet (hooks and nets) dominating in vessel number, landings and value of landings (Table 12). Demersal trawls are comparatively disproportionate in terms landings and value against number of vessels as are purse seines in the lower value small pelagic fishery. With the exception of direct removal of individuals in the catch demersal trawls are perceived as the most environmentally damaging of gears with the high bottom contact force and footprint during trawling activities.

Table 12. Gross percentage composition of the Greek fishing fleet by vessel number, landings weight and landings value.

Category	Vessel Number	Landings (wt)	Value
Demersal Trawl	1.8	18.8	16.4
Hooks (long line and handline)	26.0	17.4	14.8
Nets (trammel and gillnet)	63.0	30.0	55.6
Purse Seine	1.6	31.5	11.6
Other	7.6	2.3	1.6

Landing weight and landings value are not available for trapping vessels although the 2014 fleet register has 330 pot/trap vessels at 2.4% of the total fleet. These vessels tend to be small artisanal vessels with limited effort although there are a few *Nephrops* trapping vessels up to 18 m length in local areas. Trapping has not expanded primarily due to potential conflict with other fishing métiers and lack of acceptance (Smith & Papadopoulou 2003, Papadopoulou et al. 2006). A major part is also due to a lack of information/data and reluctance to invest. The general benefits of trap fishing are well-known with high selectivity, good condition of catch and often targeted to high value species (cod, sparids, grouper, lobster, crab, shrimps and Nephrops) (e.g. Bjordal et al., 1986; Furevik et al., 2008). In terms of general negative impacts, bycatch and therefore discarding is low, damage to the seabed is limited to a short scrape in the footprint of each individual trap as it is deployed or lifted and the potential for ghost fishing should traps be lost (Bullimore et al., 2001; Eno et al., 2001; Kaiser et al., 2000).

A *Nephrops* trap fishery had previously been studied in a localized area in Greece under the NECESSITY project (Papadopoulou et al., 2006; Smith et al., 2007). The study highlighted the positive benefits of trapping mentioned above including fuel efficiency, and opened up the prospects for other trap studies towards the expansion of the gear as an alternative to other fishing practices particularly demersal trawling, where trawl areas may be restricted in the future for the expansion of less damaging gears.

As an alternative gear the further expansion of trapping fulfils many of the BENTHIS project goals in mitigating trawling impacts by: potential reduction in overall effort, reduction in contact with the seabed, increase in selectivity and reduction of discarding.

The sub-options concern the introduction of fish pots in the coastal trawl fishery and the shrimp traps in the shelf fishery. In the coastal fishery, Norwegian fish pots (similar to those trialled in shallow waters in Italy above) will be trialled on coastal sandy/maerl grounds at 70-100 m depth, a fishery area worked by both small artisanal netters and trawlers, targeting “redfish” (sparids and red mullets) (Figure 26). Shrimp traps (similar to those used in previous *Nephrops* fishery) will be trialled on shelf muddy grounds at 200 m depth, a typical trawl fishery targeting “whitefish” (gadoids, angler fish) and shrimps (Figure 27). For both gears, seasonal trials will be undertaken during the closed trawling season or adjacent to the trawling ground during the trawling season and compared and compared with trawl catches.

Figure 26. Norwegian fish pot as an alternative to coastal fisheries in the Greek 70-100 m ‘redfish’ fishery.

Figure 27. Shrimp traps as an alternative to shelf trawl fisheries in the Greek 200 m ‘whitefish’ and shrimp fishery

BLACK SEA

General introduction to case study

Samsun Shelf Area (SSA) is one of the most important fishing areas along the Turkish Black Sea coasts. The bottom trawl fisheries began to flourish in the Black Sea coast of Turkey by the end of the 1950s. In addition, the rapa whelk invaded the Black Sea ecosystem in 1940 and has spread rapidly throughout whole Turkish Black Sea coast. The fishery on rapa whelk became economical by 1980s and reached an industrial scale still being supported by an intense fishery in the same marine area. For this reason, SSA is under high pressure of drag-nets since 1980s. The rapa whelk generally inhabit the near shore benthic waters and reproduce in summer months peaking between June and July. The commercial fishermen prefer to operate mostly on this period because of high catch per unit effort. In fact, these areas are forbidden by government for beam trawl fisheries on summer months as most of the demersal fish species spawn along this area and in this period. The time and area restrictions were generally violated by rapa whelk fishermen in SSA. The main catch of rapa (82%) mostly came from beam trawls. Nearly 400-450 vessels are operating in SSA, dragging the substratum and creating a serious impact on epi- and infaunal organisms.

In bottom trawl fishery, the growing fleet and effort by 1980s raised a collapse in demersal fish stocks affecting all ecosystem components. In monitoring studies on trawl fishery (2000-2013), high discard rates were estimated for two target species; as nearly 25.8% for red mullet and 42% for whiting. Commercial and beam trawl fishery in SSA was monitored monthly in 2013 relevant to tasks in WP7. The gear metiers and catch data (landing, discard and by catch) obtained from bottom trawl vessels larger and smaller than 18m were recorded. The beam trawl activities were also monitored between June 2013 and May 2014 and still in progress. Beam trawls are generally 6-15m in size and their engine power ranges between 35-350 HP.

Trawl gears (ground gear and doors in bottom trawl and shoes in beam trawl) have larger scrapping impact especially on soft substratum types. This continuous and heavy pressure prevents some types of living forms such as sessile organisms. There is nearly no benthic organism living attached to substratum except a few species distributed on small areas of hard substratum which is unavailable for trawling. The collaboration was realized with external partners to get advice about the modifications to be made both on bottom and beam trawl in order to mitigate the impact on benthic habitat. The technical specifications were defined in four different ground gears that are currently being used in traditional bottom trawls. Furthermore, any other alternative model for the ground gear was discussed.

In SSA, there are some technical differences between the design of the beam trawls gears used in different sub locations such as western (Kızılırmak shelf area: Dereköy-Koşuköyü-Toplu-Yakakent) and eastern (Yeşilırmak shelf area: Canik-Costal-Fenerköy-Terme-Ünye) stations. In western locations fishermen attached a thick rubber plate under the net to prevent the deformation of mesh due to relatively hard substratum mostly covered by dead bivalve shelves and to minimize the force of friction.

Presentation of some realistic options

Beam trawl fisheries

Option 1. Modification in fishing techniques

Prof. Dr. Tosunoğlu suggested the trial of traps/pots (Figure 28) that are widely used by fishermen in different coasts around the world as an alternative method to the traditional gear Algarna/beam trawl currently operating along SSA for rapa whelk fishery. The scope of this task is to check whether the pots may be an efficient alternative fishing method against beam trawl or not.

Figure 28. The pot which is widely used for the fishery of a species belonging the same genus with *Rapana venosa* in Korea.

Option 2. Fishing gears modifications to reduce seabed impact

In Algarna, it is decided to mount 'sledges' made of steel instead of shoes in traditional model to mitigate the impact on substrate. It will be technically designed by Dr. Kaykaç and will be produced by Mustafa Sadıklar (SME 15) by the mid of June 2014.

Two kind of Algarna/beam trawl will be prepared equipped with 72 mm and 88 mm mesh size for experimental surveys. The legal mesh size for Algarna gear is 72 mm in practice. It was applied as 90 mm until 2008. But, in some cases fishermen prefers the larger mesh size since it is more profitable to catch larger individuals. For this reason both of the mesh sizes will be tested to make any comparison for economy.

Bottom trawl fisheries

Option 1. Implementation of pelagic otterboards in bottom trawl fisheries

It is decided to make two kind of modification in bottom trawls to reduce the impact on benthic habitat. The first was to use the 'flying doors' in water column instead of dragging doors on substratum (Figure 20 and Figure 29). The flying door that is suggested by Dr. Sala (CNR/ISMAR), Dr. Tosunoğlu and Dr. Kaykaç and the other equipment and devices will be transported from ISMAR, Ancona/Italy. The transportation will be carried out by Kemal Malkoç, by the support of Project partners for the legal and bureaucratic processes. The date for transportation will be decided after communication with Dr. Sala ensuring the arrival at least two weeks ago from the start of experimental surveys.

The second modification to be made in bottom trawl is about the type of mesh size in trawl codend. We are going to apply 40 mm square mesh and T90 (the attachment of diamond mesh to the bag by a 90 degree torsion) as gear material (Figure 30). Two designs will be realized in the codend. Kemal Malkoç will supply the gear material as well as the codend-cover method (Pope et al., 1975) using one of the commercial trawl gears of the vessel required for experimental of mesh size selectivity.

Figure 29. The use of flying/pelagic doors in bottom trawls

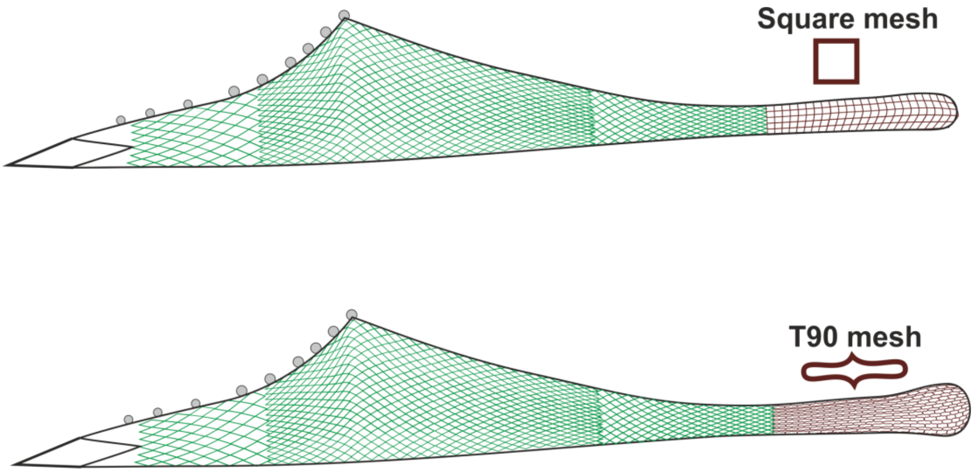


Figure 30. Investigation of square or T90 mesh in bottom trawl codends of Black Sea: different types of mesh in the bottom trawl codend

DISCUSSION AND CONCLUSIONS

Baltic Sea

In the western Baltic trawl fisheries technical management measures to reduce ecosystem impacts of fisheries have focussed on gear modifications to increase gear selectivity with the purpose to avoid un-intended by-catch and to reduce discard, as well as fishing closures of certain areas and seasons to protect certain species. The latter has been closures of some areas in Kattegat and in the Baltic Sea to protect cod, and closure of certain fishing seasons to protect spawning flatfish. Management measures according to ecosystem impacts of the western Baltic fisheries have so far focused on by-catch and discard reduction, and no measures exist at present for reduction of benthic impacts of the western Baltic trawl fisheries. However, certain protective measures to reduce benthic impacts of fishing gears have been implemented for mussel dredging in the western Baltic Sea. Benthic ecosystem impacts from demersal fishery in the western Baltic is assumed to come mainly from Nephrops trawling in the central and southern Kattegat, mussel dredging in the Belt Sea, and mixed species cod trawling in the western Baltic Sea. The Baltic case study has focus on gear technological innovations to reduce effort, benthic contact of fishing gears, and discarding. There are conducted experimental fisheries in relation to evaluation and comparison of ecosystem and habitat impacts, catch efficiency (target/by-catch/discard/invertebrates), selectivity, energy efficiency, and economic efficiency (vessel specific cost-efficiency/cost-benefit analyses) of different gear modifications compared to standard gears. Furthermore, the case study evaluates potential fishing closures directed towards sensitive benthic habitats and communities. The case study explore in cooperation with the industry a number of possible innovations, gears and their modifications to reduce fuel consumption, maintain catch efficiency towards target and by-catch species, reduction of discard, and to reduce direct benthic impacts by the gears in order to reduce ecosystem impacts compared to standard gears. This cover among other testing of lighter mussel dredges, pelagic trawl doors in the cod trawl fishery, short sweep lengths in the Nephrops trawl gears, and alternative Nephrops creel fishing. Also, it involves evaluation of certain fishing closures in the cod fishery, as well as intelligent fishing with pre-monitoring of optimal fishing grounds in the mussel (and cod fisheries), to reduce overall effort and fishing pressure and to reduce impact on sensitive benthic habitats and communities.

North Sea

A wide mix of fishing methods is being used in the North Sea ranging from active gear like beam trawls, otter trawls, twin rigs, dredges and rope seines (flyshooting) and passive gear like set nets, pots and lines. Bottom impact and effects on the marine ecosystem were found to be considerable for beam trawls, although all towed gears significantly impact the seafloor and its communities. One of the main impacts of trawling on the marine environment is the homogenization of the sediment (removal of physical structure), which in turn leads to more homogeneous benthic communities. Beam trawling also has a reputation of producing high discards although the minimum mesh size used plays a significant role. The pulse trawl, as an alternative to the traditional beam trawl, lacks the heavy tickler chains which significantly reduces the seafloor and benthic impact. The towing speed has been reduced from some 7 kn to somewhat more than 5 kn which decreases the fished surface, benthic impact and fuel consumption. The average penetration depth has also been reduced from over 2.5 cm to less than 1 cm. There are also indications that discarding may be reduced with this technique. The Sumwing, as an alternative to the beam trawl, reduces fuel consumption with 12% on average for the same catch with maxima over 20%. The average reduction in sediment penetration for the whole gear is 10%. The development of the Hydrorig as an alternative for the beam trawl is still in a too early stage of development to draw any conclusions. Demersal seining (such as flyshooting) also shows a wide variability in gear design and operation. There are undoubtedly many positive benefits of seining when compared to trawling with respect to bottom impact, fuel economy and fish quality, however, concerns have been expressed about levels of discarding and high-grading as seine netters aim to maximize returns.

Western waters

Through very contrasted sub-case study and approaches, the Western water case study covers a range of innovative gears and management options in some important fisheries of the Western European seas. Two promising innovative fishing gears are tested: Enviro dredge for Scallop and Jumper board for Nephrops twin trawls. Those innovative gears both fill the main objectives of Benthis project by reducing the impact of fishing on the benthic ecosystems and increasing energetic efficiency of fishing activity.
Moreover, western waters case study proposes approaches combining both technical innovations and new spatial and/or temporal management rules. To take into account both dimensions is especially important when technical conflicts occurs between alternative gears and traditionally utilized ones (e.g. traps vs trawls for Nephrops). VME's sub-case study especially stressed that developing new gears only is not sufficient to reach impact reduction objectives. In those habitats where fishing immediately produce severe and long lasting impacts, even the best practices developed for more resilient areas (e.g. evolution from trawls to enlighten or passive gears) are not sufficient to efficiently protect fragile biogenic structures such as corals. In that specific case, the development of new spatial management rules appears as the exclusive way to reach impact reduction objective and to offer a substantial protection for those fragile ecosystems.

Mediterranean

In the Mediterranean trawl fisheries technical management measures to reduce ecosystem impacts of fisheries have mainly focussed on gear modifications to reduce physical contact and fuel consumptions. New “pelagic” otter boards have been tested on board of research vessel. Moreover, some initial trials have been carried out during commercial fishery resulting in growing fishermen interest in new otterboards. Further options of mitigations have been assessed. Proposal of alternative gears as in the case of Ligurian traditional boat seine fishery, appears the best solution taking into account the difficulties to obtain local management plans for the traditional fishery. Considering the artisanal characteristics of the Mediterranean fisheries another alternative gear can be represented by the use of particular fish pots, already known in EU Northern waters. Also in this case, fishermen have showed interest in testing this “new kind” of pots.

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