Deliverable 7.9

Report on technological innovations and management scenario's to mitigate fishing impacts on the benthic ecosystem and their socio-economic consequences in regional seas

Due date of deliverable: month 48 (August 2016)

Actual submission date: month 49 (October 2016)

Grant Agreement number:	312088
Project acronym:	BENTHIS
Project title:	Benthic Ecosystem Fisheries Impact Study
Funding Scheme:	Collaborative project
Project coordination:	IMARES, IJmuiden, the Netherlands
Project website:	www.benthis.eu

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Document Change Record

Authors	Issue	Date
Sara Bonanomi	Draft of outlines	10/08/2016
Emilio Notti	WP7 contributions	12/08/2016
Antonello Sala	Revisions to the Mediterranean case study	23/08/2016
Elena Pagliarino	Revisions to the Mediterranean case study	16/09/2016
Emilio Notti	Draft of the deliverable	06/10/2016
J. Rasmus Nielsen	Baltic CS Contributions	12/10/2016
Emilio Notti	Final Draft	24/10/2016
Antonello Sala	Final revision	25/10/2016
Adriaan Rijnsdorp	Summary	31/10/2016
Adriaan Rijnsdorp	Update of list of authors	26/02/2017

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Summary

This report provides a detailed account of the field and modelling studies carried out in the BENTHIS project in the Baltic Sea, North Sea, Western Waters, Mediterranean and Black Sea on the mitigation of bottom trawling impacts on the seafloor and benthic ecosystem. The studies were conducted in close collaboration with fishers and gear manufacterers and focused on the major bottom trawl fisheries in European waters: otter trawl fisheries for demersal fish, otter trawl fisheries for Nephrops, beam trawl fisheries for flatfish, beam trawl fisheries for brown shrimps, beam trawl fisheries for whelks, dredge fisheries for bivalves (mussel, scallops). Both technological innovations and alternative management scenarios were explored.

Technological innovations

The following technological innovations were studied: (i) Lifting otterboards (semi-pelagic otterboards, jumper boards); (ii) Reducing sweep length in Nephrops otter trawls; (iii) Gear modifications (weight, chain, mesh size); (iv) Pulse trawls replacing mechanical stimulation by electrical stimulation; (v) Use of passive gear (creels and pots).

Semi-pelagic otterboards. New scaled otterboards designed by Italian SMEs (Small and Medium Size Enterprises) were preliminary tested in a wind tunnel and in a flume tank and finally tested in full-scale at sea. Sea trials showed a reduction in fuel cost and bottom contact, while the catch efficiency was not significantly affected. Jumper otterboards, tested in the French Nephrops fishery, produced considerably lower level of sediment re-suspension compared to the conventional otterboards, while catch rates were not statistically different.

Reduced sweep length. Sea trials with reduced sweep length in the Nephrops fishery in the Kattegat (western Baltic) indicated that it is possible to maintain similar catch rate of Nephrops, flatfish (plaice, sole) and codfish (cod, haddock) with shorter sweeps.

Gear modifications (gear weight, application of chains, mesh size). Sea trials comparison in Danish coastal waters between light mussel dredge and Dutch dredge showed impact reduction on the ecosystem: (i) reducing resuspension of sediment, (ii) reducing of fuel consumption, and (iii) potentially reducing energy transfer to the sediment through a reduced gear drag resistance, while obtaining a higher catch per unit of effort of blue mussels. In the Black Sea beam trawl fishery for rapa whelks, gear modifications reduced fishing impact on benthic ecosystem by using sledges and removing the steel wire stretched in the mouth of the gear, which also reduced the fuel consumption. Mesh size changes were explored in the Black Sea to reduce the bycatch of small fish.

Electrical stimulation. The use of electrical stimulation in the North Sea beam trawl fishery for sole greatly reduced the bycatch of benthos. The pulse stimulation is particularly effective for sole, the main target species of the fishery. The catch efficiency of other fish species is lower. Since the towing speed is reduced from 6-7 knots to about 5 knots, the footprint of the trawl fishery for sole will be reduced. Sea trials showed that the electrodes had a reduced penetration in the seabed compared to the traditional tickler chains, but no significant differences in direct mortality of benthic invertebrates were found. Pulse trawls for brown shrimp have great potential to reduce the bycatch of undersized fish by 75%. It is noted that there is a lack of knowledge on the effects of electrical stimulation on marine organisms and benthic ecosystem functioning.

Passive gears. The use of passive gears as an alternative for bottom trawl gears could be an alternative for bottom trawling for Nephrops in the Kattegat (western Baltic) in waters in close range of the harbours for small vessels (cost benefit analysis suggested a positive daily profit for vessels with two persons on board), but not for larger vessels. Sea trials in Kattegat showed that mean length of Neprhops increased and by-catch of other species decreased in the creel fishery compared to mixed trawl fishery, and also that the benthic impact per kg of landed Nephrops was lower for creels than for trawls. Also in the Bay of Biscay, profitable pot fishery

for Nephrops seems feasible. Although the benthic impact seems lower, the high spatial and technical interactions between trawlers and potters did not enable the development of a larger *Nephrops* pot fleet. Trials with baited pots in the Mediterranean and Black Sea showed catch rates that were not satisfactory for the commercial fishing activity.

<u>Innovative management scenarios</u>

Several specific fisheries (e.g. hydraulic dredging for razor clams, otter trawl fishery on the shelf slope) were studied to collect and analyse information on fishing pressure in relation to benthic habitat characteristics to estimate benthic impacts of the fishery, as well as interactions with other pressures and seasonal and spatial veriations herein, that can be used to develop management scenario's to mitigate trawling impact.

Closed areas and seasons to reduce the impact by demersal towed gears were studied for the inshore scallop dredge fishery and for the otter trawl fishery as well as for the mixed fishery with other demersal gears (e.g. seines) on the shelf slope in different marine ecosystems and case studies where VME's (Vulnerable Marine Ecosystems) may occur. Detailed maps of VME will help to mitigate the adverse effects on vulnerable habitats by establishing MPA's. For the conservation of Cold water corals (CWC) in Bay of Biscay and Norwegian waters information on their occurrence is incomplete. Hence, the depth distribution and species composition of the bottom trawl fisheries on the slope of the shelf where we can expect VME's to occur, may provide information to mitigate the risk of trawling impact. It is shown that in the Bay of Biscay continental slope fishery with both towed and passive gears, a large proportion of landed fishes are not the typical deep water species but are dominated by ubiquist species (mainly Monkfish, Hake, *Nephrops* and Megrim) represented more or less 90% of the landed biomass in the 200 m to 1000 m depth area during the 2005 to 2013 period. It highlighted that CWC would hardly benefit from management rules based only on Deep water species targets regulations. Since biodiversity indicators are negatively correlated with bottom trawling disturbance, the impact of bottom trawling can be reduced by restricting the fishing activities in the areas trawled more intensively (freeze the footprint). A modelling study for North Sea demersal fisheries showed that a habitat credit system could create incentives to mitigate the trawling impact by reducing fishing activities in sensitive habitats. The habitat credit system was received positively by stakeholders as one of the possibilities that could potentially be applied in the certification of individual fisheries.

<u>Factors affecting the uptake of technological innovations to mitigate trawling impact.</u>

The studies showed that economic profitability is an important condition for technological innovation. In addition social factors and governance factors may play a role. The introduction of limitations or incentives at legislative level, and the change in consumers' preference and style towards sustainability may directly affect the demand and the prices of fish product and create an incentive for improving the environmental performance of the fisheries.

Table of Contents

Introduction

Fishing can affect benthic ecosystems in several ways, by modifying the sedimentary habitats, increasing or decreasing nutrient fluxes, killing benthic invertebrates and through the redirection of energy from discards to the seabed. These impacts in turn lead to changes in the functioning of the benthic ecosystem and the availability of food for commercial fish species. Conservation of marine ecosystems may be achieved by reduction of fishing impact through limiting fishing pressure or banning fishing activities or by introducing gear types with reduced impact on the ecosystem.

In the present deliverable a review of all technological innovations and management scenario's results is reported for each regional case study.

Selected alternative fishing gears and techniques have been tested and developed through sea trails and ecological and economic data required for various models have been collected and tested in collaboration with the SME's.

Furthermore, fishing gears and management alternatives selected on the basis of the suggestions from SMEs and other stakeholders have been studied using tools developed in the generic WP2 – WP6.

The impact of alternative gears on the benthic ecosystems have been assessed by using models developed in WP4. When available, data were incorporated in a spatially dynamic model of changes in fishing effort. WP5 provided the framework to assess the response of the fishing fleets to innovative management measures and their socio-economic impact on the fleets and the related sectors (processing, shipyards, etc.). Different degrees of compliance have been tested for management alternatives and social indicators such as employment have been also calculated for the different fleets. The required economic data needed for the analysis have been defined in collaboration with WP5 and have been derived from data already available (fishing calendars and effort per métiers, landing data, DCF data) and from newly acquired data in close collaborative work with SMEs (economic survey and bookkeeping at fleet level).

Finally, the economic data have been used to parameterize cost-benefit analysis developed in the WP5 and the indicators produced fed the multi-criteria analysis developed in WP6.

BALTIC SEA

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Case Study summary

In the Baltic Case Study a series of gear technological mitigations and management scenarios in relation to re-allocation of fishing effort have been investigated in order to reduce benthic impacts of fishery with demersal, hauled fishing gears. The gear technological mitigations cover:

a) Catch and profitability of Danish creel fishery compared to trawl fishery targeting Nephrops in Kattegat;

b) Swedish creel fishery compared to trawl fishery targeting Nephrops in Kattegat and Skagerrak;

c) Reduction of benthic impacts of Danish Nephrops trawl fishery in Kattegat by use of reduced trawl sweep lengths;

d) Reduction of benthic impacts from blue mussel dredging by use of modified (light) mussel dredger.

The above mitigations naturally include aspects of management scenarios by implementing them into management. Direct technical management measures, in relation to spatial and seasonal management measures (e.g. fishing closures) are also evaluated covering:

a) The allocation and intensity of fishing effort with hauled gears according to sensitive habitats and seasons in the Western Baltic Sea;

b) The effects of bottom trawling intensity on soft seafloor macrofauna in the Kattegat among other in relation to MPA management;

c) Impact of trawl fishing on Benthos in Danish waters of Kattegat from 2005-2013 on different benthic habitats.

Overall, the results of the different investigations show that it is possible to reduce the benthic impacts of fishery with hauled gears in the Western Baltic Sea, through gear technological mitigations and technical management measures covering spatial and seasonal re-allocation of fishing effort, away from areas with more sensitive habitats and seasons where the fishing impacts are higher on the benthic communities.

Technological innovations

Technological innovation 1. Catch and profitability of Danish creel fishery compared to trawl fishery targeting Nephrops in Kattegat

Introduction

The purpose of the study is to investigate the profitability of a potential Danish creel fishery targeting Nephrops. At present no Danish creel fishery harvesting Nephrops exists and, therefore, information on harvest and costs from the Swedish creel fishery is used in this investigation.

Results from pilot investigations in medio 2013 with creels on standard hard and and soft (muddy) non-trawling bottom in Swedish fishing area conducted by Swedish creel fisher showed that:

a) Camera monitoring indicated that the creels sank down into the sediment;

b) The bait attracted Hagfish (Myxine) which scared the Nephrops in the creels => some escapement;

c) The catch rates was about 180 g/creel per day;

d) Preliminary cost-benefit-analyses (CBA) indicated a daily profit about 3800 DKK per day for small vessels with two persons on board;

e) The CBA showed that this is comparable with trawl fishery for trawlers < 12 m which in 2013 had a profit about 3000 DKK per day, i.e. comparable, but that larger trawlers have higher profit.

Materials and Methods

In the follow up study (2013-2015) a simple method is used to evaluate the profitability of a potential creel fishery and this method contains three steps:

1. The revenue is estimated.
2. The costs are calculated.
3. The profit given by the revenue minus the costs is estimated.

For each of the three steps four scenarios is covered:

4. One-man vessel < 12 meter
5. Two-man vessel < 12 meter
6. One-man vessel > 12 meter
7. Two-man vessel > 12 meter

The revenue is defined as the price times the quantity. For the Swedish fishery the price of Nephrops obtained by creel vessels is larger than the price of Nephrops from trawlers mainly because of a larger size of the Nephrops. Therefore, a mark-up on 10% over the current (2015) Danish market price of Nephrops is assumed. The quantity can be decomposed into the number of creels per day and the harvest per creel. The number of creels per day is estimated to 400 creels in scenario 1 and 3 and 700 in scenario 2 and 4 following Swedish experiences. Also based on Swedish information, the harvest per creel is estimated to 100 g Nephrops.

Results

Based on the above method, the revenue can be calculated as shown in Table 1. From Table 1 it appears that the revenue depends on the number of crew employed on a vessel (one-man vessels have lower revenue than two-man vessels). Naturally, the size of the revenue is sensitive to the size of basic input parameters (the price, the number of creels, and the harvest pr. creel). Therefore, sensitivity analysis has been conducted by varying theses parameters with +/- 50%.

The calculations of costs are also based on Swedish fishery information and three cost components are included. First, the fuel costs are taken into account and these depend on the distance to the fishing ground. Here we assume that it in average takes 1 hour to reach the fishing ground. Second, the costs for gears must be estimated and here we assume that each creel costs 400 DKK. This number corresponds to the market costs of creels lasting 5-10 years. Finally, a cost arises in connection with bringing the Nephrops to auctions, i.e. transport costs, etc. According to the account statistics for the Danish fishery this corresponds in average to 22% of the total costs. With these three components included in the calculations the resulting estimated total costs are shown in Table 2 below.

It appears from Table 2 that the costs increase with both the size of the vessel and the number of crew members on the vessel, and this corresponds to the expectations. The profit is estimated by subtracting the costs (Table 2) from the revenue (Table 3) and the resulting profit is shown in Table 3.

The results in Table 3 show that the profit decreases with the vessel size and increases with the number of crew members on-board the vessel. Thus, vessels < 12 m with 2 crew members on-board receive a larger profit than other vessels. However, these results may be sensitive to the values of basic input parameters and the results of selected sensitivity analysis are shown in Table 4.

Naturally, the profitability varies with the value of the input parameters. By varying the mark-up price and the amount of fuel used it appears that the variation in profit is reasonable low. However, varying the harvested quantity has a large effect on the profit.

In order to investigate whether a Danish creel fishery targeting Nephrops is overall profitable there is made a comparison of the above estimated profits (Table 3) with the average profits for Danish Nephrops trawlers in 2012 obtained from account statistics. Table 5 contains the results of this comparison.

The results in Table 5 indicate that a potential Danish creel fishery may be profitable for small vessels with 2 crew-members on-board the vessel. However, it appears that a number of factors influence the profitability and these include the number of creels, the number of fishing days, the harvest per day, the price on Nephrops, the fuel costs, the gear costs, and the auction costs.

From Table 4 it is evident that especially the size of the harvest in the potential creel fishery affects the profitability of harvesting Nephrops. The found profits for potential Danish creel fishery is, accordingly, at the same levels as for small trawlers. The profit for larger Danish Nephrops trawlers is, however, considerably higher.

Table 1. The estimated revenue for a potential Danish creel fishery targeting Nephrops.

	I	Ii	Iii	Iv
The size of the vessel	<12 m	<12m	>12m	>12m
Number of crew	1	2	1	2
Number of creel pr. Day	400	700	400	700
Number of creel days pr. Year	150	150	150	150
Number of fishing days pr. Year	150	150	216	216
Harvest pr. day (kg)	44	77	44	77
Price pr. kg – trawlers	65,7	65,7	65,7	65,7
Price pr. kg. + 10%	72,3	72,3	72,3	72,3
Revenue (DKK/day)	3180	5565	3180	5565

Table 2. The estimated costs for a potential Danish creel fishery targeting Nephrops.

	I	ii	Iii	iv
The size of the vessel	<12 m	<12m	>12m	>12m
Number of crew	1	2	1	2
Number of creel pr. Day	400	700	400	700
Number of creel days pr. Year	150	150	150	150
Number of fishing days pr. Year	150	150	216	216
Fuel cost (L/day)	100	100	200	200
Fuel cost (DKK/day)	900	900	1800	1800
Gear cost DKK/day	284	498	284	498
Maintenance (DKK/day)	150	150	150	150
Auction costs	300	420	300	420
Total costs (DKK/day)	1634	1968	2534	2868

Table 3. The estimated profit for a potential Danish creel fishery targeting Nephrops.

	I	Ii	iii	iv
The size of the vessel	<12 m	<12m	>12m	>12m
Number of crew	1	2	1	2
Number of creel pr. day	150	150	150	150
Number of creel days pr. Year	150	150	250	250
Number of fishing days pr. Year				
Revenue (DKK/day)	3180	5565	3180	5565
Costs (DKK/day)	1634	1968	2534	2868
Profit (DKK/day)	1545	3597	645	2697

Table 4. Selected sensitivity analyses of the obtained results (in DKK per day).

Scenario	i	Ii	Iii	Iv
Benchmark	1545	3597	645	2697
Mark-up price +50%	1690	3850	790	2950
Mark-up price -50%	1401	3344	501	2444
Fuel + 50%	1095	3147	-255	1797
Fuel - 50%	1995	4047	1545	3597
Harvest + 50%	3135	6379	2235	5479
Harvest - 50%	-45	815	-945	-85

Table 5. Comparison of profit for creel vessels and trawlers in Danish Nephrops fishery.

Scenario	i	Ii	Iii	Iv
Profit (DKK/day)	1545	3597	645	2697
Profit for trawlers (DKK/day)	2.717	2.717	2.798	2.798

Technological innovation 2. Swedish creel fishery compared to trawl fishery targeting Nephrops in Kattegat and Skagerrak

Introduction

The European Common Fisheries Policy has in its 2013 reform increased in complexity, such as a call for coherence with the Marine Strategy Framework Directive and a landing obligation, posing new requirements and challenges to managers, scientists and the fishing industry. Therefore, re-evaluations of current practice are important as a basis for management actions.

The Swedish fishery for Norway lobster (Nephrops norvegicus) in the Kattegat-Skagerrak area provides an interesting case study of relevance to emerging policies. Sprung from an unbalance in available fish- and Nephrops quotas and an ambition to protect coastal areas, the current fishery has been directed towards three separate fisheries (mixed trawling, directed trawling using a sorting grid and creeling).

Studying direct and indirect effects from alternative Swedish quota allocations among gear types is therefore interesting. Accordingly, this screening study was conducted, taking into consideration area-gear interactions in catch rates, to compare the three different fisheries regarding quantified pressures on the target species, the by-catch species, and on the seafloor, as well as to qualitatively discuss social and economic dimensions. In the final step, alternative quota allocations were studied.

Nephrops fisheries in the Skagerrak and Kattegat area: In 2014, the total landings of Nephrops in the Skagerrak-Kattegat area (ICES Division IIIa: SD 20, 21) was 4 150 metric tonnes (ICES, 2015). Demersal trawling accounted for 91 % of the landings, the remaining part were landed by creeling (mainly Swedish from the Skagerrak). Denmark has a 67% share of the Total Allowable Catch (TAC), Sweden has the second largest share (31%), while Norway and Germany also have small shares.

The Nephrops trawl fisheries in this area are highly restricted by an EU long-term cod (Gadus morhua) management plan which aims at restoring depleted cod stocks by limiting effort on gears catching cod (EC 2008b). A by-catch reduction device, known as the Swedish grid, has been gradually introduced in Sweden since 2004 (Madsen and Valentinsson, 2010) as a management strategy, partly to cope with the imbalance between available fish- and Nephrops quotas.

The implementation of the grid was incentivised by allowing fishermen to continue to exploit certain coastal areas otherwise closed for trawling, such as within the national trawl border (new regulations in place 2004) and in a marine protected area in the Kattegat established in 2009. In addition, fishermen who opted to use the Swedish grid were exempted from effort restrictions due to documented low cod catches (i.e. <1.5%; art. 11 in EC 2008b).

At present, 50% of the Swedish Nephrops quota is allocated to trawlers using the grid and 25% to vessels fishing with other trawls and creels, respectively. Creel and grid trawl fishermen exploit roughly the same areas closer to the coast, i.e. areas where grid trawling is the only trawl practice allowed (Anon. 2010); however, creeling and trawling may not exploit the same fishing grounds simultaneously due to incompatibility of the fishing methods.

Aim

The objectives of the present study are i) to do a broad evaluation the three different Swedish Nephrops fisheries (mixed trawling, grid trawling, and creeling) with regards to policy requirements in the Kattegat-Skagerrak area, and ii) to quantify the outcome of alternative quota allocations between gears. The pressures evaluated are those on the target stock, commercial and fishing-sensitive fish stocks and seafloor area usage; an overview of social and economic aspects is also included.

Methods

The three different Swedish fisheries were quantitatively compared with each other with regards to Nephrops catches and catch size distributions, price of landings, fishing areas, seafloor pressure, fishing season and fish by-catch. For further details see Hornborg et al. (2016).

The different Swedish fleet categories (hereafter called fisheries, identified by gear type) in this study were defined as: mixed trawling, i.e. the mixed demersal trawl fishery targeting Nephrops in combination with fish using a minimum mesh size of 90 mm; grid trawling, i.e. the demersal trawl fishery using the 35-mm Swedish grid and a 70- to 89-mm square mesh cod-end; and creeling, i.e. static, baited pots typically arranged as 40–70 connected pots forming a string with approximately 10 strings hauled daily.

The quantitative effects on Nephrops stock parameters, fish bycatch, seafloor area affected of alternative quota allocation scenarios relative to present quota allocation (i.e. 2013) and MLS of 40 mm were estimated assuming the same catch rates and composition. The effects were visualized as a continuous difference in the creel quota share, and for seven different ratios of mixed and grid trawl shares.

Results

Our study revealed that with a MLS of 40 mm for Nephrops, allocating a larger proportion of the Swedish Nephrops quota to creeling can result in a substantial reduction in fishing mortality for both undersized Nephrops and fish.

Grid trawls caught considerably less commercial and fishing-sensitive fish stocks (e.g. depleted gadoids and elasmobranchs) per kilogram of Nephrops compared with mixed trawling, but caught more flatfishes compared with creeling. Creeling compared with demersal trawling involves a much lower seafloor pressure per kilogram Nephrops landed in Sweden. As for potential pressure, grid trawling has a higher effort concentration and LPUE of Nephrops compared with mixed trawling.

Grid trawling is allowed in areas otherwise closed for trawling, and is spatially more concentrated than mixed trawling, and may as a result leave areas un-trawled to a larger extent. Creeling occur mainly in areas closed for trawling. Different areas are thus to some extent exploited by the three fisheries, and some are more intensively fished than others.

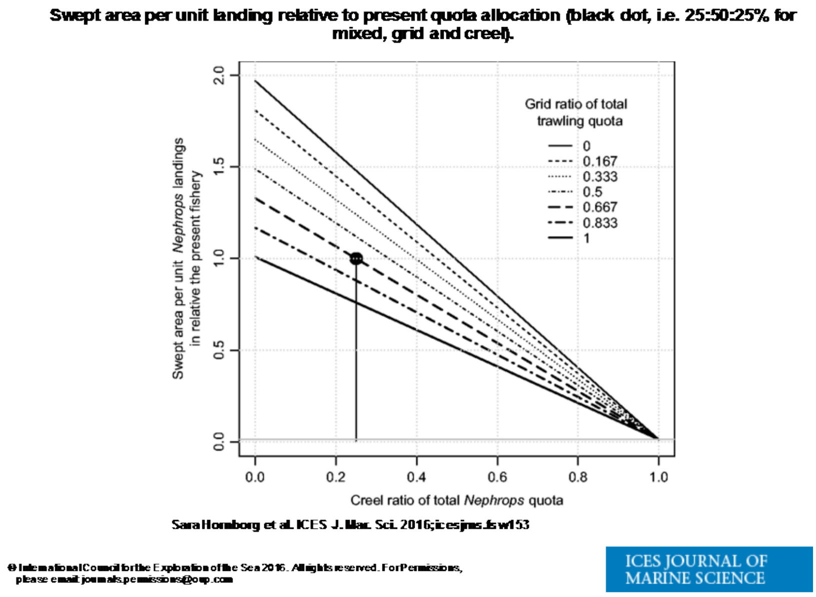

Figure 1. Swept area per unit landing relative to present quota allocation (black dot, i.e. 25:50:25% for mixed, grid and creel). The different lines represent different grid and mixed ratios of the trawling share (Courtesy of Ices Journal of Marine Sciences).

Technological innovation 3. Reduction of benthic impacts of Danish Nephrops trawl fishery in Kattegat by use of reduced trawl sweep lengths

Introduction

In 2015, there have been conducted fishing trials in Kattegat with a Danish demersal Nephrops trawler to evaluate potential changes in catch rates of target and by-catch species in the Kattegat Nephrops trawl fishery when shortening the trawl sweep lengths. This gear technological mitigation is expected to reduce benthic impacts in the Nephrops trawl fishery because of reduction of the seabed area in contact with gear during fishery.

Aim

The purpose of the experiment has first of all been to investigate whether it was possible to conduct an efficient Nephrops trawl fishery when using shorter sweep lengths and, secondly, to evaluate potential changes in catch rates, economic efficiency and energy efficiency in the fishery in a comparative study between standard fishery and fishery with this gear mitigation. This also involves considerations of changes in by-catch and discard of fish because of changed herding by the sweeps.

In theory it is expected that there is a larger herding of roundfish (e.g. cod, haddock, whiting) and maybe flatfish (e.g. sole, plaice) by longer sweeps while it is not expected that there is a herding effect of the sweeps on Nephrops (which are not as fast and mobile as fish), i.e. shorter sweeps will reduce the herding area for fish but maintain the trawl swept area (Figure 2).

Materials and Methods

The experiments were carried out during one week trial fishery with the Nephrops trawler SG92 (Danish 17m steel side trawler) in the southern and central Kattegat in August 2015. The experiments was conducted as repeated, pairwise hauls according to type of locality/habitat, depth, day-night (light), and sweep lengths (long 45 fathoms / short 15 m sweeps) with random sequence.

All other fishing and trawling conditions were kept constant. In total 18 hauls were conducted, besides a couple of test hauls, under similar weather conditions. For each haul the total catch in weight and number by length group of the species Nephrops, cod, plaice, sole and haddock was registered. All catch in each haul was measured for those species.

Each trawl set and heaving position and time were registered. The haul duration was registered from set to hiving and ranged between 4 to 6 hours. Every half hour the speed over bottom (trawl speed), ship course, wind conditions, water current, and the bottom depth was registered for the full duration of each fishing operation. Furthermore, trawl height and trawl wideness (wing spread) was measured and registered among other by use of DST tags on the trawl head rope and ground rope with pressure measurement of depth for each fishing operation.

On this basis fishing time, swept area, average trawl height, average trawl width, average depth, as well as catch per unit of effort (CPUE) by time unit and catch per unit of swept area by species and length group was estimated for each fishing operation.

Statistical analyses

A statistical model estimating the relative selectivity of the two hauls in each species and length class has been used for analyses of differences between the pairwise hauls of standard and short lengths. This has been done based on the sampled data from the paired trawl hauls performed with the two gear set-ups.

The model is a non-linear mixed effect model implemented in R, in which there is done inference using numerical maximum likelihood estimation, employing the Laplace approximation to integrate out random effects. The model explains size composition of the catch in the trawl hauls.

The statistical assumption is Poisson distributed catches conditional on log-Gaussian variables that describe the expected catches, which allows for over-dispersion and correlation between catch counts in neighboring size classes.

The model estimates are the following:

- size spectrum of the underlying population at each station,
- size-structured clustering of fish at small temporal and spatial scales,
- The relative selectivity for the two gears in each length class by species.

The statistical assumptions:

- Poisson distributed catches conditional on log-Gaussian variables that
- describe the expected catches,
- which allows for over-dispersion
- The correlation between catch counts in neighbouring size classes.

Results

The estimated relative selectivity for the two gear set-ups in each length class per species are shown from Figure 3 to Figure 7 for the individual species by length group based on initial analysis of the data.

The preliminary results indicate that it is possible to conduct efficient fishery and maintain high catch rates with short sweeps. The obtained catch amounts in the sampled data were high enough to perform statistical analysis of differences in length frequency distributions (CPUE per length group) between the different gear set-ups in the paired hauls.

The results demonstrate that it is feasible to estimate the relative selectivity in each size class, and to test statistically the hypothesis that the selectivity is independent of size. For all species analysed no significant difference for any length groups was observed, except for larger cod where there was significant higher catch rates with short sweeps. So far the effect of the locality parameter and the single pair/station effect has not been analysed into depth (especially for cod), which continued statistical analyses will focus upon.

Accordingly, the preliminary analysis of the data collected during the one week trial fishery with pairwise trawl experiments to reduce sweep length in Nephrops otter trawl fishery indicates that it is possible to maintain similar catch rate with shorter sweeps of Nephrops, flatfish (plaice, sole) and codfish (cod, haddock). So far there has not been conducted any analyses of changes in economic and energy efficiency between use of standard and short sweep lengths in the fishery based on the sea trials.

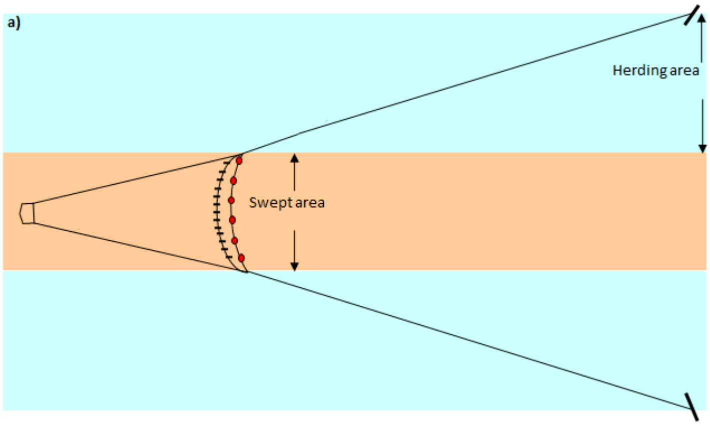

Figure 2. Schematic overview of trawl herding area with the sweeps and trawl swept area by the trawl footrope. The shorter sweep lengths (15 fathoms) compared to the longer sweeps (45 fathoms) reduces area impacted by the gear with respect to benthic seabed surface abrasion.

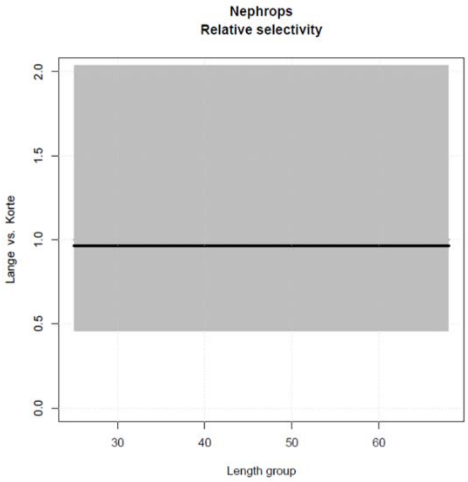

Figure 3. Relative selectivity of long (standard, "Lange") and short ("Korte") sweep lengths for Nephrops by size group (carapace length in mm). Values below 1 indicate that the short sweeps has higher catch efficiency (catch rates) than the standard (long sweeps). The shaded area indicates the confidence limits of the estimated relative selectivity.

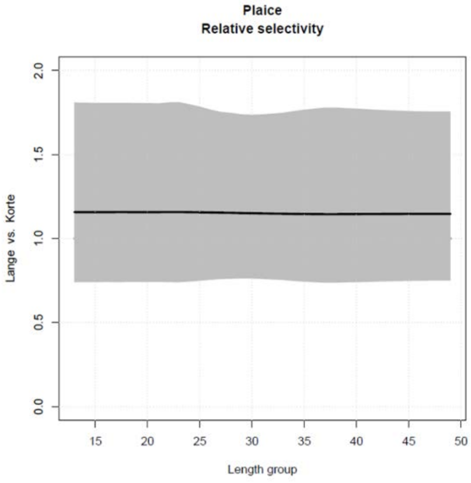

Figure 4. Relative selectivity of long (standard, "Lange") and short ("Korte") sweep lengths for Plaice by size group (total fish length in cm). Values below 1 indicate that the short sweeps has higher catch efficiency (catch rates) than the standard (long sweeps). The shaded area indicates the confidence limits of the estimated relative selectivity.

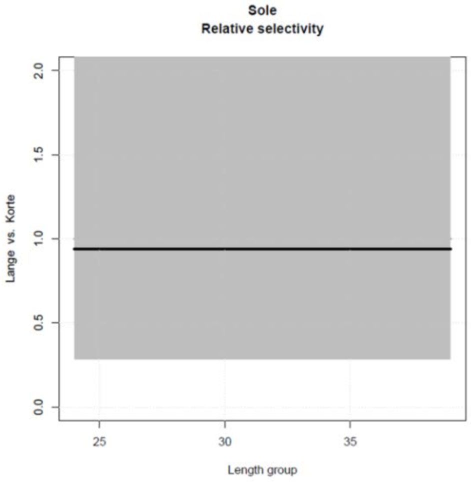

Figure 5. Relative selectivity of long (standard, "Lange") and short ("Korte") sweep lengths for Sole by size group (total fish length in cm). Values below 1 indicate that the short sweeps has higher catch efficiency (catch rates) than the standard (long sweeps). The shaded area indicates the confidence limits of the estimated relative selectivity.

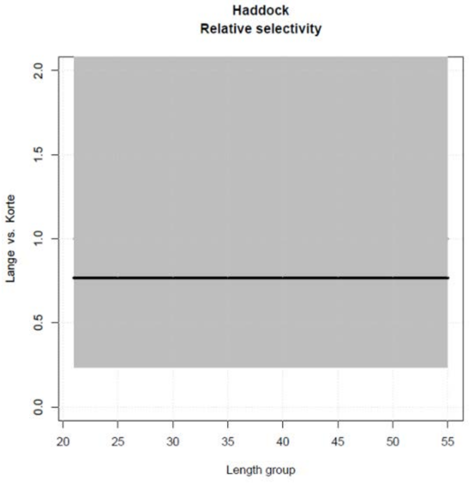

Figure 6. Relative selectivity of long (standard, "Lange") and short ("Korte") sweep lengths for Plaice by size group (total fish length in cm). Values below 1 indicate that the short sweeps has higher catch efficiency (catch rates) than the standard (long sweeps). The shaded area indicates the confidence limits of the estimated relative selectivity.

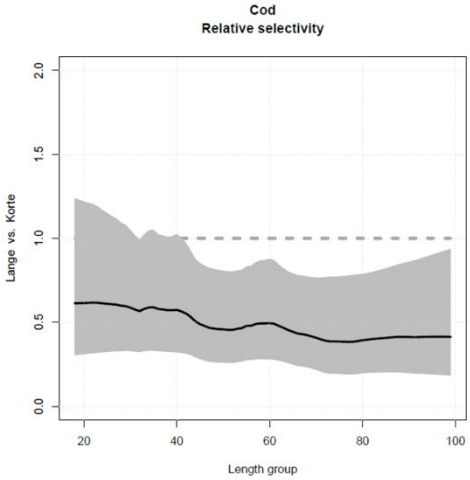

Figure 7. Relative selectivity of long (standard, "Lange") and short ("Korte") sweep lengths for Cod by size group (total fish length in cm). Values below 1 indicate that the short sweeps has higher catch efficiency (catch rates) than the standard (long sweeps). The shaded area indicates the confidence limits of the estimated relative selectivity.

Technological innovation 4. Reduction of benthic impacts from blue mussel dredging by use of modified (light) mussel dredger

Introduction

Subtidal beds of blue mussels (*Mytilus edulis*) are fished with dredges in several countries including UK, Ireland, and Denmark. 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). Dredging is reported to affect benthic fauna and flora and to change the seabed structure (Dolmer and Frandsen, 2002; Neckles et al., 2005).

In Denmark, 30 000–40 000 tons of blue mussels are harvested annually by dredging in coastal areas. 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 directed at NATURA 2000 areas.

The mussel fishery was banned in habitats vulnerable to dredging, e.g. Zostera beds, while a restricted fishing effort with low impact gear was permitted in the remaining NATURA 2000 area.

Material and methods

The aim of this sub-task was to develop a mussel dredge with reduced ecosystem impact, which can be implemented without compromising commercial viability of the fishery. To achieve this aim, several different mussel dredges were developed and tested in relation to fishing abilities and effect on the environment. The gears were developed in collaboration between DTU Aqua, Danish Shellfish centre, and participating mussel fishermen, with focus on reducing impact on the bottom.

A number of alternative dredges were tested in pilot-trials, and after several adjustments and re-designs the most promising innovation - a new dredge with lighter and smaller design (Figure 8 - left) - was brought forward to the final tests. The new light dredge was tested on commercial vessels using two different experimental setups.

First, a twin haul experiment tested the standard gear (i.e., a Dutch dredge, Figure 8 - centre) against the light dredge by fishing the two gears side by side on board the same vessel. Second, a single dredge experiment tested the absolute performance of the two gears by deploying them alternately from the same vessel in areas with a known blue mussel density.

Figure 8. Pictures of the light dredge (left), the standard/Dutch dredge (centre) and a double light dredge (right).

Results

The results of the trials are described in Frandsen et al. (2014). The main finding and conclusion is that dredging for blue mussels and thus removing structural elements, inducing resuspension of sediment as well as reducing filtration capacity, will inevitably affect the ecosystem. The study did, however, also demonstrate that the impacts of fishing can be reduced through gear developments:

- In the twin haul experiment the drag resistance of the light dredge was significantly less (177.1 kg m^{-1} versus 202.7 kg m^{-1}) (Figure 9a).
- In the twin haul experiment the weight of sediment retained in the gear per square meter fished was 49% less in the light dredge compared to the Dutch dredge, which will reduce resuspension of sediment at the surface (Figure 9b).
- In the twin haul experiment no significant difference was found in the catch per unit effort (CPUE) of the two gears, although the catches in the light dredge were higher in 7 out of 9 haul comparisons (Figure 9 c) .
- The single dredge experiment, on the other hand, demonstrated a significant increase in CPUE exceeding 200% when using the light dredge.

Seafloor tracks made by the two dredges could not be distinguished from each other by use of side-scan sonar and the tracks were still detectable 2 months after fishing. It was concluded that replacement of the Dutch dredge with the light dredge would reduce the impact of the fishery on the ecosystem by (i) reducing resuspension of sediment, (ii) reducing fuel consumption, and (iii) potentially reducing energy transfer to the sediment through a reduced gear drag resistance. In the single dredge experiment, the light dredge was found to catch three times more of the available mussel biomass than the Dutch dredge. This increase in catch efficiency of the light dredge has the potential to significantly reduce the area affected (depending on mussel biomass density) as illustrated below (Figure 10).

It should, however, be noted that the difference in catch efficiency was estimated only in the single dredge experiment and estimates of the area affected are therefore based on results from this experiment. The CPUE estimates from the twin haul experiment did not demonstrate a significant difference in the efficiencies of the two dredges (although efficiency tended to be higher in the light dredge (Figure 9c)) and therefore some uncertainty is associated with the estimates in Figure 3.

All measured parameters such as towing speed and wire length were standardized between the two experiments and there is no explanation that validates one result over the other. References on catch efficiency estimates of mussel dredges are scarce (Narvarte et al., 2011), but for the Dutch dredge there is a single estimate of 0.17 (a down-scaled version of the Dutch dredge (Dolmer et al., 1999) that is comparable with the present efficiency estimate for the Dutch dredge (0.20). Narvarte et al. (2011) estimated the efficiency of an artisanal mussel dredge to be 0.89 and the estimate for the light dredge (0.68) is therefore within the range of previous experiments on dredge efficiencies.

An evaluation of the Danish mussel fishery indicated that it targets a mean biomass density of approximately 2.5 kg m^{-2} (Dolmer et al., 2011). At this biomass the fishery is estimated to affect from 0.6 to 2.0 m^2/kg depending on the gear used. Introducing gears with higher catch efficiency, and closing areas with low densities of blue mussels, may significantly reduce the area of habitat dredged to catch the quota (Figure 10).

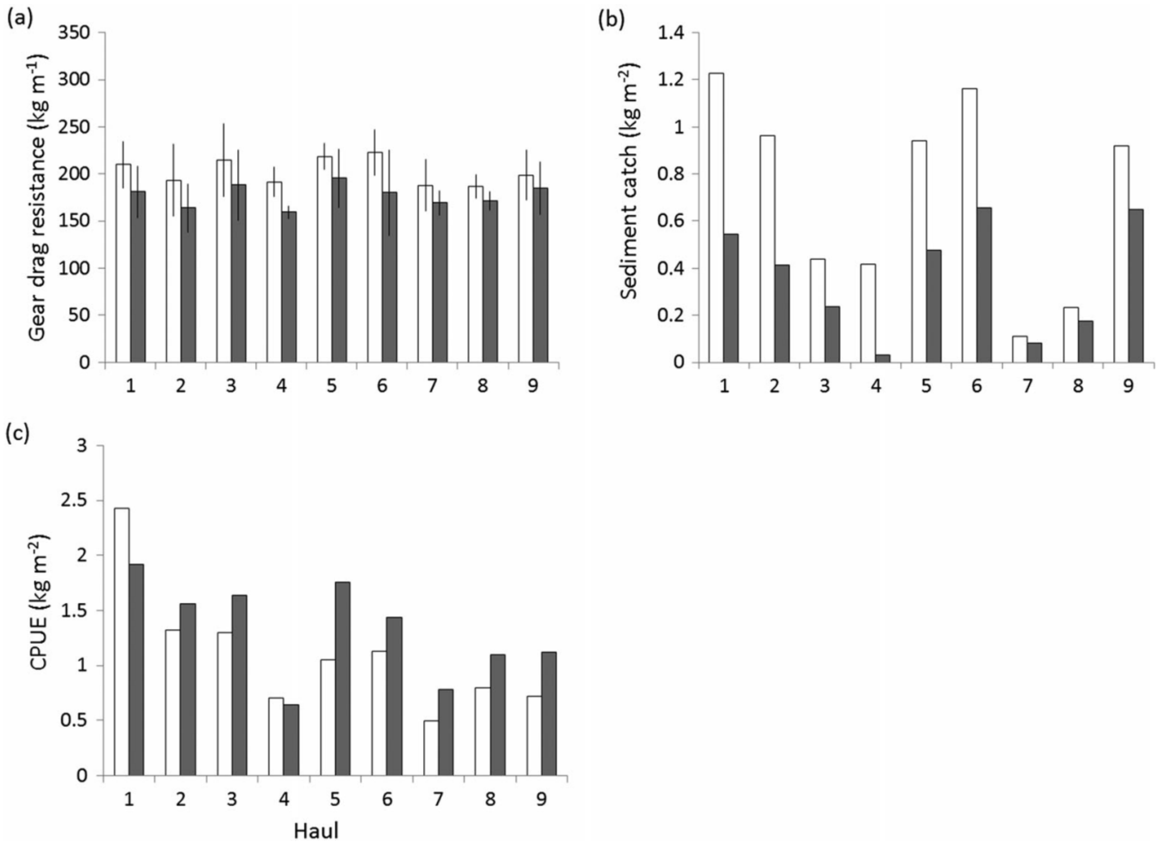

Figure 9. Pair-wise comparisons of gear performance on an individual haul basis for the Dutch dredge (white bars) and the light dredge (shaded bars) for: average drag resistance per meter of gear width with standard deviation (a), weight of sediment retained in the gear (b) and catch per unit of effort (c).

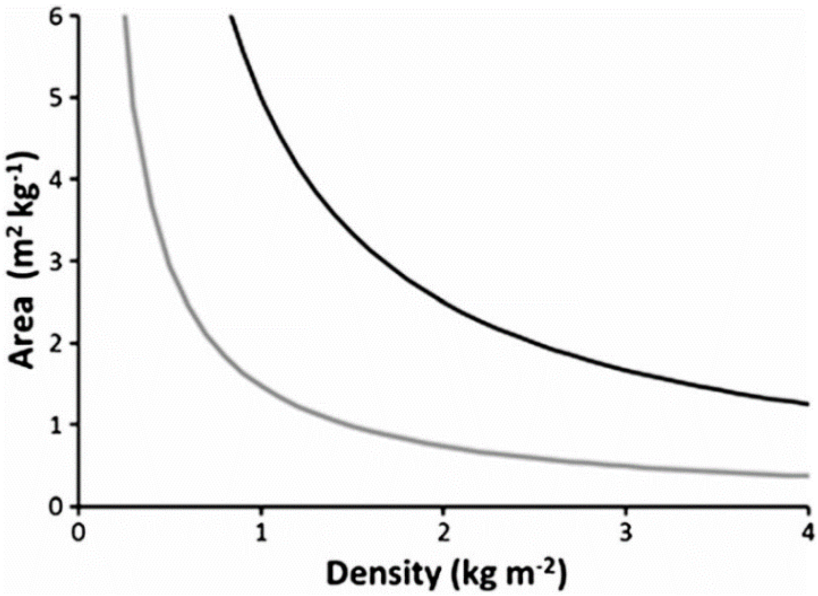

Figure 10. Area affected area as a function of biomass density when dredging mussels assuming constant efficiency (E) of the light dredge (E=0.68: grey line) and Dutch dredge (E=0.20: black line) as estimated in the experimental fishery.

Innovative management scenario's

Management Scenario 1: The allocation and intensity of fishing effort with hauled gears according to sensitive habitats and seasons in the Western Baltic Sea

Introduction

The aim of the study is to evaluate ecological side effects of fishery with hauled gears in relation to impacts on the benthic environment, habitats and communities. This involves analyses of influence of fishing pressure on benthic invertebrate species diversity and density in the Western Baltic Sea and evaluation of robust indicators for this taking into consideration hydrographical and physical habitat characteristics.

The following 0-hypotheses are tested: (i) The species diversity (biodiversity=BD), given the number of individuals (density= N) of benthic invertebrates, is not affected by fishery and not dependent on different levels of fishing pressure (FP). The above hypothesis is tested not only for BD but for several parameters (indicators), i.e. BD given N, N alone, B given N (overall or by species). (ii) There is no difference between different habitats and impacts of FP levels on BD (given N) - or on N or B alone or B given N - for benthic invertebrates. (iii) All species and species groups of benthic invertebrates are equally affected by different levels of FP. (iv) It is from the present data not possible to obtain robust indicators for impacts of different levels of FP among any species and species groups in the benthic invertebrate community.

Materials and methods

Benthic Invertebrate Community Data: The benthic fauna and habitat data was sampled and compiled by a consortium under the Femern Belt A/S lead by the Danish Hydrological Institute (DHI) with participation of among other Institute of Oceanography in Warnemünde (IOW). Femern Belt A/S has granted full access to these data in present scientific context with data analyses and evaluations conducted by DTU Aqua.

The benthic monitoring program covered benthic fauna stations sampled under a carefully planned survey design with intensive, standardized, and repeated grab and frame sampling on seasonal basis in 2009 and 2010 on different types of benthic habitats and bottom depths in the Femern Belt area of the Western Baltic Sea (Figure 11; Table 6 and Table 7).

Overall, 315 locations have been sampled throughout the second and third quarter of the year, and in total 1032 unique samplings have been taken under the monitoring program. Overall, 92 samples provide quantitative FP and benthic invertebrate data where FP is above 0 (excluding blue mussels) are used in the present analyses (Table 7). An area conversion factor was used to standardize the analysed number of individuals and the dry weight per species.

Fishing Intensity Data: The fishing intensity (FP) data comprise Danish and German VMS (satellite monitoring) fishing effort registration for vessels of 15 m length and longer using demersal hauled gears (trawls, seines, dredges). Fishing effort is accumulated within a radius of 1000 m around each of the benthic invertebrate sampling stations during the previous 3 months of the benthic invertebrate sampling date.

The FP is estimated as the fraction of the area (ratio of surface) covered by fishery (accumulated fishing effort) in this 1000 m radius and 3 month period of time. The fishing effort data have been extracted from national VMS databases and compiled and aggregated by DTU Aqua (Danish fishery data) and TI (German fishery data).

The VMS data resolution, processing and aggregation for estimating FP is following the EU-FP7-BENTHIS standards, and the EU FP7 BENTHIS WP2 software has been used for the process of estimating FP as described in Eigaard et al. (2016b).

An example of the fishing pressure data for hauled gears in 2010 in the Femern Belt Area is shown in Figure 12. The FP data used for present analyses are from 2008-2010. Finally, the FP data have been merged with benthic invertebrate and physical habitat data by DTU Aqua using unique identifiers of date, position, and station number.

Hydrographical Data and EUNIS Level 3 Benthic Habitat Data: The physical data used is produced by using a Baltic-North Sea ocean-ice model HBM (HIROMB-BOOS Model) in the operational setup by Danish Meteorological Institute. A biogeochemical module (ERGOM) is dynamically embedded in the HBM. HBM is a three-dimensional, free-surface, baroclinic ocean circulation and sea ice model. The model allows for fully two-way nesting of grids with different vertical and horizontal resolution, as well as time resolution.

The HBM setup for the present hydrographic dataset has a horizontal grid spacing of 6 nautical miles (nm) and the vertical model has up to 50 levels. The model is forced with atmospheric data from the numerical weather prediction model HIRLAM (DMI). Furthermore, freshwater runoff from the 79 major rivers in the region is used.

The hydrographical parameters analyzed are near seabed temperature (t, degr. C), salinity (s, psu), oxygen concentration (o, mg O_2/l), and current speed (u, m/sec), as well as bottom depth (m). For all these parameters, the monthly minima and maxima as well as the daily mean values have been extracted for the benthic invertebrate sampling station positions.

Seafloor sediment data together with depths were extracted by DTU Aqua from EUNIS level 3 databases processed and compiled for the benthic invertebrate sampling positions using EU-FP7-BENTHIS standards described in Eigaard et al. (2016b; *In press*). Three habitat/sediment types were relevant here: 1 Sublittoral sand (A5.2), 2 Sublittoral mud (A5.3) and 3 Sublittoral mixed sediments (A5.4).

Initial two-way correlation analyses: Two-way correlations were made between BD, N, B, FP, bottom temperature, oxygen concentration, and salinity (all as minima within the sampling month), and current speed (maximum within the sampling month), as well as season and habitat type. Furthermore, similar single species correlations were mad for selected species (excl. BD).

Statistical analyses and model for multi-variate analysis of variance: A general additive model (GAM) with mixed effects was used in the statistical analyses of the same parameters (Table 8) as investigated in the initial correlation analyses. The dependent variables were BD, N, and B, respectively, and the explanatory variables were FP, habitat type, season, year, individual hydrographical parameters, and depth.

For the BD and N integer (count) dependent variables a negative binomial distribution and logit as the link function was used with the possibility of estimating over-dispersion. For the continuous B dependent variable a tweedy distribution was used. A mixed models design was used for all models with year as a random effect and with the other explanatory variables as fixed effects (Table 8).

A spatial component with tensor (te) between longitude and latitude was added allowing inclusion of the spatial and station variability, i.e. the variability between observations. Alternative model versions were compared. Significant effects were identified for each model using backwards elimination of insignificant model terms, and their statistical significance was estimated as well as model estimates of the dependent variable according to the impact of the explanatory effects.

The overall variability in the data explained by the model (estimation of deviance) was also estimated. Over-dispersion according to the negative binomial distribution, residual plots, and Q-Q plots were inspected for deviations from homoscedasticity and homogeneous distribution. Variance inflation factors were inspected to check for collinearity. All analyses were performed in R (R Core Team 2015) using the package lme4 and lmerTest (Bates et al. 2015).

The most important models tested so far are listed in Table 8. Some of the models tested FP with a smoother effect (here model 5), which increased the fraction of the variability in the data explained by model slightly and slightly improved the residuals, but gives no direct estimate of the FP effect on the dependent variable. Furthermore, the models have also been tested with interaction between factors (models 6,10,11).

Interactions were especially observed between hydrographical parameters, and between sediment types, seasons and FP. As expected there were interactions between the hydrographical parameters and depth and, accordingly, the model has also been tested with depth (model 4) and the individual hydrographical parameters separately (models 3a-3d) besides with all hydrographical parameters together (all models except 3 and 4). Seasonal differences were also tested in all models except models 1, 3 and 4.

Results

Preliminary correlation plot analyses using merged datasets:

The results from the two-way correlation analyses exemplified in Figure 10 show that there generally is a small but significant negative correlation between FP (here estimated as cumulative fishing pressure for the previous 3 months in a 1000 radius around the benthic invertebrate sampling station) and N, while there initially seems to be a very small and less significant positive correlation between FP and BD when including season in the two-way analyses (Figure 10).

When excluding season in the two-way correlation analyses, there is a small but highly significant negative correlation between FP and BD (not shown). This should be seen in context of a strong correlation between FP and season of year (as well as in relation to hydrographical factors and depth) with highest FP in the third quarter of the year compared to the second quarter.

Strong correlations between FP and hydrographical factors are observed, i.e. the lower minimum temperature (t-min) the higher FP, and the higher minimum oxygen concentration (o-min) the higher FP. Furthermore, there are as expected observed significant correlations between hydrographical features and depth.

A significant negative correlation between N and depth is observed while there is a positive correlation between depth and BD. Finally, but very important there is observed a strong positive correlation between BD and N per sample. Consequently, it is important to take the total number of individuals, N, into account when analyzing biodiversity, BD.

When investigating the seasons separately (not shown), they basically show a negative correlation between FP and both N and BD, however, in the last season these negative correlations are smaller. When looking into the habitats separately, then a negative correlation between FP and both N and BD is observed for the habitats sublittoral mud and sublittoral mixed sediments. The sublittoral sand habitat has only few observations, and is therefore uncertain. For this habitat type there is a positive correlation between BD and FP.

It should be noted here that the season effect was not included when investigating the different habitat types separately. Accordingly, the initial two-way correlation analyses indicate that there are overall different trends and interactions in the results of FP impacts on N and BD according to the different sediment types and the seasons of year, and at the same time strong correlations between some hydrographical parameters and FP, which complicate analyses of FP impacts on benthic invertebrates. Accordingly, multivariate analyses of variance are needed to further explore the patterns.

The same type of two-way correlation analyses were made for selected single species where the relationship between N and B per sample and the FP as well as the hydrographical parameters have been initially investigated. The results are in general consistent that there is a negative relationship between FP and both N and B (not shown here).

Results of the statistical modelling and multi-variate analysis of variance:

The Baseline model 2 analyses BD under consideration of N and all hydrographical factors, FP (without smoothe) and the 3 sediment types (Table 10). It explains more than 84% of the variability in the data, and there are no significant trends in the residuals analyses (not shown). The results show that N and FP highly significantly impacts BD; the higher N the higher BD, and the higher FP the lower BD (Table 9). Model 1 (Table 9) shows the same analysis as model 2 except it does not include season.

The results of the analyses with the two models are very similar with respect to significance levels and tendencies in the impacts of the explanatory variables on BD, as well as with respect to the level of variability in the data explained by the model, except that N is not as highly significant in model 2 when including season (Table 10) compared to model 1. Furthermore, the residuals performs slightly better in model 2 (not shown). Accordingly, the impact of the density N on the BD is to some extent dependent on the season of year.

From the analyses considering only main effects (Table 8) the above significance levels and tendencies with respect to impacts of the explanatory variables on BD are consistent (models 1-6). All these models analyzing BD also explain a very high proportion of the variability in the data ranging from 82% to nearly 90%.

There is a significant habitat type and according spatial effect on BD. The main effects models 1, 2 and 5 show that BD is significantly different at different habitats with a clear tendency towards higher diversity at more mixed and course sediment types and lower biodiversity at the more fine grained and soft sediment types.

When running the models with each of the hydrographical factors isolated (models 3a-3d) or with depth instead of the hydrographical factors included (model 4) the tendency in the impact of sediment type 1 and 2 relative to sediment type 3 reverses from negative to positive impact on BD except for when running with current speed alone (model 3a).

This indicates interactions between the impacts of hydrographical factors and of sediment types on BD. Similar, there appears to be a strong seasonal difference in the BD (models 2, 5 and 6) with tendency to significantly higher BD in third quarter compared to the second quarter of the year. Furthermore, a highly significant impact of all tested hydrographical factors on the BD was observed when running the main effects models (models 1-3 and 5). The lower the current speed or the lower the minimum temperature or the lower minimum oxygen concentration the lower the BD, while the higher minimum salinity the higher BD. These tendencies and significance levels are consistent when running the model with each of the hydrographical factors separately (models 3a-3d), except for minimum temperature, where the tendency in the impact on BD reverse to result in slightly higher BD when the minimum temperature increase.s Accordingly, there are interactions in the impacts of the hydrographical factors on BD. Finally, the depth factor is highly significant, i.e. the higher depth the lower BD.

This should also be seen in context of the higher depth the higher FP as well as in relation to the adverse strong correlations between hydrographical factors and depth described previously in the two-way correlation analyses. It appears that the variability explained in the data by the model decreases significantly when not considering density, N, both without and with smoother on FP to levels around 60% (not shown).

When including interaction effects between FP, sediment type and season (model 6) and keeping all hydrographical factors in then not much more of the variability in the data is explained (86%; Table 8), and the residuals only improve slightly (not shown).

The tendencies in the impacts of the different explanatory variables on BD are the same, however, in this model N is only slightly significant, oxygen is not significant, and FP as main effect is not significant (not shown). Furthermore, the tendency in the BD on sediment type 2 (sand) reverses. However, there are significant interactions between FP and the sediment types, between FP and season, and between FP-sediment type3-quarter 3. This strongly indicates that FP has different impacts on BD in different habitats dependent on season of year. Accordingly, further work is needed on reducing this model to explore the main and interaction effects more.

The use of a smoother on the FP (model 5) results in a relatively small increase in the proportion of the variability in the data explained by the model, and the tendencies are the same according to all the explanatory factors (not shown). The residuals perform equally well. However, this model does not provide estimates of the FP impact on BD. The analyses of density, N, alone (models 7 and 11), show that FP is highly significantly impacting density with same tendency as for BD, i.e. the higher FP the lower density (Table 11). Also, similar tendencies and significance levels are observed for the influence of the other explanatory variables on N as for BD, except for minimum oxygen where the tendency reverses. However, the deviance in the data explained is less (60%; Table 11) when analyzing density, and the residuals do not perform better (not shown).

Similar to BD then inclusion of first order interaction effects between FP, sediment type depth and sediment type in the analyses of impact on N does not increase the model explanation of the variability in data much (61%; Table 8). When including the interactions the explanatory variables show the same significance levels and tendencies, however, there are fewer significant interaction effects, i.e. FP and sediment type1, FP and quarter3, and FP-sediment type1-quarter3. Even less complex also the results on analyses of impacts of fishery on invertebrate density strongly indicates that the FP has different impacts on the density in different habitats dependent on season of year.

The analyses of biomass, B, (models 8, 9 and 11) show that models with this dependent variable does not explain more than 7% of the variability in the data (model 8), and this does not improve when analysing B given N (model 9) or when including interaction effects between FP, sediment type and season. Furthermore, the analyses of B in all those models show strong residual trends.

The residuals of model 6a:

Overall, it seems that biodiversity and density are strong indicators for impacts of fishery on the benthic invertebrate community with respect to different levels of fishing intensity, while benthic invertebrate biomass seems not to be a strong indicator in this respect. The indicator N/B is in the process of being analysed. It is evident that the positive correlation and impact of density on biodiversity needs to be taken into consideration when evaluating impacts on biodiversity.

Also, it is evident that there are interaction effects and that the FP has different impacts on the biodiversity and density in different habitats dependent on season of year. Overall, it seems that the impacts of fishing pressure on the benthic community diversity and density is in the same order of magnitude as the influence of natural hydrographical factors, e.g. current speed. The above results from the initial analyses indicate that we can reject all the 0-hypotheses listed in the introduction, however, more analyses are necessary, among other on selected single species, to finally conclude on this. Furthermore, it is necessary to describe into detail the potential processes for the impacts of the hydrographical factors on the indicators such as biodiversity and density.

Table 6. Overview of sampling gears used, their sampling area, the area standardization and correction factor by gear, as well as the number of samples conducted with each gear and method.

Sampling gear	Sampling area (m^2)	Area corrected	Number of samples
Van Veen Grab	0,0980	1,00	14
Van Veen Grab	0,1166	0,84	35
Dredge	0,1166	0,84	6
Kautsky frame	0,10	0,98	31
Rahmen (0.1 m^2 mit Netzbeutel)	0,10	0,98	9
Van Veen Grab	0,10	0,98	3
Van Veen Greifer (0.1 m^2)	0,10	0,98	2

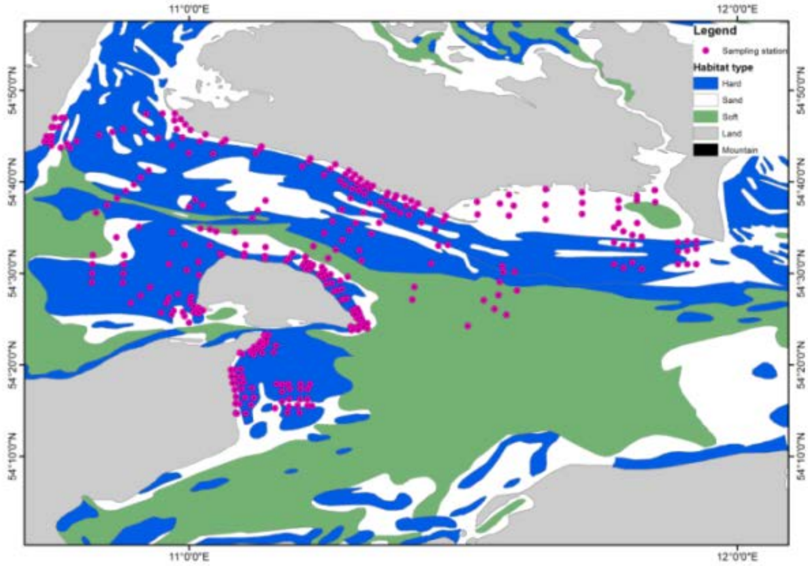

Figure 11. Grab and Frame sampling stations under the benthic invertebrate monitoring program and survey design (conducted by a consortium under Femern Belt A/S in 2009-2010) according to different types of benthic sediment types (physical habitats). Soft bottom is fine grained mud (sediment type 1, sand is sand (sediment type 2), and hard bottom is mixed sediments (sediment type 3).

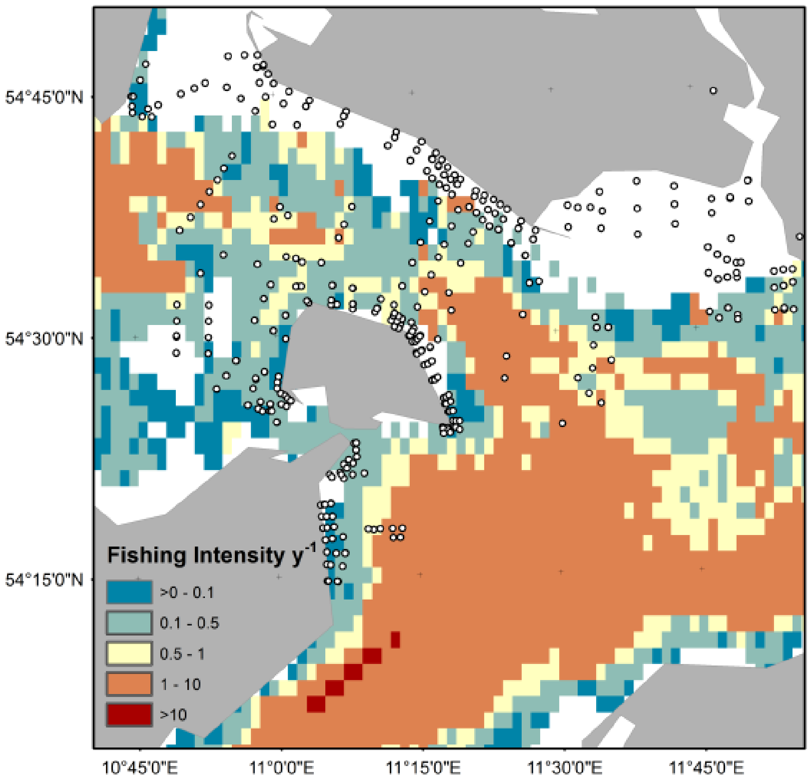

Figure 12. Fishing intensity (FP) by Danish, German (and Swedish) vessels (>= 15 m length) fishing with towed gears in the Femern Belt area in 2010. The Femern Belt invertebrate sampling stations are included in the map as well.

Table 7. Overview of the benthic invertebrate samples used in the analyses including their spatio-temporal coverage. Furthermore, average fishing pressure by category is indicated as well as the minimum and maximum FP observed at stations in given category, i.e. the FP range included in the analyses.

	No. Samples	Total No. Species (BD)	Total Density (N)	Total Biomass (B, g)	Average FP (Abrasion)	Minimum FP (Abrasion)	Maximum FP (Abrasion)
All Samples	92	239	60068	2540,91	0,35	0,01	1,93
2009	50	215	29527	1090,93	0,27	0,01	1,56
2010	42	175	30541	1449,98	0,44	0,03	1,93
Season 1	63	218	35819	1765,63	0,46	0,01	1,93
Season 2	29	178	24249	775,28	0,10	0,04	0,55
Habitat 1	35	135	23663	1790,65	0,44	0,05	1,93
Habitat 2	3	55	977	21,36	0,39	0,03	0,87
Habitat 3	54	228	35428	728,90	0,29	0,01	1,78

Table 8. Overview of selected tested statistical models with different types of dependent and explanatory variables included, as well as model settings. The overall R-square of the model and the deviance (the proportion of the variability) in the data explained by the model are given as well.

Model Number	GAM Model analysed within the R statistical software	Model R^2	Deviance Explained
Model 1	Biodiv ~ N_ind + FP_cum + t_min + s_min + o_min + u_max + sed_type + (1|year) + te(lon,lat)	0,88	84,4 %
Model 2 (Baseline)	Biodiv ~ N_ind + FP_cum + t_min + s_min + o_min + u_max + quarter + sed_type + (1|year) + te(lon,lat)	0,88	84,9 %
Model 3a	Biodiv ~ N_ind + FP_cum + u_max + sed_type + (1|year) + te(lon,lat)	0,87	83,6 %
Model 3b	Biodiv ~ N_ind + FP_cum + t_min+ sed_type + (1|year) + te(lon,lat)	0,86	82,0 %
Model 3c	Biodiv ~ N_ind + FP_cum + s_min + sed_type + (1|year) + te(lon,lat)	0,86	82,3 %
Model 3d	Biodiv ~ N_ind + FP_cum + o_min + sed_type + (1|year) + te(lon,lat)	0,87	83,6 %
Model 4	Biodiv ~ N_ind + FP_cum + depth + sed_type+ (1|year) + te(lon,lat)	0.88	83,1 %
Model 5	Biodiv ~ N_ind + s (FP_cum) + t_min + s_min + o_min + u_max + quarter + sed_type + (1|year) + te(lon,lat)	0,92	89,9 %
Model 6	Biodiv ~ N_ind + t_min + s_min + o_min + u_max + quarter * sed_type * FP_cum + (1|year) + te(lon,lat) (Incl. 1st order interactions between season, sed. type & FP)	0,89	86,0 %
Model 7	N_ind ~ FP_cum + t_min + s_min + o_min + u_max + quarter + sed_type + (1|year) + te(lon,lat)	0,52	60,2 %
Model 8	Biomass ~ FP_cum + t_min + s_min + o_min + u_max + quarter + sed_type + (1|year) + te(lon,lat)	0,02	6,8 %
Model 9	Biomass ~ N_ind + FP_cum + t_min + s_min + o_min + u_max + quarter + sed_type + (1|year) + te(lon,lat) *(Biomass considering density)*	0,02	7,0 %
Model 10	N_ind ~ t_min + s_min + o_min + u_max + quarter * sed_type * FP_cum + (1|year) + te(lon,lat)	0,53	61,1 %
Model 11	Biomass ~ FP_cum + t_min + s_min + o_min + u_max + quarter * sed_type * FP_cum + (1|year) + te(lon,lat)	0,02	7,0 %

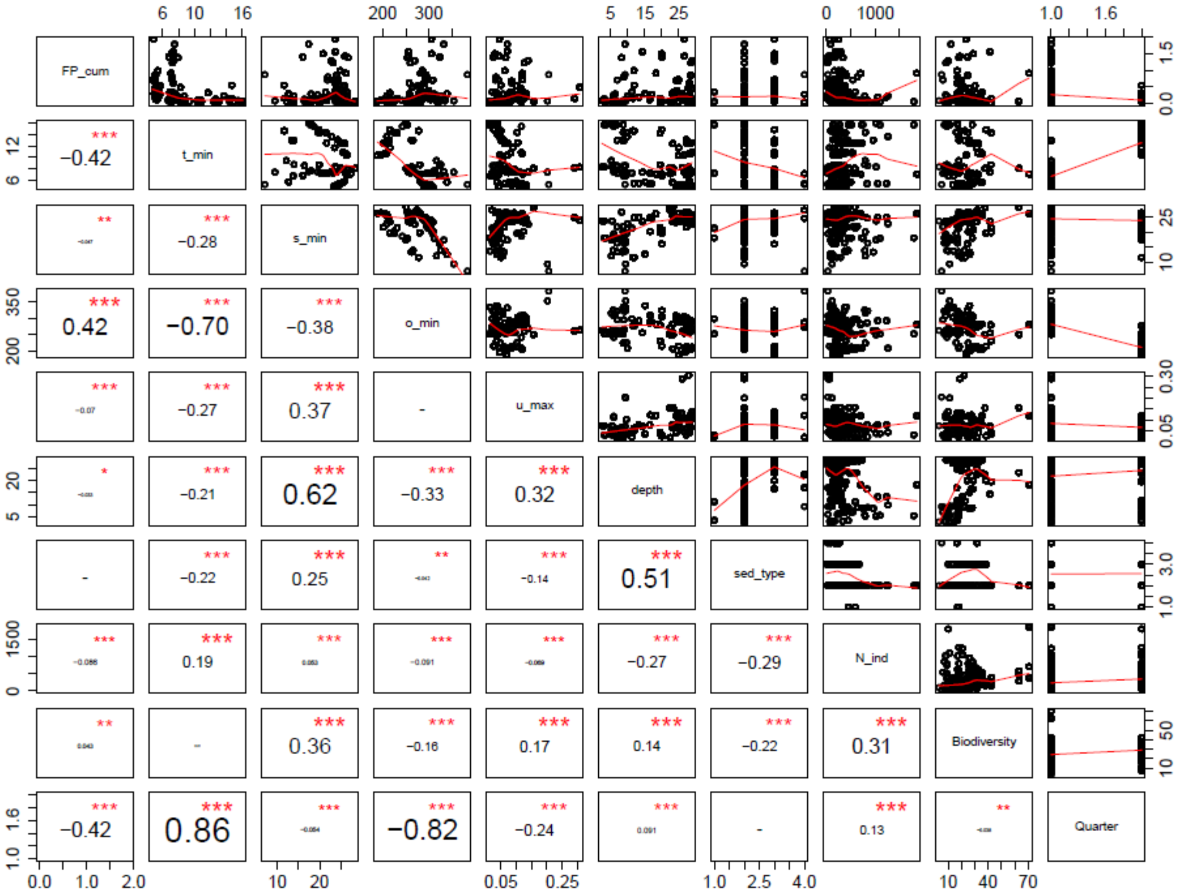

Figure 13. Two-way correlations between density, biodiversity, fishing pressure, temperature, salinity, oxygen, current speed, depth and sediment type.

Table 9. Results, parametric coefficients, and estimates of the statistical analyses with model 1.

Family: Negative Binomial (3971897.74)

Link function: log

Parametric coefficients:

	Estimate	Std. Error	z value	Pr (>|z|)	
(Intercept)	4.485e+00	2.027e-01	22.132	< 2e-16	***
N_ind	3.918e-05	1.054e-05	3.716	0.000202	***
FP_cum	-6.006e-02	1.150e-02	-5.222	1.77e-07	***
t_min	-3.527e-02	3.817e-03	-9.240	< 2e-16	***
s_min	1.553e-02	2.766e-03	5.614	1.97e-08	***
o_min	-3.816e-03	3.435e-04	-11.107	< 2e-16	***
u_max	-2.342e+00	9.969e-02	-23.489	< 2e-16	***

Table 10. Results, parametric coefficients, and estimates of the statistical analyses with model 2.

Family: Negative Binomial (3971897.74)

Link function: log

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	4.137e+00	2.043e-01	20.250	< 2e-16	***
N_ind	2.238e-05	1.065e-05	2.101	0.0356	*
FP_cum	-5.486e-02	1.154e-02	-4.755	1.99e-06	***
t_min	-6.418e-02	4.454e-03	-14.409	< 2e-16	***
s_min	1.459e-02	2.758e-03	5.292	1.21e-07	***
o_min	-1.863e-03	3.765e-04	-4.949	7.47e-07	***
u_max	-2.354e+00	1.001e-01	-23.521	< 2e-16	***
sed_type1	-6.927e-02	1.454e-02	-4.763	1.91e-06	***
sed_type2	-1.725e-01	3.431e-02	-5.029	4.93e-07	***
QuarterQ3	3.519e-01	2.812e-02	12.514	< 2e-16	***

Table 11. Results, parametric coefficients, and estimates of the statistical analyses with model 7.

Parametric coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-1.4852124	0.4006415	-3.707	0.000210	***
FP_cum	-0.1008499	0.0283910	-3.552	0.000382	***
t_min	-0.0058952	0.0107175	-0.550	0.582284	
s_min	0.0978234	0.0067883	14.411	< 2e-16	***
o_min	0.0196308	0.0008813	22.275	< 2e-16	***
u_max	-6.6897865	0.2343146	-28.550	< 2e-16	***
QuarterQ3	1.8675352	0.0704505	26.508	< 2e-16	***
sed_type1	-0.4565764	0.0365791	-12.482	< 2e-16	***
sed_type2	-1.2266952	0.0752575	-16.300	< 2e-16	***

Approximate significance of smooth terms:

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Management Scenario 2: The effects of bottom trawling intensity on soft seafloor macro-fauna in the Kattegat among other in relation to MPA management

Introduction

The impact of bottom trawling on the seafloor may result in direct and indirect disturbance of benthic habitats, communities and species (Collie et al. 2000). Sensitivity of habitats, varies significantly between shallow, high energy areas and deeper areas where physical disturbance from wind-driven energy, i.e. storms may not reach (van Denderen et al. 2015).

Sensitivity of the fauna also differ between species pending on their traits and the mechanism of disturbance. Mortality of organisms and destruction of habitats by mobile demersal fishing gear are most severe in vulnerable areas such as deep - water coral reefs and sponge communities where these fragile species make up a significant component of the habitats by their three dimensional structures (e.g. Jørgenssen et al. 2015).

Other components of the fauna like sediment dwelling infauna are less sensitive to the direct physical impact protection due to their submergence in the substrate and low catchability in fishing gears, and for these organisms other trawling induced mechanisms may be more important, e.g. changes in particle dynamics of the sediment (Dounas et al., 2007), and the balance between predators and prey following selective fishing induced mortality (Hiddink et al. 2016).

Even though the general patterns of bottom trawling impact on seafloor species, communities and habitats above are established, individual studies have generated inconsistent findings (e.g. Lökkeborg 2005). Reasons for the different outcomes of studies may depend on variation in pressures as well as the sensitivity of the system studied and other environmental factors that may interact with impact assessment. However, observational studies over gradients in trawling intensity may also suffer from lack of reference conditions, i.e. comparable un-trawled or low trawling intensity sites (Pommer et al. 2016).

In addition, in observational studies, trawling intensity is often assessed with low precision and on a different scale than the direct physical impact on a site sampled for fauna to evaluate the impact. This may lead to severe miss-match between pressure and impact, and consequently incorrect assessment.

Studying the direct effects of bottom trawling on benthic communities thus requires high precision in assessing the pressure, i.e. the intensity of the bottom trawling and when and where it occurs. Fishing activities are patchy and often localised to specific fishing grounds due to accumulated knowledge by the fishers of the catchability of target species, and accessibility by the gears used.

Likewise, are benthic communities patchy due to the heterogeneity of habitats and the variability in factors structuring the communities such as light penetration, salinity, depth and substrate. Traditional logbooks contain useful information on catches and increasingly more detailed information on the specific gears used during fishing operations.

By using logbooks in combination with satellite based position data (vessel monitoring systems, VMS), recently developed tools provide possibilities to reconstruct swept paths of trawling activities and scale the impact by the width of the trawl gear as well as the components of the gear i.e. the otter boards, the sweeps and the ground gear of the net (Eigaard et al. 2016a).

Aim

The aim of the study is to evaluate the impact of bottom trawling on benthic macrofauna structure along a steep trawling intensity gradient. We also evaluate the potential recovery of the benthic macrofauna in a marine protected area (MPA). We do this by establishing a stratified benthic macrofauna sampling programme in relation to a known bottom trawling gradient at soft seafloor trawled fishing grounds in the Kattegat.

The stratification also takes into account the establishment of the MPA from where bottom trawling was removed and trawling intensity declined sharply. We utilized newly developed tools to reconstruct swept areas of trawl paths from VMS combined with fishermen's logbooks of gear usage, and scaled this information to the sampling sites of benthic macrofauna and the previous accumulated bottom trawling intensity.

Methods

Study area:

The Kattegat is a shallow (mean depth 27 m) sea area between Sweden and Denmark and connects in the north to the Skagerrak and in the south via narrow straits to the Baltic Sea. The influence from the Baltic Sea by low saline surface waters, creates typical estuarine circulation pattern and strongly stratified water masses with a halocline persisting all year round in the area.

Beneath the halocline (10-20 m depth) more stable and marine conditions prevail and salinity conditions are usually above 32 PSU. Depths and substrate vary with shallow sandy areas to the west and deeper (30-50 m) muddy areas to the east. Dominating bottom trawl fisheries target Norway lobster *Nephrops norvegicus* and a mixed fishery tageting fish and *Nephrops*.

Benthic macrofauna:

Benthic macrofauna was sampled along a mapped gradient of bottom trawling activities established before a permanent fishing closure (MPA) was established in the Kattegat in 2009. The array of totally 58 sampling stations was stratified also to take into account the foreseen decline in trawling intensity within the MPA.

Sampling was carried out in May-June in 2009, 2010, 2011 and 2014 using a modified Smith-McIntyre grab (0.1 m^2). One sample was taken per station and sieved (1.0 mm) for macrofauna. Samples was stored in 4% borax buffered formaldehyde prior to standardised sorting, counting and weighing.

Assessing trawling intensity:

Swedish and Danish VMS data were analysed using the VMStools R-package and protocols developed and described in Hintzen et al. (2012). The VMS data set (hourly transmitted data) was interpolated into positional data with 12 minutes' temporal resolution (Hintzen et al., 2012). A specific trawl width, i.e. the spread between the trawl doors was estimated for each logbook trip based on the gear used and the vessel's engine power (Eigaard et al., 2016a).

Trawl paths were then reconstructed from 2006 to 2014. Trawling intensity was finally calculated using a search radius of 250 m swept area ratio at each benthic sampling station was estimated accumulating the area over 32 months prior the sampling date.

Statistics:

Evaluation of the correlation between the bentic fauna structure and the trawling gradient was done using Distance based linear modelling and Distance based redundancy analysis within the statistical package PRIMER v7 (McArdle & Anderson 2001; Anderson 2005). As depth has been shown to be an important structuring variable in the Kattegat, all analysis tested both Trawling intensity and Depth as predictors for dependent variables.

Experimental testing of the effect of the MPA was done in a Before-After-Control-Impact (BACI) design using permutational MANOVA (Anderson 2005) in PRIMER v7. Dependent variables examined were species multivariate composition by abundance and biomass. Univariate indices examined were number of species, total abundance, biomass, Richness as to Margalef (d), diversity as to Shannon (H'). Benthic Quality Index (BQI) was calculated according to Leonardsson et al. (2016).

Results

Our results show statistical significant macrofauna community shifts with the trawling gradient in species composition (Figure 14), and lower total abundance, number of species (Figure 15), indices of diversity H', richness d and benthic quality BQI (Fig. 2). For all variables depth was an additional predictor to trawling intensity and explained a similar amount, R^2 = 3 -12% of contribution to the total variation among stations.

We also evaluated the potential recovery over 5 years of the macrofauna following the closure. No clear effects were found when comparing previously trawled sampling stations from inside the closure over time with control stations where trawling continued.

We conclude that accumulated bottom trawling impact the benthic macrofauna in the Kattegat. However, a shift towards recovery is not detectable following 5 years of closure of bottom trawling.

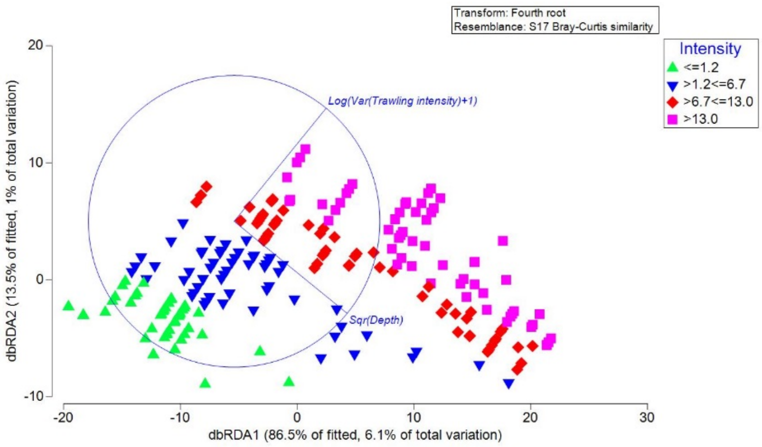

Figure 14. Distance based redundancy analysis (dbRDA). Distribution of multivariate species abundance at sampling stations along the two axes (dbDRA 1 & 2) explaining most of the variation using the DistLM procedure and selected as "Best" with and the modified Akaike Information Criterion. Trawling intensity is indicated in quartile grouping according to the palette in upper right corner. Ordination of the main predictors Trawling intensity and Depth along the multivariate axes are shown in the circle.

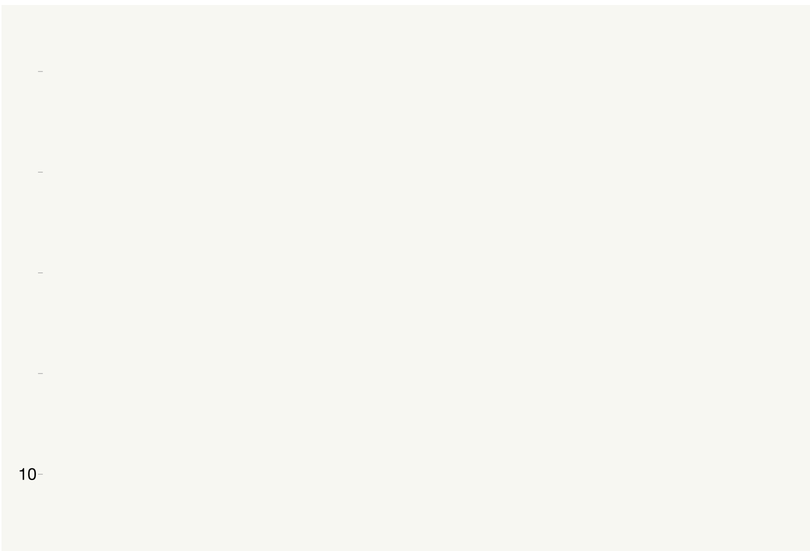

Figure 15. Box-plot with quartiles and median for number of species (blue) and benthic quality index, BQI calculated according to Leonardsson et al. 2016 (green). Trawling intensity on the x-axis in lower to upper quartiles.

Management Scenario 3: Impact of trawl fishing on infauna benthos in Danish waters of Kattegat from 2005-2013 on different benthic habitats

Introduction

DCE has monitored benthos diversity and density in the interior Danish waters for many years. Previous analysis of these data has shown benthos richness and density to change with salinity, eutrophication, and depth (e.g. Henriksen *et al*. 2014), but no analysis has so far linked benthic species richness and density in Danish waters to bottom trawling. Here we combine seven years of benthos data collected at 22 benthic monitoring stations in Danish waters of Kattegat with estimates of bottom trawling intensity in 1x1 nm rectangles based on interpolated VMS data (Eigaard *et al.* 2016a,b). We use these data to study how benthic species richness and population density respond to changes in trawling intensity.

Material and methods

Benthos data from the NOVANA benthos monitoring program and associated variables (depth, average salinity, and EUNIS level 3 habitats) were provided by DCE in the form of seven years of benthos density and species density (number of species per sampled area) from 22 NOVANA sampling stations.

At each station five HAPS corer samples each covering 0.0143 m^2 of seabed had been collected in April 2005-2008, 2010, 2011, and 2013 (Figure 16). To increase sample size the five subsamples were merged prior to analysis. Total monthly fishing intensity was calculated from hourly VMS pings for all Danish vessels fishing with mobile, bottom-contacting gears. The speed of each vessel was used to separate trawling from time spend steaming or on gear retrieval and setting.

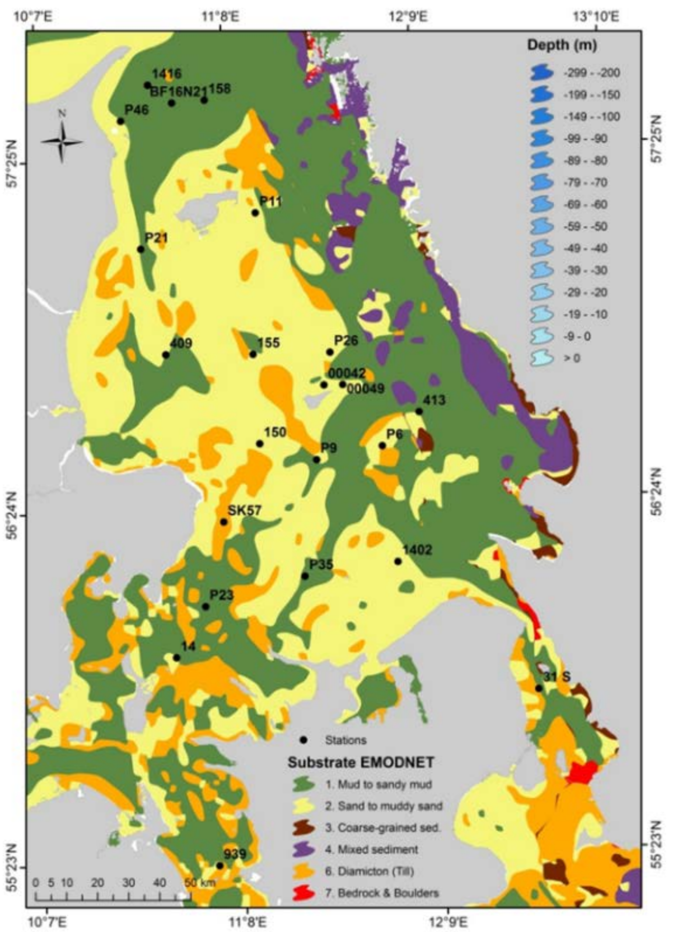

Figure 16. Benthos habitat and sampling stations.

Information about the gear employed was extracted from the Danish logbook system and used to calculate the area swept by gear types by combining the typical width of the gear parts in contact with the seabed with track lengths, estimated from interpolation of VMS pings using the algorithm developed by Hintzen *et al.* (2010; 2012). To account for the uncertainty in the geo-location of the interpolated tracks and to match the benthos data, the area swept were subsequently cumulated on a spatial grid of 1x1 nm. Plotting the data showed that the highest area swept per grid cell was found in the deeper parts of the central and northern Kattegat where the *Nephrops* fishery operates.

The benthos stations were plotted on the grid and the fishing intensity in the 1x1 nm cell surrounding each benthos sampling station was cumulated over the period from April to March and used to characterize the intensity of the local fishery at the station. The benthos samples were collected in April before the annual settling of benthos larvae in the area, and using the calculated fishing intensity in the preceding year provided information about the fishing pressure that had been experienced by the benthos remaining after fishing had taken place.

Analysis

Linear mixed effects models were used to analyze the relationships between population density, species density, fishing intensity and environmental covariates. Habitat, depth, salinity and log trawling intensity were considered as fixed effects and station and year were used as random effects to account for random station differences in community composition as well as random inter-annual changes in benthic recruitment success (22 stations sampled over 7 years).

Residual plots and Q-Q plots were inspected for deviations from homoscedasticity and normality. If necessary variables were log transformed to linearize relationships and normalize residuals. Variance inflation factors were inspected to check for collinearity. Significant variables were identified using backwards elimination of insignificant model terms. Alternative model versions were compared using likelihood ratio tests and AIC-values.

Initial plots of the dependent variables showed a high correlation between the logarithm of the number of individuals sampled and log species density ($r = 0.74$, $t = 12.98$, $p < 2.2e-16$) (Figure 17). A high correlation indicates that it is necessary to consider changes in the number of individuals caught per sample across stations and years when analyzing the species density data (see Gotelli & Colwell 2001).

This is because the number of individuals in a sample constitutes an upper limit to the number of species that can be recorded and the number of individuals will therefore directly influence the number of species recorded. Log population density was hence included in all models of species density. All analyses were performed in R (R Core Team 2015) using the package lme4 and lmerTest (Bates *et al.* 2015).

Results

The initial model of log population density included log trawling, salinity, habitat and depth as fixed effects and year and station as random effects. Salinity, habitat, and depth were found to be insignificant and were sequentially removed, while log trawling was highly significant (estimate $= -0.428$, SE $= 0.114$, df $= 99.22$, $t = -3.765$, $p = 0.000283$), and so was the intercept (estimate $= 3.363$, SE $= 0.195$, df $= 44.92$, $t = 17.248$, $p < 2e-16$).

Density thus declines significantly with trawling intensity, but not with any of the other environmental variables, as long as station and year are included as random effects. Replacing the random station effect with a separate fixed slope for each of the 22 stations, revealed that log density declined with log trawling effort at all stations except 2, and that on 14 stations this decline was significant.

Modelling log species density with the same covariates as used for population density, but with log population density included among the explanatory variables, revealed that none of these covariates were significant, leaving log population density, an intercept and the random year and station effects to explain 86% of the overall variance.

The effect of log density on log species richness was positive and highly significant (estimate $= 0.506$, SE $= 0.041$, df $= 134.74$, $t = 12.32$, $p < 2e-16$) and so was the intercept (estimate $= 1.636$, SE$= 0.135$, df $= 92.63$, $t = 12.07$, $p <$ 2e-

16). The analysis shows that bottom trawling significantly affects the population density of benthic organisms in Kattegat. However, at the same time species density is positively related to population density, and when population density is reduced so is species density (Figure 17).

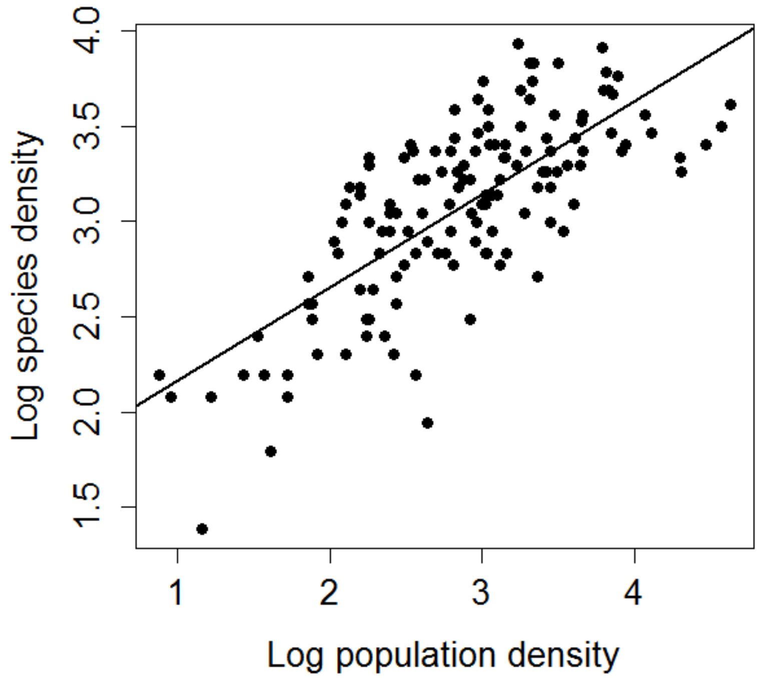

Figure 17. Species density versus population density.

Discussion

Catch and profitability of Danish creel fishery compared to trawl fishery targeting Nephrops in Kattegat

Nephrops creels and trawl fisheries (Kattegat). After favourable initial experiments in 2013, the follow up study in Swedish waters suggests that creels may be an alternative to the trawl fishery in particular for the smaller boats at soft bottoms but not for larger otter trawls which have a much higher profitability. Camera monitoring indicated that the creels sank down into the sediment, and that the bait attracted Hagfish (Myxine) which scared the Nephrops in the creels, which resulted in some escapement.

The profit for small creel vessels with 2 persons on board was comparable to the profit for similar small Nephrops trawlers. However, when transforming the experiments in Swedish waters to soft bottom localities in Danish waters in Kattegat it is evident that the economy is very dependent on catch rates similar to Swedish fishery catch rates, that extra price for live lobsters from creel fishery is possible as buffer, that there are close fishing areas in the creel fishery to assure low steaming costs and good time at the fishing locality to handle a high number of creels, that the expenses are kept low (i.e. keeping fuel expenses low), and that there is not too exposed and windy conditions because creel fishery demands that there is not too much wind making it more attractive in seasons with average low wind speeds compared to other seasons.

Consequently, the creel fishery can typically only be conducted around 150 days per year, so it is necessary to ascertain that there are possibilities for optimizing the number of fishing days on fishing localities, which are in close vicinity of the home harbour.

Swedish creel fishery compared to trawl fishery targeting Nephrops in Kattegat and Skagerrak

An evaluation of three Swedish Nephrops fisheries in Kattegat and Skagerrak (mixed trawling, selective trawling, and creeling) was done using a modelling approach with three scenarios (before: 80% mixed trawl – 20% creel; Current: 25% mixed, 50% grid trawl, 25% creel; Future: 20% mixed trawl, 80% creel).

For the Swedish fishery it appears that the by-catch of juvenile Nephrops, flatfish and other species are lower in the creels compared to the two trawl fisheries, and the creels have most likely less benthic footprint compared to the trawls in the investigated Swedish fishing areas.

Consequently, creeling results in reduction of fishing mortality of both undersized Nephrops (because of larger mean size in catches) and fish (less by-catch of other species) and also reduce seafloor pressure per landed kilo of Nephrops in the Swedish area. Accordingly, potential discard will be relatively lower from the creel fishery.

However, some by-catch species in the trawl fishery is intended by-catch which is an important integrated part of the targeted catch by weight and value in the mixed Nephrops fishery. Today the Swedish creel fishery is conducted in near shore areas, and the implications of expanding this area to more offshore areas which are today trawl areas should be further investigated and discussed in relation to socio-economic consequences.

From the perspective of environmental policy, these results show that Swedish *Nephrops* creeling compared with trawling exerts markedly less pressures on several of the MSFD descriptors for GES: biodiversity, sustainable exploitation and sea-floor integrity (EC, 2008a). There are also other conservation frameworks, such as the EU Habitat Directive (EEC, 1992), which based on these results would also favour creeling over demersal trawling.

From the perspective of the current EU fishing policy (CFP Reg 1380/2013), article 17 on criteria for the allocation of fishing opportunities by Member States may call for incentivizing creeling; compared with trawling, creeling offers reduced environmental pressures such as lesser seafloor area damage and higher selectivity (species and sizes) compared with trawls to target *Nephrops* when fish quotas are limiting the fisheries.

The higher selectivity of creels in Swedish fishery would also be beneficial to the landing obligation (CFP 1380/2013 Article 15), which was enforced in 2016 in the area and resulted in a decrease in MLS of *Nephrops* to 32 mm. The mortality rates of, e.g. cod discarded from creeling are also in general much lower than for trawling—0–25% compared with 100% (Evans *et al.*, 1994; Carbines, 1999; Weltersbach and Strehlow, 2013.

In terms of social and economic differences between the Swedish fisheries, creel-caught *Nephrops* normally implies higher prices than trawl-caught ones due to larger sizes and better quality. Mixed trawling may on the other hand have additional income from the fish in the catch, making the profitability margin of more interest.

The creel fishery in the area has previously been found to have a poorer economic performance compared with trawling, depending on labour cost scenario, as the latter has a considerably larger total landing value (Eggert and Ulmestrand, 1999). However, more recent studies have shown that, for similar vessel sizes, the fuel cost share of variable costs is double for trawling compared with creeling for *Nephrops*, 22% compared with 10% in 2007 (Bengtsberg, 2010), and the average economic return has been found to be higher for creelers than for trawlers when targeting *Nephrops* (SWaM, 2014), even if there is variability between vessels.

Alternative quota allocation

The largest reduction in discard pressure on fishing-sensitive stocks, e.g. depleted gadoids and elasmobranchs, in Swedish *Nephrops* fisheries has been achieved by reducing the mixed trawl fleet. In the present quota allocation system, the grid trawl fleet still puts a larger pressure on seafloor habitats (Fig. 1.) and has higher discard mortalities than creeling. Directing the *Nephrops* fishery towards increased creel use is a matter of pushing the development further to comply with new policies, i.e. the MSFD.

Besides the quantified differences in ecological pressures for Swedish *Nephrops* fisheries, an altered quota allocation favouring creeling may offer benefits from social and economic perspectives in terms of employment, but also raise other issues that need to be solved. A substantial redirection of how quotas are allocated would of course have social and economic implications for fishermen currently involved in Swedish *Nephrops* trawl fisheries, and it will have to be examined if the fish quotas may still be caught. Among Swedish creelers, there is also a concern for overcrowding if the creel fishery is allowed to expand without new areas being made available.

The study focuses on Swedish *Nephrops* fisheries and how these are, have and could be managed to meet new environmental policies. Additional aspects are needed to consider if other *Nephrops* fisheries are to be similarly evaluated. Firstly, Swedish grid trawling and creeling are highly species-selective; this stands in contrast to most other *Nephrops* trawl fisheries where by-catch of fish are very important components, both in weight and value.

Secondly, the socio-economic considerations of the study is merely intending to illustrate the viability of the Swedish fleets as they stand now; a thorough analysis on the implications of an altered quota allocation for both trawl and creel fishermen is furthermore needed.

Thirdly, different effort allocations by gear relative to seafloor pressure will differ between countries from different relative occurrence of seabed types. It is also important to acknowledge that also Denmark, and to a lesser extent Norway, fish in the area, both in the EEZ and inside the territory.

Even if there is limited spatial overlap at present between fisheries, area use conflicts between creeling and trawling is likely to happen if the Swedish creel fishery expands. Denmark holds larger quotas than Sweden in the Kattegat for all species, essentially all the Danish *Nephrops* is taken in a mixed trawl fishery, and most of the fishery catching *Nephrops* in the Kattegat takes place in Swedish waters.

Consequently, if a future harvest strategy would be increased substitution of trawls by creels in the Swedish *Nephrops* fisheries also in shared waters this would need to be addressed in a regional process.

Reduction of benthic impacts of Danish Nephrops trawl fishery in Kattegat by use of reduced trawl sweep lengths

Fishing trials in Kattegat with a Danish demersal Nephrops trawler has been conducted and initial analyses of the sampled data have been performed to evaluate potential changes in catch rates of target and by-catch species of Nephrops trawlers when shortening the trawl sweep lengths. This gear technological mitigation is expected to reduce benthic impacts of the Nephrops trawl fishery.

The preliminary analysis of the data collected during the one week trial fishery with pairwise trawl experiments to reduce sweep length in Nephrops otter trawl fishery indicates that it is possible to maintain similar catch rate with shorter sweeps of Nephrops, flatfish (plaice, sole) and codfish (cod, haddock). The shorter sweep lengths (15 fathoms) compared to the longer sweeps (45 fathoms) reduces area impacted by the gear with respect to benthic seabed surface abrasion.

More detailed statistical analyses are ongoing on this, and the results are expected to be included in a scientific peer reviewed paper submitted for publication in 2017. Furthermore, there has so far not been made any analyses of changes in economic and energy efficiency between use of standard and short sweep lengths in the fishery based on the sea trials.

Finally, the change in physical abrasion of the gear on the benthic habitats is not measured and investigated because it is simply assumed that there is less benthic impact of the trawl bottom gear because of the lighter and shorter sweeps compared to the standard gear set-up with longer sweeps. However, potential changed abrasion of the trawl doors and their impact on the benthic habitats should be considered when changing the sweep lengths.

Reduction of benthic impacts from blue mussel dredging

Based on the gear comparisons, the conclusion is that the light mussel dredge is a usable alternative to the regular dredge; with reduced impact on the seabed - including reduced sediment mobilization/resuspension and drag resistance - while catch rates were estimated to be equal or higher. Hence the light dredge has potential for reducing area of impact and fuel consumption - and accordingly for increasing economic efficiency.

The gear tests also indicated that a double light mussel dredge is an equally usable alternative, which could potentially increase economic and environmental benefits even more. In all cases, the positive effects will depend largely on individual fishing practice, loading capacity, quotas, etc., but unfortunately an economically oriented analysis to clarify this has been outside the scope of this WP7 task.

During the BENTHIS Regional Stakeholder Events (RSE) for the Baltic Sea case study fishermen questioned less benthic impact of the light mussel dredger because of ground gear mounting, vessel movements, etc. On this basis it was suggested and agreed also to investigate possibilities for smart fishing by use of advanced monitoring equipment in the blue mussel fishery.

This resulted in investigations of possibilities and technical solutions for this by DTU Aqau and subsequent purchase of cost efficient side-scan sonar equipment fit for the purpose by the mussel fisher SME04 involved in BENTHIS.

The purchased system consists of a Humminbird Onyx plotter, a side-scan transducer and a 360 degrees transducer (which can be hull mounted or mounted on towed bodies), as well as of a PC with the program AutoChart Live Pro. Onyx can only show maps, but cannot make them.

Real time maps and other mapping are therefore made on the PC with AutoChart. Different data processing software have been purchased and tested in cooperation with DTU Aqua to produce geolocalized sidescan autocharts combined with GPS and single beam echosounder data to make real time maps over depth, seabed hardnes, side-scan forward imaging, and side-scan 360 degrees imaging given position. This enables detection of mussel banks and the high density areas as well as mapping and avoidance of between bank areas.

Accordingly, several trial fisheries by the SME with participation of DTU Aqua have been carried out under the BENTHIS project with use of combined and overlapping side-scan-monitoring, video sledge monitoring and mussel dredging trial fishery to evaluate the efficiency of the different mussel monitoring methods.

The approach is to use side-scan-sonar and video monitoring in advance of the fishery to estimate: (i) location of mussel banks and edges of the banks, (ii) higher mussel density areas and non-target areas between banks, and (iii) higher value mussels (large size mussels) in order to reduce effort totally in the fishery and especially in non-target areas and low density areas between high density banks. This will result in higher catch rates in average and reduce overall effort to catch the same amount of mussels.

Consequently, the overall effort will be reduced which again will reduce benthic impacts of the fishery. Furthermore, the effort on sensitive low density seabeds will be reduced, and effort used for search and test hauls will be reduced, which overall also will reduce benthic impacts of the fishery. Overall, the higher average catch rates and reduction of effort for search and test fishery will result in higher gross value added in the mussel fishery by used of such methods.

The initial results of the trial fisheries with SME04 in Horsens Fjord, Denmark, with the side-scan monitoring method are promising. Based on comparison of real time side-scan monitoring and video-monitoring it is evident that the side-scan-sonar signals and outputs are easy to distinguish between seabeds with low mussel density, seabeds with medium density, and seabeds with high densities of mussels. Furthermore, it is also easy to distinguish the edges of the mussel banks. A challenge has been to read the sampled side-scan-data with software that can geolocalize the data (GIS-based) and integrate data from the different monitoring transects carried out. Work is ongoing to meet this challenge, and the trial fisheries will continue in 2017 as well as the analysis of the data.

The allocation and intensity of fishing effort with hauled gears according to sensitive habitats and seasons in the Western Baltic Sea

The preliminary conclusions from the evaluation of effects of fishing with hauled gears on different habitats and seasons in the Femern Belt Area, Western Baltic Sea are that there is a:

a. Slight significant negative correlation between species richness (biodiversity) and fishing pressure;
b. Slight consistent and significant negative correlation between invertebrate density and fishing pressure for all habitats as well as for all single species where significance is found;
c. No strong correlation between invertebrate biomass and fishing pressure;
d. Consistent positive correlation between density (number of individuals per sample) and biodiversity (number of species per sample) – accordingly, sensitivity indices need to take this autocorrelation into consideration;
e. Dependency of habitat effect and accordingly spatial effects on biodiversity and density (according to season and hydrographical pressures), where significant lower diversity and density is observed at soft, fine grained sediments compared to more rough mixed sediments;
f. Dependency of season effect on biodiversity and density with higher diversity and density in the third quarter compared to second quarter;
g. Significant effect on benthic infauna biodiversity and density of hydrographical factors which individually is in the same order of magnitude as the negative fishing pressure impacts on the benthic community - that is hydrographical pressures such as current speed and salinity, which all are significantly impacting diversity and density;
h. Significant effects of depth and fishing pressure on benthic infauna bio-diversity;
i. Significant interaction effects which results in the FP has different impacts on the biodiversity and density in different habitats dependent on season of year;
j. Auto-correlation between hydrographical parameters and depth and also between hydrographical factors internal,– here interactions in pressures need to be taken into consideration;
k. It makes a difference whether a radius of 1000m or 1500m is used for fishing pressure around the benthic sampling stations – i.e. the scale is important and needs to be considered.

During the BENTHIS Project, a trial fishery with a demersal cod trawler was conducted during 2014-2015 in the Western Baltic Sea including the Femern Belt area at different types of benthic habitats and in different fishing seasons to investigate catch rates on different habitat types and in different seasons for different target and by-catch fish species.

Furthermore, catch and effort allocation of Danish and German fisheries with hauled gears from the EU STECF databases are analyzed with respect to effort allocation, catch, and catch rates of target and by-catch species according to different Benthic habitats and fishing seasons.

Biological and socio-economic importance of effort allocation and catch rates by Danish and German fishery with hauled gears in different areas of the Western Baltic Sea, according to type of habitat and placement of sensitive habitats, as well as in relation to different fishing seasons in the same area, during the same period is in the process of being evaluated with the DISPLACE model where also management strategy evaluation of potential fishing closures will be evaluated using the model.

The DISPLACE model is an individual vessel based bio-economic model evaluating effects on fish stocks according to their sustainability as well as effect on the fisheries according to their economic efficiency and viability, and their energy efficiency, in relation to the allocation or re-allocation of fishing effort. This can for example be management scenarios with respect to evaluation of the displacement of the fishing pressure according to different sensitive benthic habitats or to certain fishing seasons.

Here impacts are evaluated with respect to effects on the benthic communities (biodiversity, density, biomass, etc.); effects on the economy of the vessels (per fisheries, and types of vessels, etc.); effects on the stocks with respect to selective extraction, i.e. species / stock and age specific fishing mortality according to stock sustainability; effects on energy efficiency according to effort displacement.

The model can evaluate: What are the most sensitive habitats to fishery given other pressures; displacement of fishing pressure on different habitats, e.g. closure of certain sensitive habitats in the Western Baltic Sea (and potentially Kattegat); partial closure of the parts of these habitats which are least fished (least fishing pressure/intensity area which is most sensitive) – how big areas can be obtained by such management and what is the relative part of this of the total habitat area – e.g. in relation to biological connectivity between areas/habitats. The combined results from the trial fishery and the analyses of the STECF fishery databases will be put in context and compared with the results of sensitivity of benthic invertebrates for fishing pressure in different habitats and seasons in the same areas and period of time analyses. The results are expected to published in scientific peer reviewed papers submitted primo 2017.

The effects of bottom trawling intensity on soft seafloor macro-fauna in the Kattegat among other in relation to MPA management

The study of benthic fauna status in relation to fishing pressure and closed areas in the Kattegat (Swedish investigations) show:

a. A clear effect of the fishing intensity gradient on - Species composition, -total abundance, -biomass, and -diversity index;
b. That 26 % of the species decreased, 6 % increased, and 68 % showed no contribution to the multivariate effect of fishing intensity; and
c. That effect of the closure was less pronounced probably due to the relatively short time for recovery of species (5yrs).

Impact of trawl fishing on infauna Benthos in Danish waters of Kattegat from 2005-2013 on different benthic habitats

The analysis show that bottom trawling significantly affects the population density of benthic organisms in Kattegat. However, because species density is positively related to population density, and when population density is reduced so is species density. When population density is included in the model of species density neither trawling nor any of the other independent variables are significant.

Species density, the number of species found per sample, seems thus to be affected by trawling, due to the effect trawling intensity has on population density, the number of individuals found per sample, but there is no additional effect of fishing on species density. Importantly, the study thus highlights the importance of including the number of individuals in the samples in the statistical analysis.

The lack of an independent effect of trawling on species density, however, does not preclude that trawling could change the species composition of the benthos in heavily trawled areas. If species differ in vulnerability to trawling, the most vulnerable species might decline more in density than other more resilient species. Furthermore, changes in trophic interactions and interspecific competition may result in species replacements, while keeping total species richness constant.

Finally, the sample size and therefore the number of species recorded at each station may have been too small to reveal any significant difference in standardized richness. Further analysis should investigate the response on a species by species base.

WESTERN WATERS

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Western Waters sub-case study 1: Bay of Biscay Nephrops fishery

Sub-Case Study summary

The French *Nephrops* fishery counted 155 vessels in 2014. From 2000 to 2014, the fleet decreased by around 35% from 238 vessels in 2000 to 155 vessels in 2014. Total crew in full time equivalent decreased more than the total number of vessels with a 40% reduction, from 858 to 522 crew members.

No significant change is observed however in the crew average size per vessel. The main reasons for these changes are decommissioning programs[1] and reallocation of effort to other fisheries. Capital intensity measured as kW/crew remained unchanged, GT[2]/crew increased between 2001 and 2006 and remains stable after.

In 2014, the main fleets fishing for *Nephrops* in the Bay of Biscay are the specialized *Nephrops* bottom trawlers with around 100 vessels, 75% being in the 12-24 m category[3]. These fleets are main contributors in terms of *Nephrops* landings and effort. Appendix 1 detailed the evolution of the characteristics of these vessels. The second main fleets are the so-called unspecialized *Nephrops* bottom trawlers with 35 vessels in 2014.

It is mainly composed of vessels between 12 and 24 m, their number was reduced by nearly 70% over the considered period. Other trawling vessels (bottom or pelagic) are also included in the analysis because they contribute to *Nephrops* landings. Their number was 18 in 2014. A small *Nephrops* creel fleet is also identified. 3 vessels were concerned in 2014 and this number has changed from 3 to 6 between 2010 and 2014. 4 to 13 vessels were involved between 2000 and 2009[4] (Table 12, Figure 18 and Figure 19).

Table 12. Evolution of the French fleet operating in the Nephrops fishery

[1] Since 2003, eligibility for national policies has been based on specific fish stocks and/or fishing areas and/or associated fleet segments criteria.

[2] Capital value of the vessels is not available over the period. GT to be checked

[3] Most of the vessels are under 20 meters (to be verified)

[4] The criteria selection was different from trawlers as the objective was to identify all the vessels involved in pots for *Nephrops*.

Fleets	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Nephrops bottom trawlers (specialized) < 12m	21	25	25	22	22	23	22	22	18	20	22	26	20	25	21
Nephrops bottom trawlers (specialized) 12-24m	104	122	128	118	101	106	118	99	96	87	86	84	75	75	77
Nephrops bottom trawlers (unspecialized) < 12m	5	5	2	4	11	11	10	9	10	5	8	10	10	4	3
Nephrops bottom trawlers (unspecialized) 12-18m	64	66	53	54	46	50	40	52	45	49	34	39	41	35	24
Nephrops bottom trawlers (unspecialized) 18-24m	11	6	7	8	10	12	20	19	19	12	11	10	11	10	8
Mixed bottom trawlers < 12m	2	1	0	5	3	3	4	1	0	5	3	9	7	4	5
Mixed bottom trawlers 12-18m	5	5	7	4	9	3	2	4	6	1	2	2	3	3	2
Mixed bottom trawlers 18-24m	5	2	4	2	4	4	6	2	5	1	1	3	2	1	1
Pelagic trawlers 12-18m	5	2	4	4	2	4	6	2	3	1	6	5	2	4	1
Pelagic trawlers 18-24m	1	1	2	3	8	5	6	3	3	6	8	10	5	4	9
Pots < 12m	13	7	6	4	6	5	7	4	5	5	3	3	6	6	3
Other	2	5	3	2	1	2	1	1	1	0	2	1	0	1	1
Total	238	247	241	230	223	228	242	218	211	192	186	202	182	172	155

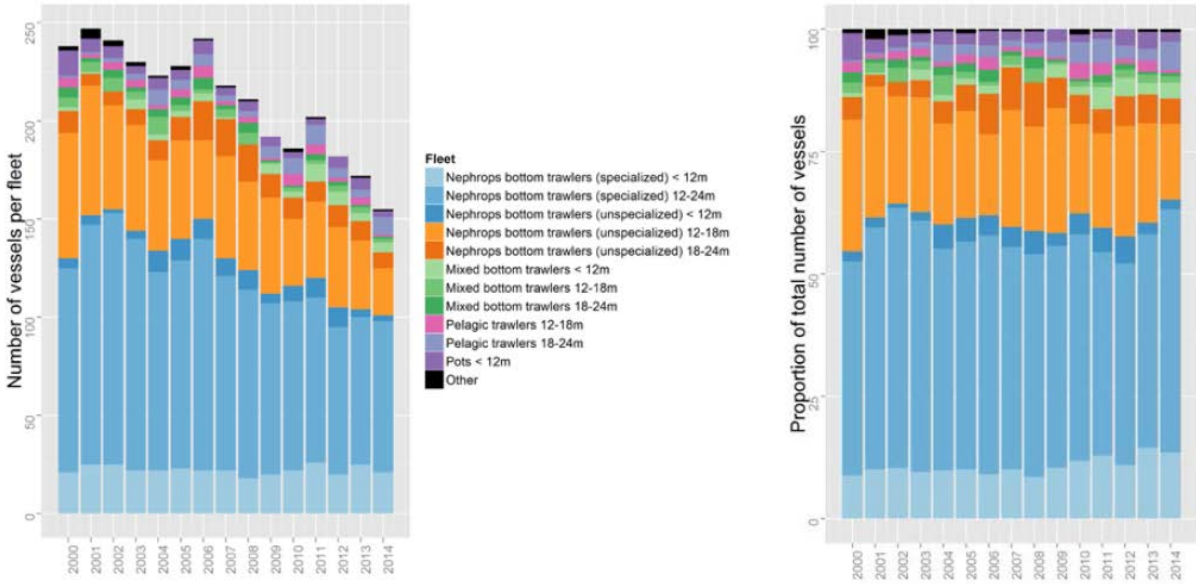

Figure 18. Evolution of the fleet (number and percentage of vessels per segment) between 2000 and 2014

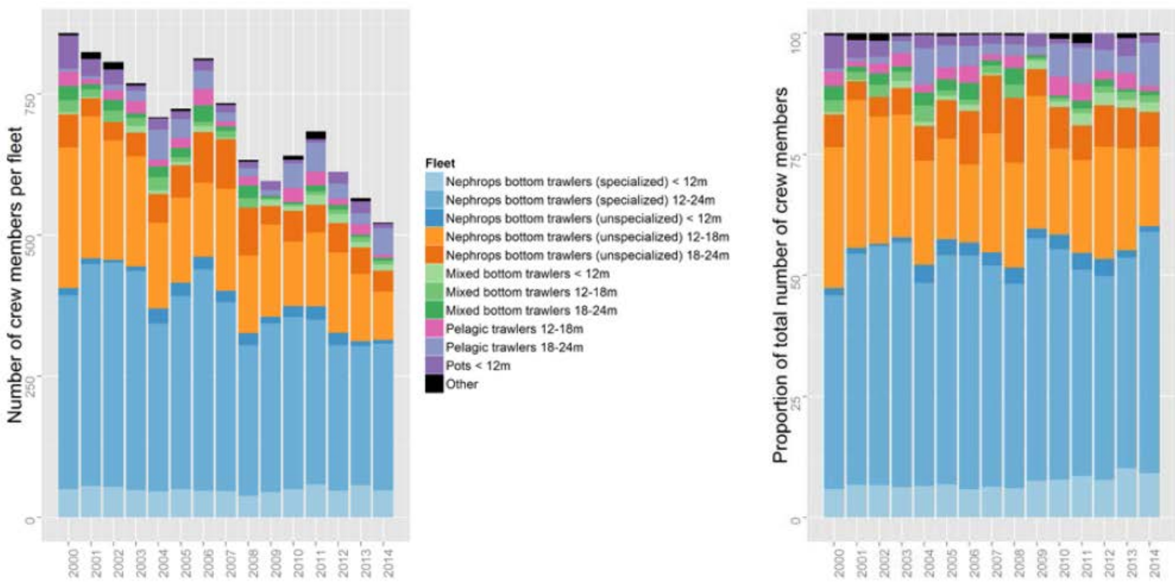

Figure 19. Evolution of the total crew members (in full time equivalent) between 2000 and 2014

Experimentations and drivers for innovation

Over the past decades, several experimentations, research and development projects were conducted on the *Nephrops* fishery (Figure 20) mainly with the objective to increase the selectivity of the fishery. Investment in new fishing gears and selective devices in the *Nephrops* trawl fishery in the Bay of Biscay has been the results of the economic drivers (fuel price increase) and mainly the regulation drivers such as fishing permits allocated only to vessels with selective devices.

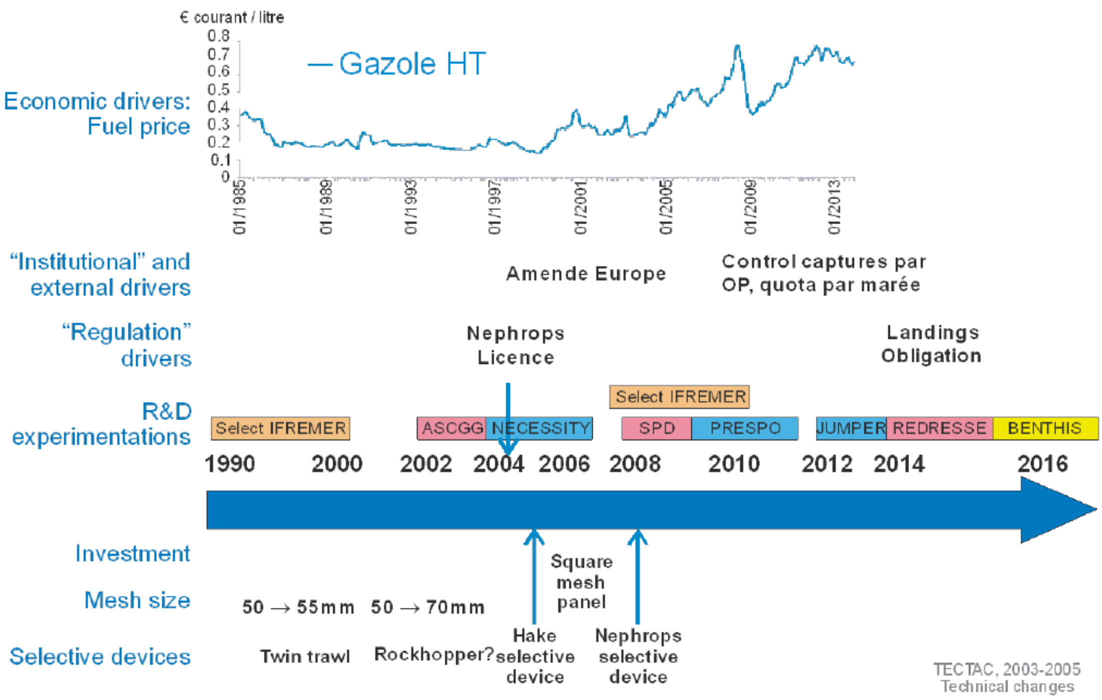

Figure 20. Technical changes in the Bay of Biscay Nephrops fishery

Options for mitigations: short description & main objectives

Options for mitigations have been fully described into the Benthis deliverable 7.7. For the bay of Biscay *Nephrops* fishery, 2 main options have been tested (summarized into Figure 21):

1. Trawling gear modification by replacing traditionally utilized bottom otterboards by boards having reduced contact with the bottom ("jumper board").
2. evaluation of *Nephrops* traps feasibility and efficiency in the bay of Biscay: test for alternative gear utilization and technical interactions of metiers mixing trawling and traps

For option 1, the strategy of trawling gear modification is based on the replacement of traditionally utilized bottom boards of the *Nephrops* twin trawls by less impacting gears with boards having reduced contact with the bottom ("jumper" board). Those boards are being developed since few years through different national and European projects: 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 boards 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). Jumper boards are designed in order to have the barycentre lower than for a classical board (Figure 22).

The board rotates and leans on the water that makes it going up into the water column. When the position of the board changes (e.g. due to trawling speed variations), making it going down to the bottom, a small shoe allows it to jump on the bottom.

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.

For both trawling gears and traps, fishing efficiency and economic viability of those new gears is tested through mid-term data acquisition involving the professional fishermen partners of Benthis (SME09 and SME10). Data acquisition is based on already designed specific questionnaire to be implemented during regular fishing trips all the yearlong and utilizing trawling gear with classical or jumpers boards for the trawler ("Côte d'Ambre", SM09) and *Nephrops* traps for the potter ("Bugal Spontuz", SME10).

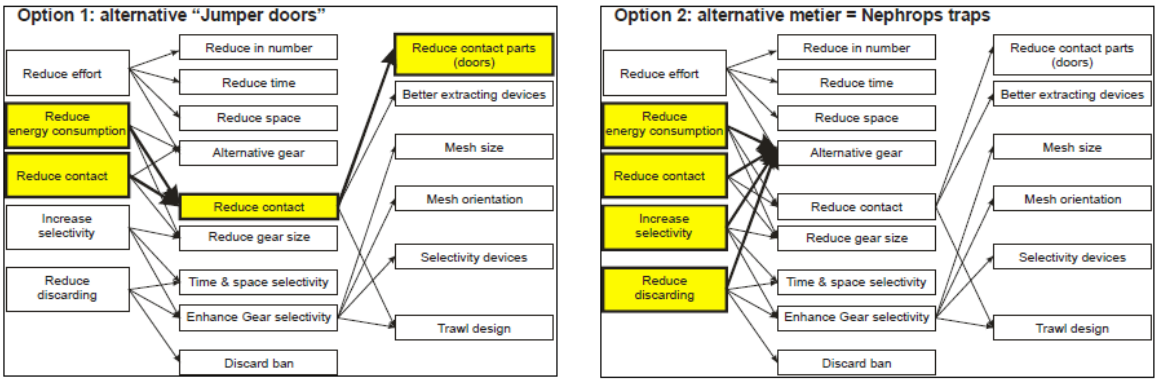

Figure 21. Diagrams summarizing specificities of the 3 options to be tested in the sub-case study dealing with the Nephrops fishery of the Bay of Biscay.

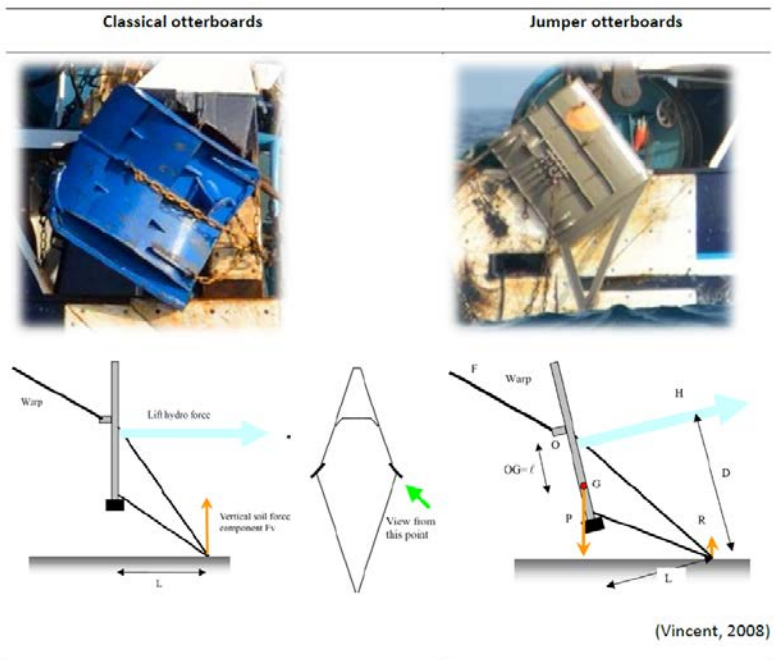

Figure 22. Comparison of classic (Thyboron type 11) and jumpers boards

Technological innovations or innovative management scenarios

Option 1: "jumpers" boards

Test and comparison of classical vs "jumpers" boards:

The surveys FEBBE 3 & FEBBE 4 (**F**ishing **E**ffects on bay of **B**iscay **B**enthic **E**cosystem) have been respectively performed in May-June and October 2014 to analyze physical effects of a standard twin *Nephrops* trawl (Table 13) equipped with current boards ("Thyboron" type 11) as compared to alternative "jumper" boards.

One scientific vessel (N/O Thalia, Ifremer) and one fishing vessel ("Côte d'Ambre", SM09) have been involved to fulfil experimental protocol requirements (Figure 23). Surveys have been performed within two muddy areas representative of the Bay of Biscay *Nephrops* fishing grounds. The main objectives and operations realized during both surveys were:

- to run alternative jumper boards operational tests and comparisons to current gear, and especially to test the utilization of "jumpers" with a *Nephrops* twin trawl that was never tested before
- to quantify sediment re-suspension processes behind the current and alternative gears.

Those experimental surveys have been completed by "standard" fishing trips with the fishing vessel "Côte d'Ambre" (SME09). A total number of 22 fishing trips have been realized during 2015 spring, 10 and 12 fishing trips corresponding to 60 and 70 trawls with Thyboron and jumpers respectively. The fishing vessel alternatively utilized the two kind of fishing boards.

During both experimental and "standard" fishing trips, behaviour of the fishing otterboards (otterboards spread, altitude) into the water column has been measured with MARPOR system and depth probes. Due to technical issues, such measurements were not acquired when operating the "classical Thyboron" boards (FEBBE 3 survey).

During "standard" fishing trips fuel consumption has been estimated by the fisherman himself (based on engine speed) and catches have been recorded. To complete collected dataset, catches values have been retrieved from the officially declared landings amounts as recorded from logbook (SACROIS Fishing Information System, Ifremer, DPMA).

In order to better evaluate effects of trawling gear parts onto the seafloor, a numerical model based on a finite element method (Priour, 2009) has been utilized to estimate the drag of the trawl and expressed as the energy put onto the seafloor.

Twin trawls model parameters included a trawling speed settled at 3 knots, 7m for the horizontal and 0.8m for the vertical opening of each gear, an otter-board spread size of 60m (Figure 24), and an effort on each trawling cable of 1 ton.

Estimation of the energy transmitted to the bottom from models

Otter-boards represent a few percentage (less than 5%) of the parts of the trawling gear in contact with the seafloor. However, the energy transmitted to the bottom by the boards (around 55%, Figure 25, Table 14) is much higher than any other part of the trawling gear. Twin *Nephrops* trawl with "jumpers" would lead to a 55% decrease of the amount of energy transmitted to the bottom (Table 14) as compared to gears with classical fishing boards.

Otter-boards behaviour from experimental sea surveys

"Jumpers" boards displayed efficient spread level with median values from 48 up to 58m during the FEBBE sea trials (Figure 26). Much higher variability has been observed during the first sea trials (FEBBE4-2) as compared to the second series of trials. Moreover, when the "jumpers" are correctly settled, they were mostly above the seafloor touching it fewer times and mostly flying over the bottom with higher altitude (Figure 27).

Such a difference illustrates the need for adaptation from the fisherman to correctly settle the gear with those new boards. As compared to classical fishing boards (Thyboron type 11, operational doors spread of 50m), jumpers one involved increased boards spread especially when they are not correctly adjusted (Figure 27, FEBBE-4 part 1).

To correctly settle the fishing gear with those new otter-boards, the speed of fishing vessel has to be reduced. The engine speed has to be lowered around 100 revolutions per minutes (fisherman personal observation); it induced a decrease in fuel consumption from 5 to 10%.

Due to higher variability of "jumpers" otter-boards behaviour as compared to classical ones and to correctly operate "jumpers", the skipper has to constantly adapt the trawling speed during the haul depending on currents, vessel speeds or sea conditions. Doors spread and their diving depth are among the most essential information for the skipper in order to detect any changes in gears behaviour and to constantly adapt the haul parameters (*e.g.* vessel speed, warp length).

To optimize the "jumper" utilization, the trawling gear sweep length need to be modified. During the Benthis sea trials, too short sweep length (40-50m) probably increased variability in otter-boards behaviour. To reduced such variability, it seemed obvious to the fisherman that an increase of that sweep length up to 60m would greatly help to stabilize the boards. Moreover, the warp length ratio with depth has to be increased and more trials are needed to optimize it.

Sediment reworking and re-suspension process

Twin otter trawl with alternative "jumpers" boards produced considerably lower level of sediment re-suspension as compared to the same trawl with the classical otter-boards. For the classical "Thyboron" boards median amounts of re-suspended sediment were about 150 mg.L-1 (Figure 28) boards up to 200 mg.L^{-1}.

Re-suspended sediments were confined near the seabed and mostly reached an altitude lower than 5 m above the seafloor (Figure 29). for the "jumpers" otterboards, median amounts of re-suspended sediments were about 10 mg.L^{-1} (Figure 28) and up to 100 mg.L^{-1}, the sediment being confined near to the seabed too (Figure 30).

With jumpers, burst of sediment especially occurred at the very beginning of the haul when the boards reached the bottom and that the hauling parameters were not fully stabilized. During the rest of the haul, turbidity could occasionally increase when boards were touching the bottom. It is especially true during FEBBE 4 surveys where the fisherman was learning to drive that new trawling gear. The sediment re-suspension level has been globally reduced by more than 85% with the new otter-boards.

During experimental measurements realized behind *Nephrops* twin otter trawl, most of the re-suspension process seemed to be produced by the boards themselves. Such results could be explained by the *Nephrops* twin otter trawls characteristics. It especially displays a reduced vertical opening (less than 1m), the clump made of chains mostly operates above the bottom and the weight of the ground gear is relatively low as compared to others types of bottom otter trawls.

Test and comparison of classical vs "jumpers" boards:

From realized sea surveys observations, we were not able to detect any significant differences of the total catches per unit effort for the fishing gear equipped with jumpers boards as compared to classical ones (Figure 31, median values around 60-65 kg.h^{-1}). For both gears, catches composition were similar with *Nephrops* (NEP), Monkfish (MNZ),

Hake (HKE) and Megrim (MEG) corresponding to the four main species in the catches (Figure 32). *Nephrops* and Monkfish corresponded to about 70% of the catches. For the main species, sizes classes' compositions were globally equivalent for both fishing gears (Figure 33).

Scenarios and parameters for Senseco application

The SENSECO tool developed in BENTHIS (Deliverable 5.2) was parameterized for *Nephrops* trawlers vessels <12m and 12-24m to explore the economic impact of the adoption of the jumper by the *Nephrops* Trawl Fishery under several conditions.

Parameterization

SENSECO input files for *Nephrops* bottom trawlers <12 m and *Nephrops* Bottom Trawlers 12-24 m were created based on2014 data from the Fisheries Information System of IFREMER and collected in the DCF framework (vessel characteristics, production and effort transversal data, price data). Economic cost structure was derived from CASD data from DPMA. Input data are presented in Table 15.

Parameterization of the alternative jumper métiers is based on data collected on board in the BENTHIS project and on interviews with the fisherman who tested the device. CPUE and prices were assumed to be unchanged (see previous section) while fuel consumption was assumed to be reduced by 5% or 10% as observed during field trips. Jumper was assumed to be adopted by trawlers for all the métiers.

Scenarios and options

Following scenarios were tested with SENSECO to assess the economic performances of the *Nephrops* fleets:

1. Status quo scenario with Classical Board
2. Scenario of full adoption of jumper boards by all the vessels with 5% reduction in fuel consumption observed
3. Scenario of full adoption of jumper boards by all the vessels with 10% reduction in fuel consumption observed

Economic impacts of the adoption of Jumper by the Nephrops Trawl Fishery

Results in terms of variation of gross cash flow and gross value added according to fuel consumption and fuel price assumptions are represented in Figure 34 for the *Nephrops* trawlers <12 m and 12-24m and in Table 16.

Assessment of the variation of gross value added and gross cash flow generated by the adoption of jumper by the specialized *Nephrops* trawler fleet shows that the adoption of jumper by *Nephrops* Trawlers increases the Gross Value Added by 4 to 7% and the gross Cash Flow by 12% to 23% according to the fuel consumption variation (5% to 10%). Positive impacts are distributed between owner and crew with a distribution depending on the crew share.

Adoption of jumper provides a better resilience to external factors such as fuel price increase. The higher the fuel price, the higher the variation of economic performances thus highlighting the increasing incentives to change boards in a fuel price increase context.

Figure 35 illustrates the resilience to fuel price increase according to fleet and scenario of adoption of jumper. Decrease in fuel consumption observed with jumper (assumption -5% to -10%) provides a better resilience to higher fuel price for both sub-fleets. The Break even fuel price (fuel price that annuls gross cash flow) is at about 1.7 euros/L for small *Nephrops* trawlers and at 0.91 to 0.96 euros/L for larger *Nephrops* trawlers while with traditional boards, it is 1.59 euros/L and 0.86 euros/L respectively.

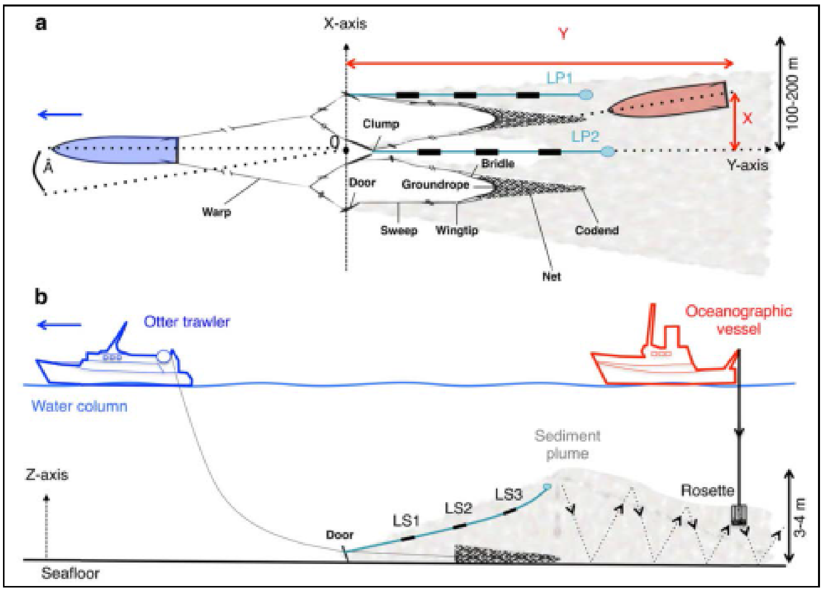

Figure 23. Schematic view of the sampling strategy utilized to measure sediment re-suspension amounts by a Nephrops twin trawl during sea surveys (FEBBE-3 and FEBBE-4, modified from Mengual et al,2016). a.top view and b. lateral view. LS1 to LS3 indicate turbidimeters attached behind the trawling gear; LP1 and LP2 indicate position of that turbidimeter line behind boards and clump respectively.

Table 13. - Characteristics of the otter twin trawl utilized during sea trials

Device	Part	Characteristics
Trawling gear (excepted boards)	Floatline length	14 m for each trawl
	Sweep length	50 m
	Bridle length	13 m
	Wing spread	7 m for each trawl
	Door spread	50 m
	Vertical opening	0.8 m
	Codend mesh size	70 mm (stretched)
	Trawler length	16.5 m
	Trawling speed	3.5 knots
Classical boards (Thyboron type 11)	Length	1.70 m
	Weight	330 kg
	Height	0.95 m
	Groundrope	
	Length	17 m for each trawl
	Weight	60 kg for each trawl
	Disk type	Regular
	Disk thickness	10 mm
	Disk diameter	50 mm
Clump	Type	Chains
	Weight	100 kg

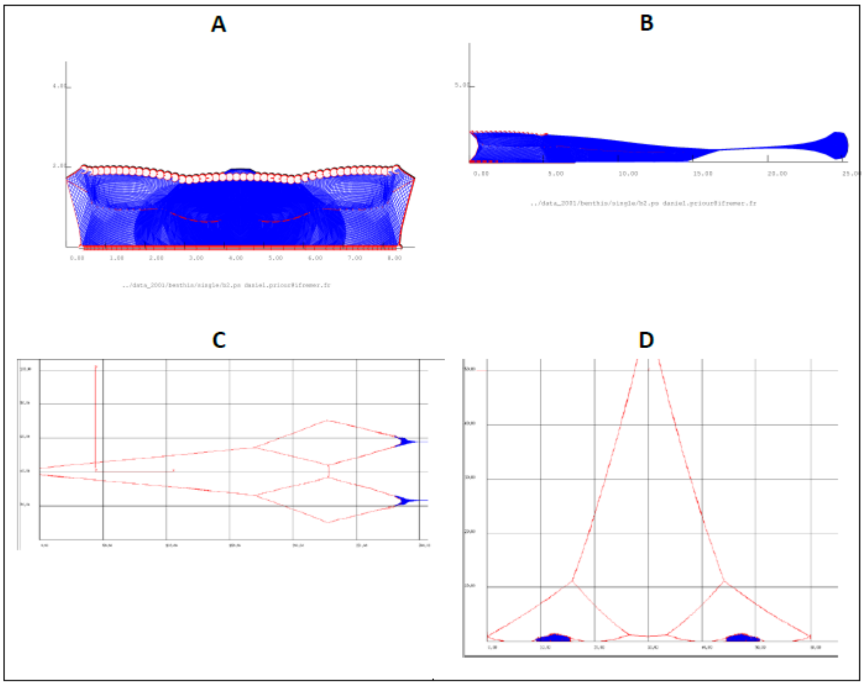

Figure 24. Characteristics of the modelized Nephrops twin trawl. A - Front view of one of the two fishing nets, B - lateral view of the fishing net, C - Top view of the whole trawling gear, D- Front view of the whole gear (distances in m). Blue parts represent the nets and red one the cables and boards.

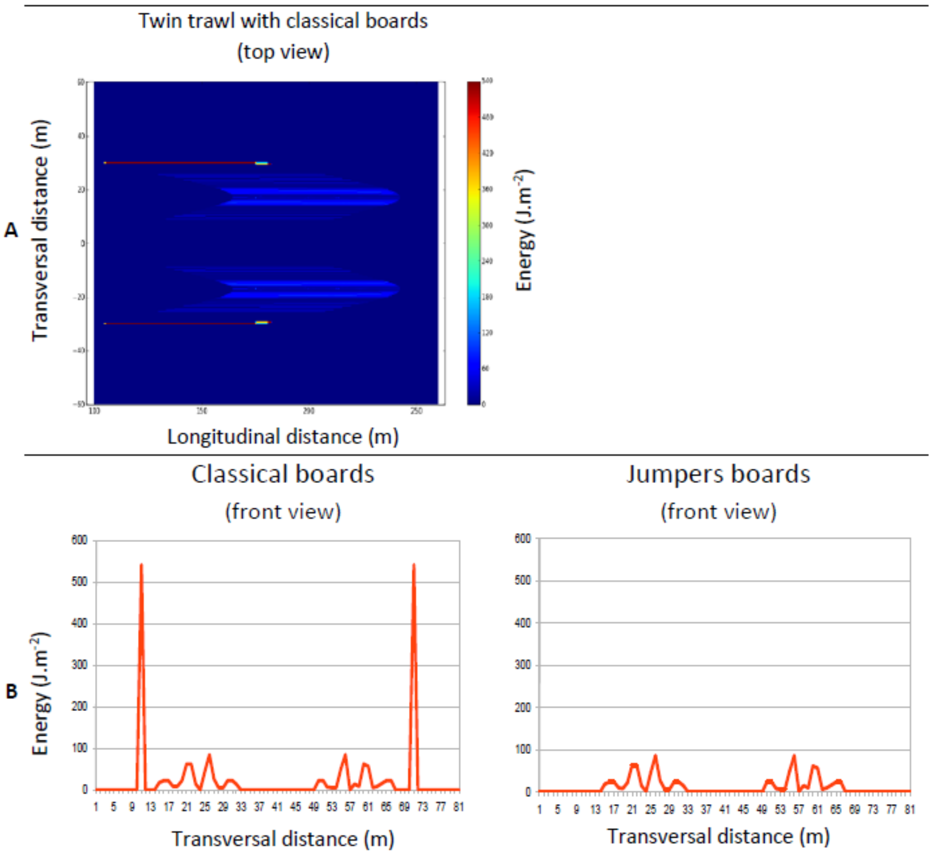

Figure 25. Results from modelling process with the finite element model of the twin Nephrops trawl. A - schematic top view of the fishing gear track showing its different parts (two boards at the top and bottom of the figure and the two trawls at the middle) and the estimated energy level. B - Energy put onto the seafloor by trawling gear ("front view") with classical and "jumpers" boards.

Table 14. Energy transmitted to the bottom from the twin otter trawl with the two types of otter-boards.

	Classical otterboards		Jumpers otterboards	
	Energy ($J.m^{-2}$)	Ratio (%)	Energy ($J.m^{-2}$)	Ratio (%)
BOARDS	**1082**	**55**	**0**	**0**
TRAWL	883	45	883	100
TOTAL	1965	100	883	100

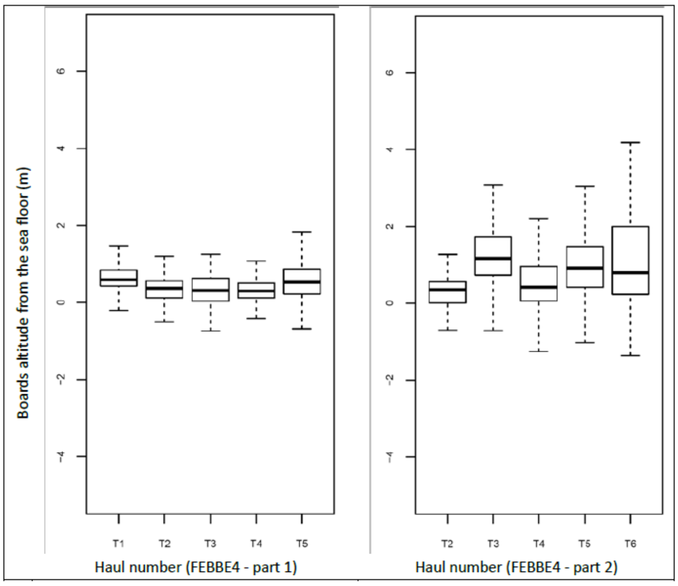

Figure 26. Jumpers boards altitude from the seafloor (in m) as measured from experimental trawling survey (FEBBE-4) utilizing modified Nephrops twin trawls with jumpers boards. A - 5 experimental hauls (T1 to T5) realized during first part of the survey (FEBBE4-1) and B - 6 experimental hauls (T1 to T6) realized during the second part of the survey (FEBBE4-2).

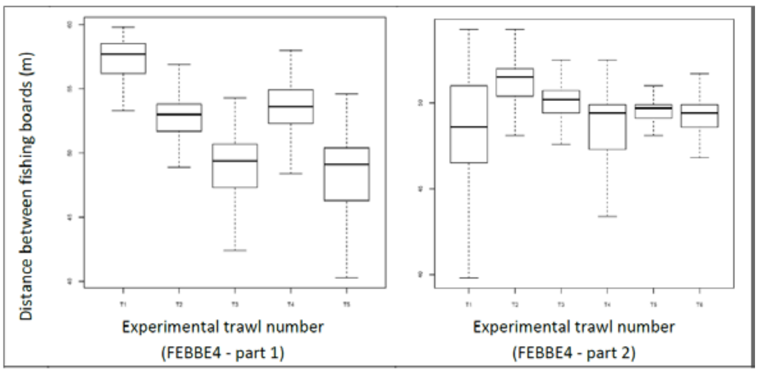

Figure 27. "Jumpers" horizontal spread as measured from experimental trawling survey (FEBBE-4) utilizing modified Nephrops twin trawls with jumpers boards. A - 5 experimental hauls (T1 to T5) realized during first part of the survey (FEBBE4-1) and B - 6 experimental hauls (T1 to T6) realized during the second part of the survey (FEBBE4-2).

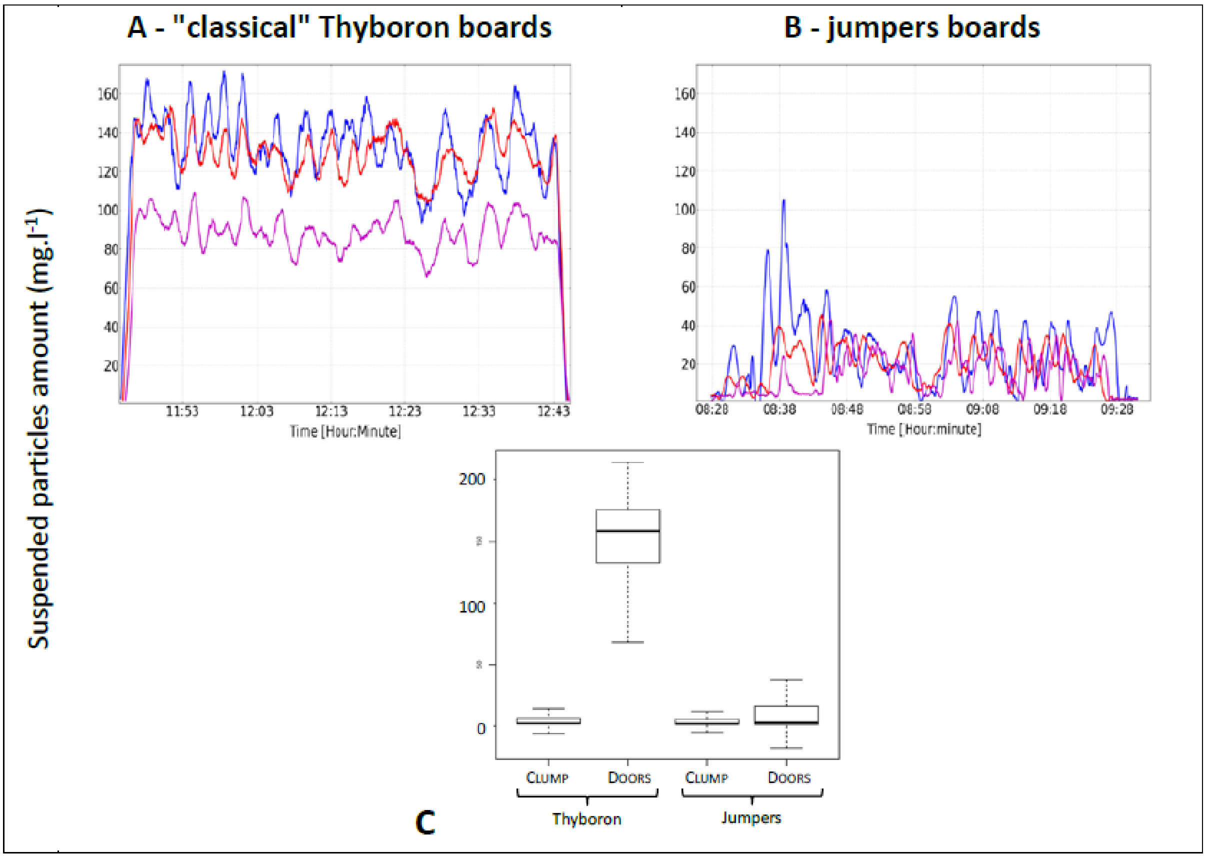

Figure 28. Continuous SSC measurements with the instrumented line. Typical records (A) during a haul behind a classical door (Thyboron) and (B) behind alternative "Jumpers" boards. (C) Summary of the records as measured behind clump or boards with Thyboron or Jumpers boards.

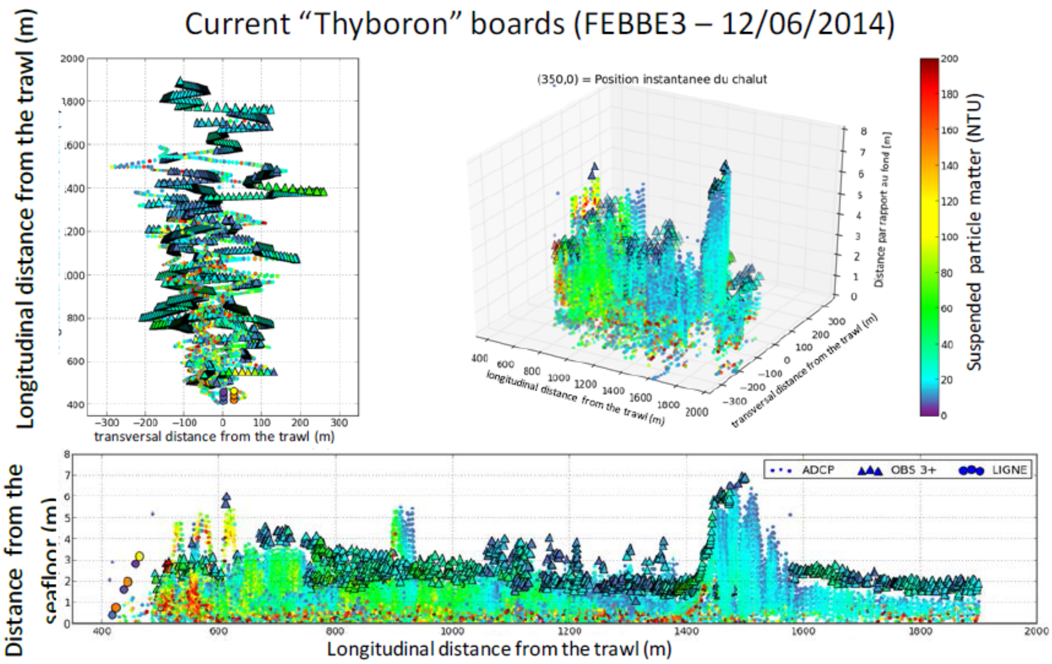

Figure 29. Sediment measurements into the water column following experimental hauls with classical "thyboron type 11" otterboards (material and methods fully described into Mengual et al. 2016).

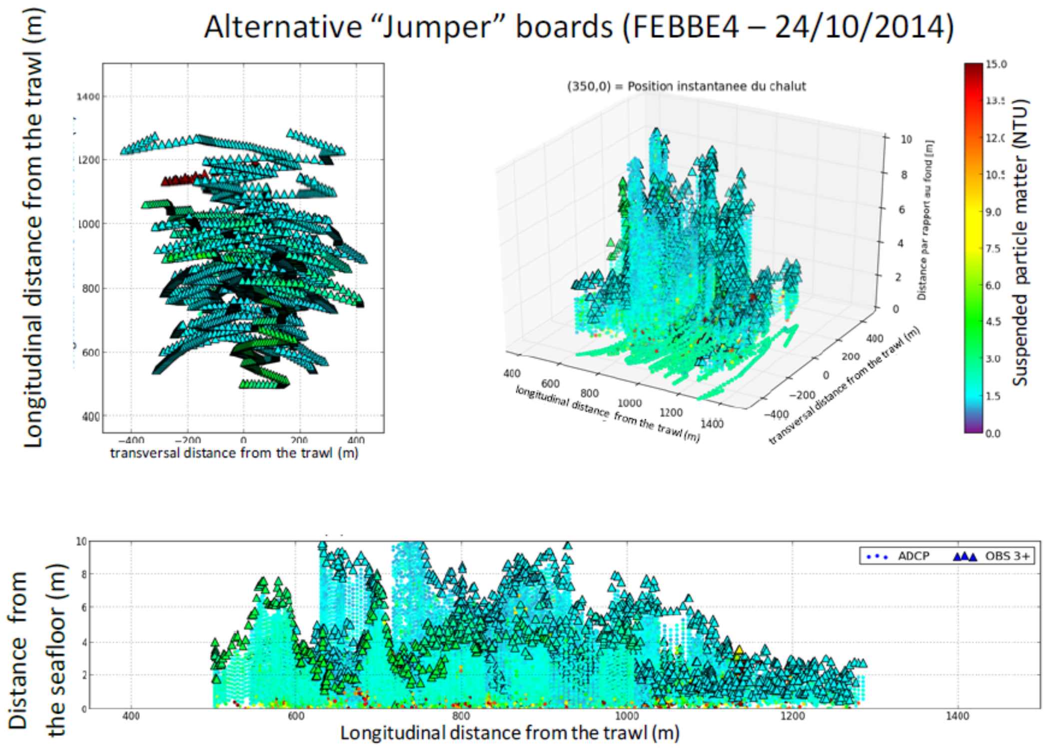

Figure 30. Sediment measurements into the water column following experimental hauls with classical "Jumpers" boards (material and methods fully described into Mengual et al. 2016).

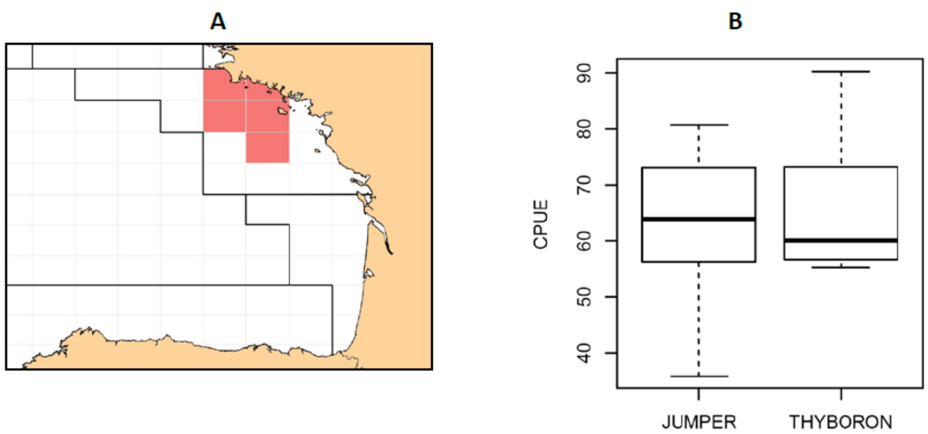

Figure 31. (A) Area of work and (B) mean catch per unit effort (CPUE in kg.h^{-1}) depending on the 2 boards type (Jumpers and Thyboron).

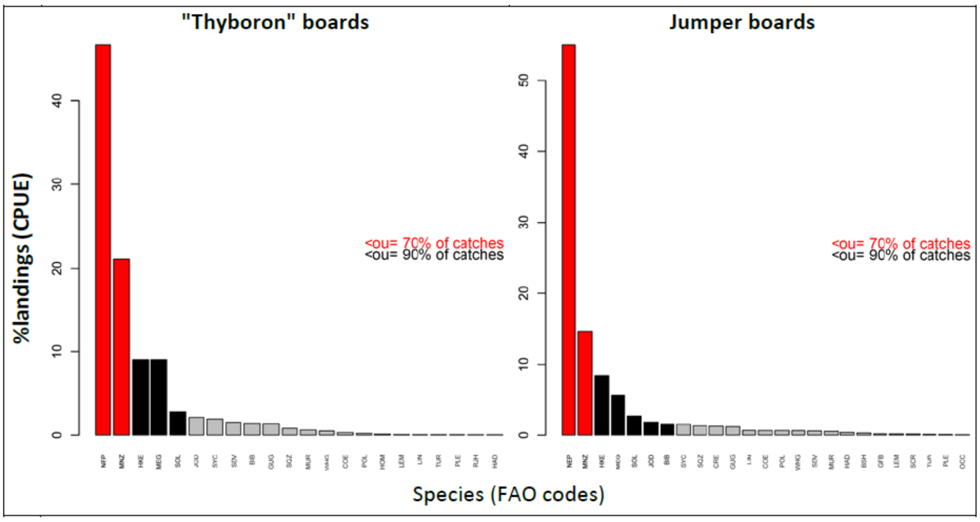

Figure 32. Relative catches composition (fresh biomass) from standard fishing trips during spring 2015. Species representing 70% and 90% of the catches are enlightened.

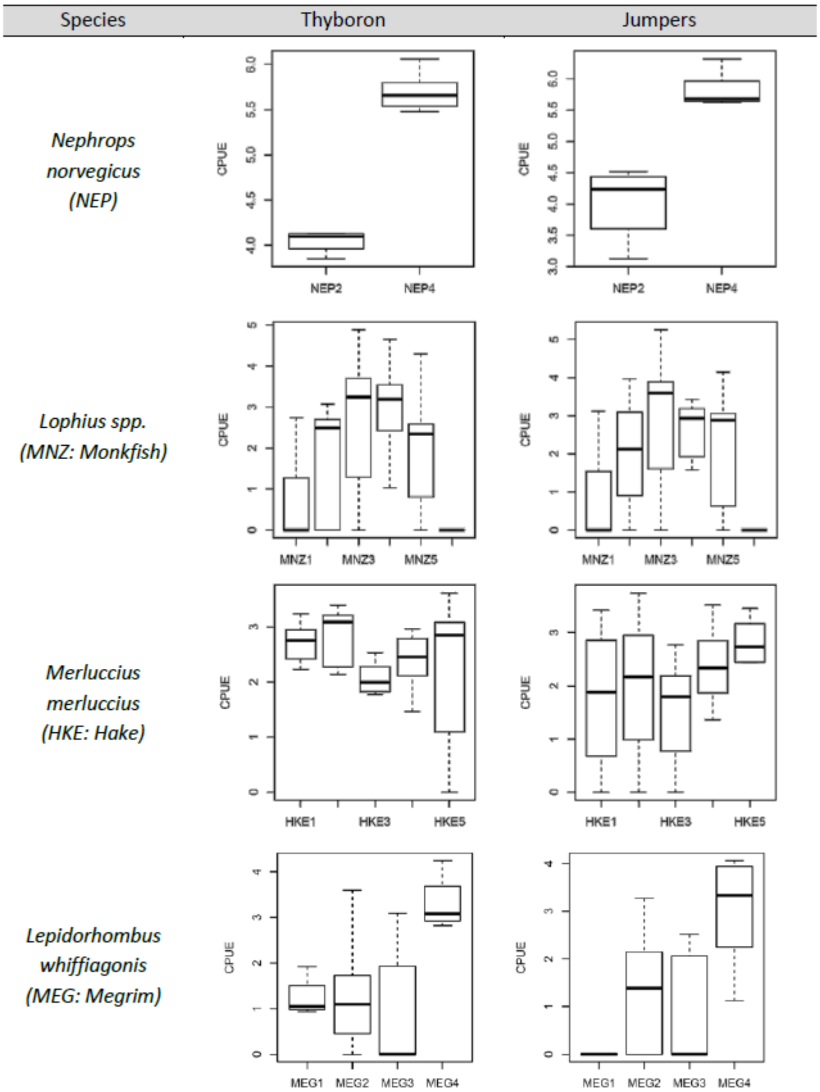

Figure 33. Catches comparison for the 4 main species depending on the 2 boards types. Each species is subdivided into commercial size classes.

Table 15. Inputs data of the SENSECO application (Sources: DPMA/IFREMER and BENTHIS surveys)

	NepTrawlers <12m	NepTrawlers 12-24 m
Number of vessels by fleet	25	75
Mean crew number by vessel	2.3	3.3
Mean number of days at sea by vessel by year	177	225
Mean number of days at sea by vessel by year on *Nephrops* métiers	141	163
Mean number of fishing trips by vessel by métier by year	166	152
Mean number of fishing trips by vessel by year on *Nephrops* métiers	136	124
Mean length of trip on *Nephrops* (hours at sea)	15	22
Landing tax (% of the gross revenue)	5.90%	5.90%
Mean Fuel consumption (L/days at sea)	430	746
Fuel price euros/L	0.68	0.68
Mean Other variable costs by vessel (euros/year)	143	208
Mean Crew share by vessel (% of the return to be shared)	53	60
Mean Repair and maintenance costs (euros/year)	17761	41583
Mean Other Non variable costs (euros/year)	17471	38246
Mean Crew costs (euros/year)	82943	152908
Mean Gross revenue by vessel (euros/year)	235000	415000
Dependence to main species (% of gross revenue)	58% NEP 11% SOL	55% NEP 12% MNZ 9% SOL

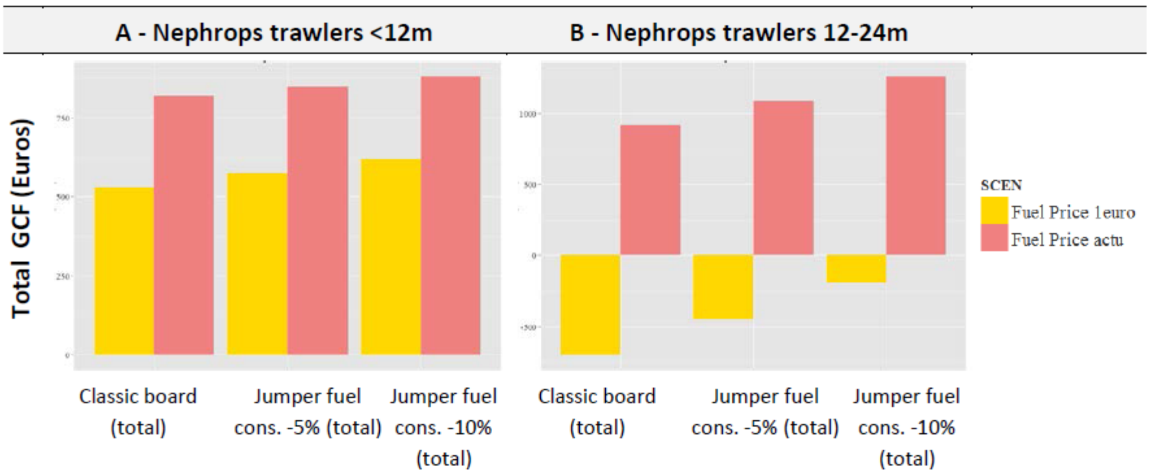

Figure 34. Variation of total Gross Cash Flow (GCF) according to board, fuel consumption and fuel price A. for Nephrops bottom trawlers < 12m and B. for Nephrops bottom trawlers 12-24 m

Table 16. A and B - Mean and total Gross Cash Flow (GCF) and Gross Value Added (GVA)according to scenario of adoption of jumper boards compared to performances with the traditional boards.

A		Mean GCF per vessel		Total GCF per fleet		Total GCF
		NepTrawlers <12m	NepTrawlers 12-24 m	NepTrawlers <12m	NepTrawlers 12-24 m	
Classical Board	Fuel Price 1€	21208	-9307	530206	-697996	-167790
	Fuel Price actu	32766	12221	819143	916557	1735700
Jumper fuel cons -5%	Fuel Price 1€	23014	-5950	575352	-446284	129068
	Fuel Price actu	33994	14501	849842	1087541	1937384
Jumper fuel cons -10%	Fuel Price 1€	24820	-2594	620499	-194572	425927
	Fuel Price actu	35222	16780	880542	1258526	2139068

B		Mean GVA per vessel		Total GVA per fleet		Total GVA
		NepTrawlers <12m	NepTrawlers 12-24 m	NepTrawlers <12m	NepTrawlers 12-24 m	
Classical Board	Fuel Price 1€	84219	96578	2105485	7243365	9348850
	Fuel Price actu	108680	150428	2717001	11282077	13999078
Jumper fuel cons -5%	Fuel Price 1€	88041	104973	2201034	7873009	10074043
	Fuel Price actu	111279	156130	2781974	11709785	14491759
Jumper fuel cons -10%	Fuel Price 1€	91863	113369	2296584	8502652	10799235
	Fuel Price actu	113878	161833	2846948	12137492	14984440

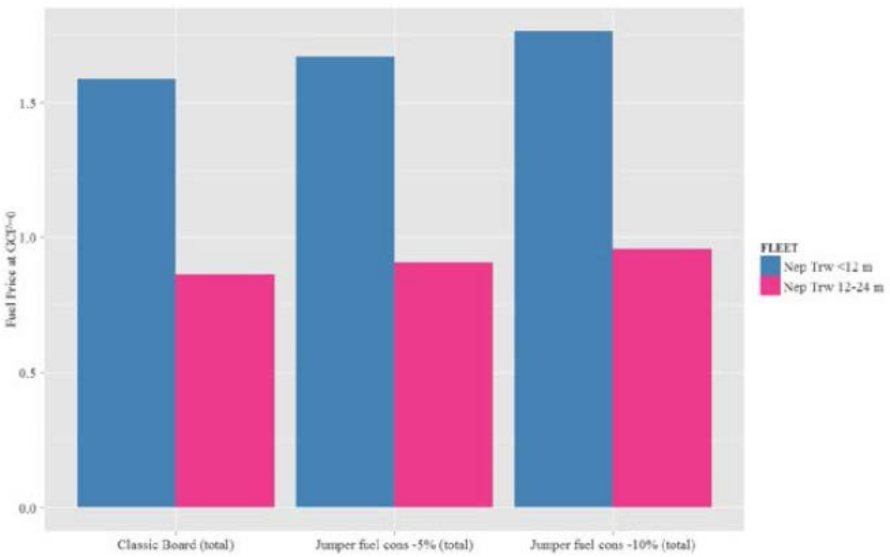

Figure 35. Break Even fuel price: fuel price such that Gross cash Flow is nul according to scenario and fleet

Option 2: Nephrops pot

Context

Several *Nephrops* pot fisheries exist in European waters that have high economic profitability (Ungfors et al. 2013), lower dependency on fuel price increase and lower impacts on benthic ecosystems than trawlers fleets (ref). Interest raised by the European examples of performing pot fleets led to experiment *Nephrops* pots in the Bay of Biscay. Experiments were conducted with Scottish pots in 2005 in the ITIS-SQUAL project and then at a larger scale in a project by AGLIA (Figarède & Bigot 2011).

Most of the *Nephrops* pots used in the fishery are of the Scottish type[5]. They are are semi-cylindrical and their rigid galvanized iron frame is covered with a green polyamide net. The two entries or trays are mounted in an asymmetric way. They are maintained in constant tension by tensioners so as to remain open. The bait is fixed horizontally within a small net (Morandeau et al., 2007).

The length of the racks is generally 60 cm, width of40 cm and 35 cm high. Their weight is around 5.5kg. Different models adopted by fishermen. Norway lobster traps are used in sets of dozens of units. They are spaced from fifteen to fifty meters depending on fishing depth and area of operation. In most of the cases, fishing takes place in specific areas called the "coursives" (e.g. canyons) with a depth of 50-60 m.

Fishermen Interviews show they chose this gear either by continuity of a technique they learned from their elders, or in a desire to diversify or retrain after first conclusive tests. According to interviews, the southern Britanny pot fishery began in the end of the 70s with *Nephrops* as bycatch of crab pots or sole trammel nets.

In the Bay of Biscay, historical analysis of the fleet structure of vessels operating in the *Nephrops* fishery highlights the existence of a small number of potters (3 to 7 vessels) that have been operating on the fishery with pots over the past decade.

It is likely that the number of vessels using *Nephrops* pots is higher than the registered ones since all vessels are allowed to fish *Nephrops* without holding a European license in so far as they land less than 2 tons per year and less than 200kg per day. In 2010, only 2 potters were registered to the European license system. There is no certification scheme in the pot fishery.

Drivers of the fishery, incentives and disincentives of investment in an alternative gear with lower impact on benthic ecosystems

The objective was to identify the factors that influence the switch to new alternative fishing gear. Face to face interviews with four fishermen were carried in number 2015. We followed the questionnaire provided by LEI and included other question related to their fishing activity. Within the sample, two are still operating in the *Nephrops* fishery as exclusive potters < 12m. One decided to stop (potter-netter <12m) and the other (exclusive potter 20-24m) decided to stop after trials at sea. The next figure (Figure 39) presents the histories of each vessel and main dates of entry and exit when relevant.

For vessel #1, operation with *Nephrops* pots was inherited from family (father) when *Nephrops* were a bycatch of crab pots. The fisherman decided to switch invest in *Nephrops* pots in 2000, with a gear type perfectly suited to target this species. The investment cost was not subsidized. This vessel is still in activity with *Nephrops* as a complementary activity to other pot fisheries.

The *Nephrops* activity is seen as way to improve revenues and to diversify the landed species portfolio. It is considered as too risky to operate only a given species considering the seasonality in crustacean yields and price. However, *Nephrops* long term price evolution is reported as positive with high demand for these type de products

[5] The Danish *Nephrops* pots were also tested in the fishery

(*Nephrops* size and quality). All the landings are sold at auctions and bought by specialized fishmongers mainly for restaurants.

As for vessel #2 (see below), *Nephrops* landings are stored into refrigerated pounds to improve products conservation. This vessel uses from 150 to 200 *Nephrops* and vessel is equipped with pots ramps to facilitate their handling. Considering prices and yields and the low of costs of operation, the fishery is considered as profitable. Operation costs are low because the *Nephrops* areas are located in the vessel range of operation for the other fisheries. Travel costs are limited and do not generate extra-costs. Pots repairs and maintenance is managed by the crew and is not very costly.

The main drawbacks for the maintenance and development of the pot fishery are narrow fishing areas with some interactions with other *Nephrops* potters and conflicts with trawlers. *Nephrops* fishing areas in canyons are maintained but with conflicts with trawlers and high risks of lost gears. As a consequence, there are no or few possibilities to harvest in other areas. Protection of these areas by regulation including the prohibition of trawlers is required (fisher #1).

The vessels #2 characteristics (Exclusive potter <12 m) are similar to vessel #1. The vessel owner began to use *Nephrops* pots in 2003 with another vessel. He decided to invest in 50 pots for targeting *Nephrops* considering the fishing activity of other *Nephrops* potters in the area but also the bycatch of *Nephrops* in his Common Sole trammel nets. In 2012, he decided to buy a vessel on the second hand market and operate on different pot fisheries including the *Nephrops* fishery.

Similar to vessel #1, he operates with 150-250 pots (no investment subsidies) with landings sold mainly to auctions and also directly to fishmongers. *Nephrops* seasonal pattern and range of operation maintain this activity as complementary to other pots activity. Operating at a larger scale would require a larger vessel to harvest more distant areas and increased level of effort to make the activity economically viable. As mentioned by fisher#1, fishing in more distant areas would also require protected areas from trawling.

For the coastal potter-netter (vessel #3), *Nephrops* landings (5-10 kg per day sold at 25€/kg) was a complementary revenue but was also considered as an attraction product for direct consumers who bought fish at the same time. As a netter, bait (avoid blue fish) for pots was free. Beyond economic interest, the pot activity with a limited number of pots (50 light pots hauled in an hour) was also viewed as a pleasant activity. However, interactions with trawlers and the loss of pots led the fisher to sell the remaining pots after 6 years of operation.

The fisherman considers investment cost as not very expensive as well as annual repairs and maintenance. The main cost is the re-investment cost when the pots are lost after trawlers operate in the area of operation. As for other vessel using *Nephrops* pots, investment costs were not subsidized. Additional cost of exploitation was limited because *Nephrops* pots were hauled during the same trip after hauling of the nets and other crab pots.

The *Nephrops* areas were not so distant from the places other gears were set limiting travel costs. All the areas were located within the 12 naut. Miles. When the fisher decided to enter the fishery, some fishers in the area decided to bundle the purchase of pots to a cooperative.

Vessel #4 is a 18-24 m vessel operating mainly in the pot edible crab fishery of the bay of Biscay. The vessel owner experimented *Nephrops* pots provided by IFREMER. He considers the *Nephrops* fishery potential attractive because the yields were quite interesting. However, he also mentioned the interactions with trawlers and he did not continue the activity because of risk of gear lost due to the trawling activity in the same areas.

According to fishers, higher catches occur in clear water conditions often associated to North-Eastern winds with no swell. From a technical perspective, vessels designed for the fixed gears are adapted for the use of *Nephrops* pots.

<u>Fleet description and socio-economic performances</u>

As mentioned before, the size of the *Nephrops* potters fleet is quite small with 3 vessels mainly operating in the fishery in 2013. Table 17 presents the main characteristics of these 3 vessels. On average, the number of days at sea per vessel is 232 with an average crew of 2.8 members.

Average *Nephrops* landings are 2.6 tons per vessel but the dispersion between vessels is high. *Nephrops* gross revenue per vessel reached 60 k€ in 2014 compare to a total gross revenue of 227k€. The level of dependence is 26% meaning that these potters operate in other fisheries.

With the fleet, 2 vessels used only pots and the third one used nets; as a consequence, the so-called "average" vessels is a combination of the fishing activity of the 3 vessels. The main gears used are crab pots (GC, Table 18), common prawn pots (CPR), *Nephrops* pots (NEP) and Nets (gillnets and trammel nets) to target demersal-benthis species and Common sole (DP and SOL).

The main species landed in 2014 (Figure 40) were Spinous spider crab (20%), Norway lobster (18%), Edible crab (18%), European lobster (15%), Pollack (8%), Common prawn (3%), Monkfishes (2%), Atlantic bonito (2%), Common sole (1%) and other species (11%). The following figure (Figure 41) presents the monthly evolution of landings per species in 2014 giving an idea of the seasonality of the catches.

The monthly landings of the vessels over the period 2010-2015 are indicated on Figure 42. This figure highlights the seasonality of the *Nephrops* activity with the highest landings in summer, between July and September. However, the seasonal patterns are not homogenous between years and high level of landings occurred in autumn between October and December, sometimes in January. This seasonal pattern is different from the *Nephrops* trawl fishery.

The analysis of current price evolution between 2010 and 2015 indicates an increasing trend between 2010 and 2014 (+ 32%), then a 12% reduction between 2014 and 2015. The mean price was 25 €/kg in 2014 and 22€/kg in 2015. This global positive evolution was underlined by the fishermen during interviews as a favourable factor for the development of the pot activity. As illustrated on Figure 43, average price tends to be higher during the second semester of year compared to the first semester, with peaks in July-August and in December. It is also interesting to note that higher prices during the second semester are combined with higher landings during this period.

As illustrated in Table 21, The main landed categories are "Cat UE10" with 36% to 65% of the landings and "Cat EU20" with 25% to 48% of the landings over the 2010-2015 period. The price differences between the first and second categories were minimum in 2013 (Table 20) with 0.5€/kg and maximum in 2014 with 3€/kg and this confirms than larger is the size of *Nephrops*, higher is their prices. This is also true when we consider the landings of the *Nephrops* trawlers, which are mostly concerned with category "Cat EU30" and "Cat EU40".

Benthis sea trials

Observations made for Benthis by the potter partner of the project (SME09) resulted in very low catches efficiency from the two periods of sea trials (May and June 2015, Figure 44 and Figure 45).

Added to technical issues that a new potter encountered when adapting to a new gear or metiers, the main difficulties were linked to the lack of availability of productive fishing grounds. It is especially due to spatial conflict with trawlers and with already operating potters over the few available areas.

Scenarios and parameters for Senseco application

We have considered different scenarios for the following items:

1. Fuel price (status quo, 1€/liter, price Break even revenue=0)
2. Effort per vessel (days at sea) for the *Nephrops* métier (-25%, status quo, +25%, +50%)
3. Catch per unit of effort (CPUE) for the *Nephrops* métier (-25%, status quo, +25%, +50%)

For effort scenarios, we consider vessel can expand their activity by exploiting other areas or reducing their activity due to conflicts with trawlers. Catch per unit of effort can increase due to stock recovery or be reduced in case of higher fishing pressure on the local *Nephrops* stocks.

Scenarios and items of change can be combined. The investment in pots can be considered as low (30€/pot). The life span depends on the annual repair and maintenance of the gears. 10-15 years life is considered as usual but the main cost is when the pots are trawled and lost. The following figures (Figure 46, Figure 47 and Figure 48) present the main key parameters used for the Senseco application for the *Nephrops* pots case study.

Results

The following results consider 1) fuel price scenarios, 2) a combination of fuel price, effort and catch per unit effort scenarios for the *Nephrops* pots fishery. In the fuel price scenarios (1), the vessels are assumed not to adjust their effort to fuel price changes. Three scenarios are considered: i) 0.71€/L used as the current price, ii) 1€/L, iii) fuel price for which the break-even revenue is null.

Considering the parameters used in the Senseco application, the calculated fuel price for which the break-even revenue is null is around 3€/L. This results shows the capacity of the vessels to cope with fuel price increases compared to a current of 0.71€/L or less in 2016. As shows in the following figure, the price scenarios do not change the incentives to operate in the different metiers.

The changes in the return to be shared per metier are proportional to the changes in fuel price as fuel price consumption is similar between the different metiers. With a 40% increase in fuel price (0.71€ to 1€/L), the gross cash flow and value added reduction are 11% (from 51 to 45k€ for the 3 vessels). The impact on total wage is limited too. The next figures present the impact of the selected indicators of combinations of fuel price, effort and catch per unit effort scenarios for the *Nephrops* pots fishery. The selected indicators are the following:

- Gross value of landings per vessel (GVL),
- Revenue to be share per vessel (RTBS),
- Gross value added per vessel (GVA),
- Gross cash flow per vessel (GCF),
- Annual gross wage per crew member

The last figure includes the fuel for which the break-even revenue is null considering the different effort and CPUE scenarios for the *Nephrops* fishery. 48 hypothetical scenarios are considered including different management options, vessels adaptation to management and stock adjustments. Transitions to steady-state situation are not studied hereafter. Within these scenarios, three reference scenarios can be described

1. Establishment of larger exclusive areas reserved for pots give the possibility for the vessels to expand their effort (+50%) with to a significant increase in stock biomass with larger *Nephrops* individuals (+ 50% in *Nephrops* CPUE).
2. Potters involved in the fishery increase their effort (+25%) with no extension of their fishing areas leading to decrease in local stock (-25% in *Nephrops* CPUE) due to increased fishing pressure.
3. Potters have to reduce their effort (-25%) due to increased competition with trawlers in their fishing areas leading to 25% decrease in *Nephrops* CPUE.

Compared to the status quo situation, scenario 1 lead to a significant increase in gross value of landings from 227k€ to 318k€ (+40%) with strong impact on vessel gross cash flow (+148% from 17.5 k€ to 43.3 K€) and annual gross wage per crew member (+47% from 37.7k€ to 55.7 k€) when fuel price is 0.71€/L. The potential impact of a fuel price increase to 1€/L on these indicators is limited in scope as indicated in the following table.

Scenario 2 implies strong interactions between potters at local level with depression on the local fish stock abundance. Increase in fishing effort (+25%) with a decrease in local stock (-25% in *Nephrops* CPUE) results in a limited reduction in *Nephrops* landings value and total gross value of landings (-2%) considering the situation on the other metiers unchanged. The impact on gross cash flow and annual gross wage per crew member is -21% and -6% respectively despite increased effort and more time at sea.

Scenario 3 is the less favourable to the potters with increased competition from trawlers. Gross value of landings is reduced by 14% leading to a reduction of gross cash flow from 17k€ to 9k€ (-55%) and of gross wage from 37.6k€ to 31.7k€ (-16%) for a fuel of 0.71€/L. As indicated in the fuel price figure, a 2€/L could in such a scenario reduce the gross cash flow to a null value, jeopardizing the short term viability of the vessels. Intermediate scenarios between these reference scenarios can also be considered using the Table 22.

Figure 36. Nephrops pots

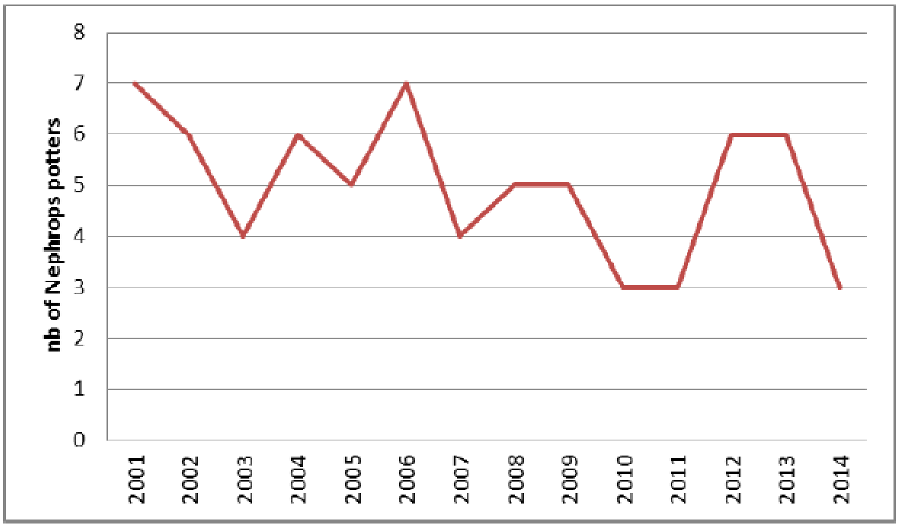

Figure 37. Evolution of the number of pots<12m with Nephrops landings > 50kg (Source: DPMA-Ifremer).

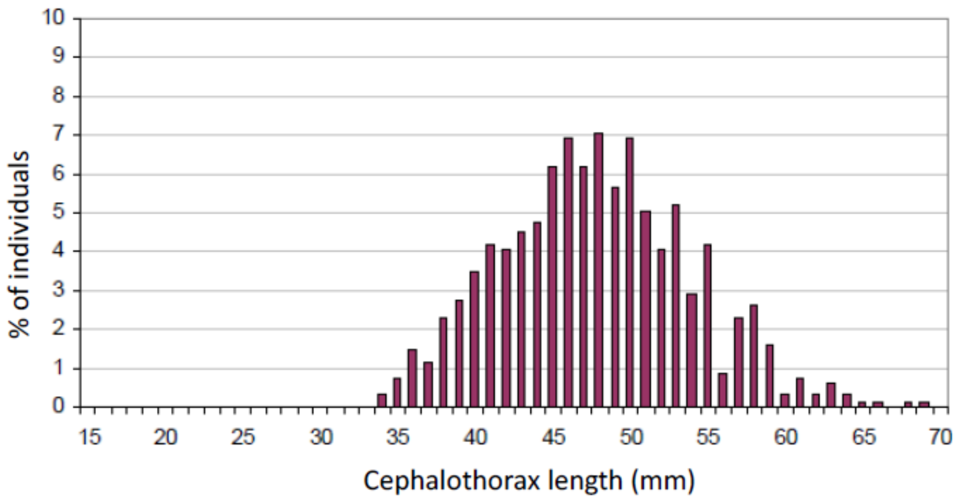

Figure 38. Size distribution of Nephrops during 2 trips in October-November 2010 (Source: Sourget et al. 2011).

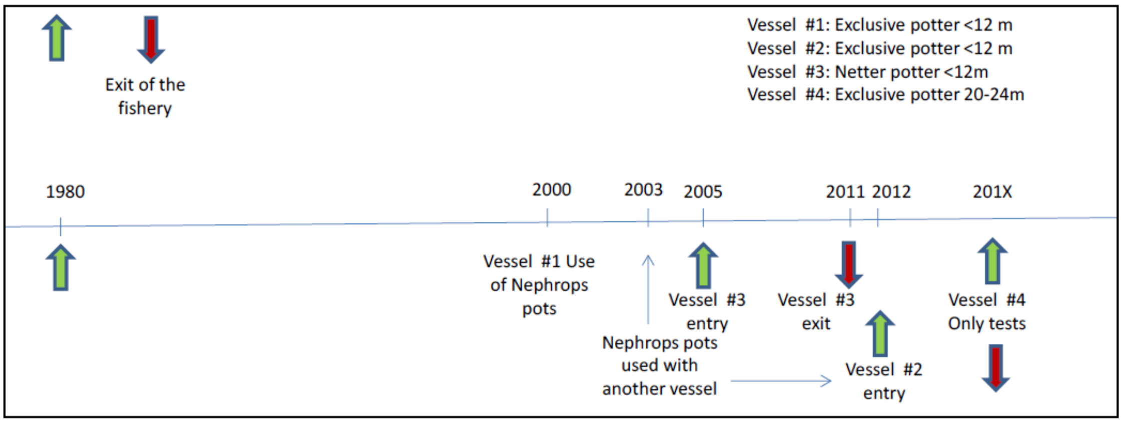

Figure 39. Vessel histories in the Nephrops fishery

Table 17. Mean characteristics of the 3 Nephrops potters <12m in 2013

Indicators	Value
crew number	2.8
nb of days at sea	232
Nephrops landings (t)	2.61
Nephrops gross revenue (keuros)	60
Total Gross revenue (keuros)	227
Dependence on nephrops (%of the TGR)	26%

Table 18. Number of days at sea per métier per vessel

Métiers	Days at sea
Pots_GC	92,3
Pots_CPR	4,7
Pots_NEP	87,3
Pots_DP	6,0
Nets_DP	114,0
Nets_SOL	9,0
Other	7,0

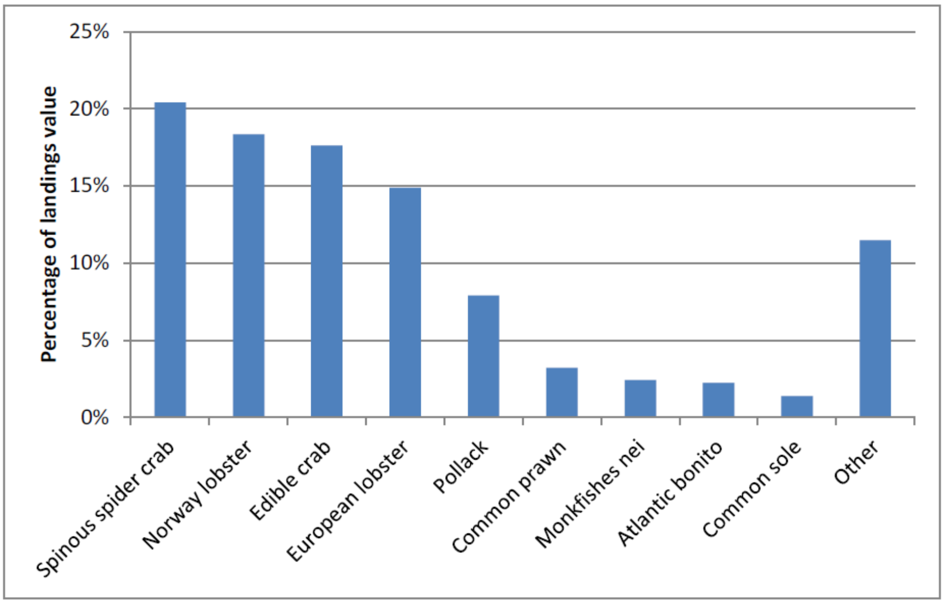

Figure 40. Dependence to the main species (% of landings in value in 2014)

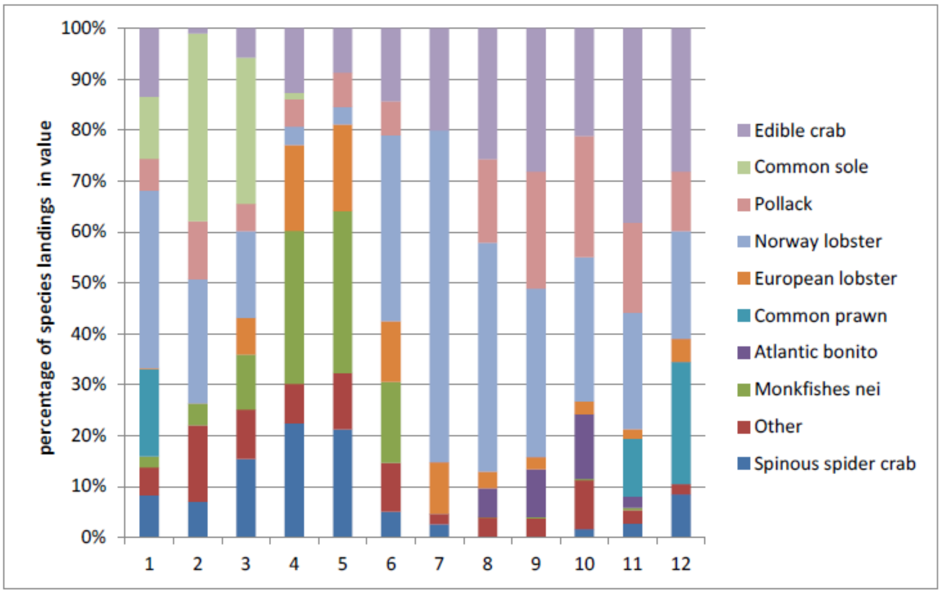

Figure 41. Monthly distribution of species landings value (2014)

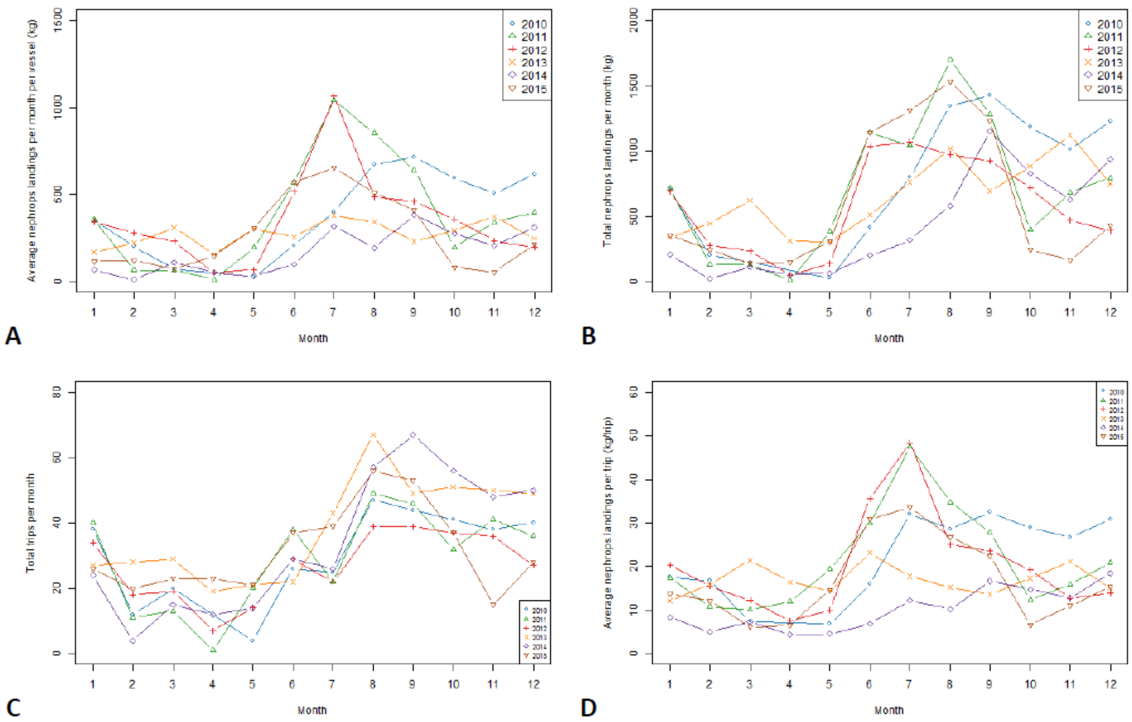

Figure 42. Average and B.total Nephrops landings per month ; C.Total number of Nephrops trips for the selected vessels (2010-2015); D. Average Nephrops landings per trip (2010-2015, Source: DPMA-SACROIS)

Table 19. Evolution and distribution of Nephrops landings prices for pots (in current Euros)

€/kg	2010	2011	2012	2013	2014	2015
Min	6	6	8	10	8	13
Median	19	22	25	23	24	22
Mean	19	22	24	24	25	22
Max	52	45	48	47	55	72
CV %	37	36	30	24	26	25

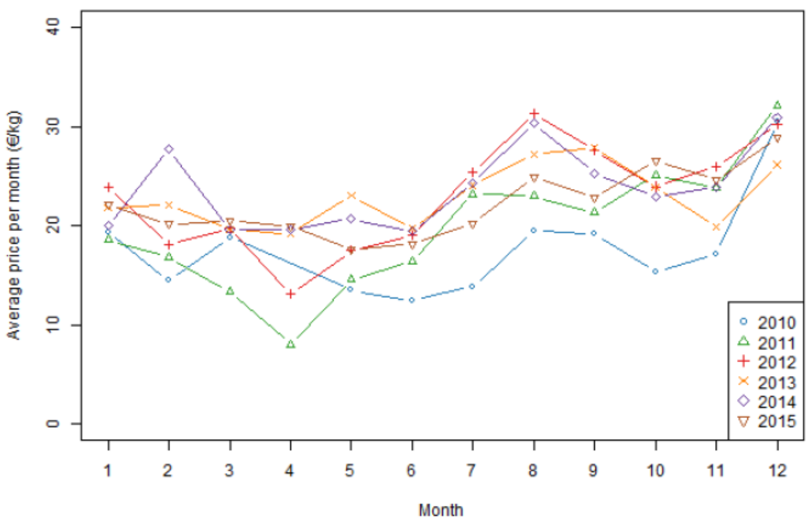

Figure 43. Evolution of Monthly Nephrops landings prices (2010-2015)

Table 20. Nephrops pots prices per commercial categories

	2010	2011	2012	2013	2014	2015
Cat UE10	21,9	24,0	25,7	23,5	26,8	22,7
Cat UE20	20,5	22,7	24,8	23,0	23,7	21,0
Cat UE30	11,7		21,5	22,0	21,6	20,5
Cat UE40	16,2	19,4	22,6	20,9	20,1	18,7
NR*	11,2	14,2	17,7	21,9	22,0	22,0

Table 21. Distribution of Nephrops pots landings per commercial categories (NB. :category 40 : + de 41 Nephrops/kg ; category 30 : 31 to 40 Nephrops/kg ; category 20 : 21 à 30Nephrops/kg ; category 10 : < 20 Nephrops /kg ; category NR : non registered.).

	2010	2011	2012	2013	2014	2015
Cat UE10	54%	52%	43%	36%	65%	50%
Cat UE20	33%	35%	48%	46%	25%	38%
Cat UE30	0%		0%	6%	1%	2%
Cat UE40	0%	0%	1%	6%	1%	1%
NR*	13%	13%	8%	7%	8%	9%
Total	100%	100%	100%	100%	100%	100%

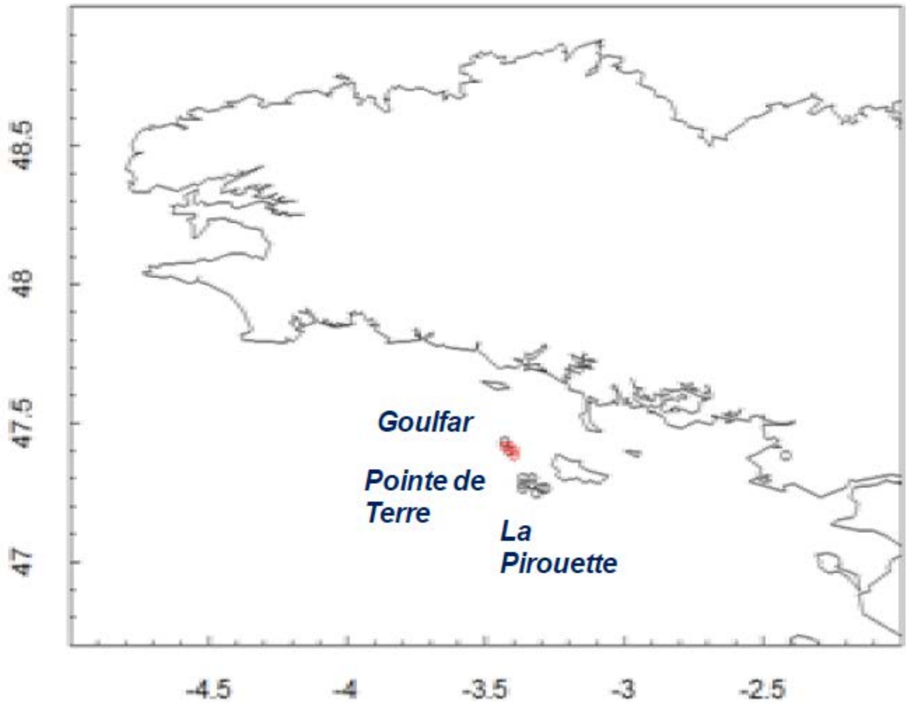

Figure 44. Locations of BENTHIS potter (SM10) sea trials during May (red circles: 2 lines of 40 pots and 18 fishing operations) and June (black circles: 1 line of 40 pots and 8 fishing operations) 2015.

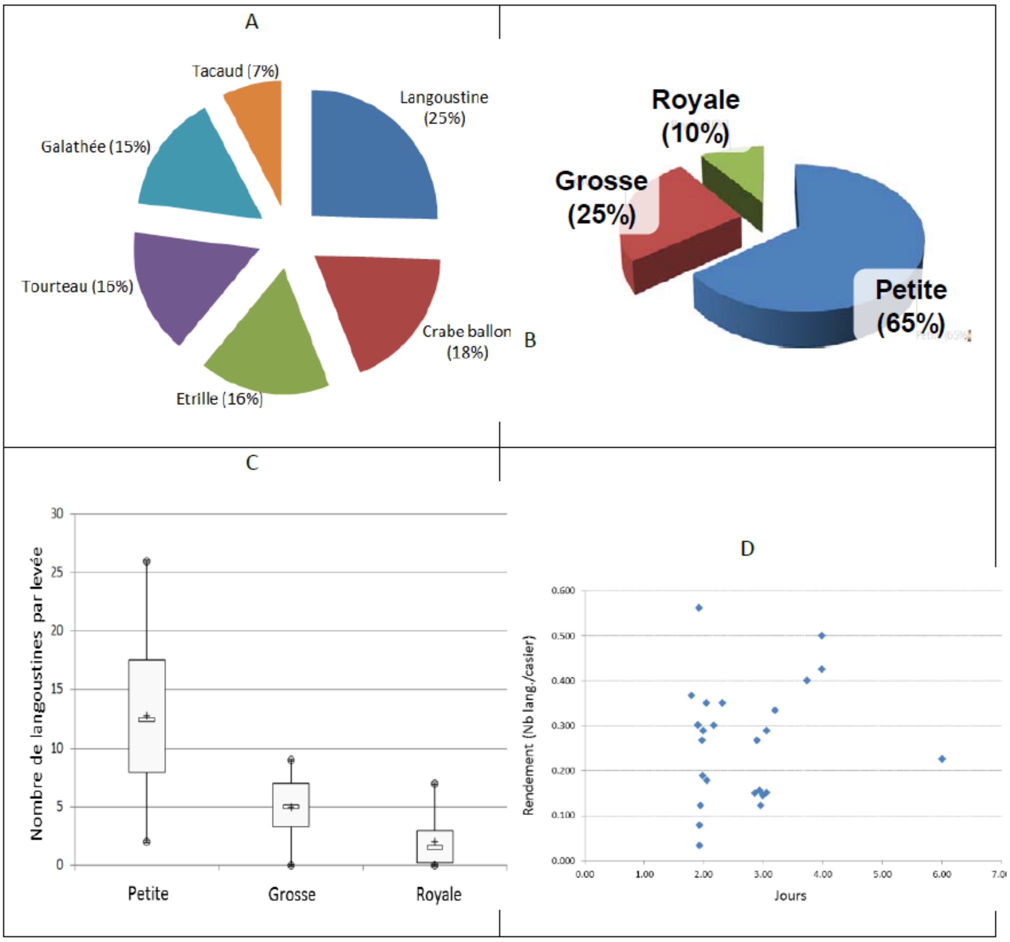

Figure 45. Catches amount and characteristics from potter's sea trials. A - global species composition of the catches, B - distribution of Nephrops ("langoustine") commercial size classes (Royale=<20 individuals/kg, Grosse=30-40 individuals/kg, Petite=>40 individuals/kg), C - Number of Nephrops individuals by fishing operation, D - mean yield per pot (number of Nephrops individuals) per fishing operation.

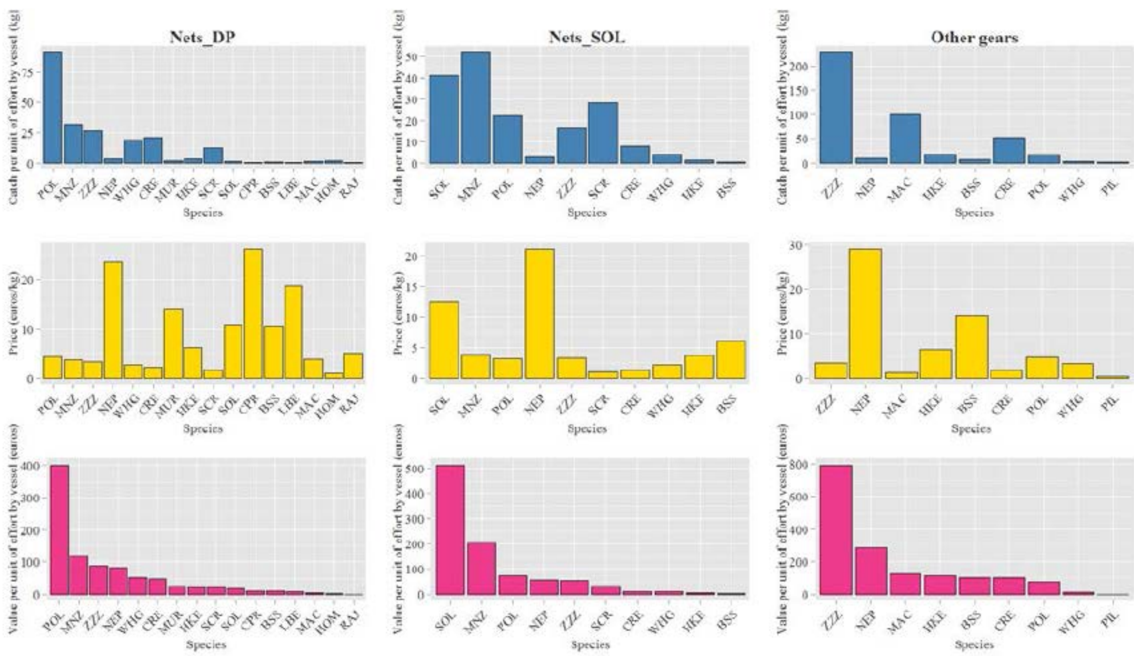

Figure 46. Catches per unit of effort, prices and value per unit of effort per metier (A).

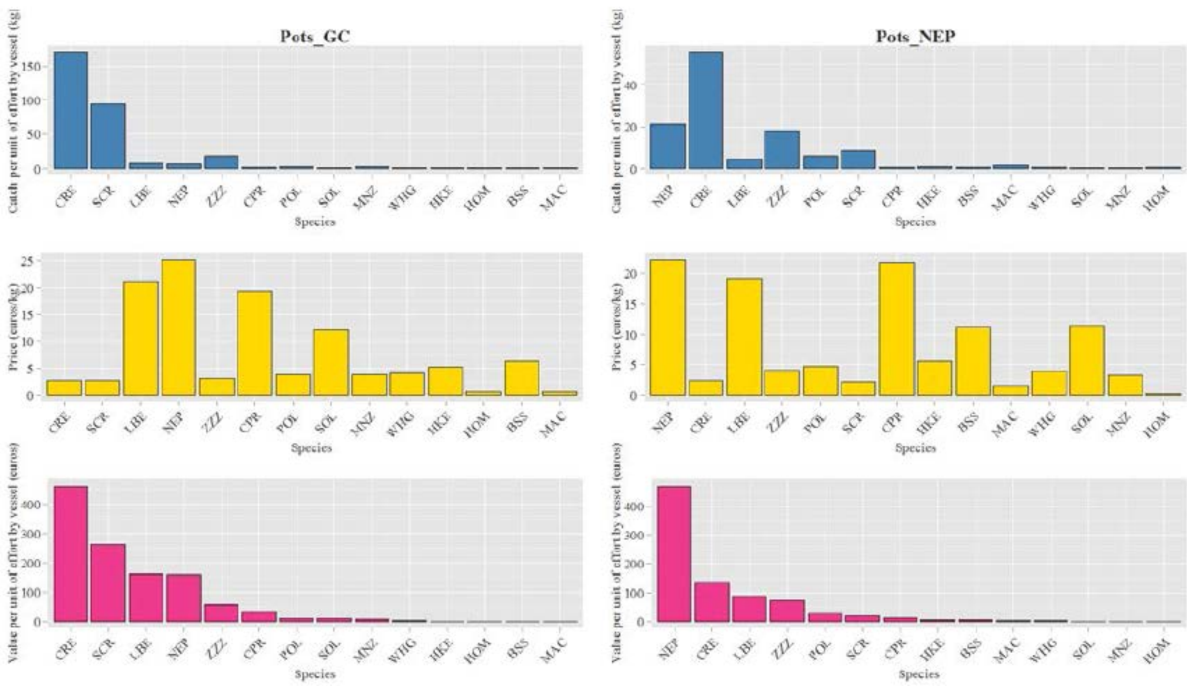

Figure 47. Catches per unit of effort, prices and value per unit of effort per métier (B).

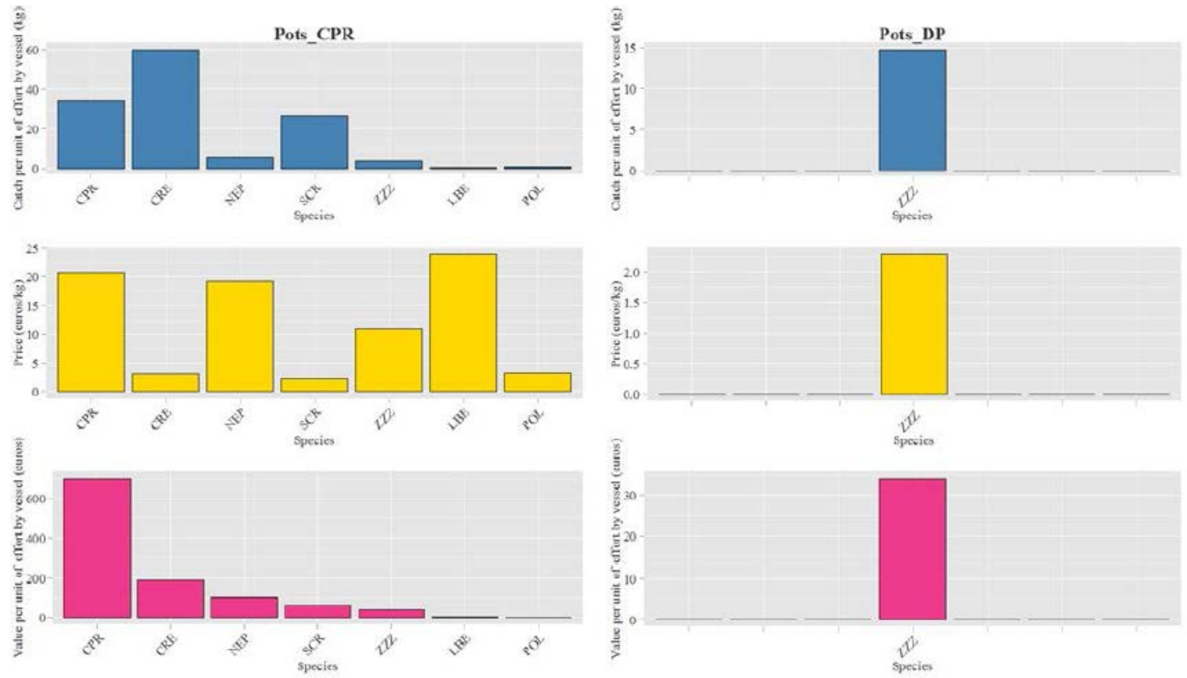

Figure 48. Catches per unit of effort, prices and value per unit of effort per métier (C).

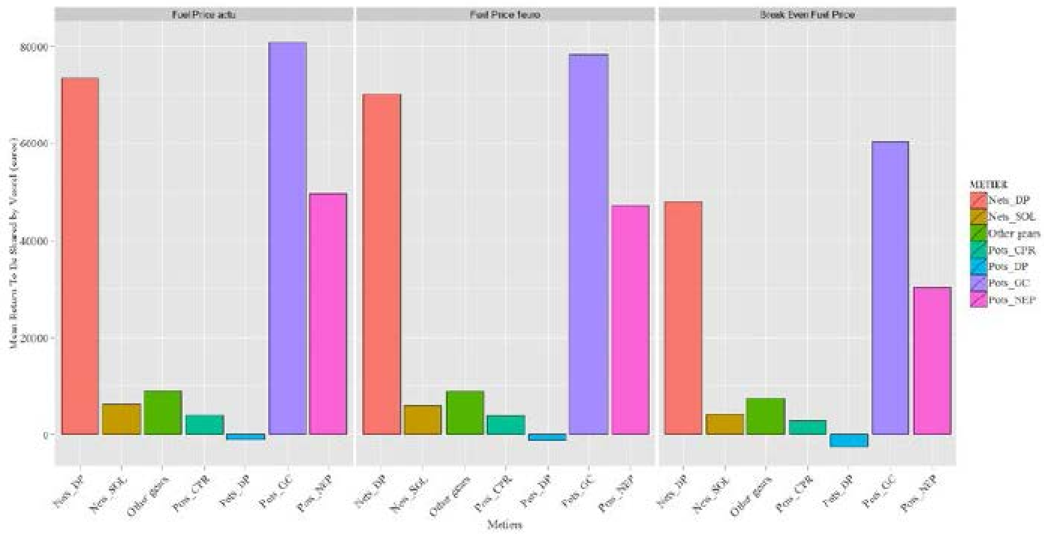

Figure 49. Impacts of fuel price scenarios on mean return to be shared per métier and vessel

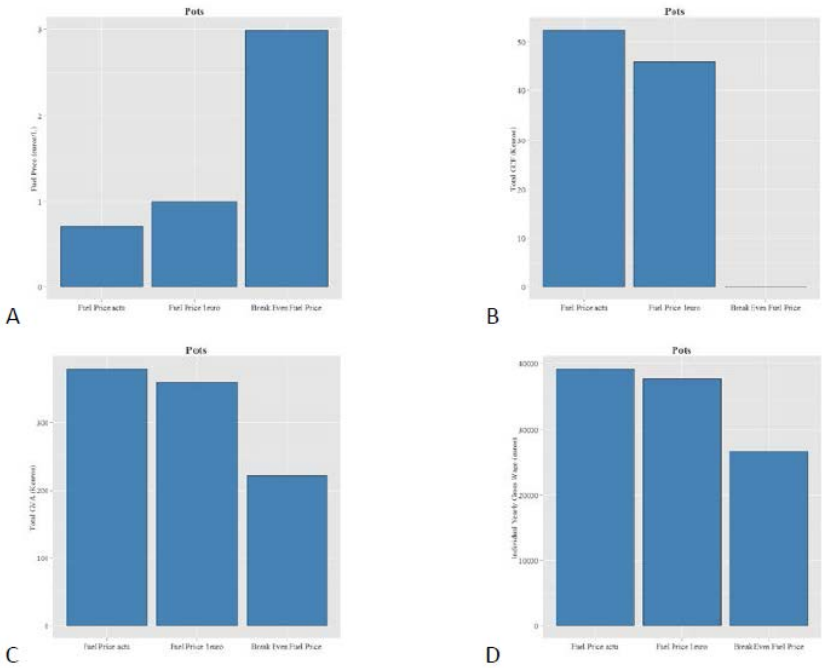

Figure 50. A. Fuel price scenarios, B. Impacts on gross cash flow, C. impacts on gross added value, D. Impacts on wages

Table 22. Impact of scenarios on selected indicators (Average vessel using Nephrops pots)

SCENARIOS		FUEL PRICE	INDICATORS	VALUE in €	% change status quo		FUEL PRICE	INDICA	VALUE in €	% change status quo
CPUE -25%/EFF -25%		0.71 euro	GVL	195191	-14%		1 euro	GVL	195191	-14%
CPUE -25%/EFF 25%		0.71 euro	GVL	222569	-2%		1 euro	GVL	222569	-2%
CPUE 0%/EFF 0%		0.71 euro	GVL	227132	0%		1 euro	GVL	227132	0%
CPUE 50%/EFF 50%		0.71 euro	GVL	318392	40%		1 euro	GVL	318392	40%
CPUE -25%/EFF -25%		0.71 euro	GCF	8928	-49%		1 euro	GCF	6927	-55%
CPUE -25%/EFF 25%		0.71 euro	GCF	14426	-17%		1 euro	GCF	12008	-21%
CPUE 0%/EFF 0%		0.71 euro	GCF	17475	0%		1 euro	GCF	15266	0%
CPUE 50%/EFF 50%		0.71 euro	GCF	43267	148%		1 euro	GCF	40641	166%
CPUE -25%/EFF -25%		0.71 euro	WAGE	33152	-15%		1 euro	WAGE	31729	-16%
CPUE -25%/EFF 25%		0.71 euro	WAGE	37060	-6%		1 euro	WAGE	35341	-6%
CPUE 0%/EFF 0%		0.71 euro	WAGE	39228	0%		1 euro	WAGE	37657	0%
CPUE 50%/EFF 50%		0.71 euro	WAGE	57564	47%		1 euro	WAGE	55696	48%

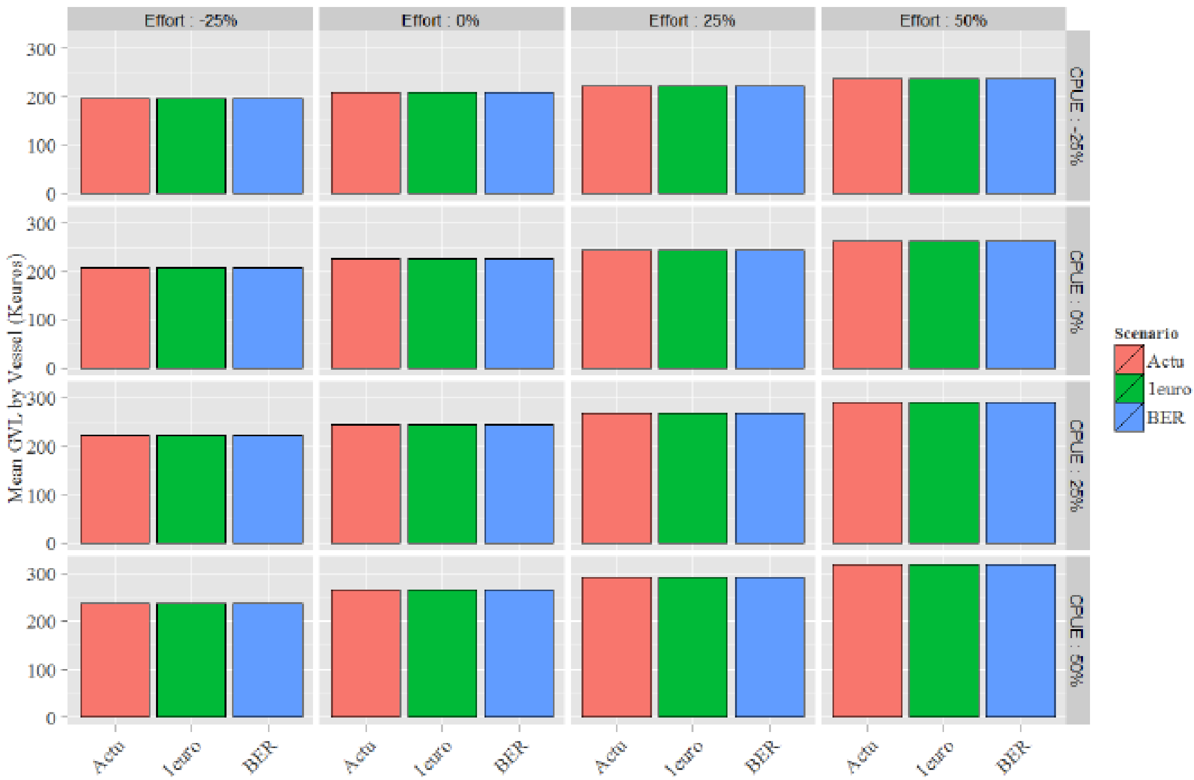

Figure 51. Impact of effort and CPUE scenarios and fuel price scenarios on GVL: Gross value of landings

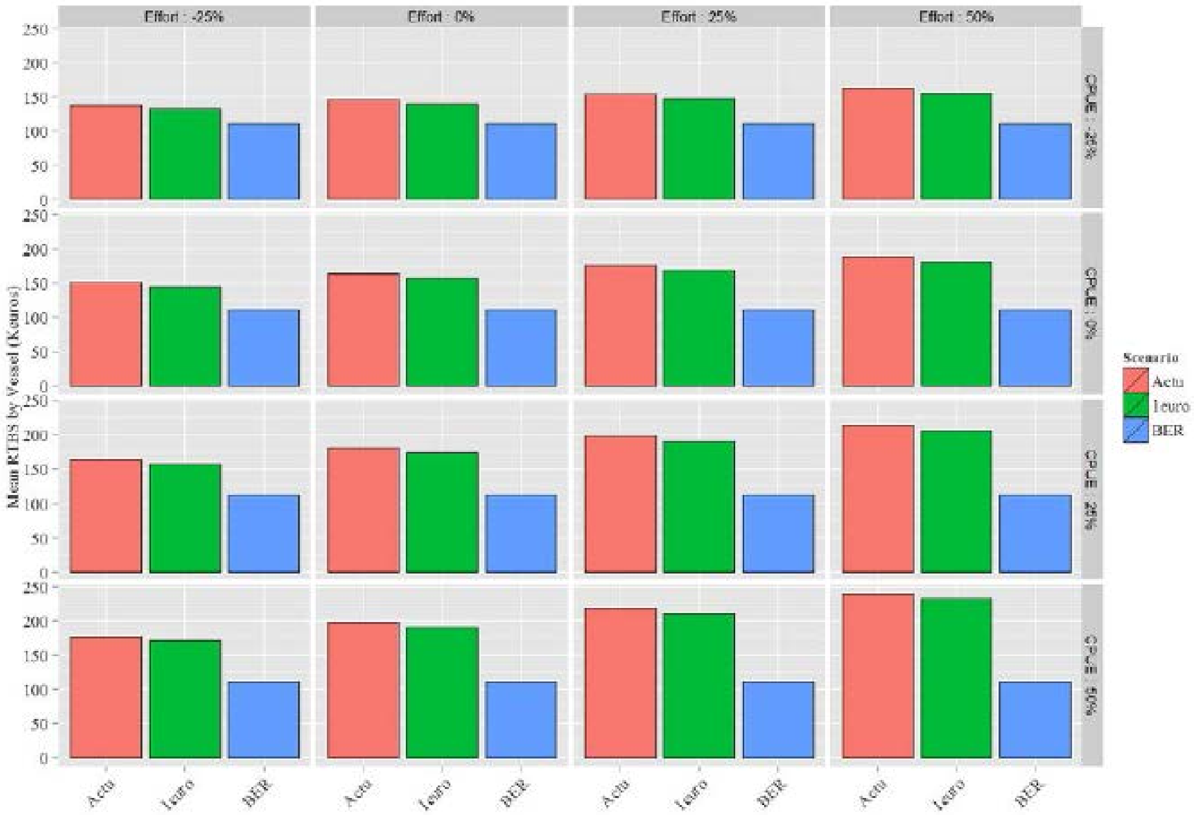

Figure 52. Impact of effort and CPUE scenarios and fuel price scenarios on RTBS: Revenue to be shared.

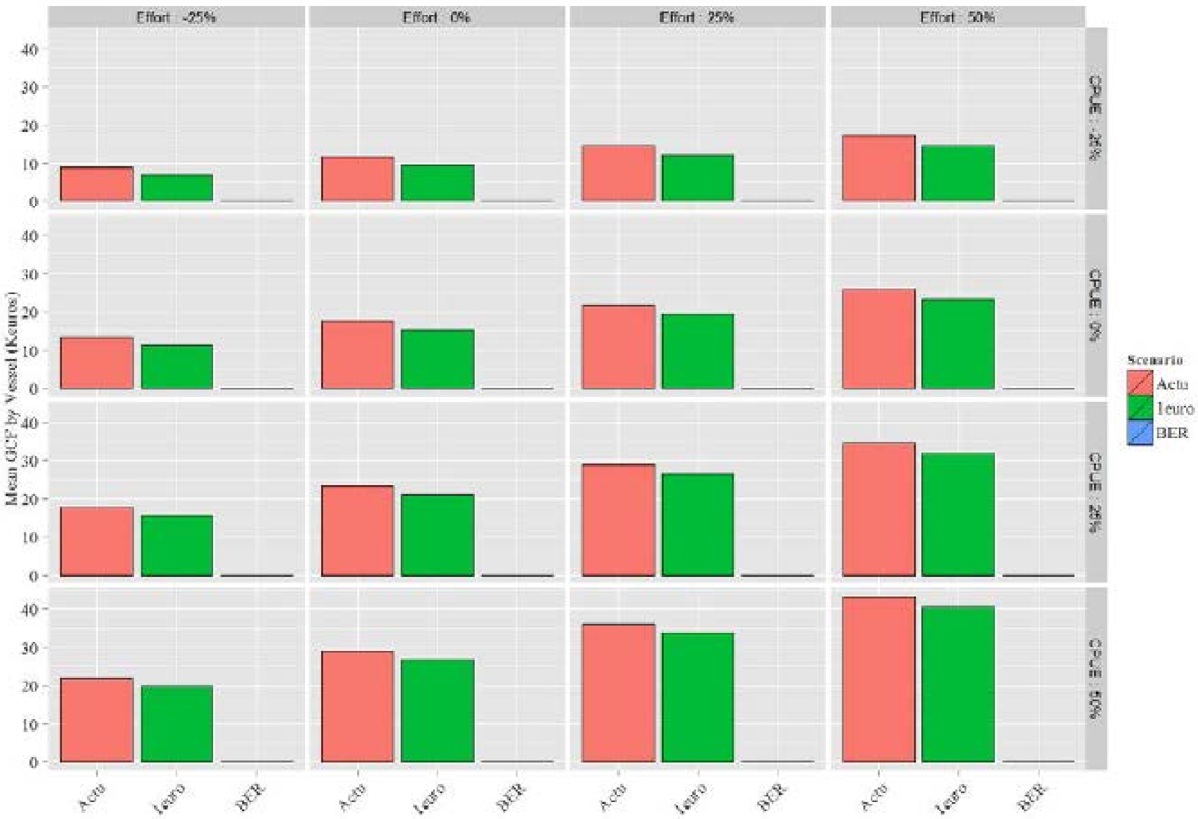

Figure 53. Impact of effort and CPUE scenarios and fuel price scenarios on GCF: Gross cash flow.

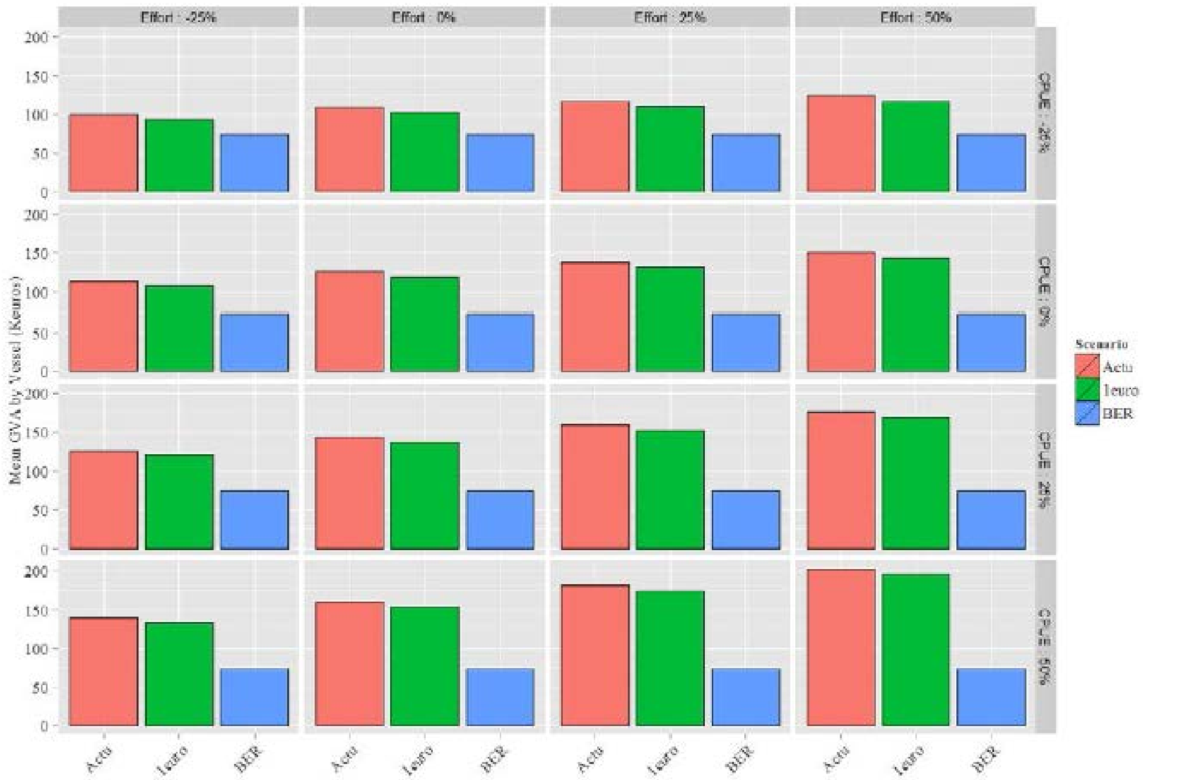

Figure 54. Impact of effort and CPUE scenarios and fuel price scenarios on GVA: gross value added.

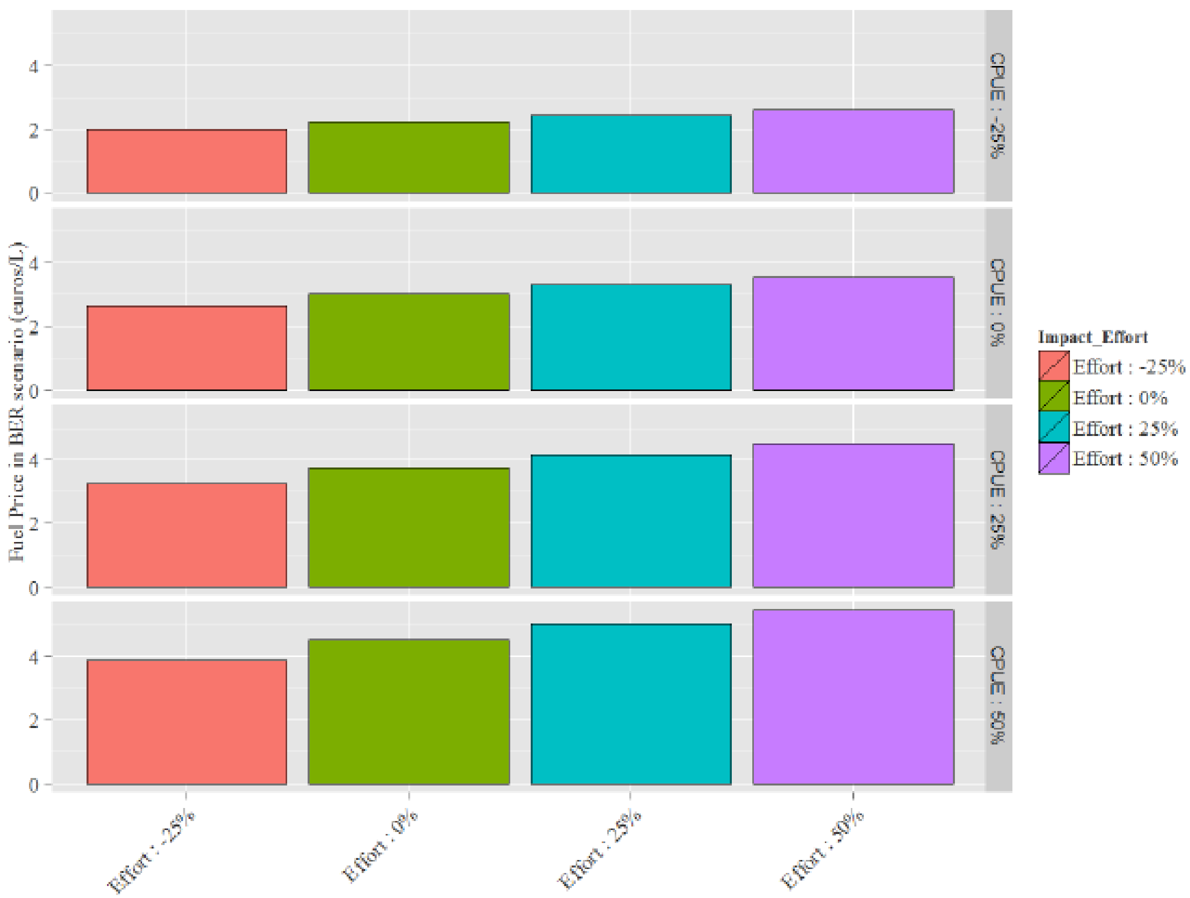

Figure 55. Fuel prices for which BER (Break- even revenue) is null considering effort and CPUE scenarios.

Discussion and conclusion

Incentives to adopt jumper

The new "Jumpers" otter-boards globally offered a positive progress as compared to the classical otter-boards (Table 23). With 55% less energy transmitted to the seafloor and 85% reduction in amount of suspended sediment, "jumpers" boards offered significant reduction of impact on benthic habitats. A reduction in vessel speed would involve around 5% to 10% less fuel consumption.

Investment costs for the jumper themselves are close to those of traditional otter-boards (around 4.5k€ each pair of otter-boards). Positive return on investment would be observed in the short term and risk is thus limited. However investment dynamic also depend on habits. Knowhow and training period required to fish with the jumper as compared to the classical board can also prevent from the adoption of "jumpers".

Surveys with the fisherman involved in experiments highlight the high requirements to fish with jumper. It especially required much more attention than classical boards during the haul. As compared to the traditional boards landed on the seafloor, the higher variability of the behaviour of the "jumpers" otter-boards imposed a permanent control of the haul parameters (otter-boards depth and spread).

It is especially true at the very beginning of the haul when warp length and vessel speed are not stabilized. Additional costs should therefore be included: cost of monitoring tools to correctly settle the trawling gear (*e.g.* MARPOR system utilized during our sea trials) and modifications to the rigging depending on the initial type of fishing gear.

From an economic point of view, dynamic of investment in the "jumpers" innovation will strongly depend on the fuel price and the fuel costs that could be spared. Fisherman had globally a very positive feeling of the new "jumpers" otter-boards from Benthis sea trials and encountered issues could be easily solved. However, conclusions about gains in fuel consumption as well as the fishing efficiency need to be reinforced by complementary observations during standard fishing trips over a longer period and involving various fishing vessels and crew.

Pro and cons of the adoption of Nephrops pots

The following Table 24 provide a synthesis of the pros and cons of adopting *Nephrops* pots by small scale <12 m vessels already using pots or nets in Southern Brittany coastal areas. A more general emphasis is given on the impact of *Nephrops* pots on the benthic habitats and stocks. High spatial and technical interactions between trawlers and potters did not enable however the development of a larger *Nephrops* pot fleet.

Table 23. Pros and cons of the adoption of Jumper by Nephrops trawlers

Criteria	Pros and cons	
Impact on benthic habitats	Lowered (55% less energy to the bottom, ≥ 85% less sediment re-suspension level, limited depth of sediment reworking)	green
CPUE & Selectivity	Unchanged or minor changes	green
	Reduced trawling surface/time ratio	red
Quality of landings	Unchanged or minor changes	green
Seasonality of the landings	A priori unchanged or minor changes	green
Landing prices	A priori unchanged	green
Investment costs	"Jumpers" ≈ classical otter-boards (≈ 4.5 k€)	green
	System to control gear parameters (*e.g.* MARPOR)	orange
	Potential investment to adapt rigging (need increased sweep length)	orange
	Potential investment to adapt fishing vessel to ensure safe onboard storage of otter-boards	orange
Variables cost	Lower fuel consumption (5 to 10%)	green
Skills	Important know how and training time, high requirements to fish with jumper, potential short term losses	red
Labour	unchanged level for crew	green
	increased level for skipper (continuous control of fishing gear parameters)	red
Security	Jumpers size > classical otter-boards	orange
	Higher variability of fishing gear behaviour	orange

Table 24. Pros and cons of Nephrops pots (NB: Adapted from Sourget et al. 2011).

Criteria	Pros and cons	
Impact on benthic habitats	Lower level of sediment reworking	green
	Greater fishing ground surface (for the same CPUE as trawlers)	red
Lost gears and ghost fishing	Probable (trawling interactions increase the risk of lost)	red
Selectivity	Good (possibility to include an exhaust grid)	green
	Good state of the *Nephrops* released	green
Quality of landings	Very good (conservation improved with refrigerated tanks)	green
	Loss in catches diversity as compared to trawlers (especially commercial fish species)	red
Seasonality of the landings	Higher catch rates during the second semester in current exploited areas. complementary métier to other fishing activities (pots or nets)	orange
Landing prices	High prices related to the size and quality of products	green
Investment costs	Quite low but depending on the number of pots used.	green
	Investment Deck gear equipment limited for potters	green
	Higher for non-specialized vessels	red
Variables cost	Quite low as compared to mobile gears Fuel costs dependent on the distance to fishing areas and the combination or not with other gears during a trip Gear costs: low maintenance and repair costs	green
Skills	Low training time for the new gear,	
Labour	*Nephrops* pots are light gear easy to work with Viewed as pleasant activity (interview)	green
Fishing area availability	Limited to narrow areas due to interactions with trawlers. Fishing in more distant areas increase the cost of operation (travelling) and increase the risk of conflicts with trawlers	red
Interactions with other activities	High spatial conflicts especially with trawlers (one of the main important drawback preventing from switch)	red

Aknowledgement: « This work has been partly supported by a public grant overseen by the French National Research Agency (ANR) as part of the « Investissements d'avenir » program (reference: ANR-10-EQPX-17 – Centre d'accès sécurisé aux données – CASD) »

Western Waters sub-Case study 2: Dredging for scallop in the north east Celtic Sea

Sub-case summary

Scallops are fished using dredges in both offshore and coastal waters of the north east Celtic Sea. The fishery encroaches on a number of European Marine Sites (EMS; SACs, SPAs). Seafloor and habitat mapping combined with VMS and high resolution VMS has facilitated the discussion and development of closed areas with the industry in order to comply with conservation objectives for these habitats. Multibeam data also provides detailed analysis of fine scale distribution of sediments (sand and gravel) and by proxy the distribution and abundance of scallop which are more abundant on gravel. These data are provided to scallop fishing vessels to improve efficiency (reduced costs, fuel consumption per unit of catch).

Technological innovations

1. Multibeam mapping of the seafloor to provide detailed high resolution information on bathymetry and sediments (reef, sedimentary)
2. Installation of iVMS (5 min reporting frequency) on inshore scallop vessels fishing in the area.
3. Mapping of fishing pressures relative to distribution of ground type (Figure 56).

Innovative management scenario's

Based on distribution of habitats from multibeam data areas closed to fishing are being proposed. The detailed seafloor maps have facilitated the discussion of the design of these closed areas with industry (Figure 57).

Discussion

High resolution seafloor maps and high resolution fishing activity data significantly facilitates the discussion of the design of closed areas with industry. The data can also be used by the fleet to direct fishing activity onto small patches of sedimentary habitats within reef and also to differentiate sand and gravel patches which have different abundance of scallop. These data are uploaded to vessel plotting systems to increase vessel efficiency and reduce fuel consumption and fishing costs per unit of scallop landed.

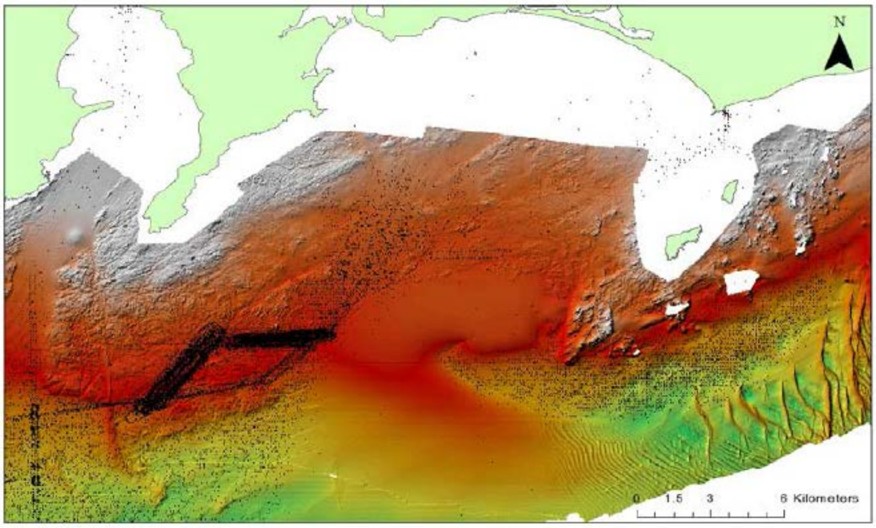

Figure 56. Shaded relief bathymetry (depth) image of the seabed off the Saltees Is and Hook Hd European marine Sites with scallop VMS data superimposed. Scallop fishing occurs in a uniform gravel bed which is deeper than the surrounding sand terrain. Highly concentrated activity is by vessels <12m in narrow channels in the otherwise rocky terrain. Reporting frequency by vessels under 12m is 5min compared to 2hrs for vessels over 15m. Shaded relief data provided by INFOMAR.

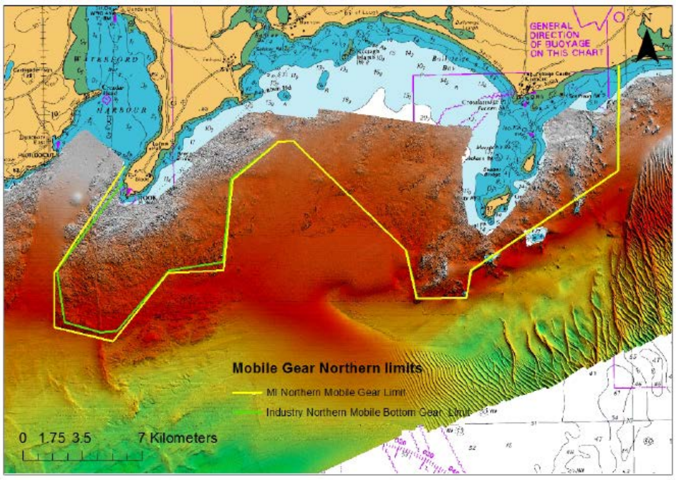

Figure 57. Shaded relief bathymetry (depth) image of the seabed off the Saltees Is and Hook Hd European marine Sites and proposed northern limits for scallop fishing. Areas north of the lines are proposed for closure to scallop fishing.

Western Waters sub-Case study 3: Hydraulic dredging for Razor clams

Sub-case summary

In the north west Irish sea razor clams have been fished using hydraulic dredges since the mid 1980s. Activity has been market led and management of the fishery has until recently been weak. In order to assess the impact of the fishery on the benthic ecosystem and determination of good environmental status (GES), to enable informed design of closed areas, to assess impacts to European marine Sites (EMS; SACs, SPAs), to enable improved seafood traceability and compliance with hygiene regulations, to enable complete monitoring of fishing effort and to develop novel methods of deriving biomass estimates from commercial catch and effort data the fleet of 70 vessels were fitted with vessel monitoring systems (VMS) that report vessel speed, position and bearing every 5 minutes. The data has been used to design stratified (based on fishing effort) impact studies of the seafloor in order to identify thresholds for fishing activity relative to specific conservation objectives in EMS and GES descriptors.

Technological innovations

Installation of iVMS

a. development of reporting system and database including GUI for real time views of vessel activities
b. identifying optimum reporting frequencies relative to known distribution of vessel fishing speeds
c. creation of fishing pressure maps (Figure 58).

Innovative management scenario's

1. *Impact assessment on the seafloor based on high resolution VMS data*

The high resolution VMS has been used in a seafloor impact study in July 2016 (Figure 60). Spatial correlations between species composition and abundance, diversity indices, community composition, side scan and multibeam imagery of the prevalence of scarring from dredging can be related to fishing pressures (dredge hrs per sq meter of seabed) in the previous months at resolution of $50m^2$.

2. *Estimation of biomass from commercial spatially referenced catch and effort data*

As it is possible to identify individual fishing operations from the high frequency of reporting relative to very low fishing speeds (<0.4knots) track length and swept area (given known dredge widths) can be estimated for these operations.

The catch associated with a number of such operations for single 12 hour (fishing day) periods is known and can be distributed across the fishing tracks for that period. Catchability is known to be very high (>90%). The significant volume of data from 70 vessels can be used to generate LPUE (kgs.m^{-2} of seabed) maps at 50m grid resolution and biomass can be

3. Spatial management of effort in relation to seafood safety and hygiene regulations

The iVMS data enables seafood safety and hygiene regulations in relation to risk of microbiological contamination to be closely monitored. There is higher certainty regarding the location of fishing and traceability to origin.

4. Design of closed areas relative to conservation objectives of EMS

A number of EMS occur within the area of the fishery. The fishery occurs on the borders of a number of SACs and SPAs. High resolution VMS enables the interaction of the fishery and these sites and their constituent habitats to be closely monitored.

5. Potential to change the fishing method from hydraulic dredging to electro-fishing

Based on assessment of the relative impacts of dredging and electro-fishing the options to change between these fishing methods are being explored.

Multibeam and side scan sonar mapping

The area where the hydraulic dredge fishery operates was mapped using Multibeam and side scan sonar (Figure 59).

Discussion

The implementation of high resolution VMS data on inshore fishing vessels using hydraulic dredges to fish for razor clams in the Irish Sea has enabled improved monitoring of fishing pressures, fishing location relative to protected sites and impact assessment of benthic habitats affected by fishing. Although the improved data provision has not yet led to reduced impacts on benthos the data and data products are necessary precursors to demonstrating the level of impact and in designing the solutions with industry.

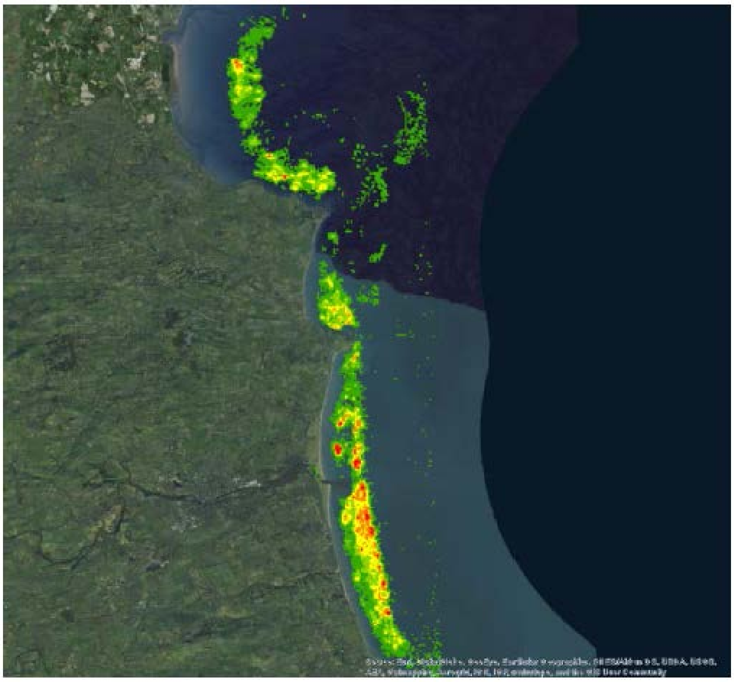

Figure 58. Fishing pressure map for dredge fishery of razor clams north Irish Sea in 2015 at 50m² resolution

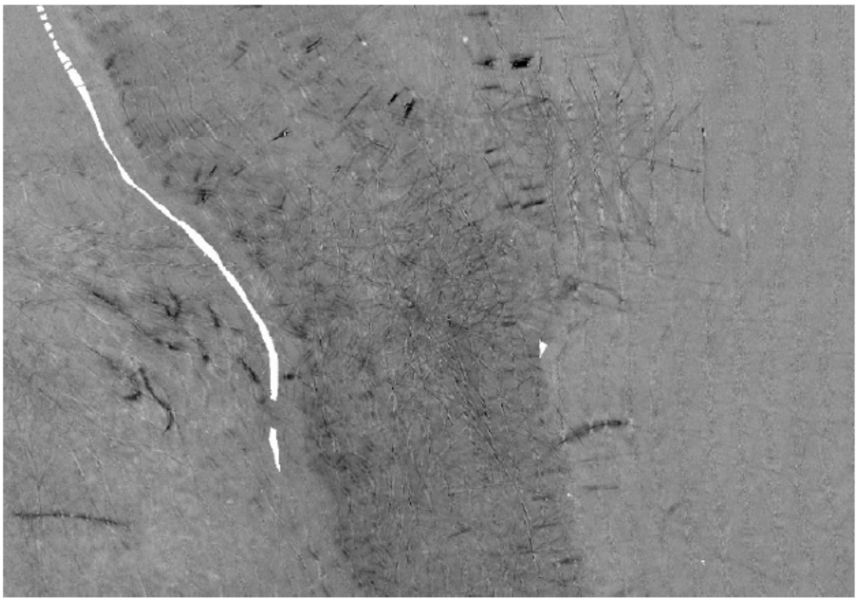

Figure 59. Dredge track scars on the seafloor derived from multi-beam data in the North West Irish Sea

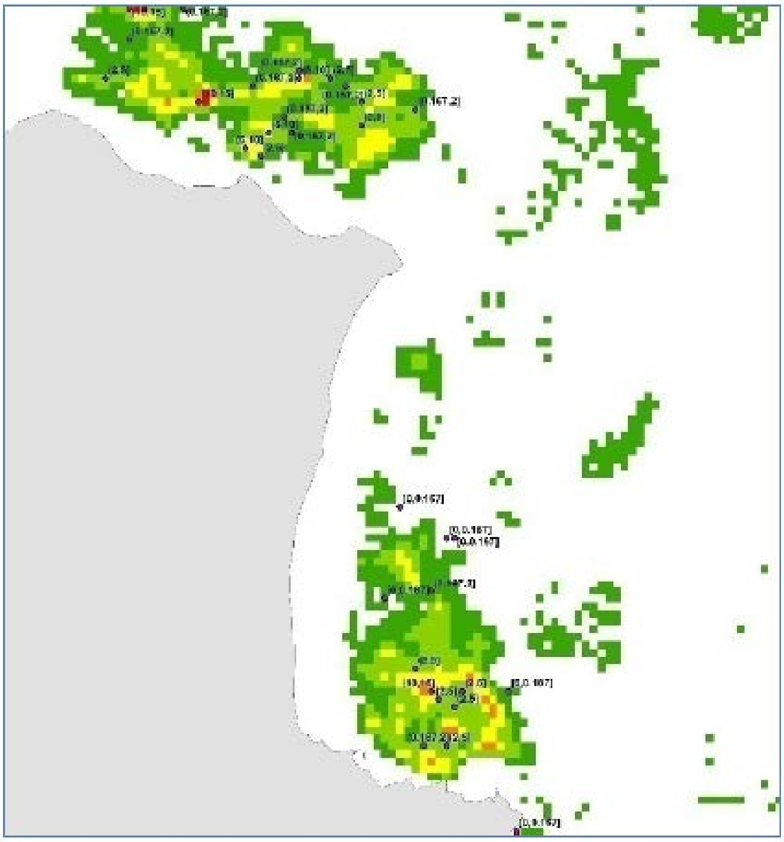

Figure 60. Assessment of impacts of dredging on the seafloor using a stratified random station allocation over high resolution (50m²) VMS data.

Western Waters sub-case study 4: VME's interacting fisheries from the bay of Biscay to the Norwegian Sea

Sub-case summary

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 26) and followed by others closures in the following years. In the North East Atlantic in recent years, the Northeast Atlantic Fisheries Organisation (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 (Figure 61).

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, Table 26). 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 focused on a restricted list of sensitive habitats (Table 25). Description and maps of those habitats are given into the deliverable D7.6. In the Bay of Biscay we exclusively analysed fisheries interacting with soft bottom CWC habitats.

Table 25. List of vulnerable marine ecosystems (VME) that have been 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	
Umbrella stands		X	
Glass sponge community		X	

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

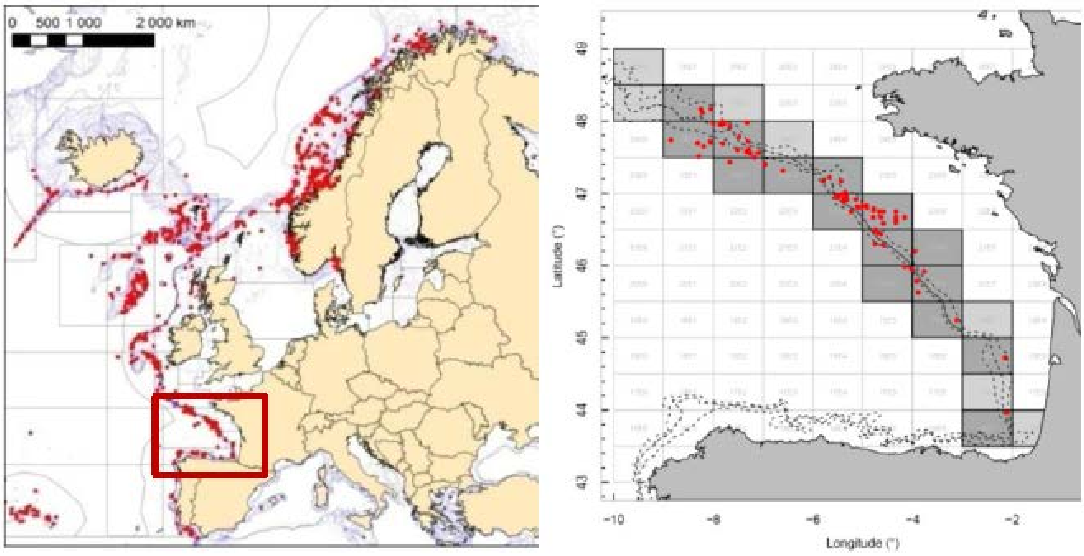

Figure 61. Observed CWC (Lophelia & Madrepora) in the BoB from poor dataset (Ospar dataset), Main CWC area of the french EEZ from 200 to 1000m

Table 26. 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)				

Presentation of some realistic options for the Case Study Region

CWC of the Bay of Biscay

The bathymetric distribution of the density of fishing operations (expressed in hours/km^2, Figure 63) 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. 2012) 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 highlighted a high dispersion feature of the fishing activity over the fishing grounds of the shelf break. It indicates that spatial management rules restricting fishing areas to those with the highest fishing effort 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.

To complete that previously realized work, high resolution VMS data have been utilized to derive distribution of fishing events on CWC locations of the Bay of Biscay. CWC habitat distribution is still not well defined for the Bay of Biscay. Bottom characteristics and hydrological processes that favor 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 helped us to better define how much those fishing grounds benefit to the fisheries. Such an analysis allowed us to evaluate the consequences of the implementation of new spatial management rules (*e.g.* implementation of closed MPAs).

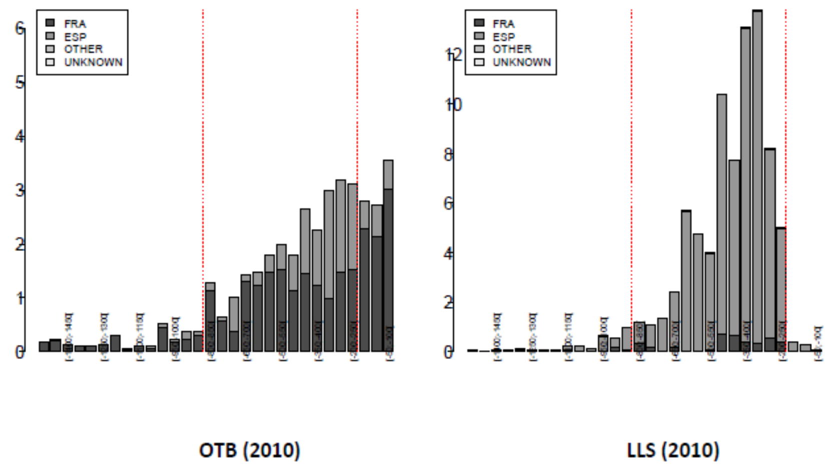

Figure 62. Bathymetric distribution of fishing activity (yearly total duration of fishing operations expressed in hours by km2) in the bay of Biscay for main active (OTB) and passive demersal gears (LLS, GNS and FPO) potentially operating in the CWC area of the Bay of Biscay in 2010. Data are derived 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.

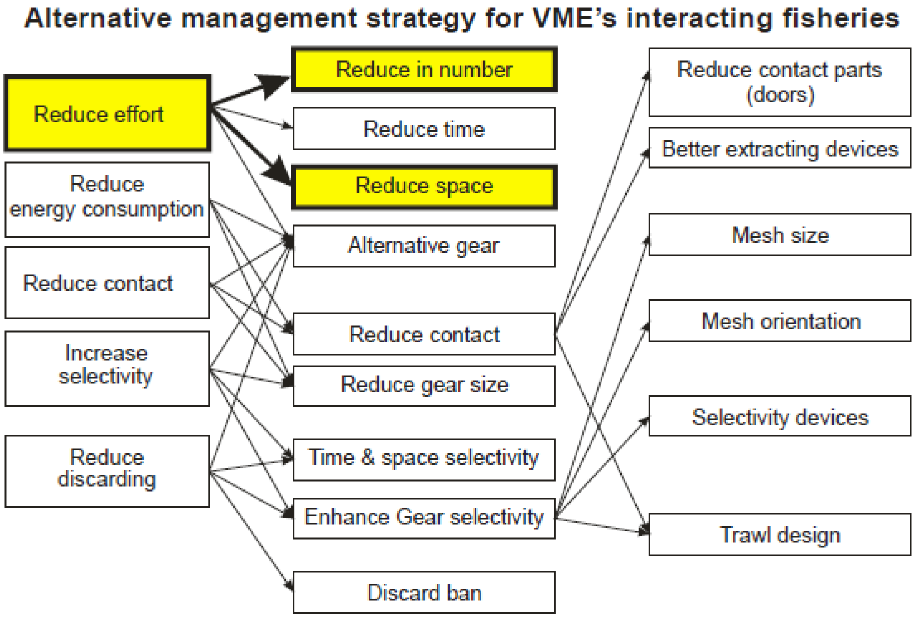

Figure 63. Diagrams of the option to be tested in the sub-case study: fisheries interacting with VME's in French and Norwegian waters

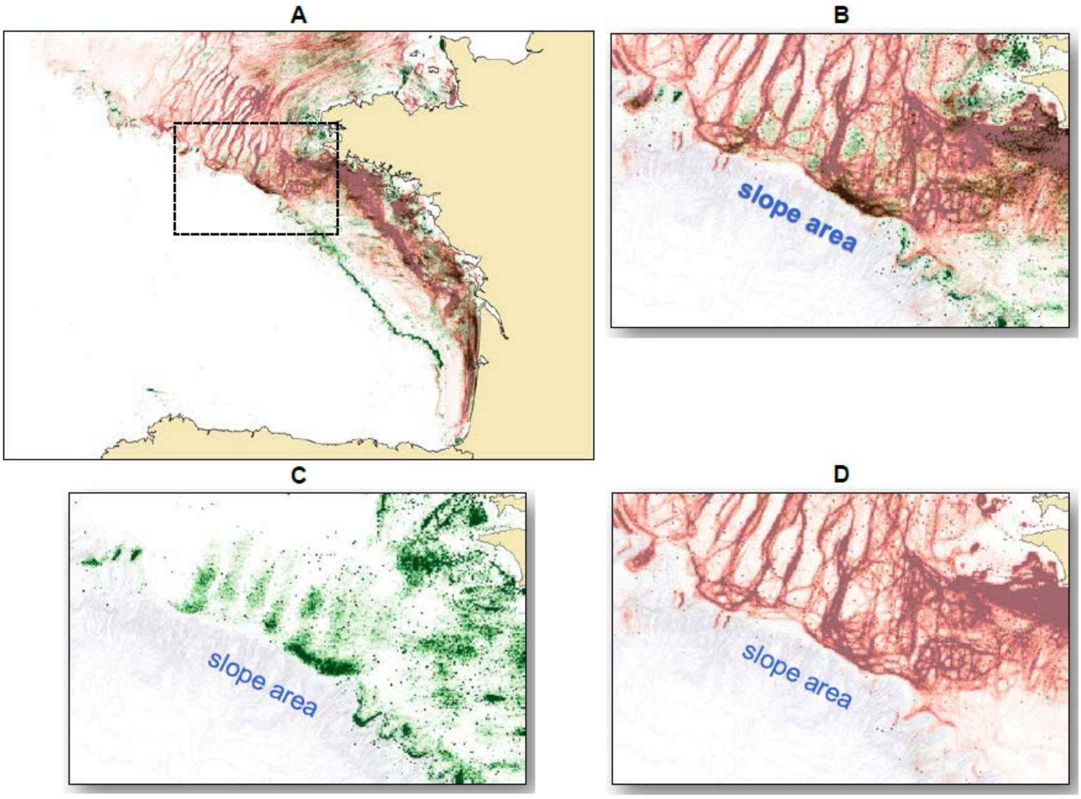

Figure 64. Distribution of fishing activity from raw VMS records in 2013 for A. the whole Bay of Biscay for towed gears (in red, OTB,OTT,PTB) & passive gears (in green, GNS, LLS, FPO, GTR), B. a zoom in a representative part in the northern part of the BoB for both types of gears, C. zoomed area for the static gears only and D. zoomed area for the towed gears only.

Norwegian VMEs

Lophelia reefs are the only category of VME that is protected directly by Norwegian law. In the marine resource law "Havresursloven" the rule of conduct§ 66 *Forbids fishing activity close to coral reefs.*

- To protect coral reefs against destruction related to fishing activity…..increased cautionhas to be taken when fishing is conducted in the vicinity of known occurrences of coral reefs.
- It is forbidden to wilfully destroy coral reefs
- It is forbidden to fish with gears that are towed during fishing and could touch the seafloor in 19 specified areas.

One important objective has been to inform Management and fishers about distribution of VMEs. Position of reefs has been delivered directly to fishermen organization for use on the electronical map system used in fishing boats e.g.Olex or MaxSea. The information of the distribution of VMEs in areas mapped by Mareano (Figure 66) has helped in the process of MSC's fisheries certification for some fisheries.

The Mareano mapping programme allowed for an analysis of chronical impact from bottom trawling (Buhl-Mortensen et al. 2015) by comparing trawling activity last three years with observed fauna and trawl marks on the seafloor. This study concluded that diversity and abundance of long-lived megafauna decreased in areas with high fishing activity and that some sponge species were particularly vulnerable.

Other rules are applied by Norway to avoid fishing on VMEs. Nicols et al (2014) states that impact on VMEs such as corals are considered to be low due to higher risk of gear loss and gear damage in these areas and their complete avoidance by trawler skippers. "There are rules for avoiding known areas and move on rules if coral or sponges are encountered. These rules are statutory with regards to coral and sponge, not voluntary."

"Regulations applicable to coral habitats (e.g. reporting of by-catches of corals and respecting move on rules, marine protected areas and 12 nm ban on trawling of the baseline, where the most of coral habitats are located) by cod and haddock fishing vessels in the UoC seems to be respected. Skippers are also required to avoid all known coral reefs and report all catches of coral >60 kg and sponges >800 kg (but frequently report lesser quantities: Directorate, pers comm.), and move on ≥2 miles."

"PI 2.4.1 (Principle): The fishery does not cause serious or irreversible harm to habitat structure and function

Sponges: Principal areas of sponge communities have been mapped and others are known. There are regulations to protect sponge communities and precise GPS navigation and ground-discrimination echo sounders enable vessels to avoid known areas of sponge with a high degree of reliability and compliance (Directorate of Fisheries). Directorate is satisfied that there is a high degree of compliance with protection measures. Score 80.

Burrowing megafauna: Most burrowing fauna, indeed, most epibenthic fauna are not subject to direct effects of rock-hopper trawls. The principal possible exceptions are the (flexible) upright Pennatulacea – sea pens. Their distribution is known in the MAREANO mapping area, and they are widely, albeit sparsely, distributed throughout the Barents Sea, which suggests that the fishery is unlikely to reduce habitat structure and function to a point where there would be serious or irreversible harm even though they are vulnerable to damage or removal. Score 60.»

Reference for "Move on rule": 0 J128-2011. Regulations on regulation of fishing with bottom gear in the Norwegian economic zone, fishery zone around Jan Mayen and the fisheries protection zone around Svalbard. http://www.fiskeridir.no/fiske-og-fangst/j-meldinger/gjeldende-j-meldinger/j- 128-2011 also http://www.fisheries.no/ecosystems-and-stocks/Environmental-measures/Vulnerable-marine-ecosystemsprotected-in-Norwegian-waters/#.VMPF2V5yZ9A

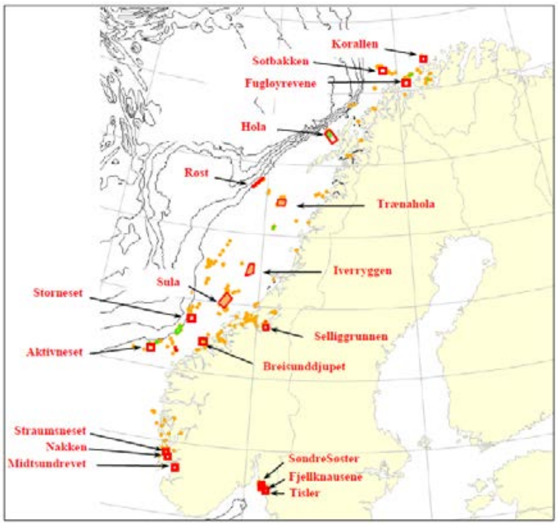

Figure 65. Protected Lophelia-reeds in Norway (updated 2016). Orange dots: single reefs; Red polygons: coral protection sites; and Green areas: reef areas. MAREANO-Seafloor mapping initiative 2005-16 was started to provide information to secure sustainable resource use and ecosystem based management.

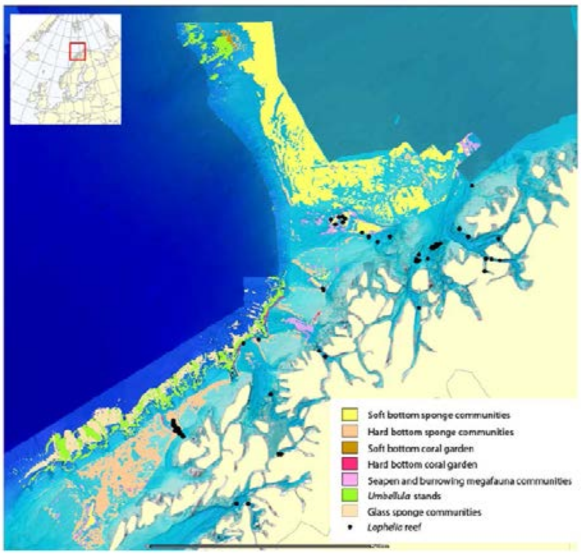

Figure 66. Distribution of VMEs in areas mapped by Mareano

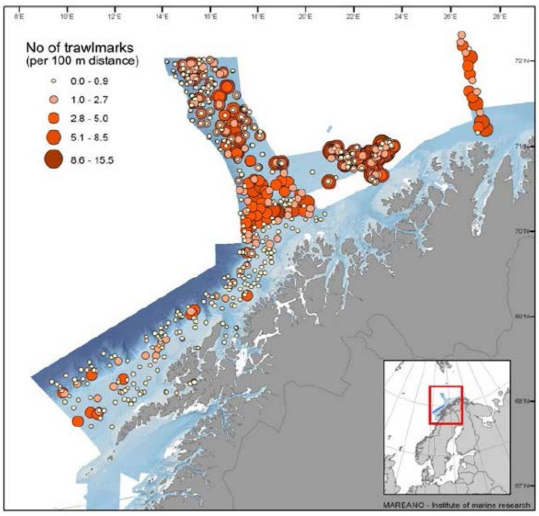

Figure 67. Trawlmarks observed on video. Size of circle indicates numbers observed per 100 m bottom recorded.

Innovative management scenario's / Discussion

Mitigation of fishing impact on the CWC habitats of the Bay of Biscay

From the VMS data analysis realized in Benthis, we get new valuable insight on the fishing effort distribution over the main potential CWC areas of the Bay of Biscay (BoB). Results confirmed the high fishing pressure encountered by upper continental slope habitats by trawling and to a lesser extent by static fishing gears.

From 2005 to 2013, 55% to 75% of the "continental slope, within 200-1000m depth range, was submitted to some trawling pressure (Figure 68 and Figure 69). However, during the same period, 90% of the trawling effort only covered 25 to 35% of the slope area. Moreover, level of trawling pressure significantly and constantly decreased from 2009 onwards.

In the bay of Biscay continental slope fishery for both towed and passive gears, a large proportion of landed fishes are species occurring both on the slope/deepest areas and over the whole continental shelf (Figure 70). Those ubiquist species (mainly Monkfish, Hake, *Nephrops* and Megrim) represented more or less 90% of the landed biomass in the 200m to 1000m depth area during the 2005 to 2013 period. It highlighted that CWC would hardly benefit from management rules based only on Deep water species targets regulations.

Only specifically designed MPAs network over the margin would help to ensure an efficient protection of those fragile ecosystems. Those MPAs has to be based on knowledge about CWC habitat distribution, reefs viability and resiliency capabilities. Accurate maps of CWC habitats are the main missing information for the BoB to efficiently define those MPAs network.

Such maps are being developed from newly acquired observations records (*e.g.* high resolutions records with ROV over the BoB slope) as part of others scientific projects (*e.g.* EU-H2020-ATLAS). They will be completed with modelling effort from empirical observations of links between healthy CWC habitats and optimal chemical and geological features. Those maps will help to better define areas of interest in order to develop a spatial management strategy of fishing and others anthropogenic activities as well over the BoB deep habitats.

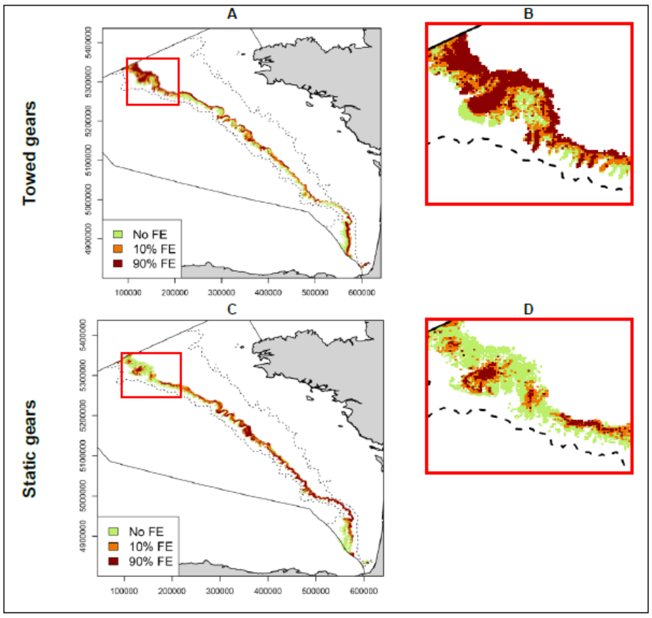

Figure 68. Estimation of the proportion of the Bay of Biscay (BoB) habitats in the depth range 200-1000m submitted to fishing effort (FE) corresponding to 3 thresholds: 90% of the FE, 10% of the FE and with no fishing effort as derived from VMS maps (BENTHIS algorithm). Example is given from VMS dataset of 2013 for the whole BoB for tow and static gears (A and C respectively) and for a zoom over the northern part of the slope. Dashed lines figure the 130 and 2000m isobaths.

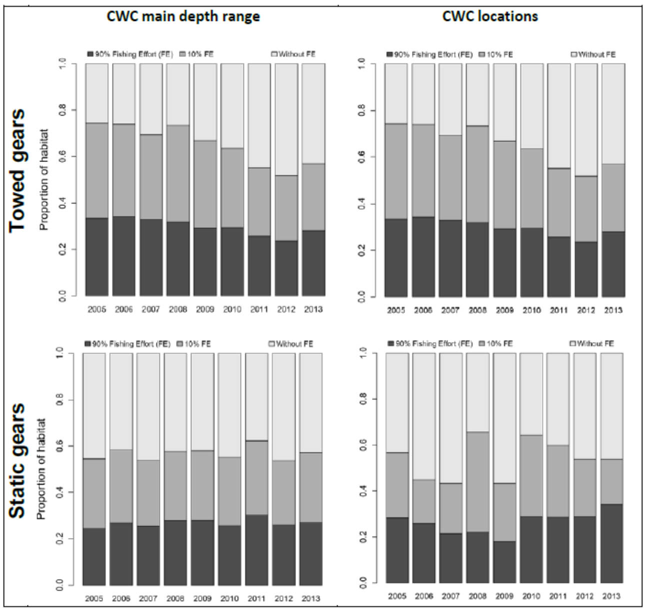

Figure 69. Proportion of habitat corresponding to 90%, 10% and no fishing effort (FE) for the years 2005 to 2013. Two main gears types, towed and passive gears, and two areas, CWC main depth range (n=8887 cells) and observed CWC locations (n=80 cells) are considered.

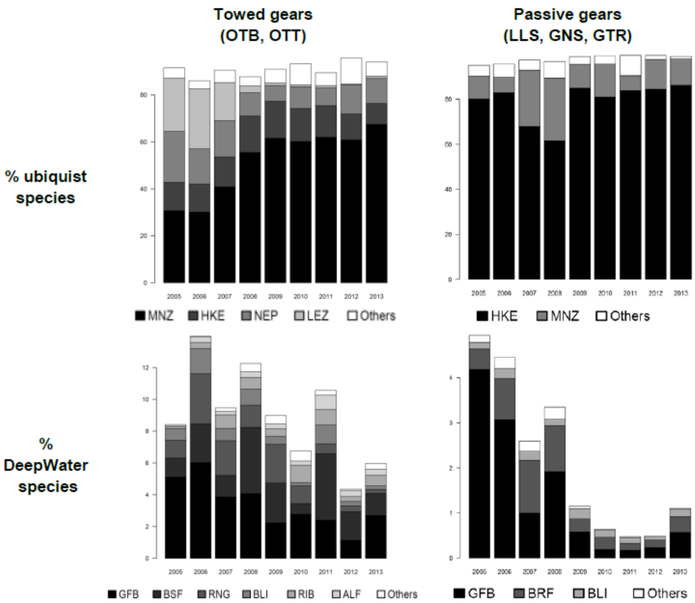

Figure 70. Proportion in the total catches biomass of the ubiquist species (i.e. species occurring on the slope and deepest areas and over the whole continental shelf) and "deep-water" species. Lophius spp. (MNZ), Merluccius merluccius (HKE), Nephrops norvegicus (NEP), Lepidorhombus spp (LEZ), Phycis blennoides (GFB), Aphanopus carbo (BSF), Molva dypterygia (BLI), Coryphaenoides rupestris (RNG).

Table 27. Mean values in% of cells with fishing effort and tendencies over the period 2005-2013 for the two considered areas, CWC depth range (200-1000m) and CWC recorded locations.

		Static gears (LLS, GNS, GTR)	**Trawlers (OTB, OTT)**
	% vessels / total fishing fleet	5% (**36**/680)	13% (**69**/530)
CWC depth range (200-1000m)	% cells submitted to some FE	64% →	68% ↘
	% cells submitted to 90% of FE	**30% →**	**31% ↘**
CWC recorded locations	% cells submitted to some FE	54% →	72% ↘
	% cells submitted to 90% of FE	**26% →**	**37% ↘**

Mitigation of fishing impact on benthos in Norwegian waters

A series of recommended actions to be taken to mitigate fishing impact has been reported by the Institute of Marine Research expert group (Buhl-Mortensen et al 2013 pp 51-53). The committee outlines nine measures that should be taken but point out that this is a constantly changing field, both in Norway and internationally.

The proposed measures should therefore be seen as stages in a process, to be revised and expanded as required. From those measures, height of them are of relevance for BENTHIS project to reduce trawling impacts over VMEs.

➢ Introduce trawling techniques with a lower impact on the seabed

Current bottom trawling practice and certain other fishing techniques can have a harmful impact on sediments. The committee wants to outline the following measures that could help to reduce those impacts:

- Changes to rules and regulations to promote a gradual transition to fishing gear types and fishing methods with a lower impact on sediments.
- Improvements to existing fishing technologies and techniques in order to reduce the impact on the seabed.

➢ Report observations made by the fishing fleet in a format that allows further analysis

Both the new Norwegian bottom trawling regulations and a NEAFC rule state that in the event of hitting corals or sponges, fishing vessels should stop fishing, move two nautical miles away from the area and report the type and quantity of coral/sponge. The committee believes that there ports of the fishing fleet on benthic organisms in their catches will be an important source of data to help with managing seabed habitats. Moreover, it is important for this data to be available in a format that allows further analysis. The committee believes that these reports should be included in the electronic reporting system, which requires resources to set up, and that the data should be presented in a way that allows further analysis (cf. letter from the Ministry of Fisheries and Coastal Affairs of 26 March 2012,and the response from the Directorate of Fisheries/IMR of 11 June 2012).

➢ Produce a handbook for classifying sponges and corals

A handbook (with illustrations/photos) of relevant benthic fauna/groups of benthic fauna should be produced, to help the fishing fleet classify these creatures in its electronic reporting. The Institute of Marine Research has started work on producing identification guides (code lists and species identification sheets) for sponges and corals. This work is being done in collaboration with the Directorate of Fisheries, and the final product is intended for use on fishing vessels over15 m (12 m in Skagerrak). This measure will help to improve the quality of future reporting bythe fishing fleet. The level of taxonomic identification required for reporting must be realistic. The identification guides will be made available through the catch log on the Directorate of Fisheries' website.

➢ Mapping coral communities

In the management plans for the Barents Sea and Norwegian Sea, mapping coral communities is listed as a very important priority. Moreover, the Marine Resource Act of 2009 forbids trawling on known coral communities. Meanwhile, our knowledge about the distribution of corals and other habitats in Norwegian waters is growing. The Institute of Marine Research has worked with the Directorate of Fisheries to get quality-controlled data on coral communities included on sea charts. The current status of this project is that a list of coral reefs to be included on sea charts has been sent to the Norwegian Hydrographic Service, with the Ministry of Fisheries and Coastal Affairs being in charge of what happens next. The committee recommends that the completion of this project be prioritised.

➢ Improve the "Fisheries table"

As part of the implementation of the Marine Resource Act, the "Fisheries table" was introduced as a tool to help with prioritisation, and to provide a summary of the impacts of the various fishing gears on ecosystems. This is a very useful starting point for assessing how to monitor and prioritise measures as part of a practical approach to ecosystem-based management. The Directorate of Fisheries and The Institute of Marine Research should also consider whether the table can be improved and be made more useful.

The committee proposes the following measures as possible improvements:

- Including information such as the fishing time/affected area, extent and catch/bycatch.

- Include confidences (e.g. with categories such as "no underlying data", "anecdotal
- information", "scientific experiment")
- Add relevant variables (columns) to the table
- Establish a weighting system for the relative importance of the variables, so that a reasonable balance can be achieved between various factors
- Formalize the process for updating the fisheries table, for instance by introducing an annual review by representatives of the industry, scientific community and management authorities

➢ Assess reference areas to help study of fishing impacts

The committee believes that reference areas are an important tool for mapping fishing impacts on sediments and seabed habitats. The committee suggests that the following actions be considered:

- Protect some untouched habitats (where there has been little or no bottom trawling to date)
- Compare areas where bottom trawling does and doesn't take place (with the same sediment types)
- Study the effect of stopping bottom trawling in areas with intensive trawling activity
- Study the effect of increasing trawling activity in areas with little or no activity
- Introduce protected areas (MPAs, trawl-free zones or other forms of protection) in order to protect particularly vulnerable areas

➢ Awareness about newly ice-free areas in the Arctic that may become exposed tofishing activity

The new areas that become available for fisheries in the Arctic as the ice retreats are in principle untouched by fisheries. The committee believes that it will be useful to initiate research in these areas, in order to provide advice on the use of fishing gears and impose any local restrictions.

➢ Establish a multi-disciplinary group

The committee proposes setting up a group with multi-disciplinary expertise, which can help to monitor the current situation and advise on the introduction of new measures. The committee believes that the following areas of expertise should be represented: seabed habitats, fisheries research and fishing gear technology.

This group should study reports sent by fishing vessels when they hit vulnerable habitats, as well as data from research vessels, hired fishing vessels, MAREANO and the reference fleet. Based on its assessments, the group should advise on new measures to reduce the negative impacts of fishing on benthic organisms.

NORTH SEA

Authors: Hamon, K. (2), Polet, H (1), Bartelings, H. (2), Batsleer., J. (3), Buisman, E. (2), Bush., S (4), de Vos, B., Hiddink, J.G. (5), Hintzen, N., Piet, G.J., Poos J.J. (3), Scherders, V (2)., van der Reijden, K.(3), Vanderperren E. (1), van Overzee, H., Turenhout, M. (2), Verlé K. (1), Rijnsdorp A.D. (3).

Institute: (1) ILVO, Oostenden, Belgium; (2) Wageningen Economic Research; (3) Wageningen Marine Research; Wageningen University; (4) Bangor University.

Case Study summary

The North Sea case Study focused on the mitigation of the benthic impacts of the beam trawl fisheries for sole and brown shrimp. The options for mitigation studied were the use of electricity as a technological innovation (pulse trawls replacing traditional beam trawl), and the use of a habitat credit system as an alternative management system.

Several field studies show that flatfish pulse trawls are more selective in catching sole. The catch rate per swept area of sole, the main target species, is at least equal to the catch rate of a traditional beam trawl (van Marlen et al., 2014), but there are recent indications that the efficiency may have increased (Rijnsdorp, pers comm). The catch rate of other fish species tend to be lower, while the catch rate of benthos is greatly reduced (van Marlen et al., 2014).

Also, the penetration of the pulse trawl is lower as compared to the tickler chain beam trawl (Depestele et al., 2016). An important improvement of the flatfish pulse trawl is the reduced towing speed. This implies that benthic impact when expressed per kilogram of sole, may be reduced in comparison with the conventional tickler chain beam trawl.

Field studies with shrimp pulse trawls and comparison of the shrimp beam trawl and the shrimp pulse trawl showed that any effect on catches and seafloor disturbance depends on the design of the trawl, which is now steered by regulations that still allow a large degree of freedom.

A sea trial covering several seasons has demonstrated that, if the pulse trawl is designed to reduce impact, it is possible to attain an up to 75% reduction of unwanted by-catch (undersized commercial fish, non-commercial fish and non-commercial invertebrates) and an up to 80% reduced seafloor contact.

This trawl then still allows a small increase in commercial shrimp catch of up to 10%. Two comparative fishing experiments in the Benthis project with a traditional shrimp trawl and a pulse trawl were inconclusive. In an indirect way, seafloor disturbance could be demonstrated but as to a difference in seafloor disturbance between the two gears, no significant difference could be shown.

In this report, the economic consequences of the gear transitions and the drivers of the technological change are studied in order to get insight in the factors that may promote or hamper the use of more environmental fishing technologies.

The studies show that the pulse trawl is economically more profitable than the traditional beam trawl when targeting sole. This is particularly true when fuel prices are high and also when the landing obligation is implemented (because the catch is more selective).

In the Dutch fishery, the wages of the crew operating with pulse are also higher which probably explain the support that the pulse trawl received from the crew. However, this is not the case in the Belgian fleet where crew wages are based on value of landings only (as opposed to value of landings minus fuel price in the Dutch fishery). In addition to the good economic performances of the pulse trawl, non-economic factors have played a role in the uptake of the pulse trawl in the sole fishery.

In particular, the information sharing amongst fisher through study groups and demonstration days have accelerated the process in the Netherlands. The support of the Dutch government was also influential. In contrast,

barriers such as limiting days at sea in the North Sea for Belgian fishers and the controversial image of the pulse in Belgium may have hindered the adoption of pulse in Belgium.

While the pulse trawl for sole has successfully been adopted in the Netherlands, the uptake in the shrimp fishery remains limited. The positive impact of the pulse on the economic performance of shrimp fishers is lower than for sole. The fuel use is only decreased by 10% while the commercial catch is slightly increased. In addition, the number of pulse licences in the shrimp fishery is low and the industry itself is conflicted about the introduction of the pulse trawl because if the increase catchability led to higher landings from the pulse trawlers (there is no TAC in the shrimp fishery), this would mean a drop in the shrimp price for everyone.

In addition to the technological innovations, the simulation study of the habitat credit system revealed that innovative management measures may create incentives for fishers to reduce the benthic impact of their fisheries. It is expected that targeting the fishing ground with higher catch rates would also lead to a positive impact on the economic performance of the fishery.

The habitat credit system was received positively by stakeholders who see potential application in the certification of individual fisheries. In the following sections, the results of the different studies are summarised.

Technological innovations

Introduction of pulse

Economic performance of a transition to pulse trawling: two case studies in the North Sea flatfish fishery (for full text see appendix A)

Katell Hamon, Katrien Verlé

We investigated the transition from traditional beam trawl to pulse trawl in the North Sea flatfish fishery using two fleets as case study. The Dutch fleet of vessel larger than 40 m which already transitioned to pulse since the early 2010's and the Belgian fleet of vessels between 24 and 40m which hasn't transitioned. It appears that for both fleets, the pulse is an economically viable metier, especially when the price of fuel is high.

However, additional rules and regulations such as days at sea limitation in the North Sea per vessel, or limiting sole quota and the controversy still surrounding the use of pulse in European waters are barriers to investment. The same is true for diversification of fishing activity towards the plaice stock.

The larger mesh size metiers are viable, especially with moderate to low fuel prices, but the cod management plan has drastically limited the possibility to switch effort to the plaice targeting metiers.

We usually assume that investment in new gears such as shifting from traditional to pulse trawl is decided by skippers/owners only. However we found that the Dutch wages were the highest fishing with pulse whereas Belgian wages would be the lowest fishing with pulse as the reduction of fuel costs is not passed on to the crew. This could partly explain the lack of support within the Belgian fishing industry while Dutch crew members seem to have pushed to switch to pulse.

Comparing the costs of the landing obligation for traditional beam trawl gears and pulse trawling in the Dutch cutter fleet (for full text see appendix B)

Erik Buisman, Mike Turenhout

This study is an update of Buisman et al 2015, for which discard rates per gear were used in order to assess the potential impact of the landing obligation on vessels using traditional beam trawls and vessels using pulse trawls. This study shows that the extra costs caused by the landing obligation are much lower for a pulse trawler than for a beam trawler.

An important limitation of this study are that the data on extra labour costs for sorting and handling fish on board and on shore are based on just a few pilot trips.

Similarly the data on prices for selling of undersized fish is based on just a few transactions. Nevertheless the analysis in this study shows quite convincingly that a pulse trawler will probably suffer much less from the extra costs incurred by the landing obligation than a beam trawler. Besides the lower fuel costs for pulse trawlers this can be seen as an additional economic advantage of pulse trawling over beam trawling under the new CFP.

Mixed fisheries management: Is the ban on discarding likely to promote more selective and fuel efficient fishing in the Dutch flatfish fishery?

Batsleer, J., Rijnsdorp, A. D., Hamon, K. G., van Overzee, H. M. J. and Poos, J. J. (2016) Fisheries Research, 174, pp. 118-128.

We model the potential effects of a discard ban on the annual fishing strategy of individual fishers in a mixed fishery under individual quota management. The North Sea beam trawl fishery, which catches large amounts of undersized plaice, is used as a model system. Under a discard ban, fishing is restricted to the fishing grounds and weeks where the maximum revenue can be realised with other species while catching the quota of the restricted species with a reduced bycatch of undersized fish.

Model results suggest that, if properly enforced, a discard ban provides an incentive to implement more selective fishing gears that catch fewer small fish and are more fuel efficient (pulse trawl). If a discard ban is not properly enforced, restrictive quota do not necessarily result in the intended decrease in discarding as the fishery continues to fish while discarding the over-quota catch and least valuable size classes caught.

Capital Utilization and Investment decisions: a case study for the Netherlands (for full text see appendix C)

Heleen Bartelings

Many vessels in the Dutch fleet are switching from traditional beam trawl gear to innovative gears like pulse and sum wing. In this paper we will explore why certain vessel chose to switch to new innovative gears and whether these vessels become more efficient than vessels sticking to the more traditional gears.

In this paper we will use data envelopment analysis to determine how efficient the Dutch beam trawl fleet is before and after the transition to innovative gears. With data envelopment analysis we can show which vessels are more likely to choose to invest in the innovative gears.

The results show that economic capital utilization can be used to predict investments. Vessels with a low capital utilization are far less likely to invest in innovative gears than vessels with a high capital utilization. Vessels with a capital utilization that is higher than unity almost always will choose to invest in innovative gears. The results further show that vessels fishing with innovative gears are employed more fully, they are far less likely to be kept idle for part of the time and on average vessels fishing with innovative gears are more efficient which means that the revenue of efficient vessels is on average higher.

Understanding gear transitions in the Dutch cutter fleet from a social practice perspective : A social practice analysis of the gear transition from conventional beam trawl towards pulse trawl and twin rig technique in the Dutch cutter fleet

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The aim of this study is to understand gear transitions and how they can be shaped from a social practice perspective. A comparative case study design is used by analyzing two cases of gear transitions in the Dutch cutter fleet; the gear transitions from conventional beam trawl to either twin rig or pulse trawl technique. By using social practice theory focusing on practices rather than individuals this study takes a different approach than most governance approaches which focus on changes in individual behaviour.

Practices are social because they are always shared, therefore, it is used to understand the social nature of gear transitions. Using social practice literature a framework for analysis is build according to three mechanisms which are able to influence a gear transition. 1) Individuals [fishers] are seen as the carriers of practices who perform the gear transition. 2) Bundle of practices constituting single social practices which are carried out in the same location are significant. Because fishing is more than just a practice on board three different sites were chosen: on shore, on board and in the market. 3) Every practice consists of three elements; materials, meanings and competences which can evolve and change with a practice.

The methods constitute of a document analysis, observations and semi-structured interviews with 14 fishers that made a gear transition towards either the pulse trawl or twin rig technique. Moreover, 5 expert interviews were conducted to verify the data.

The results show that a gear transition as a practice cannot be focused on the bundle of practices on board alone. The practices on shore play an important role in influencing and accepting a new gear. The gear transition towards pulse and twin rig were clearly dependent on dealing with uncertain circumstances, such as rising fuel prices which affected the future of the fishing company.

Fishing is a way of life and an embodied habit for a lot of practitioners, therefore the social nature of fishing should be acknowledged in order to understand and steer gear transitions. Moreover, fishers relationships and their social circle are based on trust. Knowledge and meanings are shared among fellow fishers in the fishing community, with family and even abroad. Results show that fishing communities, contact with fellow fishers abroad and organised study groups and demonstration days positively influenced the gear transitions.

Furthermore, on board the new gear replaces the old gear and therefore the transition is also a change in fishing practice. New materials and technologies require new competences and skills that are socially shared and learned from experienced fishers. Fishers need to put their old embodied habits and fishing routines aside and need to be open for change. Some practitioners need to perform the practice first before they can make the transition. Therefore, sharing knowledge and meanings while performing with the new gear on board influenced practitioners to also transition.

Lastly, the social practices in the market appeared to have no influence on both gear transitions. However, one gear transition did influence a change in the market. The first Dutch fishery to be MSC certified made the transition from beam trawl towards twin rig. Certification created access to supermarkets and even created new sales organisations besides the fish auction.

The result of the study is that fishers and non-fishers carry and perform a gear transition. Non-fishers can share their knowledge and expertises with fishers and thereby influence the recruitment of practitioners for a gear transition. Gear transitions are of a social nature and also dependent on the social relations fishers have with non-fishers. In addition, the fishers can be divided into 2 categories, pioneers, who are keen on experimenting, exploring and taking risks and followers who prefer to wait until others have proven things to work.

To introduce new techniques pioneers are necessary while followers ensure a broader adoption of existing, tested gears. Understanding the process of gear transitions and the types of fishers who carry them can then contribute to overcome environmental challenges caused by unsustainable fishing practices

This research was carried out in the framework of a MSc thesis. For full text contact Vera Scherders (link to full text on the WUR website to follow).

A transition from traditional beam trawl to more sustainable fishing techniques

Birgit de Vos (Wageningen Economic Research)

Since 2000 a transition is taken place in the Netherlands from traditional beam trawl to other, more sustainable types of fishing techniques (see Figure 1) with less bottom disturbance, bycatch, and fuel consumption. Several factors played a role in the decision of fishers to invest in another fishing technique.

The aim of this section is to provide an understanding of the factors that played a role in these investment decisions. We do this by analysing two distinct cases: 1) pulse (wing), and 2) twinrig (see Figure 2). During a period of two years (2015-2016) 22 qualitative interviews were held with fishers, policy makers, NGOs, and researchers. This data was completed with information from documents, reports, and newspapers, which were analysed on its content.

There are some vital differences between the pulse and twinrig fisheries (see Table 28) that explain that different factors have played a role in the decisions of fishers to switch.

1. Factors that played a role in the switch to the pulse technique

The decision of fishers to invest in a new technique cannot be understood by looking at just one isolated factor. Based on the interviews we have identified three factors that played a role in the switch from the traditional beam trawl: 1) economic, 2) social, and 3) governance. In the next sections we will explain these factors in more detail.

Economic

Four economic factors can be distinguished that played a role in the decision of fishers to switch to the pulse technique: 1) fuel costs, 2) quota availability, 3) finance for investment, and 4) prices.

For many pulse fishers that switched in 2010/2011 it was important that a new technique lowered the fuel costs, as these costs had been increasing enormously, making the fishery non profitable. The first results of the pulse trawlers were financially positive.

These results were shared on many occasions leading to a change in the attitude of the fishers (Haasnoot, 2015). In addition, a catch comparison was done between two pulse trawl vessels, and a traditional beam trawl. Results showed a positive performance of the pulse compared to the beam trawl in terms of fuel consumption, costs, and catches *(ibid)*.

Secondly, in order to switch to pulse one had to have access to sole quota. This access was secured either through ownership or through renting sole quota. A fact is that the rental prices for sole quota have increased substantially after the switch to pulse due to an increase in demand.

Thirdly, in order to switch to the pulse technique fishers needed to have access to finance, either through the bank, with help from the government, or with private capital. Some fishers have received a (regional) subsidy to stimulate them to switch to the pulse, but most fishers had to request the bank for a loan. It was clear that the banks wanted to stimulate the fishers towards sustainability. In 2011, a 'Think Tank' of the ING published a report in which they stated that from then onwards they would only invest in fishing techniques that are not damaging the environment (Visserijnieuws, 2011).

"The bank pushed us, because in their opinion we were not innovative enough. That is how it all started in 2010." (personal interview with fisherman, 2015).

Lastly, prices. Although the market price for sole was not mentioned by all fishers explicitly, it most likely played a role in the switch to the pulse technique. The fact is that the pulse technique mainly targets sole, and sole is a fish that has a considerable higher market value than plaice.

Social

Besides economic factors, fishers are, in their decisions, highly influenced by the behaviour of their peers, but also by their own norms and values. In this section, we refers to these factors as social factors.

The transition to the pulse trawl is highly influenced by a couple of fishers that took the lead in this process, stimulated by the government. In 2005, a regular fishing vessel (UK153) started testing the gear for the first time in practice. Before that, research institute

Imares had been developing the gear with subsidy from the government. In 2008, the Ministry set up Study Groups with the aim to stimulate innovative fishers to work together in small groups towards innovation and sustainability. Of the 14 groups in total, one group focussed on further uptake and development of the pulse fisheries, and another group focussed on the twinrig technique. The fishers from the Study Group pulse were the first ones (after the UK153) who installed the technique on board.

The group of pioneers (i.e. UK153, and Study Group fishers) played an important role in the further uptake of the pulse in the Netherlands. Fishers learned about the technique through their peers, through demonstration days, experienced relatives, and local communities. The community of Texel is an example of a community that played an important role in the information exchange. According to interviewed fishers who switched to pulse, the fishers in Texel were very open, and willing to show them how everything worked. This helped other fishers in their decision.

The important role social networks, and status also came up when an important shipping company ordered four pulse gears at the same time (Haasnoot, 2015). This together with the promising financial results, triggered a further uptake of the pulse trawl in 2010.

Lastly also the crew played a role in the further uptake of pulse. Some crew members left their company to start working for owners that had already switched to the pulse technique. They did this because they foresaw to gain a higher salary at pulse vessels than at vessels that still applied the traditional beam trawl. As good crew members are rare, this development provided an incentive for owners to switch as well.

Governance

Finally, the switch to the pulse technique was influenced by several aspects that can be grouped under the term governance. The development of the gear was highly stimulated (top down) by the government through subsidies, but also through the release of permits. In the pulse fishery, fish are caught by means of light electric pulses that cause muscle contractions in fish, resulting in them being released from the sea bottom and caught in the net (Quirijns et al, 2014).

As electric fishing is not permitted in Europe a derogation is required. In the Netherlands there were three rounds of derogation in which a certain number of permits was released (84 in total). By pushing for the permits in Brussels, the Dutch Ministry gave a clear sign of support for the pulse technique.

In addition, two important institutional arrangements were set up by the Ministry to push innovation, and sustainability in the fisheries sector further (more bottom up). These arrangements were: 1) The Fisheries Innovation Platform (VIP), which was set up in 2006 with the aim to stimulate the debate on fisheries, as well as investments in sustainable initiatives, and 2)

The already mentioned Study Groups. Innovative fishermen were invited to participate in the VIP and the Study Groups. This resulted in more contact and collaboration among fishers from different regions (de Vos and Mol, 2010), as well as more collaboration between innovative fishers and the government. Knowledge, and information regarding opportunities for permits as well as subsidies were exchanged:

"I was a member of the VIP feedback group. There I met one of the fishermen who participated in the Study groups. We got in closer contact. As a member of the feedback group, I also talked to many other fishermen and to the Ministry. There we heard about the permit, and we decided to go for it. "(personal interview with fisherman, 2015).

With additional subsidies, research, and networking the uptake of the pulse fishing gear became a fact. Once the development of the gear had reached a level that made it attractive for fishers to invest in the gear.

2. Factors that played a role in the switch to twin-rig fishery

In this section we will address the factors that played a role in the switch from the traditional beam trawl. Based on the interviews we have identified three main factors: 1) economic, 2) social, and 3) environmental. In the next paragraphs we will explain these factors in more detail.

Economic

As becomes clear from table 1 the switch from beam trawl to twinrig took place far before the switch to the pulse technique. Although fuel prices had not increased that much yet, the interviewed fishers state that their fishery was not profitable anymore, and that is why they had to switch.

Besides the rising fuel prices, fishers also mention that it was time for them to rethink their strategy. Many fishers claimed they owned too many vessels that were also old. Another difficulty was the decrease in quota. So the fishers took the opportunity to get rid of some old vessels, and to build a new vessel that was ready for the future. "There were all kinds of regulations, and the quota decreased. We needed to be careful not to exceed the quota limits. We decided to buy more quota for 5 million euro, but when quota decreased the next year, we started from scratch again. That was the moment we decided we had to change things completely." (Personal interview with fisherman, 2016).

Social

The fishers who switched to twinrig obtained their knowledge from their colleagues abroad; they went to Spain, Denmark, Portugal, Ireland, and Scotland. The fishers that switched were all fishing under foreign flag, and that is why they had more international contacts.

Fishers state that the twinrig fishery is a 'relaxed' fishery. With the traditional beam trawl they had an average towing time of 1,5-2,5 hours, while with the twinrig this was 3-4 hours (Scherders, 2016). This gave more time to the fishers and their crew to relax, and also more time to process the fish resulting in a higher quality.

Environmental

Although fishers do not mention that they switched to twinrig for environmental reasons, they did seem to play a role. Driven by economic factors, they wanted to change their way of fishing completely, and once switched they became more and more aware of the environmental benefits.

After the switch, they started to fish with lower speed, and they used larger mesh sizes. In addition, the fishers pursued and obtained the MSC label. This created a new mind-set for the fishers, as the following quote shows:

"The nice thing is that we also learned a lot from them (the NGOs). One starts to think 'why not protect the seafloor better?' If these people want that, and it is better for the benthic environment, why not do it? They gave me advice on how to improve it.

3. Conclusions

From this chapter it becomes clear that many factors play a role when fishers decide to switch gears. These factors are of economic, social, environmental, and juridical nature. From the two cases we can learn that the twinrig fishers who already switched in 2000 were pioneers that organised their own knowledge exchange with fishers abroad. They did not need a lot of steering from the side of the government.

Also because twinrig fishers were able to obtain the MSC label, they were in a position to exchange knowledge with NGOs. The twinrig fishers took the time to rethink their business strategy, and this led to a change in the number of boats, market strategy, and way of fishing.

The role of the government, as well as research institutes was larger in the switch from beam trawl to pulse. The development of the technique, the permits, and the knowledge exchange was arranged by the Ministry.

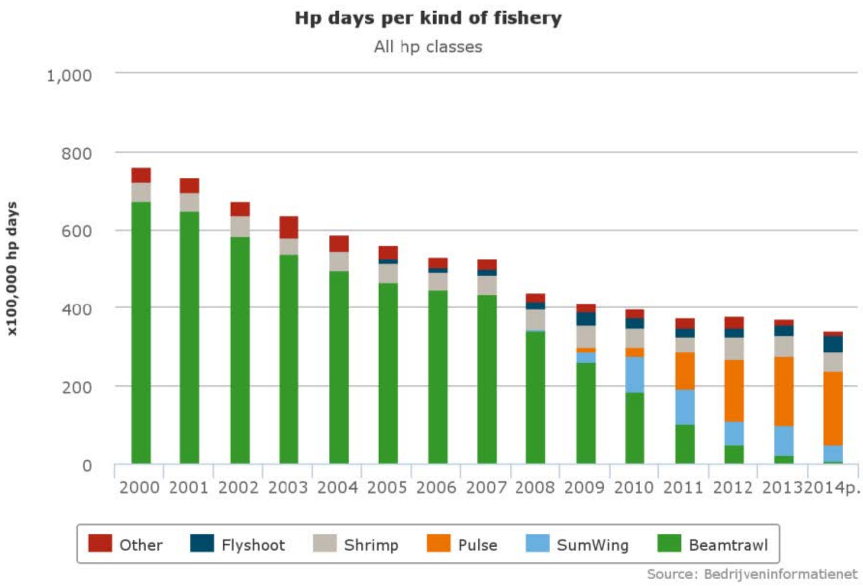

Figure 71. Horse Power (HP) days per kind of fishery from 2000-2014 (retrieved from agrimatie)

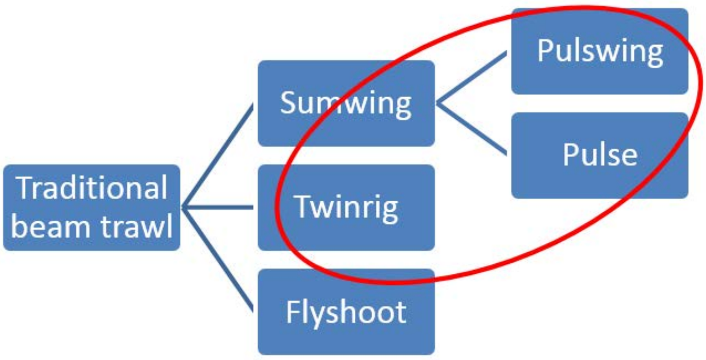

Figure 72. Two case studies: 1) The switch from beam trawl to pulse (wing), and 2) the switch from traditional beam trawl to twinrig.

Table 28. Comparison between pulse and twinrig fisheries (adapted from Scherders, 2016)

Twinrig	Pulse
Switch took place from 2000 onwards	Switch took place from 2010 onwards
Targets plaice	Targets sole
MSC certified	Not MSC certified
Developed by Danish fishers	Development stimulated by the Dutch Ministry
Accepted fishing technique	Prohibited fishing technique (EU ban 1988)

Fisheries Credit system

Gerjan Piet, Jan Geert Hiddink, Niels Hintzen, Karin van der Reijden, Adriaan Rijnsdorp

Fisheries credit systems show considerable potential for incentivizing changes towards achieving management goals that improve the environmental performance of fisheries, by supplementing rather than replacing existing management approaches (Van Riel et al., 2015). This contribution to ecosystem-based management aimed at conserving seafloor integrity (SI) involves a fisheries credit system (FCS) where behavioural credits (Van Riel et al., 2015) are applied based on the assumption that the behaviour of fishers can be influenced through incentives aimed at reducing their fishing impact on the seafloor.

This approach is implemented through quotas of fishing-impact credits through tariffs. The basis of the approach is that the area would be divided up into grid cells, each with a certain "cost" applied to fishing in that cell. Fishers would then "pay" these costs in SIQs from their individual SIQ account, allocated at the start of the management period, e.g. year.

The costs, or tariffs (e.g. in SIQs per day), associated with fishing in each of the cells would be shown on tariff maps. Using these maps, fishers are then free to fish when and where they choose as long as their SIQ credit lasts; they would not be allowed to continue fishing once they exceed their SIQ quota.

The development of this FCS is based on a methodology that allows calculation of seafloor integrity (SI) and how this is impacted by fishing. In this methodology the benthic community biomass relative to an undisturbed situation is used as a proxy for SI.

The impact of trawling on the biomass of the benthic community is calculated using a population dynamic approach, where the reduction in biomass depends on the habitat-specific sensitivity of the benthic community to specific types of fishing. This impact is expressed as an uptake of SIQs. Based on the Dutch bottom-fishing fleet in the North sea period 2006-2012 (~300 vessels, ~26.000 trips) we estimated the SI state of each grid cell, which determines its sensitivity to further fishing and hence the impact that a specific level of fishing intensity will have. For each grid cell with known seafloor integrity we calculated two metrics that capture the catch opportunities of the fleet and its performance in terms of its catch efficiency in relation to swept area or seafloor impact (Figure 73).

If SIQ uptake is proportional to the reduction in SI that is caused by a vessel, and SIQ unit are limiting, implementing SIQ as a FCS will force fishermen to take the real environmental impacts of their fishery in to account. The main attraction of this approach is that the fishers are making their own decisions about where and when to fish, without the government closing any areas to particular fishing gears, but that the effect of fishing on the seabed will nevertheless be reduced.

This has particular advantages over permanently closed areas as a management tool when the distribution of fish may change, for example as a result of climate change. Because the cost of fishing in SIQs is lower in areas that are already degraded, fishing activity is likely to become more concentrated. Fishers can still choose to go and fish in areas that are currently in a pristine state, but only at a high SIQ costs, while continuing fishing in such a location will be cheaper.

This suggests that fishers may only choose to shift their fishing activities into pristine areas if they are planning to shift their fishing operations over longer time-scales. SIQs will make exploratory fishing in previously unfished areas expensive, and as previous work has shown that such activities have a disproportionate effect on the seabed (Jennings et al. 2012), this is a particularly desirable feature.

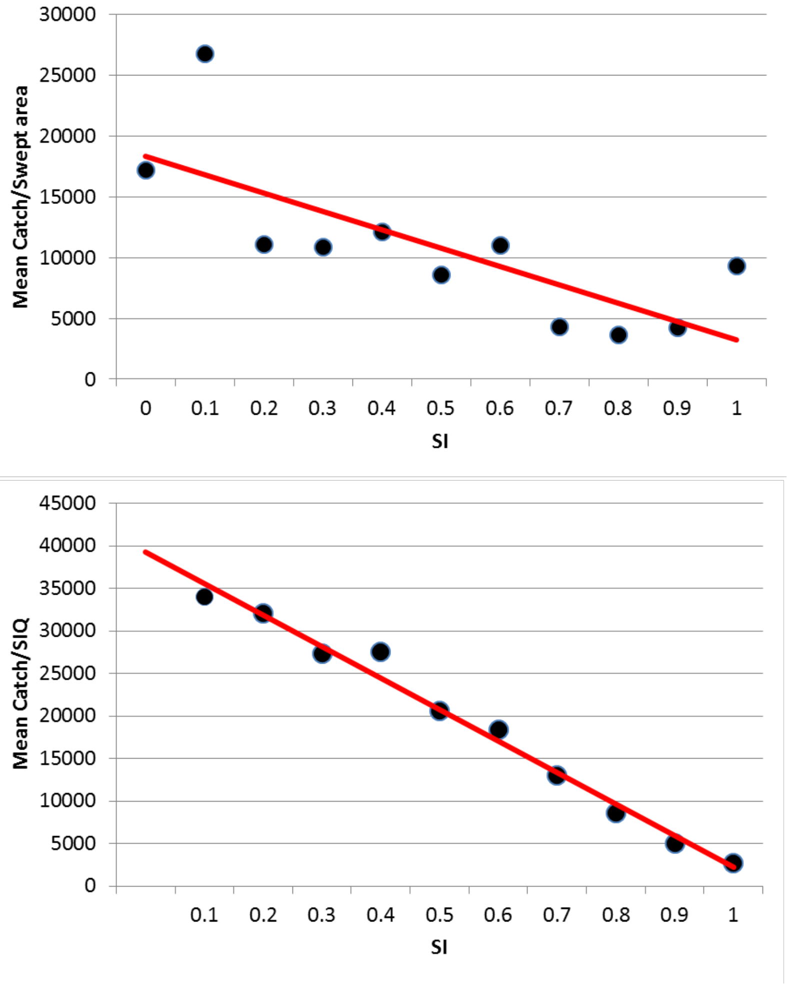

Figure 73. Catch opportunities, i.e. Mean catch/swept area and catch/uptake of SIQ, for grid cells with different calculated seafloor integrities. The line is the result of a linear regression.

Innovative management scenario's

In Table 29, the two technological and one management innovations are evaluated according to a set of standardised objectives.

Table 29. Evaluation of the technological and management innovations.

	Objective	Introduction of pulse		FCS
		flatfish	shrimp	
A	Provide food	The pulse improves the sustainability of the fishery and as such adds to food security. In addition, the landings for human consumption remain at least at the same level.		The application of FCS should guide fishers to those patches where the highest CPUE is found. The application of FCS should therefore not compromise the provisioning of food. The only proviso is that the concentration of effort could result in a lowering of CPUE.
B	Reduce fishing impact on the seafloor	By reducing the penetration depth and the swept area per unit of sole landings, the pulse trawl	There is less bottom contact and a	Application of this method should (theoretically) always

	Objective	Introduction of pulse		FCS
		flatfish	shrimp	
		reduces the physical impact of fishing on the habitat. Effects on the biological impact and potential consequences for the ecosystem are less clear.	substantial reduction of bycatch of fish and benthic invertebrates.	result in a reduced impact on the seafloor.
C	Improve state of the seafloor	Due to B, the pulse trawl helps in improving the state of the seafloor compared to a sustained traditional beam trawl fishery. However pulse trawl fishers now have access are able to fish in other habitats and the ecological consequences need to be assessed.	Due to B, we expect that the pulse trawl help in improving the state of the seafloor compared to a sustained traditional beam trawl fishery. However, no empirical proof was obtained during the project.	The reduction of fishing impact should by definition result in an improved state of the seafloor.
D	Profitable fishing enterprises	By lowering fuel costs, the pulse trawl increases the profitability of fishing enterprises. Pulse trawl lessens the economic impact of the landing obligation	For shrimp fishermen, the slight increase in commercial catch 10-20% and slight decrease in fuel consumption cover the costs of investment. Traditional fishers fear that the increased landings of the pulse fishers would lead to a lower price for all.	The mean CPUE is higher for trips where fishing impact was lower. This suggest that the application of FCS could result in more profitable fishing enterprises.
E	Wages for fishing crew	The impact of the introduction of pulse on crew wage depends on the way remuneration is calculated. For the Dutch fleet, crew wage is higher with pulse while for the Belgian fleet it is lower.	Slight increase	No change

	Objective	Introduction of pulse		FCS
		flatfish	shrimp	
F	Monetary value produced for society	No change observed	No change observed	No change
G	Reduce cost of management	The impact assessment needed to support a decision on granting a permanent authorization to use the pulse trawl required a substantial investment in research from the Dutch government. There is no reason to believe that the introduction of pulse would reduce management costs. Furthermore, if an increase of catchability on sole, the target species, would happened then the current fleet would be in a state of overcapacity, incurring additional management costs.	Investment will be required for scientific research to assess the ecological impact of the pulse in the shrimp fishery Benthis took a next step in this research agenda. Benthis delivered results of two sea trials on seafloor disturbance of beam an pulse trawls with substantial interesting information on seafloor disturbance although results were not strictly conclusive.	FCS is a management method that incentivises fishers to change their behaviour. This would be on a voluntary basis and would therefore reduce management costs (or at least not increase them)
H	Fair distribution of impacts	The number of licences are limited, the first five were preselected, but afterwards anyone could apply. However, the practice of pulse is very much linked to the access to quota for sole, which depends on historical ownership.	The number of licences are limited so only a few vessels will benefit from the increase in catch. However if the traditional shrimp fishery managed to get MSC certified, the pulse vessels would not be included.	No change

	Objective	Introduction of pulse		FCS
		flatfish	shrimp	
I	Good labour conditions	Because there is less damage to the gear and the catch is cleaner, there is more time for the crew to rest and because the gear is lighter the work is less physically demanding.	The catch is cleaner but given that a machine does the sorting, it is not expected to change labour conditions.	No change
J	Employment	No change in employment	No change in employment	No change
K	Good governance	The development was participatory and the results shared publicly but the decision to go ahead with the technique was top-down, even though the technique is still forbidden	No consensus within the fishery because some fear overcapacity. Because the number of licences is very limited compared to the number of vessels currently operating, it creates inequity and conflict within the fishery.	The main attraction of this approach is that the fishers are making their own decisions about where and when to fish, without the government closing any areas to particular fishing gears, but that the effect of fishing on the seabed will nevertheless be reduced.

The introduction of pulse trawl in the sole fishery

In Benthis, ecological benefits of the pulse trawl in the sole fishery have been demonstrated. Those include the reduction of the bottom penetration, reduction of benthos destruction and a better selectivity catching the target species, sole while reducing unwanted catch. The socio-economic consequences of the pulse in the fishery are also positive. Based on economic data collected from Dutch fishers already operating with pulse trawls, we could show that the economic viability of the fishery is improved for fishers using pulse trawls compared to the traditional beam trawl. The economic benefits of pulse are particularly important when considering high fuel prices or the landing obligation.

The remuneration system of the crew is an important factor to determine the social outcomes of the introduction of pulse. Because fuel costs, which are deduced from the value of landings to calculate the salary of the Dutch fishers, decrease the Dutch crew benefits from the switch to pulse. This is not the case in Belgium were the crew wage are a direct share of the value of landings. Therefore, a decrease in fuel costs does not benefit the crew in terms of salary. Some additional factors influence the uptake and investment in the pulse trawl for sole. The support of the Dutch government, the organisation of study groups and demonstration days and the presence of a few pioneers facilitated the transition to pulse.

Conversely, some factors have hindered the introduction of pulse: the limited sole quota availability and the difficulty to access it (e.g. buying and leasing prices have increased in the Netherlands since pulse introduction), the limiting days at sea in the North Sea for Belgium fishers while pulse is still only allowed there, and the fact that the image of pulse in society remains controversial have been barriers to the introduction of pulse.

The introduction of pulse trawl in the shrimp fishery

In terms of seafloor disturbance, Benthis was not able to prove a significant difference in penetration depth nor trawl path mortality for the shrimp beam trawl and pulse trawl, although it is clear that seafloor contact of the pulse trawl is effectively smaller compared to the beam trawl. A significant reduction in unwanted by-catch has, however, clearly been demonstrated over all seasons.

The shrimp trawlers already using the shrimp pulse trawl have proven to be economically viable (Polet, *pers. comm.*). The investment cost in the pulse system is relatively low and the slight increase in commercial shrimp catch with the pulse and the small reduction in fuel cost easily cover the investment in the short term and can increase net revenue over the longer term.

The uptake of the shrimp pulse trawl in the North Sea is very low. This is because of a conflict in the industry based on the fear of higher catching efficiency of the pulse trawl and the fear of a lower shrimp price following a high price elasticity in the shrimp fishery. If not all shrimp trawlers would change to pulse trawling, there would be a net loss in income for the non-pulsers. Despite the good results of a number of shrimp pulse trawl pioneers, of which one built a new vessel shortly after installing the pulse system, uptake has been very low. The relatively low number of pulse licences available today for the shrimp fishery and the absence of the shrimp pulse in the "brown shrimp MSC-assessment" makes the issue even more complex.

Implementation of Fisheries Credit System

The expected ecological and socio-economic consequences of the implementation of FCS are only based on theoretical considerations as the approach has not been applied in practice yet. In this evaluation we have not specifically considered its application in different fisheries as it can be applied in any fishery because it only requires behavioural changes of the fishers. However, the degree to which it actually delivers the ecological and socio-economic benefits will likely differ depending on characteristics of fishery.

The application of FCS should result in an avoidance of the areas which have previously not been trawled and are therefore likely to have a relatively good state of the seafloor and hence would be more severely impacted by fishing activities. Studies have shown that the catch opportunities should not be compromised by this behaviour (and could even improve). In general, the application of this approach should result in an increased efficiency of the fishery in terms of catches per seafloor impact.

The socio-economic consequences of the application of FCS have not been assessed. However, an analysis of >20000 fishing trips did show that those fishing trips that applied a strategy similar to what the application of FCS would achieve gained more revenue per unit of effort (here expressed as amount of swept area). It is therefore likely that the application of FCS should result in more profitable fishing enterprises.

Initially FCS is thought to be applied on a voluntary basis so this should not require any management cost. If the first results of any practical implementation are promising it could be developed into a (seafloor) quota system which would fulfil many of the good governance criteria.

MEDITERRANEAN SEA

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Case Study summary

In the Mediterranean Sea highly impacting bottom fishing (trawling, dredging, etc.) mainly affects shelf areas, where seabed surfaces are mainly muddy and sandy. Although these fishing grounds are very suitable to trawling fisheries, they represent an important part of the ecosystem since they are inhabited by a wide variety of benthic organisms.

Overall, bottom trawling has deeply affected the benthic ecosystem of Mediterranean Sea by causing structural and functional changes to seabed faunal communities and change, damage and degradation in habitats, particularly important habitats, such as seagrass and maerl beds. The impact of a bottom trawl depends on the size and type of gear components, their penetration depth as well as the speed and distance over which the gear is towed.

Thus, potential technical innovations for reducing the benthic impact in Mediterranean Sea have been mainly selected and tested on gear modifications to reduce physical contact and fuel consumptions in Italian and Greek waters.

Implementation of pelagic otterboards

In the Mediterranean Sea, 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). A semi-pelagic VF15 otterboard developed by the Danish Thybøron door manufacturer, and two novel otterboards (i.e. Grilli Fly and Mori Biplan), being developed by Italian manufacturers (SME13 Grilli and SME14 Mori) were compared with traditional commercial Mediterranean otterboards by CNR-ISMAR in the Central Adriatic Sea.

The experimental otterboards showed better geo-mechanical performances compared to their traditional reference doors, in terms of trawling power demand (TP), which directly affected fuel consumption. In terms of FTU sedimentation values, the Mori Z otterboards showed the highest impact on seabed compared to the AR-Poly and Biplan otterboards.

Testing a new trawl net design

Novel designs for a bottom trawl net were selected and tested by CNR-ISMAR in the Central Adriatic Sea in order to reduce the physical impact on seabed and fuel consumption, while catching efficiency was maintained. Such novel designs were developed in collaboration with Tecnopesca (SME12). The experiment focused on two different tasks: testing a novel net design by implementing a switch panel and testing a novel net material (Dyneema) in a traditional bottom otter trawl.

The comparison between the different materials showed, as assumed, a better energy performance of the Dyneema net. The overall fuel consumption and the total towing force were on average less for the Dyneema net, while, with respect to the geometrical specifications, no relevant effects could be related to the switch panel. Currently, CNR-ISMAR is assessing the relative catch efficiency between the novel net design and the traditional one, by using a methodological approach based on catch comparison analysis and the method described by Krag et al. (2014) and Notti et al. (2016).

Development of alternative fishing methods

Investigations on the development of alternative fishing methods by HCMR were based around trials of pots and traps in commercially trawled areas, these static gears are less damaging (more selective less impacting) than the standard Mediterranean trawl gear in the multispecies-targeted demersal fishery. This could allow for future possibilities to a) maintain fishing in areas where trawling may be closed with less damaging gears or b) allow fishing in areas not currently fished by trawling because of rough grounds.

Three types of gears were investigated; the "Norwegian Floated Pot", developed for gadoid fishes, the Greek Nephrops trap used in closed trawling area crustacean fisheries, the Kurtos fish pot for mixed fish/crustacean catches. Multiple traps were fished on replicate long-lines with over 1200 pot/trap deployments. The traps/pots were trialled during two sampling periods at depths between 30-200 m to encompass shallower 'red fish' fisheries and deeper 'white fish/shimp' fisheries in Heraklion Bay, Crete (Papadopoulou et al., 2015).

Additional trials were carried out in the central/northern Aegean in 2 deep water areas (Evoikos Gulf and Lesbos Island – both 420 m depth) and a closed trawl area with an existing Nephrops trap fishery (Pagasitikos Bay – 90 m depth). Trawls were carried out in the vicinity of each trap line to investigate the fish/invertebrate populations available to trapping. In all trials, species, abundance and biomass catches were low for each of the trap/pot types. Camera observations indicated that the traps were fishing correctly and that small fish did enter and leave the traps, larger fish, however, were rarely seen to interact with the traps.

With the very low catches and no obvious economic viability (it was estimated that bait cost alone outweighed catch value) the traps were not perceived as promising alternative gears to trawls on trawling grounds, although may be more successful in an artisanal fishery or where trap numbers could be increased and/or mesh size decreased. A cost-benefit analysis was not carried out as a direct trap/trawling replacement was obviously not viable.

Innovative management scenario's

The main objectives of the WP7 were (i) to explore innovative management scenarios; (ii) to study the economic impact of alternative fishing gears; (iii) to quantify the economic consequences on the fishery and related industries and (iiii) to draw conclusions beyond the specifics of the case study. The socio-economic work carried in WP7 in close cooperation with WP5 contributed to all of these objectives.

The focus was on bottom trawling fishery in the Central Adriatic Sea within the fleet of Ancona and on the technological innovation 1. Implementation of pelagic otterboards.

Description of the case study context - Bottom trawling in the Adriatic Sea

The Marche Region boasts a strong specialization in the fisheries sector: with its 174 km of coastline on the Adriatic Sea is one of the regions with the strongest and most ancient fishing tradition. The first Italian boat specialized for fishing and called "piropeschereccio" was built in Ancona in 1901.

Its fleets remain a point of reference and innovation for maritime fishing in Italy. The area is characterized by being a closed basin where Italian, Slovenian and Croatian fleets, not fully coordinated with each other, compete to access the same resources (Cautadella et al., 2011).

The port of Ancona is one of the oldest fishing communities with one of the largest Italian fishing fleet with a long and heterogeneous tradition of fishing activities. It is one of the largest fishing port in Italy, the third for number of bottom trawling vessels and dimensions of the boats.

Various types of fishing métier differ for target fishes, technologies and fishing areas. The Italian Ministry of Agriculture, Food and Forestry Policies – Mipaaf identified 12 different systems of fishing. Each one has a specific fishing license. According to Cautadella et al., 2011 and Irepa, 2012, the main systems present in the port of Ancona are:

- bottom trawling: it is characterized by bottom fishing with otterboards that are in close contact with the sea bottom. This type of fishing does not have a defined target species but a large group of demersal and benthic target species which live closely to the sea bottom and have a high economic value. Bottom trawling is permitted over 3 nm from the coast and within 1.5 nm from the coast only in depths greater than 50 m;
- Mid-water pair trawling: it operates in the water column at a shallow depth, targeting small pelagic fishes such as sardines, anchovies and scads. This type of fishing is done in pairs, with two boats towing a single net. The size and power of the boats are slightly higher than that of normal trawling vessels. It follows the same limitations and rules of bottom trawling.
- Hydraulic dredges: they target bivalve mollusc species (mainly clams) and shellfish. The boats are characterized by small size working with a gear that enters into the marine sediment in order to catch bivalves. Hydraulic dredges work within 0.3 nm from the coast.
- Small scale fishery: it is characterized by small boats (under 10 m in length) using various equipment such as longlines, gillnets, purse seine systems targeting multi-species.

The Ancona fleet (Table 30) is composed of 118 vessels of which: 46 bottom trawlers for demersal species, 16 mid-water pair trawls targeting small pelagic fishes, 28 hydraulic dredges fishing mollusc and shellfish and 28 boats for small-scale fishery that use a mix of gears catching various species.

Tests and analysis on innovative and traditional otterboards were performed on the vessel Orizzonte. Orizzonte is representative of the bottom trawling fishing sector of the port of Ancona (see Table 31): it is 21.50 m in length, with a Gross Registered Tonnage of 82 t, a Mitsubishi engine with a traction power of 234KW and steel hull. The crew is composed of 4-5 people. It works along the coast (within 40 miles) and targets multi-species demersal fishes.

In the last 10 years the Ancona fleet has experienced a large decline with 46 vessels scrapped reducing the residual bottom trawling fleet to half of its initial size, mainly due to the reduction of the profitability and high costs of fuel and maintenance.

The crisis of the fishing sector Ancona, as for the whole Mediterranean sector, was mainly due to the reduction in the profits caused by a decrease in catches per vessel, a steady fall in market prices since 2004, and due to increased competition of Croatian and Slovenian fleets as well as to the massive introduction into the market of aquaculture products (Cautadella et al., 2011; Irepa, 2012).

The considerable increase in the cost of fuel contributed to exacerbate the situation, with fuel prices that reached the higher peak of € 0.70 per liter in 2011, with an increase in the average fuel expenditure on total costs by 58% (Irepa, 2012).

Fuel consumption is the main cost incurred by fishing companies, especially those engaged in bottom trawling fishing. Energy costs are a large and growing part of operational costs in f wherever in the world, they have risen strongly in the last decade with high volatility rate and the medium terms forecasting showing further increasing in the next years (Suuronen et al., 2012). In the graph below it is possible to appreciate the high volatility of the fuel prices.

The World Bank and FAO (2009) reported that the global fishing fleet consume 41 million tons of fuel worth as 22.5$ billions with a generation of CO2 emissions of 130 millions of tons per year. Bottom trawling seems to be one of the most fuel intensive branch of the global fishing sector, both policy and technological improvements could help to create a more efficient and sustainable fishing sector (Suuronen et al., 2012).

Since early 2000, the cost of fuel has increased significantly in Italy, eroding the profitability of the entire sector (Irepa, 2012). In the last years, the vessel Orizzonte has experienced an impressive growth in fuel costs: where in 2002 fuel costs accounted for 19.74% of total costs, in 2014 they have reached 54.46%.

The next graph shows the weight of fuel costs on total costs reported on the Orizzonte balance sheets from 2002 to 2014. The tendency line was obtained with a linear model elaborated with MS-Excel, it is a straight line with equation $y = 3,204\ x + 19.15$.

The angular coefficient suggests that the trend is positive, so that fuel costs had a higher relevance than other costs during the period. Furthermore the coefficient value (3,204) indicates that stepping one year to another the analyzed ratio has grown of 3.2% every year. This result is relevant if we assume that experimental otter boards could help fishermen in reducing fuel consumption in their balance sheets.

Looking at the previous graph it is possible to observe a clear yearly increasing trend of the weight of fuel costs on total vessel expenditures. Therefore, if innovative gears could allow fuel savings they would have more chance to be implemented on the vessel and help to reduce environmental impacts of bottom trawling fishing activities.

Although the fishing industry of Ancona has experienced a structural downsizing, fishing remains one of the most important sectors in the local area. According to the Ancona fish market, on average from 2009 to 2014, about 1,300 t of fish have been traded annually with a volume of sales of almost 8.3 million euro per year.

In 2009 Mer.It.An. (the local fish market) was acquired by local fishermen and currently it is managed directly through the Associazione Produttori Pesca fishing association. The market deals with all the activities of marketing that follow the bottom trawling landings: quality control, weighing, product traceability, creation of market prices through fish auction and sales activities. For the sale of pelagic fish landings, there is another market. Clams and small fisheries products are mainly sold directly by the fishermen.

Fishermen have the possibility to sell their products directly from their fishing vessels along the quay on Thursday and Friday: such a direct link to the market helps them to have additional revenues and reduce unsold catches.

Ancona is a good case of study for the issue of the sustainability. Thirty years ago, the fishermen adopted a policy of self-regulation and decided to reduce their fishing effort by decreasing the days at sea from four to three per week, to preserve both fish stocks and their revenues, thus avoiding price drops.

On average, the Ancona trawling fleet spends 104 days at sea per year, compared to an average of 131 days per year in the Marche Region and 146 days per year in Italy as a whole (Irepa, 2012). This measure shows a propensity towards the sustainable management of marine resources by the Ancona fishermen who decided to intervene directly with their own self-regulation in order to improve their economic conditions and ensure sustainability of the system in the future (Cautadella, 2011).

Table 30. Fishing fleet in Ancona, Marche Region and Italy, data Irepa, 2012

	ANCONA	MARCHE REGION	ITALY	TARGET SPECIES
NUMBER OF VESSELS	118	870	13.064	
Bottom trawling vessels	46	172	2.525	Demersal and benthic mixed species
Mid-water pair trawling vessels	16	32	132	Small pelagic species
Hydraulic dredges	28	221	706	Mollusc and shellfish species
Small-scale fishery vessels	28	437	8764	Mixed species

Table 31. Main characteristics of the fishing vessel "Orizzonte".

AVERAGE SIZE (BOTTOM TRAWLING VESSELS)	ANCONA	MARCHE REGION	ITALY
LENGHT (m)	23,6	-	-
GROSS TONNAGE (t)	87,8	61,1	41,1
TRACTION POWER (KW)	352,7	234,6	197,6
AVERAGE CREW (N)	4,0	3,7	3,3

Table 32. Revenues, Fuel Costs, Total Costs, Days at sea of Orizzonte Vessel, 2008-2015, data provided by the fishing cooperative "Cooperativa Pescatori e Motopeschrecci".

Year	Revenues (€)	Fuel costs (FC) (€)	Total costs (TC) (€)	FC/TC (%)	Days at sea (n°)	Average fuel price (€)
2015	228.181	86.826	189.892	46	140	0,50
2014	250.298	118.262	217.158	54	140	0,67
2013	244.989	129.096	229.502	56	136	0,71
2012	241.555	128.606	208.360	62	127	0,75
2011	226.486	120.409	207.222	58	121	0,68
2010	210.607	97.092	208.085	47	139	0,53
2009	221.483	79.427	218.267	36	142	0,41
2008	225.877	110.789	259.098	43	129	0,62

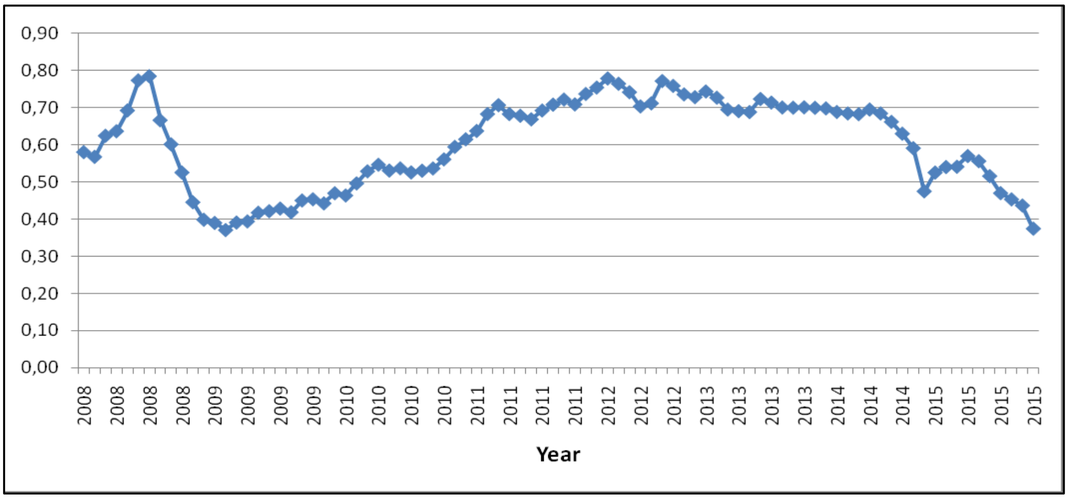

Figure 74. Monthly purchasing fuel price (€/l) for bottom trawling vessels in Ancona, 2008-2015, data provided by the fishing cooperative "Cooperativa Pescatori e Motopeschrecci".

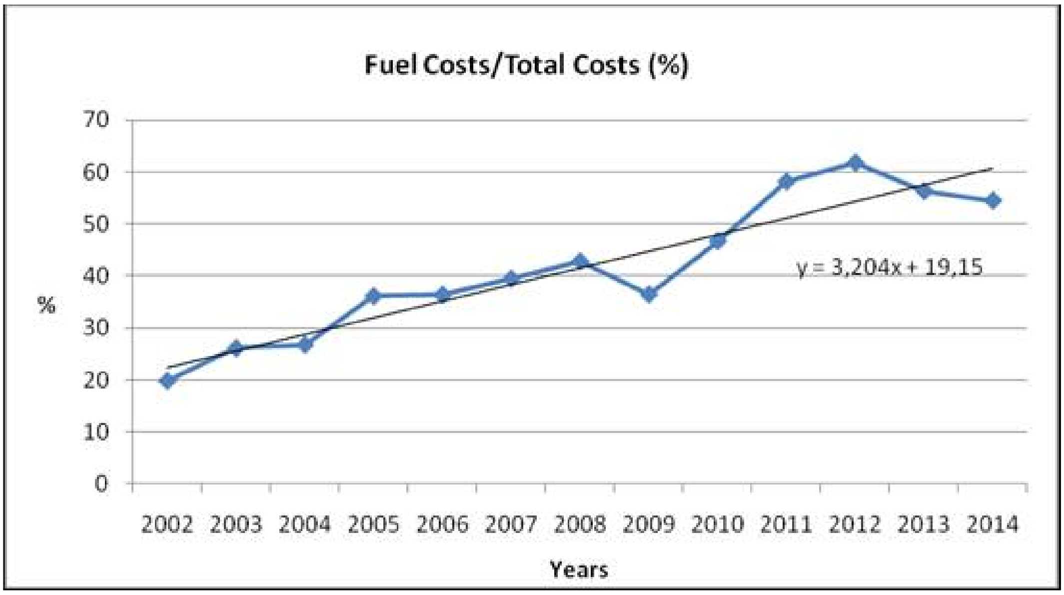

Figure 75. Fuel costs regression line, 2002-2014, data provided by the fishing cooperative "Cooperativa Pescatori e Motopeschrecci".

The analysis carried out within the case study of Ancona

Within the case study of Ancona, two main activities were carried out:

1. Using a Cost-Benefit Analysis (CBA) methodology, the comparison between traditional commercial otterboards with innovative, more sustainable and experimentally tested and developed within the BENTHIS project otterboards (steel Mori Z vs polyethylene Grilli AR-Poly). The results are useful to complement CNR-ISMAR work with the analysis of the economic performances of the innovative gear and to evaluate the economic consequences of adopting it. Shifting from traditional to new fishing gears requires the analysis of both technical and economic performances.

   The economic evaluation provides the necessary knowledge to understand if the innovation is not only technically feasible but also affordable for fishermen, which are the economic consequences of adopting the innovation, so that fishermen and other stakeholder (researchers, technology producers, and policy makers) can make informed decisions.

2. The analysis of the drivers of innovation among the fishermen of Ancona to investigate the factors that affect the decisions of fishermen to implement new sustainable technologies on their vessels.

The two activities are strongly linked because much qualitative information coming from the analysis of the drivers of innovation were used in the CBA (for example the data about installation cost, maintenance cost, time needed to learn how to manage the new gear, life span of the otterboards).

Vice versa, the data collected for the CBA allowed to draw an accurate and updated framework within which to better interpret the qualitative information obtained through the interviews of the fishermen. The results of the study contribute to define the possible scenarios of adoption of the innovation among the fishermen of the Ancona fleet.

The approach of the whole research was characterized by (i) a close collaboration with CNR-ISMAR, the fishing industry SMEs and other key stakeholders; (ii) the triangulation of data and information from different sources and methods; (iii) the common sense that has guided the analysis, by ensuring that a certain level of approximation was accepted, so as to cross technical, environmental and socio economic considerations, and an effort of simplification, not to go too far and too complicated.

Cost-Benefit Analysis

The theoretical and methodological framework for the comparison between traditional and innovative otterboards is that of Cost-Benefits Analysis as it was used in previous similar studies to evaluate various options for investment in the fishery sector (Mokua et al., 2014; Esteban and Crilly, 2013; Kronbak, 2009; Macher et al., 2008; Freese et al., 1995). CBA is used to help decision-makers, public or private, in comparing alternative investment options. Usually it is used for decisions that include social and environmental effects and thus it helps policy makers providing them with information on different possible scenarios (Perman et al., 2003).

In our case, the CBA was primarily intended to be used to assess the best otterboards among various gears tested, from the fisherman's point of view, so excluding all considerations related to negative (or positive) externalities generated by the fishing activities. The option to introduce in the analysis non marketable externalities such as reduction in sediment clouds or sediment impacts is certainly possible, if necessary technical data on both measurable and economically quantifiable impacts are provided.

For this type of analysis it is necessary to consider all the benefits and costs produced by an economic activity, on average in a year, with a standard equipment used as a benchmark and to compare the results with those obtained using an innovative gear. During the various meetings held between CNR-IRCRES and CNR-ISMAR, it was decided to use as benchmark the traditional otterboards (Z) produced by the Italian manufacturer Mori (involved in the BENTHIS project) and habitually used by the Orizzonte vessel in its fishing activity.

As an innovative gear, the Grilli AR Poly otterboards, from Grilli SAS (Italian firm also involved in the project, SME12) were chosen, because of its good results in the analysis of the technical and economic performances and the importance of the Grilli brand which is well known among Italian trawlers.

Finally, this model of trawl doors was already available on the market so it was chosen in order to avoid the reluctance of the owner of the Orizzonte to use pure prototype gears such as FLY with the fear of a reduction in catches.

The analysis involves the simulation of all the costs and benefits in terms of future cash flows discounted using the technique of Net Present Value (NPV).

$$\mathbf{NPV} = \sum_{t=0}^{n} \frac{(\mathbf{Benefits - Costs})_t}{(1 + r)^t}$$

where:
r = discount rate
t = year
n = analytic horizon (in years)

Source: Perman et al. (2003).

The data used to compile the CBA and to describe a credible scenario come from logbook data, 20 individual deep, face-to-face interviews with fishermen, interviews with key informants to better understand the characteristics, actors, relationships in the local fishery as well as the working mechanisms of the whole supply chain, the balance-sheets of Orizzonte, database on landings (quantities and prices), fuel consumption (quantities and prices), gear costs (initial investment, repair and maintenance costs).

For the traditional gears historical data of costs and revenues were available. In contrast at the beginning of the study, for the experimental gears, data were only available in reference to the days of the sea trial campaign. Initially, it was agreed to project the technical data collected on the trial days on the entire year, without considering all the variations that occur during the fishing year due to weather conditions, movement of fish stocks, etc., being well aware of the considerable simplification that this assumption implies. Afterwards, the vessel Orizzonte replaced its traditional gear with an innovative one, making a proper possible CBA. Thus, the analysis could be divided in two phases:

1) A first phase until 2014, when the available data on the innovation were only those from sea trials, during which we carried out the analysis of the economic performances of different otterboards and an exercise evaluating the fuel savings in trawling fishing vessel determined by the use of innovative and sustainable otterboards;
2) A second phase, starting from the moment which coincides with the decision of the captain of the Orizzonte to definitively adopt the innovation on his fishing boat, after that continuous data of costs and revenues were available and collected and a proper CBA was carried out.

The otterboards used in the experiments are innovations and modernizations of old technologies with the aim of reducing both environmental impacts and fuel consumption. In total there have been used for this study six otterboards of which two traditional from the Italian manufacturer Grilli S.A.S and Mori S.R.L. and four innovative, ones from the manufacturer Mori S.R.L., two of Grilli S.A.S. and one of the Danish manufacturer Thyboron. The otter boards tested were coded as:

- THY – Thyborøn
- FLY – experimental Grilli steel otterboards
- POLY – Grilli polyethylene otterboards
- BIPLAN – experimental Mori otterboards
- Z – traditional Mori in steel otterboards (used as a benchmark)
- C – traditional Mori otterboards

At the time of the study, all otterboards were present on the market with the exception of FLY which was still a prototype gear. Principally the innovation of the gear was related to the reduced contact friction on the sediment due to the introduction of light construction and plastic material instead of only steel. In the following table are shown the principal information used to the development of the economic analysis.

In the first phase of the study we undertook a statistical tests on the results of the otterboards technical sea trials done by CNR-ISMAR. This first part of the study was important in order to study whether there would have been significant functioning differences among the tested gears. The differences in technical behaviour among the various gears were tested using Student's t-Test. The variables tested were:

- TS (kn): towing speed;
- TTF (kg): total strength of the net;
- FC (l/h): fuel consumption;
- HNO (m): horizontal net opening;
- VNO (m): vertical net opening;
- HDS (m): horizontal door spread.

To analyze the data obtained during the otter boards fishing trials conducted on the Orizzonte, a hypothesis test was made related to the difference among the average values obtained by some strategic indicators. For the analysis the econometric and statistical software STATA was utilized, using a Student T-test, using all the relevant variables provided by CNR-ISMAR. Testing the hypothesis H0:

- $\overline{x}_{div\_i} \neq \overline{x}_{div\_j}$,
- where
- $\overline{x}_{div\_i}$ and $\overline{x}_{div\_j}$
- coincide respectively to the average value
- $\overline{x}_{THY}$; $\overline{x}_{FLY}$; $\overline{x}_{POLY}$; $\overline{x}_{BIPLAN}$; $\overline{x}_{C}$; $\overline{x}_{Z}$
- with div_i always different of div_j (that is we have confronted average value of different otter boards among themselves).

Regarding TS, HNO and VNO, no significant difference was detected between the various gears (Table 34). We can assume that the gear does not affect the catches neither in terms of opening of the net nor in terms of the quantity of fish caught per time unit. There were no significance differences in the catches, thus in the revenues directly linked with the use of a tested gear.

Therefore, different catch data reported for the otterboards during the trial campaign were not used in the study. Nevertheless, in the next table, means and differences for both TS variable and the product between TS and TTF have been reported. Table 34shows the differences among the mean values obtained by each gear and the mean value of the benchmark Z (in grey). The values that have presented statistically significant differences are highlighted in red. We can summarize the principal results obtained in the technical analysis in the following points:

- Otterboards tested do not influence the level of catches so this factor does not increase or decrease vessel revenues. The only significant element to be considered in gear economic performance is fuel consumption and motor stress.
- BIPLAN experimental otter boards produced by Mori is the best gear in terms of reduction of the strength of the nets, favorably impacting the wear of the boat and the maintenance costs;
- FLY experimental otter boards produced by Grilli is the best gear in terms of fuel consumption allowing a reduction of about 6.6 l/h compared to the traditional trawl doors;
- the Danish environmental friendly otter boards THY is the best gear in terms of trawl boards opening, even if this performance seems not significantly affect fish catches.

The tests carried out in 2014 lack of usable data to make up a proper economic comparison among the various innovative gears tested, so in the second phase of this study it was choose to select and use one gear for more than one year of fishing activity in order to collect usable economic data. It was choose Grilli AR Poly otterboards because of both its good results in the sea test trials and the importance of Grilli brand which is well spread among Italian trawlers, even if it was not the "first best choice" in terms of fuel reduction.

Poly AR otter boards are made in plastic and they are claimed as innovative by their producer, being cost effective by virtue of a reduction in the vessel towing effort during fishing activities and to be able to reduce drastically fuel consumption costs. They are supposed to be environmental friendly too, because they do not touch directly the sea bottom reducing soil cracks, sand clouds and CO_2 emissions by means of less fuel consumption due to a smaller trawl doors friction than conventional similar gears.

Poly AR gear was chosen also because it was not a prototype and already available on the market, so it was easy to persuade the owner of Orizzonte to adopt the gear for his standard activities of more than a year. The trawls gear was equipped on the vessel to test its economic performance during standard fishing activity, the period of consideration was from 16th of July 2014 to 31st of December 2015.

The difference between the balance sheet of 2015 and 2014 was -31.435,25 € of less fuel costs in the amount of 16,5% of total 2015 vessel costs. Such marked difference in cost is mostly depending on a considerable fall of oil price occurred in 2015, which was on average 0,5 € per litre lower than 0,603 €, the average price of the last 5 years. This work intended to analyse whether the implementation on the vessel of the innovative Grilli AR Poly otter boards might have conditioned the reduction of fuel consumption.

An indirect analysis on fuel consumption was carried out by utilizing the amount in litre of fuel purchasing occurred during the period from 2008 to 2015. It was chosen to use data on quantity of purchased fuel instead of paid fuel cost to avoid the distortion due to the high fuel price volatility. It was supposed to consider the activity of the vessel like if it was business as usual with the only change of the otterboards implementation.

In the analysed periods with the use of AR Poly otterboards data had shown a reduction of the average fuel purchasing per day at sea. On average, it was 156,35 litres per day less than all the periods considered with the use of conventional otter boards with a daily fuel consumption difference of 11,36% less than the average consumption per day at sea of the periods with the traditional otter boards Z (1.376,26 €).

Using the average price of fuel (0,6 €) of the entire considered period (2008 - 2015) it was appraised the daily saving of fuel per day at sea in unit of euro in the amount of 94,35 € per day at sea. This amount multiplied by the average days at sea of the period (134 days at sea) carried out the value of the annual savings in fuel costs using the innovative otter boards in the amount of 12.666,28 € per year of fishing activity (

Table 35).

As benefit was chosen only the fuel savings per year because the otter boards would not alter other variable of revenues such as fishing capacity, motor stress or lubricant costs, like CNR-ISMAR declared in several meetings during this study. So the total annual benefits were esteemed in 12.666.28 € as the difference between the average fuel purchased per day at sea multiplied for the average days at seas (134) and the average fuel price (0,60 €) of both during the period using the traditional otter boards and the testing period.

These days at sea are bigger than the ones mentioned above in this document because in this part of the study there were used data provided by the local market which refers to landings which occur 4 times a week (during nights), while the effective days of fishing are 3.

Then, there have been calculated the net cash flows for each year as a difference between benefits and costs and then it was computed the Net Present Values (NPV) with various discount rates: 3%; 4%; 6% and 10%. This choice was made to avoid an alteration in the reading of the results reducing the possible distortions on the various weight which each discount rate could put on the time period, because the less the discount rate the higher is the weight on the net cash flow along the time frame studied and vice versa (Perman, 2003).

Doing so, it was possible to obtain the NPV of the investment which resume the value of it along the time frame in present monetary terms. All the results obtained show that the investment is cost effective with every discount rate considered because all of them are positive (next table). The break-even was calculated as the ratio of the initial investment costs and the daily fuel savings. After the 100th day of fishing with the implementation of the new gear the investment started to produce positive economic values for the vessel.

The results of the CBA indicate that, standing at the data of the testing period with the hypothesis of no other factors occurred in the reduction of fuel purchasing per day at sea, the innovative otter boards *Grilli AR Poly* are cost effective for the vessel studied. The benefits in swapping the technology are enough to exceed the cost of the investment operations.

Considering a time period of 10 years the innovative otter boards are able to produce savings in fuel purchasing every year and to release an actual positive value with all the discount rates considered. The value of the investment is: € 117.942,03 for 3% discount rate, € 111.507,84 for 4% discount rate, € 100.155,90 for 6% discount rate and € 96.395,55 for 10% discount rate.

Based on the estimation of this study the whole cost in swapping the technology would be returned with a pay back after 100 days at seas, so already during the first year of the new technology implementation. Those values, even if are an estimation of future cash flows based on indirect evaluation of fuel consumption between two technologies, are bigger enough to be considered in the investment decision process of each trawling fisherman in Ancona.

Finally, considering that most of the trawling vessels in Ancona port have similar characteristics of Orizzonte, it has been designed a scenario where the entire trawling vessel would have implemented AR Poly otterboards on board. Imagining that all the fleet of Ancona, composed of 46 trawling vessels, would exhibit the same values appraised for Orizzonte in terms of day at seas, fuel saving per day at seas (reduction 20.990,61 litre of fuel purchased per year) at the average price of 0,6 € per litre of fuel. With this hypothesis the whole port would save € 582.648,90 in fuel purchasing.

The same estimation for the trawling fleets of Marche Region and Italy would be 2.178.600,24€ and 31.982.358,22€.Even if the results are extremely raw not reflecting all the real trawling sector differences (dimension, tonnage and power), this could be a win-win solution because there is no public taxation on maritime fuel, so the government would not lose anything. It was also appraised the value of the benefits obtained in terms of CO_2 reduction by means of the innovation introduction.

It was estimated a fuel reduction of 20.990,61 litre not consumed yearly. This value was multiplied by the CO_2 emission equivalent for the maritime sector in the amount of a 0,00266940 Ton of CO_2 per litre consumed like it was used in Crilly and Esteban (2013). Doing so it was appraised a reduction of CO2 emissions of 0,46 Tons per day and 56 Tons per year for the vessel.

To give a monetary value at the environmental benefit this amount was multiplied by 5,75€ the day value (10th of may 2016) of a single ton of CO2 in the secondary market Emission Trading Scheme (ETS) in unit of a Eu Emission Allowances (EUA). The monetary saving in avoided emissions of the vessel was appraised as 322,19 € per year for each vessel. Source: https://www.eex.com/en/market-data/emission-allowances/spot-market/european-emission-allowances#!/2016/05/10 (May 2016).

The results shown that the implementation of innovative gears studied, would allow important benefits economics and environmental benefits for the whole trawling sector, both the values obtained are noteworthy even if it was a pure simple "estimation game". Despite this, it would be interesting to examine in depth this topic in further similar studies.

Table 33. Otterboards economics data. Data provided by CNR ISMAR

NAME	MANUFACTURER	MODEL	TYPE	ON MARKET	PRICE MIN	PRICE MAX	PRICE AVG	MAINTAINANCE COST MIN	MAINTAINANCE COST MAX	MAINTAINANCE COST AVG
BIPLAN	MORI CARLO SRL	BIPLAN 139/180	INNOVATIVE	YES	€ 2.700,00	€ 3.000,00	€ 2.850,00	€ 200,00	€ 400,00	€ 300,00
Z	MORI CARLO SRL	Z	TRADITIONAL	YES	€ 1.900,00	€ 2.300,00	€ 2.100,00	€ 300,00	€ 800,00	€ 550,00
FLY	GRILLI SAS	FLY AR INOX/PE	INNOVATIVE	NO (PROTOTYPE)	-	€ 2.500,00	€ 2.500,00	-	-	-
THYBORON	THYBORON	THYBORON	INNOVATIVE	YES	€ 6.000,00	€ 9.000,00	€ 7.500,00	€ 150,00	€ 600,00	€ 375,00
POLY	GRILLI SAS	POLY	INNOVATIVE	YES	€ 1.100,00	€ 6.800,00	€ 3.950,00	€ 600,00	€ 1.600,00	€ 1.100,00
C	MORI CARLO SRL	C	TRADITIONAL	YES	-	-	-	-	-	-

Table 34. Differences among mean values obtain by each gear during the experiments. Data elaboration by CNR-IRCrES.

	TTF[kg]	Diff	TS[kn]	Diff[kn]	TTF*TS	Diff	FC[l/h]	Diff[l/h]	HDS[m]	Diff[m]
THY	-	-	3,47	-0,10	-	-	51,29	-4,40	69,17	14,93
FLY	-	-	3,41	-0,15	-	-	49,06	-6,62	59,31	5,07
POLY	3566,30	111,00	3,71	0,14	13227,40	898,20	55,26	-0,43	44,06	-10,18
BIPLAN	3414,61	-40,69	3,58	0,01	12219,00	-110,21	54,63	-1,06	51,01	-3,23
Z	3455,30	0,00	3,57	0,00	12329,20	0,00	55,68	0,00	54,24	0,00
C	3537,65	82,35	3,56	0,00	12608,65	279,45	53,43	-2,25	55,31	1,07

Table 35. Average days at sea, average daily and annual fuel saving with the implementation of the innovative trawling gear. Data elaborated by CNR IRCrES.

FUEL SAVINGS	
Average N° of day at seas	134
Average Fuel cost per day at sea with traditional otterboards 2008 - mid July 2014 (Lt)	1.376,26
Average Fuel cost per day at sea with innovative otter boards POLY mid-July - 2015(Lt)	1.219,90
Average Fuel saving per day at sea (Lt)	156,35
% of fuel savings on average fuel costs per day at sea	11,36
Average Fuel price (€)	0,60
Average Fuel costs saving per day at sea (€)	94,35

Table 36. NPV of the investment (implementation of Poly otterboards) obtained with various discount rates on a 10 years time frame. Data elaboration by CNR IRCrES.

NPV r = 0.03	€ 117.942
NPV r = 0.04	€ 111.508
NPV r = 0.06	€ 100.156
NPV r = 0.10	€ 96.396
Break-even Fuel savings (number of days at sea)	100

Table 37. Fuel savings, reduction of CO2 emissions and value of reduction for the fleets of Ancona, Marche Region and Italy. Data elaborated by CNR IRCrES.

	Number of vessels	Fuel saving (€/year)	Reduction of CO2 emissions (t/year)	Value of CO2 reduction (€/year)
Ancona	46	582.649	2.577	14.825
Marche	172	2.178.600	9.638	55.416
Italy	2.525	31.982.358	141.482	813.519

The analysis of the drivers of innovation

A qualitative approach was used for the analysis of the drivers of innovation: twenty fishermen (the list of the people interviewed, with their main characteristics is available) have been interviewed during individual deep, face-to-face, interviews collecting evidence from about a fifth of the total vessels of the Ancona fleet.

The semi-structured questionnaire prepared by LEI (Partner 1.b) was supplemented with additional questions designed to bring out the individual life stories of fishermen, the characteristics of their business and their needs in terms of training. Two types of questionnaires were proposed with different questions based on whether or not the fisherman being interviewed had recently implemented a sustainable innovation.

The questions were designed to investigate the reasons and the most important factors in choosing or refusing sustainable innovations. The respondents were also asked about their opinion on innovation possibilities in the sector, in both technological and managerial terms, the impact of European Union regulations in the sector, and the future of the industry.

The investigation has also been extended to other three key informants: the local cooperative of fishermen (Cooperativa Pescatori e Motopescherecci), the Ancona fish market (Mercato Ittico all'Ingrosso di Ancona - Mer.It.An managed by the Associazione Produttori Pesca) and the regional authority for fisheries (Regione Marche, Servizio Pesca).

The heads of the three organizations (Gabriele Falasconi for the fishermen's cooperative, Nicola Pandolfi for the fish market and Uriano Meconi for Marche Region: we thank them for their precious contribution to the research.) were interviewed to better understand the characteristics, the actors, the relationships in the local fishery as well as the working mechanisms of the whole supply chain.

The interviews were carried out on the following days:

- 28 – 29 April 2015: interviews to the fishermen's cooperative, fish market and Fisheries Department of Marche Region;
- 27 – 29 May 2015 and 17 – 19 June 2015: interviews to local fishermen.

All interviews were recorded, transcribed and then analyzed by the working group. Transcripts were reduced and corrected in team as suggested in Bertrand et al., 1992 and Krueger, 1994. The analysis was made by means of reading frame improved in an iterative manner during the analysis of the transcripts, as suggested by Dawson et al., 1993.

The respondents participated actively in the survey. They expressed interest in the investigation and seemed glad to have the opportunity to share their opinions about the sector. The interviews were made with vessel owners and skippers. The people interviewed are aged from 20 to 65 years, they all have a wide experience that comes also from a long family tradition in fishery.

Some of them have a formal education in the field (nautical secondary school), they all are competent and proud of their job that is mainly a family business. All respondents, except one, inherited the business from a relative and started to work at sea at a very young age as sailors, before specializing further and eventually becoming captains of their own vessels.

All respondents say that they come from families in which fishing is the main source of income and it involves all family members in various daily activities, also not strictly related to the sailing activities. These activities include: helping fishermen during landing operations; selling products directly or at the fish market; accounting; and helping with vessel maintenance. Relatives or family friends are usually involved in these operations, thus creating a permanent collaboration, but mostly without a regular job contract. Without this kind of help, the fishermen would have to face even more difficulties than the ones they already have.

Vessel crews vary depending on the type of fishing. On average, there are 4 crew members for bottom trawling, 7 for beam trawling and midwater pair trawling, and 2 for hydraulic dredges. The crews mainly include relatives and friends of the fishermen. Foreign sailors are often employed, principally from North and West Africa, because they are more likely to bear the harsh working conditions and the low wages.

The respondents state that employment relations are regulated by the national labor fishing contract, which provides two payment methods, one with fixed wages and one where the total daily revenue is divided fifty-fifty between the owner of the vessel and the workers (Federpesca, 2010).

The fishermen interviewed use three main types of fishing gears: otterboards (14), beam trawls (1), midwater pair trawlers (3), and hydraulic dredges (2). The differences in the various types of fishing technologies are reflected in the different needs for and investments in fishing equipment, in the fishermen' perception of how the sector is managed, as well as of the role of regulations and restrictions and in their propensity toward innovation. The answers show that fishermen share very similar opinions, especially for what concerns the management and the regulation of the sector, the perception of environmental problems and the future of the industry.

The innovations implemented are: 4 plastic AR Grilli otterboards for bottom trawling aimed to reduce the consumption of fuel and the impact on the sea bottom; 2 50-mm meshes to reduce catches of juvenile fishes; 2 plastic nets to reduce drag and fuel consumption; and an engine with greater energy efficiency. The age of the boats, ranging from 7 to 35 years, did not seem to affect the decision to innovate.

As for their environment sensitiveness, the fishermen interviewed have a strong sense of responsibility. They feel themselves active and important actors in the management of the Adriatic sea and its resources. They are concerned that their activity undermine fisheries stocks and cause impacts on the seabed ecosystem. They explain that since thirty years ago, they adopted a policy of self-regulation and decide to reduce their fishing effort by decreasing the days at sea from four to three per week, to preserve both the fish stocks and their revenues, avoiding price falls.

The main drivers of innovation appeared to be very similar among the fishermen. They report a number of heterogeneous problems: a) the high costs of fuel and vessel maintenance; b) the high level of bureaucracy in the sector and the pressure of the taxation system; c) the low level of support from and relationships with regional and national institutions; d) the difficulties in fulfilling the European Union's legislation (i.e. minimum landing size and catch recording); e) the high level of control and the sanctions they perceive as disproportionate compared to the irregularities. They suggest more appropriate regulations, fitting the local fishing conditions and systems. According to them, the European Union's regulations are largely based on Atlantic fishing studies, because there is a lack of analyses for the Mediterranean that instead would help to formulate rules more appropriate to the national and local sector. Finally, they propose that the reduction of fishing efforts would be planned in coordination with other Mid-Adriatic ports and fishing fleets in Italy, Slovenia and Croatia.

The drivers of change in adopting sustainable technologies and gears can be synthetized as follow:

1 functionality of the new gear implemented, that requires a strongest collaboration between fishermen and researchers;

2 beneficial effects of the innovation in their activity (i.e. reduction of fuel consumption);

3 public incentives to sustain part of the costs of the innovation (i.e. installation);

4 Reduction of the impact on the environment.

Drivers of innovation

Fishermen who had implemented sustainable innovations in the previous years said that their main motivations for doing so were high fuel costs, the improvement of their fishing activities in terms of quantity and quality achievable with innovations, and the need to deal with specific difficulties related to fishing in certain areas.

As for the adoption of larger mesh nets, the primary driver of change was the imposition of new gear to reduce juvenile fish catches introduced by EU Regulation 1967/2006 (UE, 2006). A key factor to boost innovation was the peer-to-peer comparison with colleagues who had already tried a new technology. Generally, the fishermen based their evaluation on both implementation costs and opportunities to save money from a reduction in fuel consumption and gear maintenance costs.

A most important aspect in the decision to innovate was that the new gear would ensure at least the same catch capacity as the previous one. Furthermore, the fishermen also considered the labor costs required to learn how to use the new equipment. The time elapsing between the initial need to change and the actual decision to buy new gear depended on the fishermen's own propensity to change, which does not appear strictly related to age, but has to do with life experiences, curiosity and discussions with colleagues and family members.

Some fishermen decided to buy innovative gear after direct contacts with the gear manufacturers, who gave them a chance to test the new equipment before purchase. The last factor taken into consideration when deciding to innovate was the presence of beneficial effects on the environment, which appears to lend added value to the choice of implementing new technologies but is not fundamental.

The main aspects causing the non-implementation of sustainable technologies were: the "traditionalism" of the fishermen and their family culture not inclined to innovations; risks related to the new technology in terms of catches, economic losses and lower income; high investment costs; and opportunities to amortize such costs.

Another important factor was professional motivation, along with the fishermen's vision of the future of their business. Some fishermen who were tired of working, childless, and had no opportunities to leave the market showed low propensity to innovate. A further element affecting the choice to innovate, for both those who implemented a sustainable innovation and those who did not, was the availability of subsidies and public incentives for innovation. Fishermen who said that they had not made any technological improvement stated that they would have reversed that decision if public incentives had been available.

Government regulations for environmental sustainability through "command and control" policies are followed by the fishermen, although innovation involves loss of income, as in the case of EU Regulation no.1967 / 2006, which imposed various restrictions on gear to protect fish stocks, among which the use of nets with larger meshes. This resulted in substantial economic losses for fishermen in terms of catches and sales, but the law was followed by all the fishermen of the fleet.

In summary, according to the answers given by the respondents during the investigation, the decision to change seems to be affected by several elements, in the following order:

1. legal obligations and controls;
2. equal catching capacity compared to the previous equipment;
3. fuel cost savings;
4. presence of subsidies and incentives;
5. maintenance cost savings;

6. risk propensity;
7. inclination to innovation (culture of the fishermen);
8. comparisons with colleagues;
9. work motivations and ideas about the future of the business;
10. Environmental sustainability of technological innovations.

The fishermen's responses also indicate that those who implemented a shift toward more innovative technologies were happy with their choice, due to lower fuel and maintenance costs and improvements in the quality of catches. None of them said that they would go back to the previous technology.

Technological improvements in the fishing sector

All respondents agreed that technological innovations in the industry should focus on increasing the energy efficiency of vessels through improvements in engines and equipment, so as to reduce fuel consumption, which is the highest cost the fishermen have to bear. Another request was improving safety during sailing and fishing. All respondents also agreed that the presence of government incentives, in the form of tax relief and grants, would increase the amount of technological innovations (aimed at sustainability) in the sector.

Some fishermen expressed the need for tighter collaboration with the National Research Council (CNR) and, in general, for greater investment in research, for what concerns both technological improvements and political and economic management of the sector.

European regulations on fishing

Although some regulations have been accepted as positive to curb the reduction of fish stocks, such as the introduction of wider mesh nets, the fishermen interviewed unanimously stated that they were not in favor of European standards to regulate fishing. This was mostly related to unnecessary bureaucracy, restrictive controls, and excessive sanctions.

According to all respondents, fishing restrictions, which force them to classify catches by size and species before landing, make fishing activities more difficult. Sanctions are considered extremely excessive and controls too tight. The fishermen also complained that regulations are unsuited to the local area, as standards and fishing methods used in the regulations refer to fishing in the Atlantic, which is very different from fishing in the Adriatic. They suggested potential solutions such as adapting the regulations to the local fishing system or giving greater decisional power on fishing regulations to national states and local authorities.

The arguments used by the respondents to explain the current situation were the lack of representation of Italian politicians at the European level and of technicians at decision-making levels; the lack of sector representation; the lack of interest in the sector by the government and of research on the local fishing system to offer alternative proposals at the European decision-making level.

The respondents asked for interventions on these aspects to improve the efficiency of European policies at the local level. However, many fishermen claimed that rules and regulations are important, since without these there would be significant difficulties in the protection of fish resources and the environment. Moreover, the coordination of the sector in the absence of central regulations would not be able to reduce fishing pressure. The latter aspect was underlined as key to reducing impact on fish stocks and ensuring continuity of fishing activities in the future.

Many fishermen also complained about the non-extension of policies aimed at reducing fishing pressure to Croatia (a country in transition toward European standards), which affects the preservation of fish stocks in the Adriatic. This transition situation has caused a major expansion of the Croatian fishing fleet and strong competition with the Ancona fishermen.

Another element of conflict was the new regulation on discards included in the new European Fisheries Policy outlined by EU Regulation no.1380 / 2013 (EU, 2013) on undersized fish discards, which forces fishermen to keep all discards instead of unloading them at sea. Fishermen claim that this would prevent the reintroduction of organic mass into the sea, which could be reused by the marine ecosystem to regenerate itself, as the accidentally caught fish are dead anyway. According to the respondents, the new regulation results in high disposal costs and greater risk of sanctions in addition to considerable costs for the entire sector.

Improvements in the management of the sector

According to the interviewees, the management of the sector should focus more on reducing fishing pressure in terms of days at sea in the whole Adriatic basin. The Ancona fleet, which carries out fishing activities one day less per week than in the rest of Italy, was used as an example of sustainable management of fisheries but, in the absence of central coordination with other fleets, the overall positive impact on fish stock is nullified.

Central coordination is also needed for the management of the biological rest period, which does not reflect the actual fish breeding period. It currently runs between July and August without coordination across fleets. Many fishermen suggested splitting it into two smaller rest periods in summer and winter, while also extending it to all Italian ports. According to the respondents, this would enable greater reproduction of fish throughout the year.

Many respondents also noted that decreasing investments in technologies and vessel power are an important factor for the reduction of fishing pressure. According to many of them, the use of twin trawls technology is unsustainable in the long run, because the depletion of resources is actually greater than the reproduction capabilities of the ecosystem. The fishermen underlined that if it is not abolished or limited, this technology will be adopted by the majority of fisheries due to its profitability in the short term. In this specific case, what seems to emerge is the classic prisoner's dilemma of game theory, in which the optimal balance in the management of collective resources is not achieved because of strong private interests in the absence of regulation (Bravo, 2009).

Another measure proposed to reduce the impact on marine resources was the introduction of quotas for pelagic fish in the whole Adriatic Sea, in order to limit depletion and avoid excessive price falls. This practice was adopted individually in the past by the Ancona fisheries to protect both market prices and resources, but it was later abandoned because other fleets did not adopt it, thus causing an inefficient solution for the local sector.

Suggestions to improve the sector included encouraging young people to start working as fishermen and giving more importance to the Italian fisheries through information, research, and dissemination activities. According to the respondents, this could be achieved through greater support to the sector, the creation of associations similar to those in the agricultural sector, an increase in collaboration with research institutions, as well as by strengthening relations with policy makers.

Environmental awareness of consumers and sustainability certification

The interviewees stressed that customers, both wholesalers and private individuals, have no interest in the environmental sustainability of fishing techniques. Customers are only interested in product quality, freshness, and purchasing price and would not be willing to pay a higher price for products which have a sustainability certification. Nevertheless, some respondents were in favor of trying to obtain a sustainability certification, but only if combined with major investments in information and customer awareness in order to disseminate a "culture of fishery".

Environmental concerns of fishermen

All respondents expressed great interest in decisions concerning the sea and fish stocks and considered themselves key players in their management and future preservation. Indeed, their main concerns related to fish stocks, which, according to the older fishermen, have decreased significantly compared to 20-30 years ago. The interviewees were aware that the collective action of the Ancona fleet has a direct effect on fish stocks and approved of the idea to reduce the number of days at sea.

Most of them mentioned the example of the Ancona fisheries, which for more than 30 years have limited the number of fishing days per week to 3 (1 less than the Ministerial guideline). This has led to a smaller amount of fish resources being depleted, thus enabling the future regeneration of natural resources and ensuring higher market prices. This has been brought about by the experience of fishermen, who have seen their profits increase by reducing fishing days. As the sector is extremely competitive, an optimal balance can be achieved only if all the actors involved in the management of the common resources succeed in working together (Bravo, 2009).

The greatest inefficiency of the industry was identified in the fact that nearby fisheries did not decide to reduce their number of fishing days (Senigallia, Civitanova Marche, and Rimini). The respondents also stated that the biological rest should be revised to allow all species to reproduce, dividing it into two seasonal rest periods, one in winter and one in summer, and extending it to the entire Adriatic coast.

Another issue of concern regarded the widespread increase in twin trawls in the Ancona area, which the fishermen believe to be a cause of over-exploitation of fish stocks and destruction of the seabed.

Future of the business

As for the future of their work, the fishermen gave conflicting answers depending on their willingness to continue their fishing activities. The most motivated respondents were those with successors able to continue the family tradition. All respondents said that they were motivated to continue the business as the main income generating activity of their family. Only a few stated that they would continue fishing because they had no opportunities to leave the market through the sale or demolition of their vessel.

Future of the fishing sector

The fishermen unanimously predicted that there will be a drastic reduction in fishing pressure as the number of active vessels will decrease, which will facilitate the development of aquaculture practices and the trading of foreign products.

Two different views emerged: the more pessimistic one predicts a contraction that will lead to the collapse of the Italian fishing sector, while the more optimistic one states that a reduction in the number of vessels will lead to improvements for the fisheries which remain in the business. Less market competition and smaller quantities of fish landed will increase prices and revitalize the sector in the future. Many believe that greater support from the institutions is fundamental to prevent the decline of the industry, a process which has already been underway for several years (Irepa, 2012).

From the analysis of the results of the interviews two main questions emerge to be answered in further studies: 1) How can the R&D help fishermen to implement sustainable innovations considering the peculiarities of the local fishing systems? 2) How can be increased the coordination among different levels of governance (local – i.e. fishermen's association, regional, national and European) in order to encourage sustainable choices thus avoiding the collapse of such important economic sector?

The analysis of scenarios

Scenarios consist of visions of future states and courses of development, organized in a systematic way as texts, charts, etc. (Miles, 1981). The foresight is a process of continuous, systemic, interactive, creative and participatory reading of the information, to go beyond the visible and present, to sense the utility of new choices, in order to develop visions for the future of the medium long period (over 10 years) and thus detect possible scenarios of new technologies or other development to guide decision-making and policy interventions towards the desired objectives (Cariola and Rolfo, 2004).

Different foresight methods such as SWOT analysis, trend extrapolation, Delphi techniques, Cross-impact analysis or scenarios, as in our case, are used often in combination to explore what might happen in the future, under various circumstances (Popper, 2008.a and 2008.b).

That of "scenarios" is one of the most used methods in foresight process. The construction of a scenario is not something static that, once defined, is valid forever. Its construction is in fact based on the prior identification of certain key elements and factors which are then continuously monitored and updated. Their changes directly impact on the scenario, on its morphology and therefore on the performance of what, situation or technology, it tries to predict.

Therefore, for the construction of a realistic scenario concerning the introduction of a new technology, it is necessary to previously identify the main critical factors whose behaviors determine its continuous adjustments in the medium-long term.

From the CBA analysis and the analysis of the drivers of innovation among fishermen three main scenarios have emerged. They are referred to the three factors that will most influence the introduction and spread of new fishing technologies in the coming years, namely the reduction in fuel consumption, the introduction of limitations or incentives at legislative level, and the change in consumers' preference and style towards sustainability that directly affect the demand and the prices of fish products. The three main scenarios to be analyzed are therefore related to: 1) the oil price trend; 2) the legal framework in the fisheries sector; 3) the trend in consumers' behavior.

Examining the macroeconomic and political framework it is possible to identify some key factors to be monitored in order to continuously redefine each scenario and thus quickly make changes and/or additions to the choices made in relation to the new technology. As an example, we will try to identify the key factors essential for the construction of the scenario on the oil price trend, which impact directly on fuel cost.

Oil price trend scenario

This scenario is important because the new experimented fishing gear has proven to allow a reduction in fuel consumption, in the economic costs for vessels and also in the environmental costs (CO_2 emissions). As much oil and fuel prices are predicted to remain high in the medium-long term, as much the impact of new technology on the costs will be significant and will therefore be high thrust to its adoption by fishermen. Conversely, in a scenario of fuel prices continuing to fall, also in the long term, it will be less strong the encouragement to introduce a new fishing technology that decreases fuel consumption.

Referring to this scenario, in the last decade, for various factors that will be briefly examined, the price of crude oil has been very fluctuating and has then collapsed by about 80% from the peak in 2008 to 2015, for an excess of supply, reaching back to the quotations before 2005. Now we are starting to report some price recovery in the first months of 2016. After an analysis of the macroeconomic and political situation, the main factors resulted important to be monitored for the construction and development of this scenario, are (International Energy Agency - IEA, 2016, iea.org):

- the production trend of OPEC, especially Kuwait, United Arab Emirates, Saudi Arabia.
- The Iran's return in the oil market. The International Energy Agency (IEA) predicted that the world would be "drowned in oil", but at the moment, despite Iran's production now has already returned to pre-sanctions levels, the IEA has changed its forecasts and estimates that the excess of oil on the market has finally begun to subside and that in the coming months there will be even a "dramatic reduction" in the surplus.
- Non-OPEC oil production, which - thanks to a long series of unexpected events (from fires in Canada to the upsurge of violence in Nigeria) - is declining at a rapid pace. The IEA now expects for 2016 a decrease of 800 thousand bd (barrels per day, 1 barrel = 159 liters), instead of 710 thousand, to 56.8 million bd. The retreat, as hoped by OPEC, is above all driven to the American oil shale. And the effects are already being seen.
- The trend of demand coming from United States, China and Japan, the three major global consumer of oil, and from Russia.
- The demand coming from India which, according to the IEA "is overtaking China as the fastest growing market for oil". Between January and March 2016 India consumed 4.4 mbd (million barrels per day), finishing

in fourth place in the world. The increase from last year was $ 400 thousand bd, a third of world demand growth.

- The trend of oil stocks in OECD countries. Currently the oil surplus, though still impressive, is decreasing compared to the more than 2 million barrels per day achieved in 2015. All this despite Iran has chalked up an amazing recovery after the end of international sanctions. Its production during the first months of 2016 has returned to the levels in November 2011 to 3.56 mbd, while exports, thanks to super-competitive prices, has grown by over 40% to 2 million barrels per day. 800 thousand of them have sailed to China, while other 500 thousand bd arrived in Europe, where evidently the difficulties have been overcome in securing the loads coming from Iran. Before sanctions the Old Continent was receiving about 600 thousand bd.
- The trend of the dollar, the currency in which oil is quoted. We must consider the currency effect for Europeans. Although in the last years the oil price in dollar has depreciated, as the dollar has appreciated considerably with respect to the Euro, the savings on oil price have been partly calmed by the currency component.
- Political events such as Brexit in UK, penalize commodities as oil, because oil consumption is considered most vulnerable to the risks of an economic decline. Although, according to international observers, it comes to short-term effects.
- The trend extraction of shale-oil in the US. After a considerable decline in recent times, Apache, one of the largest US independent companies, has just announced (September 2016) the discovery of a new field that could contain 8.1 billion barrels of oil reserves and not conventional gas: a huge amount, which could weigh heavily on the world supply trends and therefore on prices.
- The problem of excise duty and of the tax on the final price of fuel. The excise tax is a fixed amount and does not take into account the trend of oil prices, nor of the currency changes. In Italy, for example, taxes are very high and cover on average more than 60% of the final price. In Europe, only the Netherlands and the UK have a higher level of excise duty. Therefore, a reduction in the cost of crude oil corresponds only to a percentage decrease of the same amount of the consumer price.
- Because the oil price (Brent) is a quotation of the raw material which represents only a fraction of the final price for consumers, we have to consider also the trend of costs of extraction, storage, refining and distribution. Furthermore, there are the costs of research and operations and the profit margins set by the oil companies. The latter were relatively low in the last period, around 8%, as the crude oil market has suffered for excess of supply. So oil companies have had to be rather more competitive to maintain or gain market share.

A similar analysis can be done for the other two scenarios. Here just some suggestions are provided.

Evolution in the legislative framework of the fishing system

As much, the legislation will become restrictive to make fishing more sustainable, in particular by introducing rules on environmental friendly technologies to be used in otterboards fishing, which might be able to reduce fuel consumption (and thus the environmental impact). So new technologies such as the tested otterboards during this study will have actual chances of diffusion.

What drives us to believe that the legislation will also expand in this direction is that, already in the last few decades the legislative framework for the fishing sector has been continuously enriched with the introduction of directives and regulations to improve environmental sustainability.

In particular, it would be useful to evaluate the possibility of the introduction of standards that encourage or oblige the use of new fishing technologies, aimed to reducing fuel consumption and, therefore, CO_2 emissions and other pollutants.

A good news comes from the new proposal for a regulation on fishing which changes five previous regulations and repeals six previous ones, (https://ec.europa.eu/transparency/regdoc/rep/1/2016/IT/1-2016-134-IT-F1-1.PDF).

It condenses into a single document all the indications and the common fisheries policy measures and decentralizes the management of fisheries, gives power to the national and regional actors, promotes consultation of interested parties and the scientific experts.

Technical conservation measures should become more appropriate and adapted to the specific needs and characteristics of the fishing area. It is further applied to a set of general rules such as the ban on certain fishing equipment and the landing obligation instead of the discarding of unwanted catches.

Furthermore, as fish stocks in the Mediterranean are increasingly depleted and the fishermen have stated the need of a fisheries control policy to restore them, on April 2016 the MedFish4Ever European Union strategy has been launched during the Global Seafood Expo.
(http://ec.europa.eu/fisheries/inseparable/it/medfish4ever): this is an action plan to preserve the fish stocks, involving the eight Member States bordering on the Mediterranean and other coastal Countries, through the participation of all stakeholders.

Trend in consumers' behavior

For building, this scenario an important factor to consider is that consumers in Northern Europe, Germany, UK and Scandinavia already require sustainable fish resources. Suppliers must obtain certification of its products to maintain market shares.

The Southern Europe countries remain more marked by freshness rather than to the traceability of the product. Here, the push for change towards sustainability can come from no-profit organizations, from big retail chains more careful and responsible, or, as it is already happening, from the public food procurement: school canteens, hospital and elderly care facilities.

In Italy, many initiatives are spreading to promote the introduction of fresh fish, local species, organic farming, small-scale and sustainable certified fisheries in order to avoid unsustainable seafood. Public food procurement is a demand of large dimension, secure and on a continuous basis which can be a driving force for the development of sustainable fisheries and aquaculture.

One of the most active Italian regions in this area is the Marche Region. The fishermen of Ancona and the rest of the region should take advantage of the initiatives started in the regional public catering to start collaborations that enhance the fish caught with more sustainable fishing techniques and technologies. However, the offer should better organize itself to make available certain, planned, tracked and certified quantities.

BLACK SEA

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Case Study summary

Samsun Shelf Area (SSA) is one of the most important fishing areas along the Turkish Black Sea coasts. The Black Sea Case study is being conducted in Samsun Shelf Area (SSA) to outline the impact of drag-nets (beam and bottom trawl) on the benthic habitat operating for a long period along the southern Black Sea.

Samsun Shelf Area being discharged by two major river of Anatolia (Yeşilırmak and Kızılırmak) is a special ecosystem. The biodiversity of benthic and benthopelagic species is limited due to anoxic zone in Black Sea over depths of 150 m. The bottom topography is largely flat and composed of fine sand-silt sediment (mud) that makes the region available for trawl fishery (Knudsen et al, 2010) (Figure 76).

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 (Zengin, 2011).

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 (Sağlam et al, 2009).

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 (BENTHIS, Balck Sea Case Study, WP3).

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 avarage 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 (Kaykaç et al, 2014).

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 (BENTHIS, Balck Sea Case Study, Report: WP7.6).

Fishing gears used with benthic impact

There are two fishing gears that have benthic impact used in SSA. The gear specifications are presented in Table 38. The beam trawls are being actively used in near shore waters nearly 5-30 m and bottom trawl are operating in sub littoral zone nearly 40-80 m. In Black Sea Case study the primary task was to define the technical and functional characteristics of the fishing gears in SSA.

Relevantly, the tasks that has been completed; (1) structural and technical characteristics of gears (beam and bottom trawl) (Figure 77, Figure 78), (2) Fishing effort (catch per unit effort for target species, the amount of by catch species, discard and landing) (subheading 3), (3) Quantity and quality of active fishing fleet (size range, fishing capacity, etc.) (subheading 3).

As it is presented in Table 38, the drag nets (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 technical specifications were defined in four different ground gears that are currently being used in traditional bottom trawls (Kaykaç et al, 2014). Furthermore, any other alternative model for the ground gear was discussed (Figure 79).

In SSA, there are some technical differences between the design of the beam trawls gears used in different sublocations 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.

This rubber plate is not being used in eastern stations as the substratum is relatively soft composed of sand and mud in varying proportions. In relatively hard bottoms, to ease the hauling and to protect the net from damage, pallets were attached to beam ground gear with chain ropes.

The total weight of an algarna (beam trawl) with all kind of attachments (ropes, palletes and chains, leadline, mesh codend and sheath). The mean weight of palletes is 15-16 kg and the dimensions were measured as 90x300 cm (Figure 80, Figure 81) (Kaykaç et al, 2014).

The general structure of traditional beam trawl/algarna used in SSA can be outlined as from Figure 82 and Figure 83.

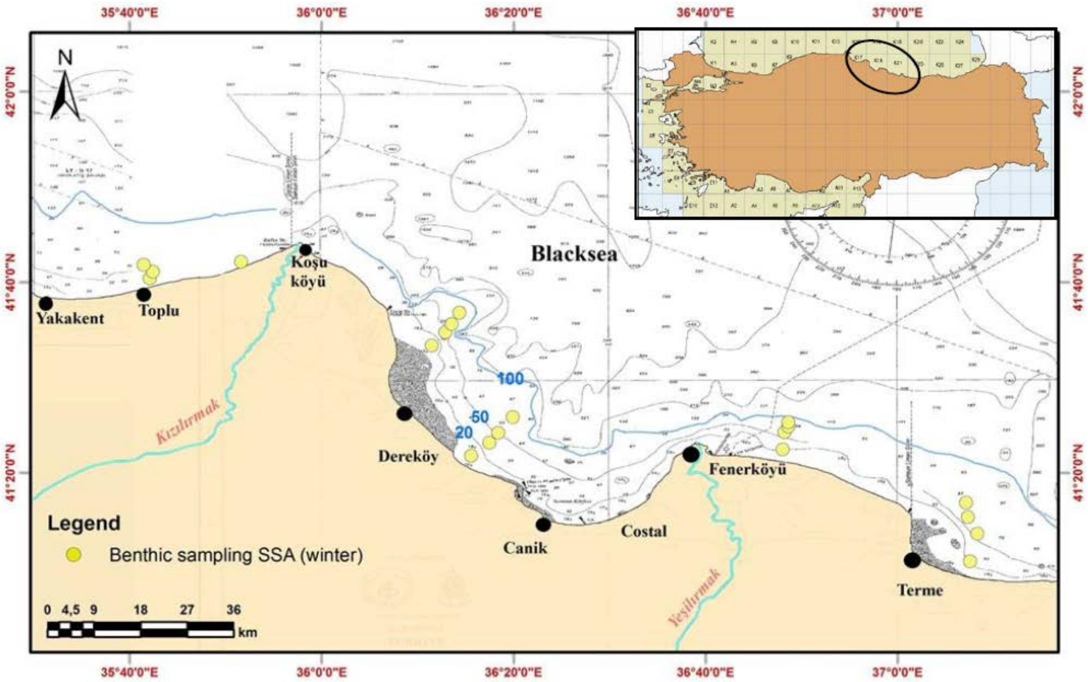


Figure 76. Map of Samsun Shelf showing case study area in the Turkish Black Sea Coast.

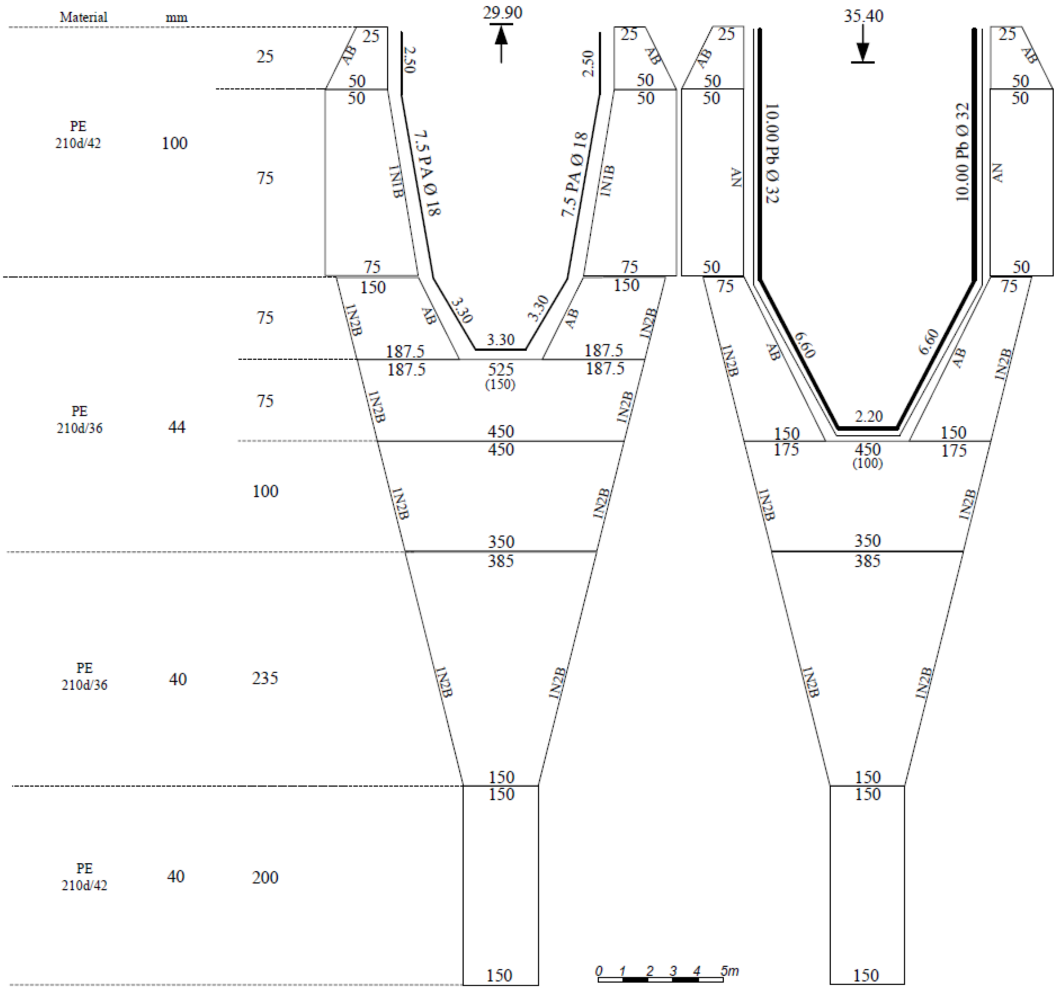


Figure 77. The model of a commonly used bottom trawl net having two panels and 900 mesh in codend (Kaykaç et al, 2014)

Figure 78. A typical rectangular bottom trawl door is using in the SSA

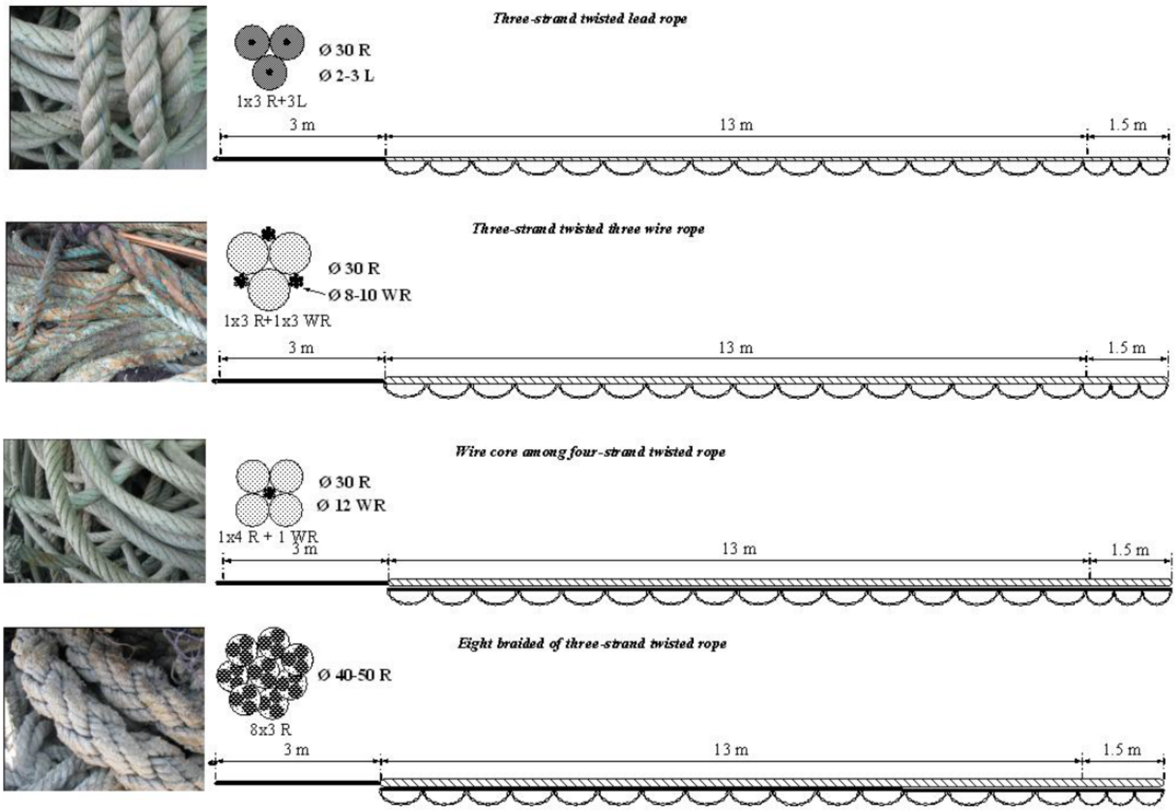


Figure 79. Using of four different groundgears for bottom trawl in the SSA (Kaykaç et al, 2014).

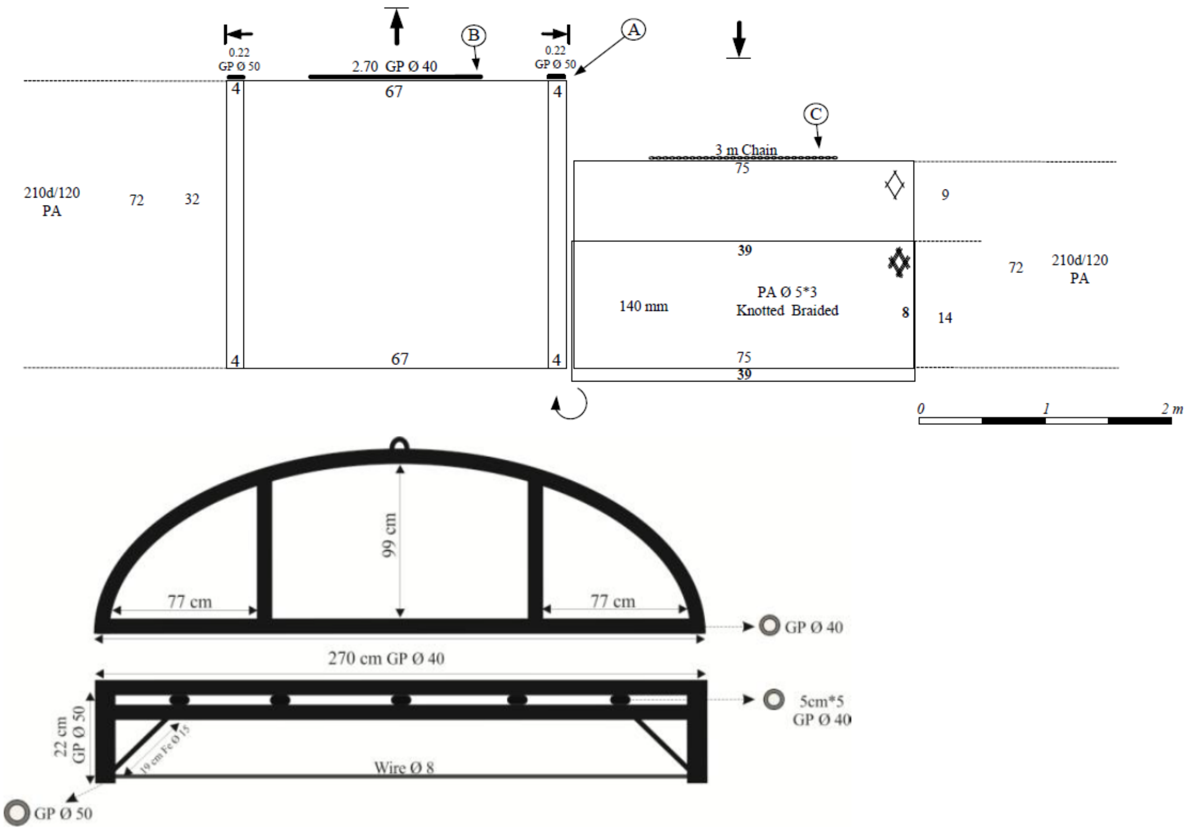


Figure 80. The diagram of the beam trawl (Kaykaç et al, 2014).

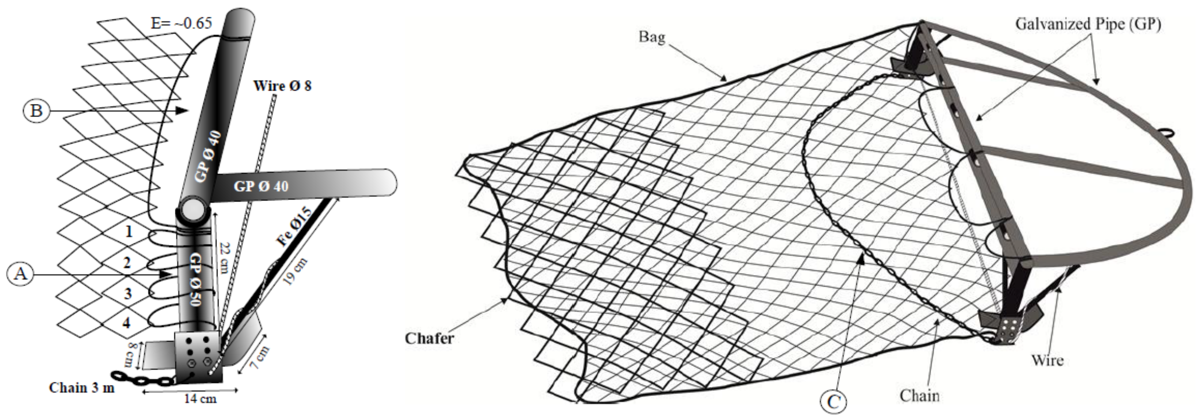
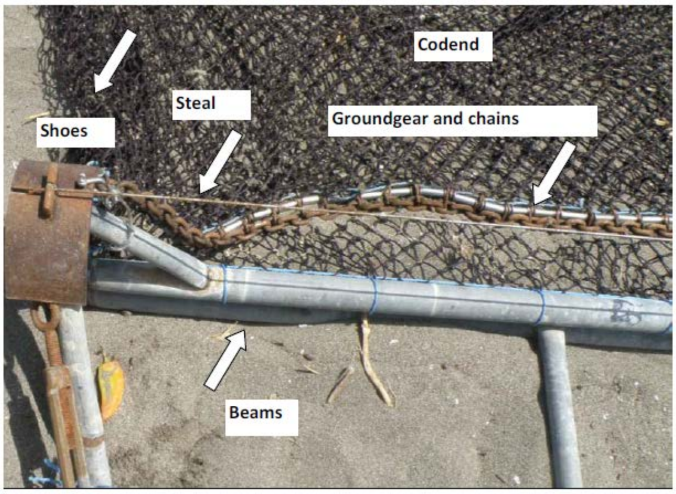


Figure 81. Illustration of the beam trawl (Kaykaç et al, 2014).



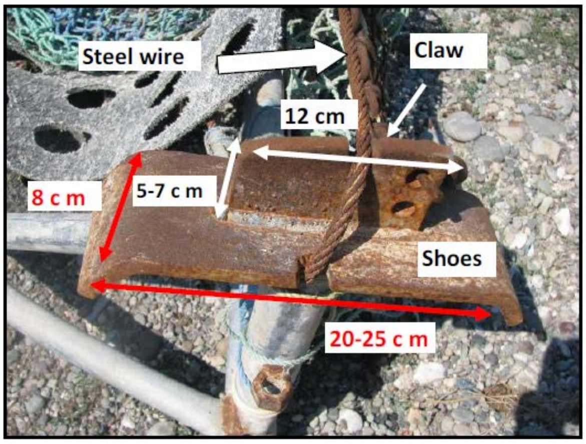


Figure 82. Leadline: It is functional to dig out the rapa whelk buried or half buried in the sediment and to direct them to the net behind the ground gear. It weighs nearly 0.5 kg and has a length of 3 m and 8 mm thick. Chain rope: It is 3.5 m long and made of small bean-shaped rings. Each ring is nearly 30-35 g in weight and there are nearly 120 rings in each side of rope. Shoes: There are two shoes in each side of the beam opening. There is an iron-made protrusion (5-7cm thick) over the shoes called 'claw' contacting the bottom. The leadline is attached to the small notch on this claw. In the course of operation this part penetrates the substratum and forms a rift of its thickness. Front-shoes: This equipment is only used in western stations in SSA. The front shoes is attached to the point connecting the mesh and the ground gear. It is 20 cm thick, made of iron and functional in floating of the net opening without sinking to the bottom. This apparatus is being used in western stations for the last three years. The front shoes also prevent the direct contact of leadline with bottom.

Figure 83. There is a perforated plastic/rubber palette attached to the chain on the opening of the gear, in order to mitigate the friction beneath the gear and to provide an easier slipping and also to minimize the gear deformation. Furthermore, to protect the upper panel of the gear, a covering (mantle) was added to the gear produced with a larger mesh size than of the bag and with a coarser thread material.

Table 38. The gear specifications of two drag nets in Black Sea (SSA) that has impact on benthic ecosystem

Specifications	Characteristics	Bottom trawl	Beam trawl
Habitat type	Active fishing area and average depth (m)	-Littoral zone: shallow, smooth, silt -40-80 m	-Coastal zone: shallow, smooth, silt -5-30 m
	Bottom type	Sand, silt	sand, silty-sandy-silt, gravelly sediment
	Characteristic invertebrates	*Mytilus galloprovincialis, Modiolus sp, Crangon crangon,*	*Rapana venosa, Mytilus galloprovincialis, Chemelea gallina, Crangon crangon, Upogebia pusilla, Liocarcinus depratur*
Primary target species	Mixed-species fisheries	whiting, red mullet, turbot	-
	Single-species fisheries	-	sea snail
Vessel	Engine power (kW)	422	107
	Trawling speed (knots)	2.5-3	1.5-2.5
	Overall length (m)	21.5	9.9
	GRT	71.2	7.1
	One or two vessels (single or pair trawling)	single	Single
	Number of trawls per vessel	1	2
Gear	Type	two panel, Italian modified model	Traditional
	Codend: stretched mesh size (mm)	40	72-88
	Trawl circumference (stretched mesh size in mm)	500-975	-
	Trawl height (m)	0.5-2.5	-
	Beam height (cm)	-	20-22
Trawl doors	Model	bottom-rectangular	-
	Length (m)	1.2-2	-
	Height (m)	0.8-1	-
	Weight (kg)	50-150	-
	Spread (m)	22-28.5	-
Groundgear	Length (m)	20-37	2.5-3.5
	Weight (kg)	25-375	3-5.5
Beam	Width (m)	-	2-3
	Complete beam weight in air (kg)+nets (kg)	-	24-58
	Beam shoes (number)	-	2
	Beam shoes (width in mm)	-	70-100
	Beam shoes (length in mm)	-	200-350
	Shoes claw (depth in mm)	-	50-70

Assessing the fishing effort and landings

Fishing effort

Some quantitative and qualitative data about the fishing fleet operating with drag nets was collected in 2013. The data sources in this task were:

(a) direct field observations (logbooks of trawl vessels, and landings for market),

(b) the records of two SMEs (BENTHIS partners; Malkoçlar and Sadıklar) such as the number of algarna fishermen, the total amount of rapa whelk catch that has been brought to factory for processing, active fishing day, etc.,

(c) official records (Turkish Statistical Institute -TUIK, Fisheries Information System-BSUGM/SUBIS) about the general specifications of the registered fishing fleet, algarna and bottom trawl fishermen).

In Table 39, some qualitative and quantitative properties of actively operating fishing fleet for both algarna and bottom trawl gears along Black Sea coasts were summarized.

It is determined that there are totally 43 fishing port or shelter between Samsun and Iğneada and 486 fishing vessels are active in 31 of them in 2013/2014 fishing season. 154 (31.7%) vessels in this fleet is belonging to SSA and 332 63.8%) to the western Black Sea (Sinop-İğneada).

Another 55 vessels are coming from the southern Marmara Sea (Bandırma: Çakılköy-Karşıyaka) and temporarily operates in the western Black Sea waters between Ereğli and İğneada during the fishing season as the trawl fishery completely banned in Marmara.

The active fishing day of these fishermen was estimated averagely as 120 per year In SSA, the algarna/rapa whelk fishery is more intense when compared to other locations throughout the whole Black Sea coast though the fleet is active in all area. There are 169 fishing vessels in SSA, 182 in western Black Sea (between Sinop-İğneada) and 105 in eastern Black Sea (between Ünye-Rize) currently operating as registered or unregistered.

There is significant diffrence in the number of day-at-sea between SSA and the two other regions. The reason may be the more available bottom type of SSA for rapa fishery and the higher CPUE. The number of active fishing day per year is 115 in SSA and averagely 45 days per year for eastern and western Black Sea.

Table 39. The general profile of fishing fleet using drag nets along Black Sea coasts of Turkey in 2013.

Geographic locality	Number of bottom trawl vessel	Number of beam trawl vessel	Sources
EBS (Eastern Part of Turkish Black Sea	-	105	1-KARTRİP, 2013 National Trawl Project 2- Turkish Ministry of Food, Agriculture and Livestock, BSÜGM 3-BENTHIS Black Sea Case Study, 2013 4-From Mustafa SADIKLAR, SME-13 Company of Sea Snail Plant: '*Sadıklar Balıkçılık*'
SSA (Samsun Shelf Area)	**154**	**169**	
WBS (Western Part of Turkish Black Sea)	332	182	
Total	**486**	**456**	
EBS- active fishing day/ for one vessel in a fishing season	Banning of bottom trawl fisheries	45 day/vessel	
SSA- active fishing day/for one vessel in a fishing season	120 day/vessel	115 day/vessel	
WBS- active fishing day/ for one vessel in a fishing season	120 day/vessel	45 day/vessel	
Total fishing day-all of the Black Sea fleet / for in a fishing season	**58320 days**	**169*115=19435 287*45=12915 Total=32350 days**	

Assessing the catch per unit effort

Marine field work was made by commercial vessels and the catch per unit effort was estimated according to '*swept area method*'. Furthermore, parameters such as geographical coordinates, depth, fishery sub locations, haul speed, duration at sea, gear and vessel specifications, the amount of catch on board, untargeted species (by catch), discard and the amount of catch for market were recorded (Daskalov et al., 2012).

Bottom trawl fishery

The bottom trawl fishery is banned in Turkish Black Sea between the mid of September to the mid of April. The study area (SSA) includes the near shore water of three miles where the fishermen operate illegally (Figure 84). Seasonal samplings were carried out around the depths ranging between 30 and 120 m and by using 400 and 900 meshes and modified 40 mm diamond mesh size in codend of traditional bottom trawl.

The monthly samplings are realized with two size of vessel; smaller than 18 m (12-17 m) and larger than 18 m(18-32 m) which is typical for Black Sea trawl fishery fleet. In each sampling period, at least two commercial vessels, representing the study area were monitored and catches were recorded on board. In the fieldwork, the total catch and the faunal composition is recorded for each of haul that is standardized for duration.

The catch per unit effort (CPUE) for whiting population is estimated as 59.6, 32.4 and 97.7 kg/h/vessel for spring, fall and winter (2013) respectively. The CPUE for red mullet population is also determined as 32.5, 18.6 and 7.9 kg/h/vessel for the same seasons respectively. For both species, the rate of discarded and marketed landing, the length and weight frequency distributions were presented in Figure 85 and Figure 86.

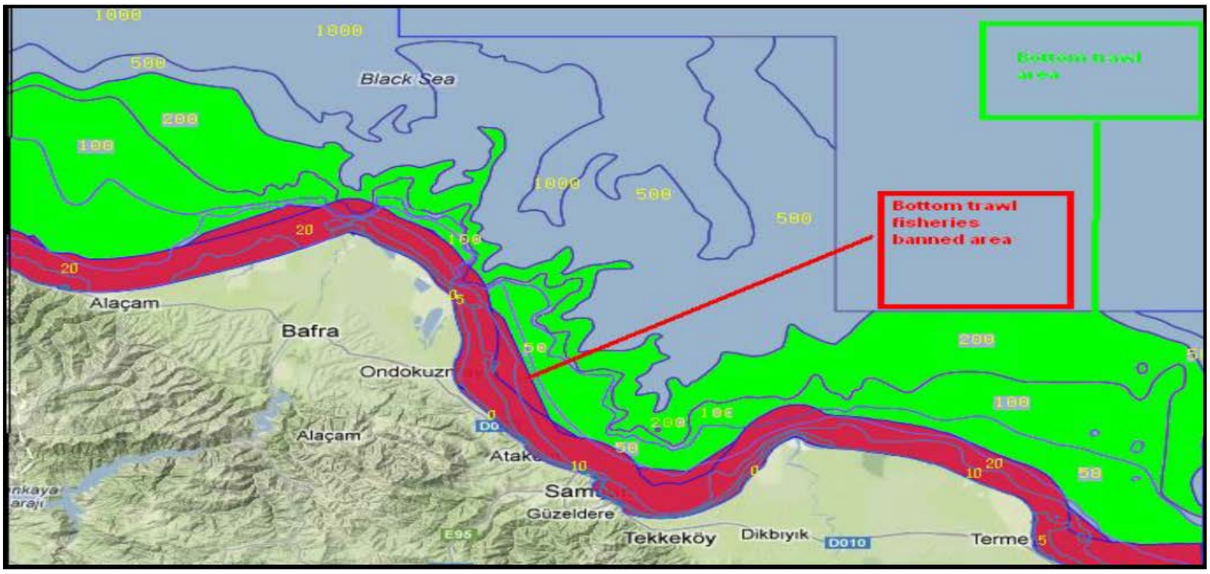


Figure 84. In SSA bottom trawl operations are carried out around the depths of 45 and 90 m. The three miles zone from land is closed to this kind of fishery.

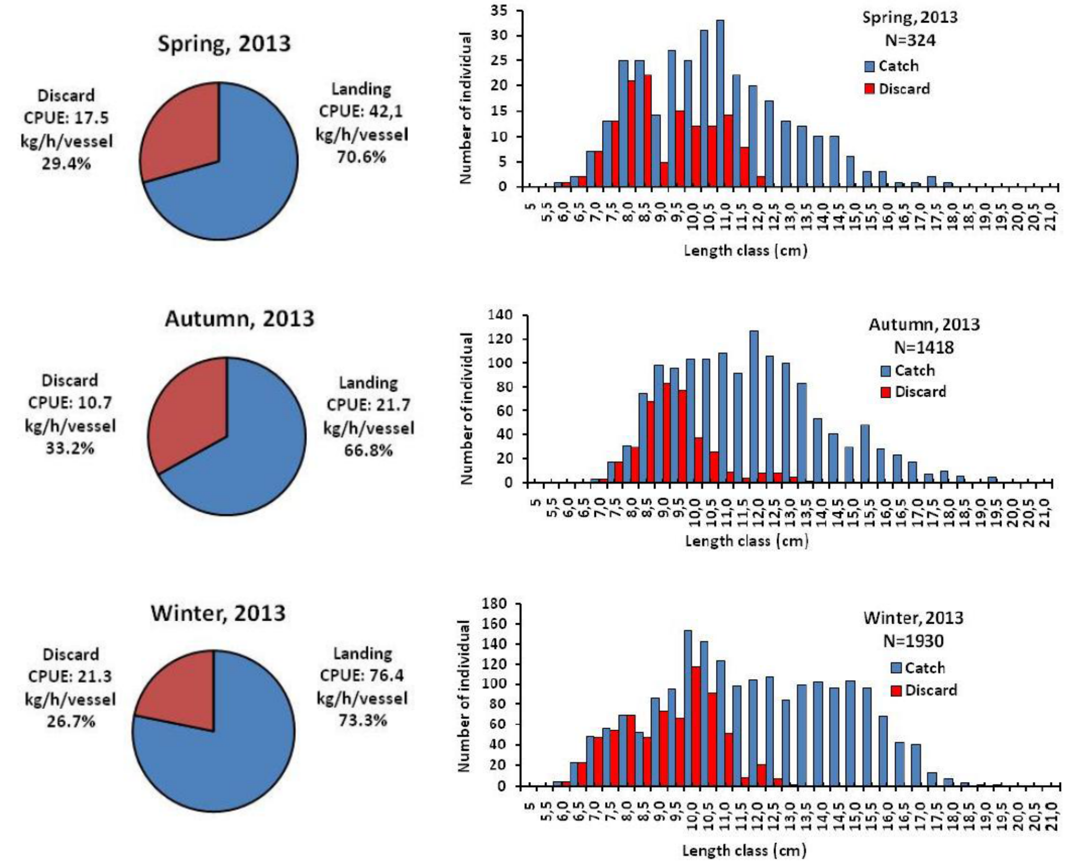


Figure 85. The seasonal variation in the CPUE of landing and number of discard (length distribution) in whiting (M. merlangius euxinus) caught by bottom trawls in SSA in 2013.

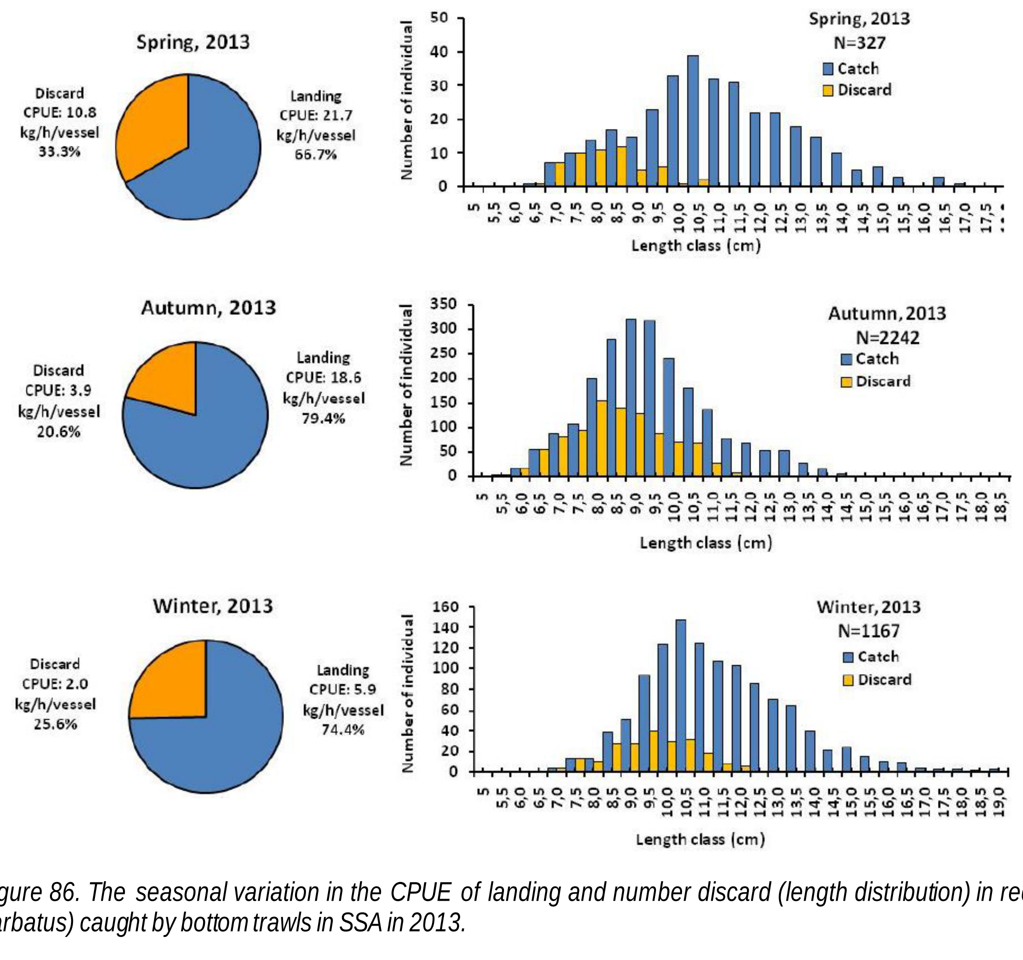


Figure 86. The seasonal variation in the CPUE of landing and number discard (length distribution) in red mullet (Mullus barbatus) caught by bottom trawls in SSA in 2013.

Beam trawl fishery

As there are no long-term studies which monitored the beam trawl fishery on rapa whelk along the Turkish Black Sea coast to present and also the ones realized previously could not fully satisfy the BENTHIS requirements, a survey was started to obtain the parameters that we need for the tasks within WP7.

There is still some problems in management of rapa whelk fishery continued on SSA between depths of 5 and 30 m and becoming intense in summer months (Figure 76 and Figure 84). The fishermen always tend to break the fishing rules in terms of location, timing and type of gear or its application. So, all kind of information about the impact of beam trawl fishery on benthic habitat in SSA will make a valuable contribution to BENTHIS outputs.

Six different local stations characterizing the rapa whelk fishery in SSA defined as Terme, Fenerköy, Costal, Dereköy, Koşuköyü and Toplu (Figure 76). The two of them; Yeşilırmak/Fenerköy and Kızılırmak/Koşuköyü is especially preferred to check out whether these estuarine zones make any significant difference for this fishery related to the type of substratum. In sampling operations, the commercial beam trawl vessels and tne nets with 70-90 mm mesh size were used.

The size of vessels ranged between 6-12 m and the engine power between 35-350 HP. The samplings were made in all locations by at least two vessels in day or nighttime. In winter months, as the catch is extremely low, it was hard to find any operating vessel and therefore the samplings limited to three stations. Except the experimental blind gear trials, all operations were carried out according to fishermen initiatives.

The tasks to monitor the beam trawl fishery in the last one year (June, 2013-May, 2014) can be seen in the following substances. (a) the monthly variation of fishing effort (CPUE) in SSA (b) the species composition of benthic and benthopelagic macrofauna ((invertebrates and fish) and their seasonal distribution as well as the target species (c) the comparison of the selectivity of gears equipped with net bags of 72 and 88 mm mesh size (commercial type) and 12 mm mesh size (blind gear) and the impact on bycatch diversity.

Distribution of fishing effort (CPUE):

The amount of catch reach its maximum in summer period. The seasonal variation in CPUEs is presented in Figure 88 and Figure 89. The summer period is also the banned season (May 1- August 30) for beam trawl fishery targeting rapa whelk. The diversity and the abundance of by catch species seems to be higher in summer months when compared to fall and spring (Figure 88 and Figure 89). The data about species diversity and abundance is an important matter in terms of a rational fishery management.

The composition of by catch (untargeted species):

The fishing mortality caused intense algarna fishery is relatively high in summer months. This fishing effort has a significant effect on juvenile fish populations which used the nearshore benthic as nursery areas. The total catch of algarna fishery is composed of target species; rapa whelk (70.3%) and other by catch species (29.7%) in summer period. In this period totally 33 species identified belonging to four different taxonomic group. Their abundance is estimated as 25.7% Mollusks, 3.5% Crustaceans, 0.2% fishes (mostly juveniles) and 0.3% Tunicates. The species number in these groups is as 9, 7, 16 and 1, respectively (Figure 90 and Figure 91).

The characteristic of landing:

As the TUİK data processing system based on yearly data and the monthly variation of rapa whelk catch is obtained from the annual catch records (Black Sea coasts and 2013) of Sadıklar which is a company leading the rapa processing and export (Figure 92). This company buys nearly 45-50 % of total catch coming from different fishery locations throughout the whole Black Sea coast. The distribution of total catch in terms of regions and months is derived from this data and presented in Figure 93 and Figure 94. We could be able to gather the data about rapa whelk fishery only in SSA relevant to the tasks in WP7, BENTHIS. Actually, 42.1% of the total catch is obtained from SSA and the rest percent is coming from other fishery locations (Figure 94). For example, 39.2% of the total catch is provided by the fishery conducted along coasts between Ünye and Rize (eastern Black Sea coast).

Beam trawl is commonly used in legally open fishery season but in western locations (Sinop and its west) fishery by diving is more common. Data gathered about the beam trawl fishing fleet and all other fishery parameters also contributes to the work in WP2 that aims to outline the level of fishing pressure and its impact on benthic ecosystems in regional seas.

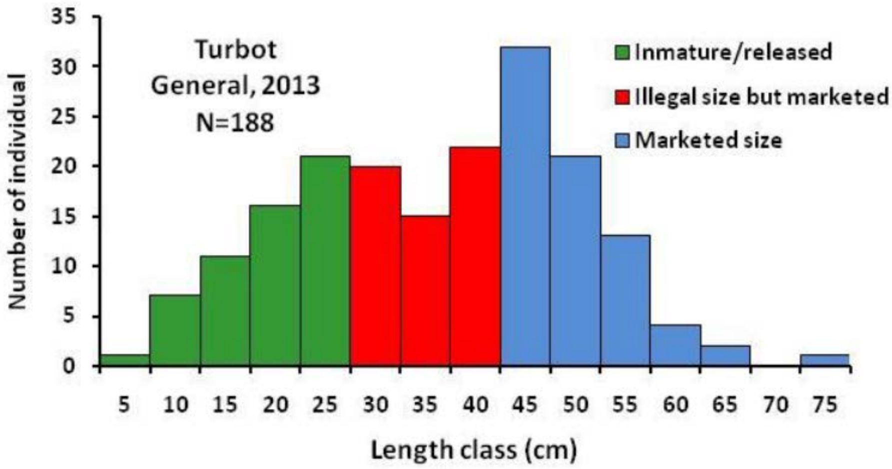


Figure 87. The length-frequency distribution of turbot obtained from sampling surveys conducted with commercial bottom trawls throughout Turkish Black Sea coast in fishing period of 2013.

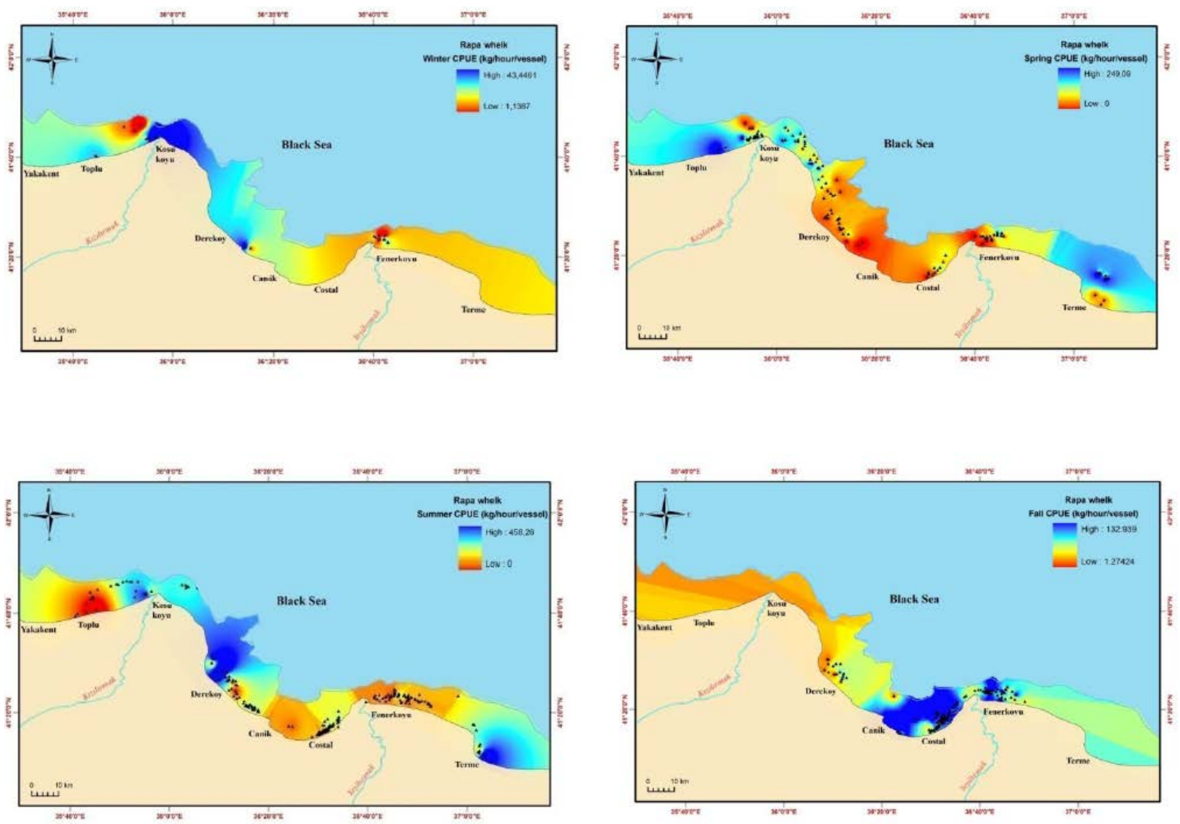


Figure 88. The seasonal catch per unit effort variation distribution of rapa whelk catch caught by traditional beam trawls (algarna) with mesh sizes ranging between 72 and 88 mm.

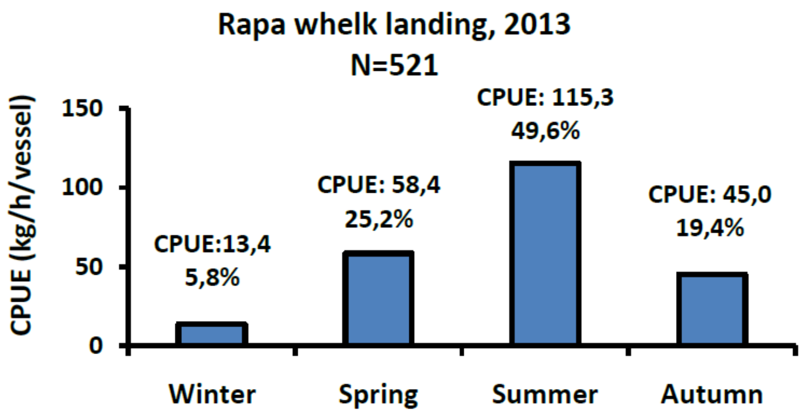


Figure 89. The seasonal variation of CPUE values of rapa whelk fishery in SSA and at fishing period of 2013.

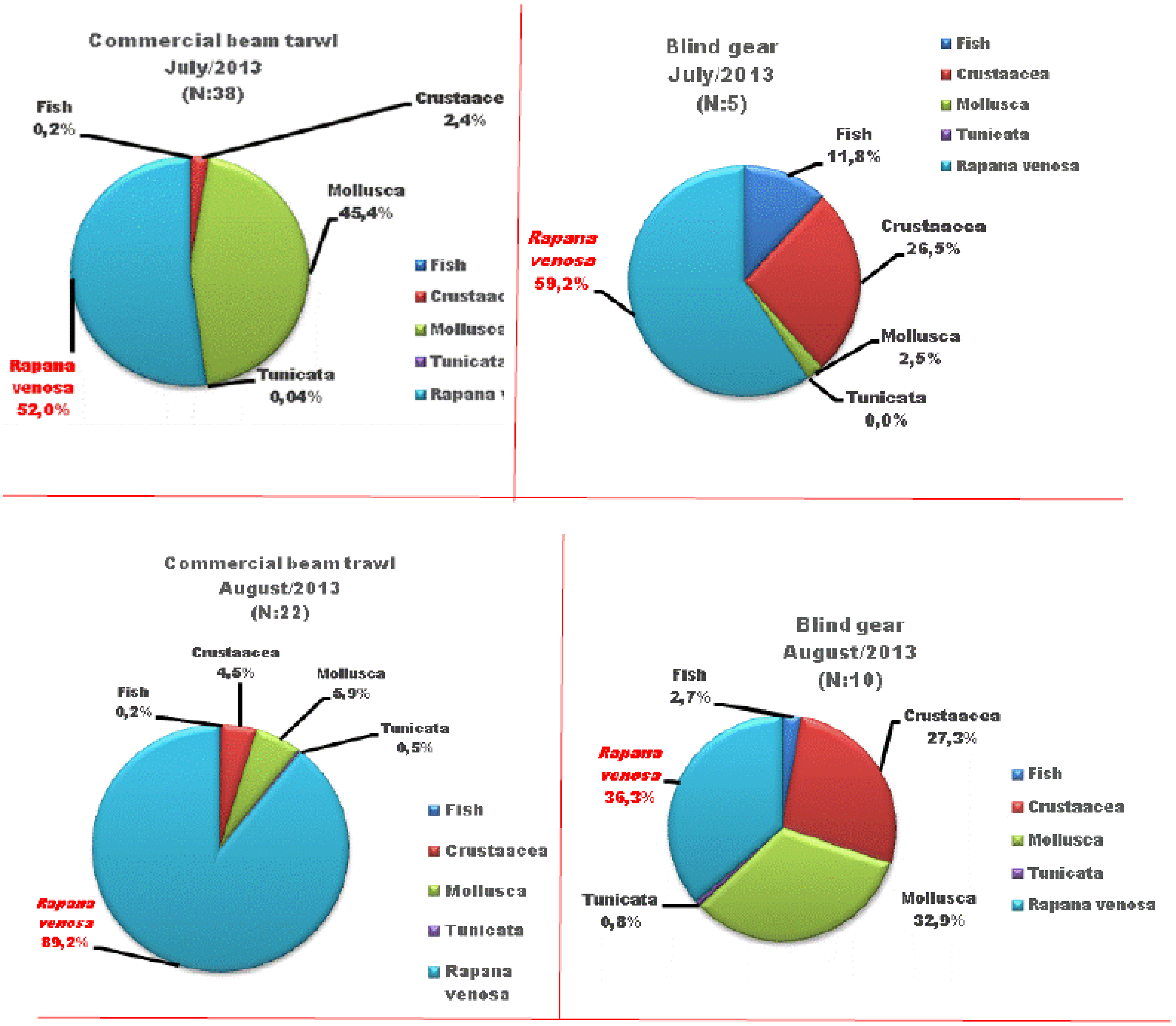


Figure 90. The relative distribution of benthic organisms in algarna (beamtrawl) catch in summer period (July-August) in SSA

Figure 91. The by catch species from different taxa caught in beam trawl fishery beside the target species, rapa whelk in SSA.

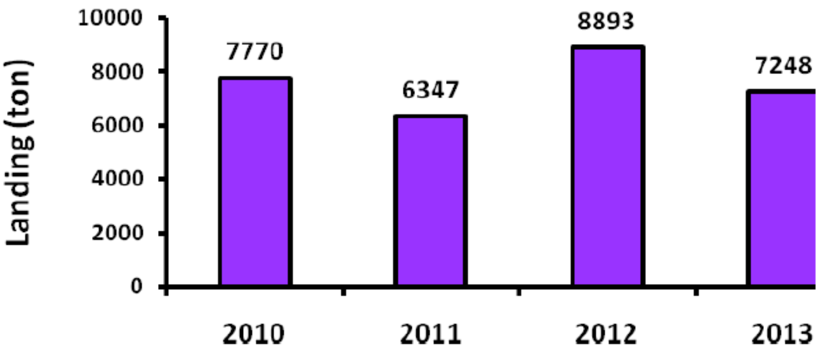


Figure 92. The annual variation of rapa landing in the last four years in Black Sea (data of 2010-2012 from TÜİK and 2013 from SADIKLAR rapa whelk Processing Plant).

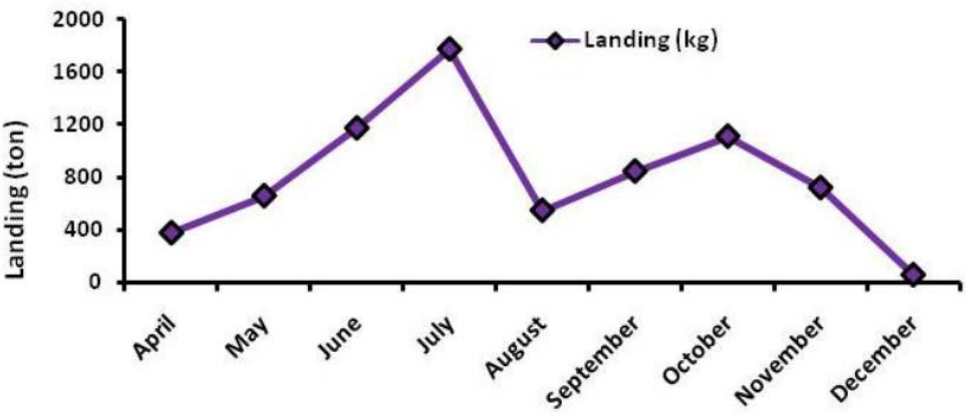


Figure 93. The monthly distribution of rapa whelk landing in the Black Sea coast (data obtained from SADIKLAR rapa whelk Processing Plant)

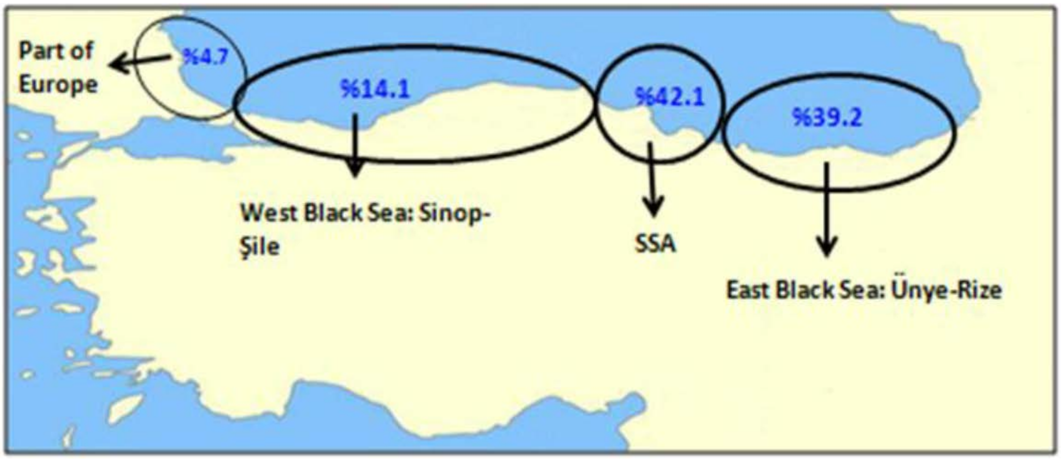


Figure 94. The distribution of total catch of rapa whelk among four sub-locations of fishery along the Black Sea coasts. These locations have some different in ecological and fishing properties. Though the area available for rapa whelk fishery is smaller than the other three, the most efficient fishery is being realized in this location. All fishermen use algarna in rapa whelk fishery. The nearshore benthic (depth of 5-30 m) is under high pressure of this algarna fishery.

Technological innovations

The impact of bottom dragging nets (algarna and bottom trawls) which were widely used along the southern Black sea littoral on benthic ecosystem have been investigated by the marine surveys held in 2013. In 2014, sea trials were realized in order to test the options for mitigation of the impacts. In this concept, three different trial studies were planned for three fishing gears (pots, algarna and bottom trawl). The identified problems and the related solution suggestions for the mitigation of the impact on benthic ecosystem discussed in RSE1 that was held in Trabzon in 30 April 2013 (WP8) were our major directives in planning the sea trials. Thus, the options for mitigation of the impact on benthic ecosystem and the related sea trials were designed as the following:

1) The trials of passive gear design (pots) in sea snail fishery,
2) The modification of algarna:
   - use of sledges instead of traditional shoes to decrease the dragging effect,
   - the removal of steel rope between shoes
   - the measurements for fuel save
3) The selectivity studies to reduce the discard rate by modification of the fishing net in terms of mesh size and design in bottom trawl fishery (red mullet and whiting).

Trials of pot/trap for sea snail fishery

The sea snail fishery along near shore waters of Black Sea has two kinds of negative impact on the benthic ecosystem; (1) the physical disturbance on the sea bottom affecting in fauna, (2) the discard of untargeted species including bivalves and fish juveniles (D7.6).

Therefore, firstly it is aimed to test a passive fishing method; the pots instead of algarna and secondly, to make some modifications in design of algarna such as sledges instead of conventional shoes and the removal of steel rope between shoes in order to reduce the dragging effect.

Material and Method

It is decided to test the pot model conventionally used in the southern Korea. It is known that the fresh bait is used in this pot model and since it is a passive gear, it reduces the bycatch in 80% (Logothesis and Beresoff, 2004). A fisherman in the southern Korea may keep 200 pots on board and operate with them. After leaving the pots in sea for three days, a catch of 3-5 kg per pot can be obtained.

They use live mussels as bait in pots. The pot has an opening near the bottom edge of the pot allowing the creeping sea snails into the pot. The pots are collapsible providing great easiness in carrying and storage. The 28 pots are produced by a fishermen in Yakakent financed by SME16- Sadıklar Fishery (Figure 95).

Summer surveys (July, 2014)

The first trials were realized two different stations where the intense fishery was localized. Also, the type of substrates were taken into account. The first station (Dereköy) has a sandy sea bottom and the second station (Costal) has sandy-muddy substrate representing the general substrate type of Samsun Shelf Area (SSA) (Figure 96). In Dereköy station 15 pots were left in water and 13 in Costal.Each pot was joined to the main thick rope (150 m long) with 1 m thinner ropes within 10 m intervals in distance. Mytilus galloprovincialis were collected from the same locality by diving.

Especially the large ones selected and 5-6 individuals packed with trasparent nylon socks and hanged on the upper part of the net inside the pots. Furthermore, a few individuals were left free at the bottom of pots to observe the response of sea snail to the live bait (Figure 97).

All pots were numerated to record the amount of catch. Pots were released to the depth of 5.5-8.3m, parallel to the coast line and east-west direction. The pots were remained submerged for the durations of 24, 48 and 72 hours (Figure 98). The positions of pots and their contacts to the bottom were observed by a diver to interfere with any problem.The pots on the sea bottom were checked and taped with a underwater camera (Figure 99). At the end of operation durations all pots were collected and the amount of catch were recorded. The results were presented in Table 40.

The pot trials in July 2014 did not reveal a satisfying amount of catch. The probable causes of the failurein functionality of the pots were discussed by researchers and experienced fishermen as the following issues.

1. It is argued that the main reason may be the design of pots especially the position of the openings. Because it is observed in the first trials that all openings or at least one of them among 10 of 15 pots turn outside in water (Figure 100).
2. The pot model that had been brought from S. Corea had three openings and the tip of these openings were tied to the central axis of the pot tensely. The pots produced in SSA was somewhat different from this model. The material used in construction of the net at the openings were thick and bright in colour. Furthermore, the openings was not tied to the central axis and turned outside in water. These may be the major handicaps in low amount of catch.
3. In some pots, the mussels left free on the bottom instead of a bag tied at the central axis. At the end of operations, it is observed that all mussels were preyed and the empty shells remained. But no rapa individuals observed inside the pots. This means probably the rapa may go outside the pot after consuming the mussels. All these issues indicated that it is necessary to repeat the sea trials with pots after fixing them adequately.
4. In further trials, it may be required that an underwater camera attached to the pots in order to observe the behaviour of rapa individuals. So, more can be learned about how rapa use the openings of pots and feed on the prey.
5. The major reason for the failure in the catch of rapa by pots may be related to the retardation period of feeding of this organism. Actually, the maximum amount of rapa catch is obtained in July in SSA and this period coincides with the reproduction period of rapa. In this period, rapa individuals move to the nearshore waters and remain on the sea bottom (not buried in the sand). Though the high mobility in rapa individual related with the reproduction habit in this period (Sağlam et al, 2009) it is expected that they enter the pots with high frequencies. However, they also cease the food intake or totally stop feeding while they are spawning. It is thought that the prey is not attractive for rapa individuals in this spawning period.
6. By August the spawning activity slows down and finishes in general (Sağlam et al, 2009. The individuals begin to feed intensely again to compensate their low physical conditions. So it may be expected that the individuals fronts to the preys in pots. The fishermen also suggested to use the pots in post spawning period. Undoubtedly, this suggestions should be test by sea trials.

When compared to the pot fishery in Southern Korea,it is known that the rapa fishery is not active in the summer period in that region (directly personal communucation in S. Korean plant owner). They generally starts the fishing in the second half of August. The spawning period is the same with the Black Sea region and possibly rapa individuals is reluctant to feed in this period. There is no ban in fisheries management to catch rapa in order to protect the stock in this spawning period (Daskalov et al, 2012).

Fall surveys (September-November, 2014)

After fixing the suffiencies in pot designs, the second term of trials was held in September and November, 2014 when the spawning is over. The trials were arranged by leaving pots for three days (72 hours) in one station (Dereköy).

The pots were remained in sea at a half mile distance in the north direction of port at the depth of 7 m. Though it is not very productive, the rapa fishery is still active in around the area in this period. The pots were placed on this fishery area. The mediterranean mussel is also used as prey tied in small bags on the top of pots.

The pots were taken on board at the end of operation time and it is determined that the catch is again very low and the fishery by pots is not satisfactory (Figure 101).The openings of the pots were tied to the central axis to prevent them turn outwards as it is in summer trials. It is observed that the openings kept in side by this way but even so, it did not make any in catch amount.

The values of CPUE in fishery trials with pots in summer and fall surveys are presented in Table 40. Totally 1525.2 g (26 individuals) catch was obtained during ten days of operation in summer trials. Only in one of the stations (Dereköy, pots remained for 48 hours) no catch was obtained (even a single individual) by 15 pots.

The average catch per day (24 h) and per pot for summer trials is estimated as 21.5 g. In fall, was lower. In fall operations, at the end of 6 day sonly 294.9 g (3 individuals) was caught. CPUE is estimated as 4.9 g/pot/day for this period. However, the bycatch was composed of 18 different species including 6 species of bony fishes, 8 species of crustaceans, 3 species of mollusk a done species of tunicate (Table 40).

The reason to repeat the pot trials in fall (September and November) was the thought of that rapa spawns in summer and reluctant to feed and did not attracted to the preys in pots (Seyhan et al., 2003). It was expected that rapa will show more interest to the preys and appealed by pots when the spawning is over and the food need is increased. But there is no change in the amount of catch in fall, too and it is rather far from a satisfactory catch which may be accepted by fishermen to adopt pots as an alternative fishing gear.

In this case different factors should be discussed for the fail of catch by pots. It may be related to the behaviour of rapa burying in sand. It is known that there are bottom currents bringing colder water to SSA at the depths where rapa lives (Oğuz, 2014). Rapa generally lives buried in sand except the times of spawning and feeding (Harding and Mann, 1999). Possibly pots may be more effectively used in very shallow and semi-closed bays that could not affected by bottom currents.

Forwarding of the Rapa whelk to the pots can be counteracted by a strong deep currents (Himmelman, 1988). It is also their acted to the pot is affected by shell thickness. Thin shell species are move more quickly than thick ones (Logothesis and Beresoff, 2004). Shell weight of the rapa whelk constitute about 80% of live weight (Knudsen et al., 2010).

Conclusion

In conclusion, no success was obtained in the trials for the use of pots in sea snail (rapa) fishery as an alternative gear in order to mitigate the fishery impact on benthic habitat. The efficiency of fishing and the catch amount was not satisfactory or the commercial fishing activity. Further studies required on topics of (a) In detail of feeding-spawning and migration behaviours and their seasonal variations, (b) The bio-ecological features of the sea snail should be taken into account in design of pots and arrangement of fishing operations.

Figure 95. The pots used in sea snail fishery in the southern Korea (provided by SMS Mustafa Sadıklar from Korea as a sample).

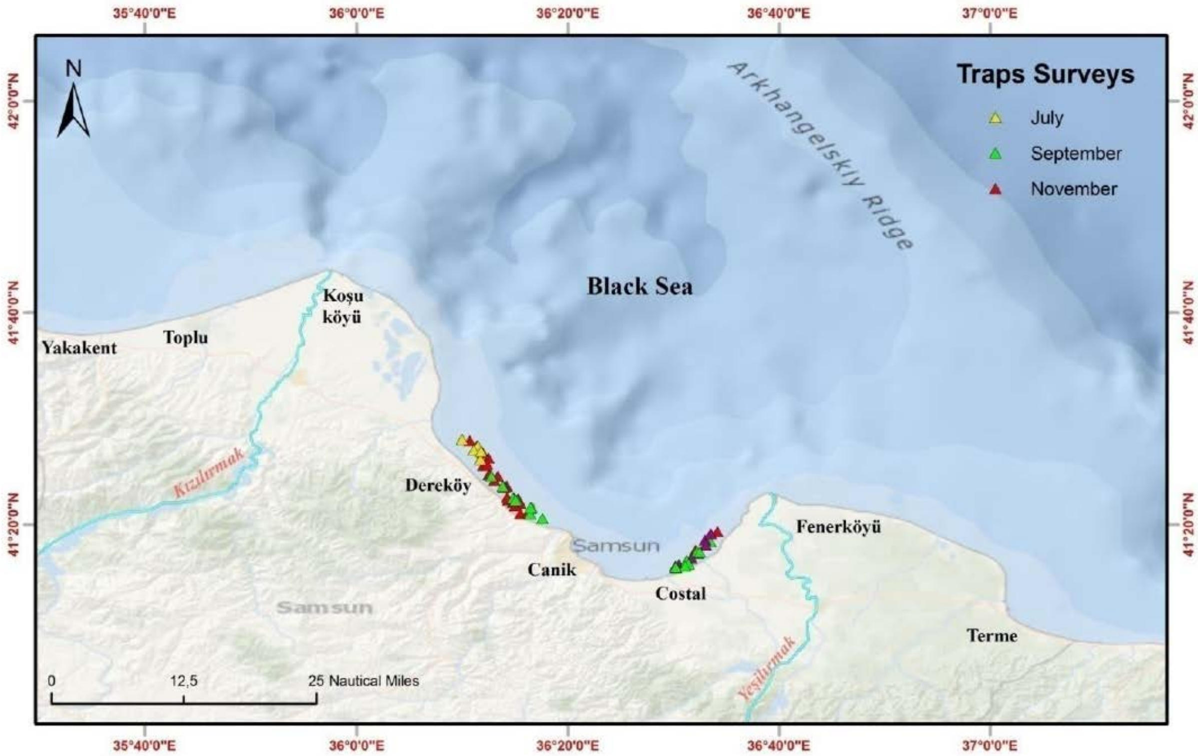


Figure 96. The stations for sea trials of sea snail pots along Dereköy and Costal localities in SSA insummer (July, 2014) andfall (September and November, 2014) periods.

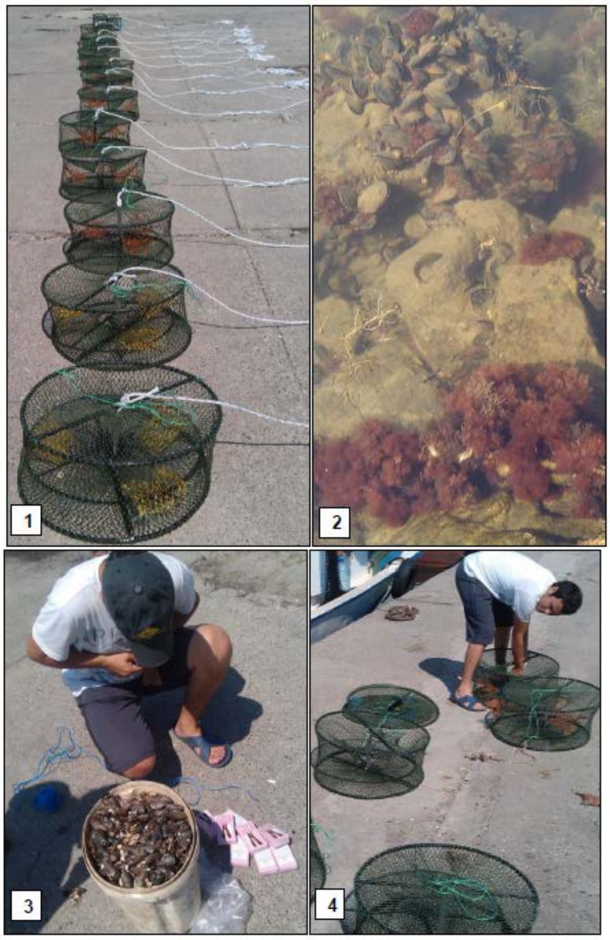


Figure 97. Sea trials for sea snail fishery at Dereköy Portin 16 June, 2014. (1) The pots for sea snail fihery (a set of 15) (2) The live bait, Mediterranean mussel were collected from moles in the port(3-4) Mussels were placed in nylon socks and tied inside the top of the pots.

Figure 98. A pot with the live bait(1). The pots on board are being taken to operation point.(2) The release of pots to the sea bottom around depths of 7-8 m for catch (3).

Figure 99. The pots at the sea bottom (16 June, 2014, Dereköy Port; east side).

Figure 100. The pots on board after operation. The openings turned outside and the egg capsules layed on the net material (19 July, 2014, Costal).

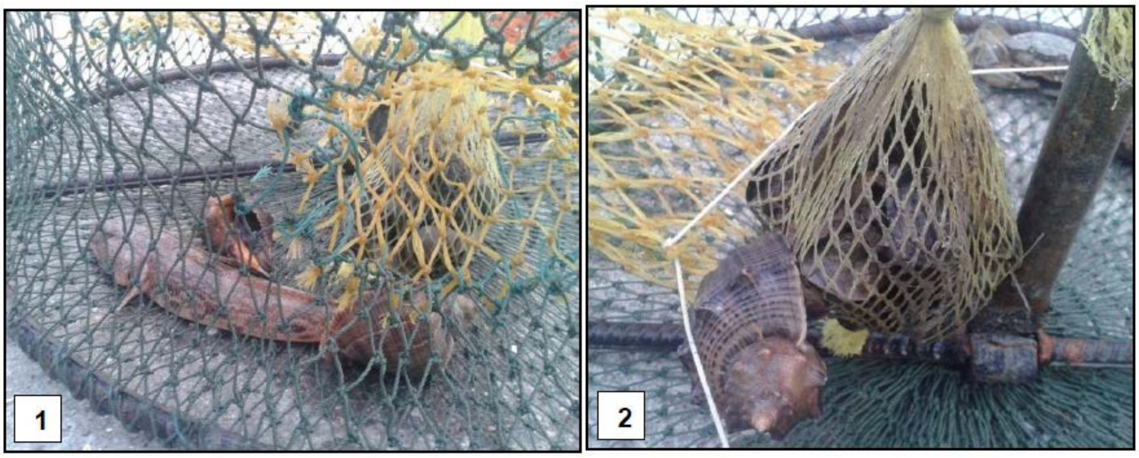


Figure 101. 1:The pots taken on board in Dereköy station. 1. A fish individual (Mesogobius batrachocephalus), as bycatch in one of the pots. 2. A rapa individual attached to the bag of bait and feeding on mussels inside the pot.

Table 40. The sea trials for pots realized at SSA stations in summer and fall 2014 for the sea snail fishery.

Survey No	Starting day	Finishing date	Operation time (hour)	Location	Average Depth (m)	Substrat type	Flow direction	Number of pot	Catch (number-weight, g) target Rapa	Catch (number-weight, g) Bycatch species
1	16.7.14	17.7.14	24	Dereköy	7.8	Sandy	Mid level: to west	15	1-121.7	-*L. depratur* (36-457.1) -*C. aestuarii*(7-872.41) -*B. sexdentatus* (16-21.1) -*A. cornea* (1-17.7) -*P. elegans* (1-2.4)
2	17.7.14	20.7.14	48	Dereköy	8.2	Sandy	Mid level: to west	15	-	-*S. porcus* (8-390.4) -*P. tentacularis* (1-7.1) -*L. depuratur* (19-241.9) -*E. verrucosa* (4-536.1) -*N. reticulates* (3-5.84) -*A. cornea* (1-10.0)
3	20.7.14	24.7.14	72	Dereköy	5.5	Sandy	Mid level: to west	15	16-922.8	-*P. tentacularis* (2-7.4) -*L. depratur* (12-140.4) -*C. aestuarii*(2-173.6) -*B. sexdentatus* (2-2.2) -*A. cornea* (1-2.3) -*P. elegans* (9-19.9) -*C.crangon* (7-20.3) -*P. hirtellus* (2-8.8)
4	18.7.14	19.7.14	24	Costal	8.3	Sandy-muddy	Mid level: to west	13	7-306.6	-*H. Hippocampus* (9-15.0) -*L. depratur* (20-287.1) -*C. aestuarii*(4-433.1) -*B. sexdentatus* (5-5.2) -*C. gallina* (6-14.3) -*N. reticulates* (2-5.6) -*D. pugilator* (18-4.9)
5	19.7.14	23.7.14	72	Costal	8.0	Sandy-muddy	Mid level: to west	13	2-174.1	-*S. smaris* (1-67.7) -*H. Hippocampus* (7-10.6) -*L. depratur* (21-263.9) -*C. aestuarii*(7-632.4) -*B. sexdentatus* (5-6.0) -*C. gallina* (10-31.0) -*N. reticulates* (4-10.4) -*D. pugilator* (18-7.2)
6	17.9.14	20.9.14	72	Dereköy	7.8	Sandy	High level: to east	10	1-139.0	-*S. porcus* (1-70.0) -*C. aestuarii* (34-3719.2) -*C. gallina* (2-5.3) -*Ascidia* (1-7.5)
7	11.11.14	14.11.14	72	Dereköy	7,8	Sandy	High level: to east	10	2-155.9	- *M. batrachocephalus* (1-85.3) -*G. niger* (2-28.2)

Gear Modifications in Algarna (Beam Trawl)

A two-stage study was carried out by the 'traditional beam trawl' which is fishing gear used and developed in time by local fishermen since the 1980s in SSA and the other sea snail fishing areas throughout the Black Sea. The stages of the study are; (1) the potential to reduce the physical and biological impact on benthic habitat, (2) the extent of fuel save that could contribute the fishermen.

For these scopes, the data received from the traditional and modified gear were compared in terms of the amount and composition of bycatch species, the size frequency distributions and CPUE values of the target species; rapa whelk in this specific beam trawl fishery and the measurements of fuel consumption.

Material and Method

To reduce the physical and biological impact on benthic habitat: In this context, some structural changes have been made on the traditional gear. Firstly, a 'sledge system' was designed instead of the shoes in the traditional beam trawl to reduce the physical destruction on the substrate. Secondly, a structural and an operational change were realized on the 'steel wire' stretching between the shoes at the mouth of the gear which is scraping the sea bottom while the gear was working.

The structural modification was to attach the steel wire to the claw of shoes nearly with any distance (0.5 cm) to reduce the penetration depth to the sea bottom. In the traditional gear, this steel wire was joined to the shoes at 5 cm distance. The steel wire stretched between shoes of the beam trawl is functional in taking out the rapa whelk individuals from the sand that they buried themselves.

The steel wire in traditional beam trawl has a penetration depth of 5.0 cm along the whole mouth of the gear and cause an important physical disturbance. The operational change in the modified gear with sledges was to remove the steel wire completely from the gear.

The fishermen are used to fix this steel wire in traditional gear with a penetration depth of 5.5 in Costal, Fenerköy and Terme a locality (eastern stations) which has a sandy-muddy substrate type. However, the fishermen operating along Dereköy, Bafra and Toplu (western stations) fix the steel wire with 1.5 cm distance to the claws of shoes.

Experimental surveys regarding the traditional and the modified beam trawls were carried out in two different localities having different type of substrates. Dereköy station has a sandy substrate and Costal station has sandy-muddy bottom type (Figure 102). Surveys in Dereköy Port were conducted with a sea snail fishing boat named 'Remzi Baba', 11.3 m in length and 135 HP engine power that is owned by İsmail Özdemir. In Costal, also a sea snail fishing boat was used named 'Two brothers-2' that is 11.6 m in length and 185 HP in engine power belonging to Cemal İş.

The structural design of the modified gear and the dimensions of the sledge part are presented in Figure 103. The width and height of the mouth (the frame length) is 297 cm and 15 cm, respectively. The thickness of the steel wire is 8 mm, the height of the beam is 120 cm, the radius of the beam conduits is 32-42 mm, the width of the sledges is 15 cm and the mesh size of the net is 72 mm.

The total weight of a beam trawl is about 45-50 kg including all parts such as ropes, pallettes and drawchains, steel rope, dry net material and the cover bag. The gear trials were made at depths around 7-8 m where also the pot trials have been realized. The operations were standardized to 30 min durations. The catch on board were classified into target and bycatch species and the total weight were recorded on survey forms. Totally, 53 hauls were done and the details of the operations are presented in Table 41. The comparisons between the modified and traditional gear in two localities were based on two operational designs; 1) Sledges with steel rope (modified) versus traditional gear and 2) Sledges without steel rope (modified) versus traditional gear (Table 41, Figure 102). The modified and traditional gear was used at the same operations hauling in parallel.

<u>Trials of Sledges with steel wire:</u> Totally, 28 operations were realized in both stations (Table 39). In this modified gear design, the steel wire attached to the claws of shoes at a distance of 0.5 cm (Figure 103 and Figure 104).This modified gear was compared to the traditional gear where this steel wire joined to the claws at a distance of 5.5 cm. This type of gear (clawed shoes) is especially preferred by fishermen to use in sandy localities (Figure 105).

<u>Trials of Sledges without steel wire:</u> Totally 25 operations were realized in both stations (Dereköy and Costal) (Table 41). In this trial, the steel wire stretching along the mouth of the gear and scraping the sea bottom while the gear is operating was removed. Thismodified gear was also tested against the traditional gear where the steel wire joined to the claws at a distance of 5.5 cm (Figure 106).

Results

The number of individuals and species variety in bycatch composition obtained in parallel haulings of traditional and modified gear (sledges with steel wire) and traditional and modified gear (sledges without steel wire) were examined. It is determined that the both modified beam trawls had lower bycatch rates than of the traditional gear. The modified gears especially the sledges without steel wire lowered the catch rate nearly 50% of total. This significant effect became more visible when the bycatch composition is evaluated within organism groups as fishes, crustaceans, molluscs and tunicates (Figure 107). The difference in number of individuals within each organism groups obtained by traditional and modified gears were controlled for any significance by a nonparametric statistical test (chi square) and the results presented in Table 42. It is concluded that the modified gear (sledges with- and without steel wire) has a significant role to reduce the bycatch species in rapa whelk fishery. This result is very vital with regards to juvenile fishes especially the flat fish species which use this nearshore coastal area as nursery grounds.

In order to examine the bycatch qualitatively, the species in each organism group were identified. The species list and their presence in terms of localities and the beam trawl type is given in Table 43. In Dereköy station, totally 21 different species were caught in the parallel hauls of traditional gear and modified beam trawl (sledges with steel wire).

The number of species were respectively 17 and 18 in the other trial done by traditional versus modified gear (sledge without steel wire). It seemed that there was not so much difference in species variety within the bycatch composition of the tested gears. However, a significant difference in species diversity is determined between two localities; Dereköy and Costal.

The station Costal having a muddy substratum seems to have less species variety (Table 44). The number of species in bycatch composition decreased to 13:18 for traditional: modified gear (with steel wire) and to 12:10 for traditional: modified gear (without steel wire). It is concluded that the modified gears decrease the bycatch only quantitatively rather than qualitatively.

The traditional and the modified beam trawls were also tested for the catch of the target species; rapa whelk. Actually, the fishing performance of the modified gears is important and decisive in the adoption by fishermen in future. For this reason, the catch per unit effort for rapa whelk was estimated in parallel hauls of traditional and modified gears. The sea trials of the beam trawls were especially designed as parallel hauls since the environmental factors should only be kept similar by this way.

Because, the wind and waves, the type of substratum and the direction of the sea bottom current could be very effective on daily actions of rapa whelk. It is known that rapa whelk individuals can immediately bury themselves in the sand in windy and choppy days or at certain times of the day (personal communication with divers working in rapa whelk fishery). As the weather can rapidly change in a day time in SSA, the gears were tested in parallel hauls instead of subsequent operations in order to avoid any variation in catch caused by sea and weather conditions.

The size frequency distributions of the rapa whelk and the catch per unit effort (CPUE) values are used to compare the fishing performance of the traditional and modified beam trawls. The size frequency distributions of rapa whelk obtained by traditional and modified gears were tested for any significant difference by Kolmogorov-Smirnov (2 sample) test (Table 45).

The difference was significant for some cases and not for the others. We could not define a clear tendency about that any of the beam trawls caught larger or smaller individuals.The size frequency distributions of rapa whelk (pooled for all operations) obtained from modified and traditional gears were presented in Figure 108.

The catch per unit effort (CPUE, kg/h) values are estimated for all set of trials. A 2-sample t-test was performed for any significant difference between the fishing performance of the traditional and modified gears. The mean CPUE was 70.11 kg/h for the traditioal beam trawl and 63.23 kg/h for the modified (sledges with steel wire). The difference between CPUE values of the two gears was not significant (t=0.399, P=0.399).

In the comparison of the traditional and the modified gear (sledges without steel wire), the mean CPUE values were estimated as 77.37 kg/h and 51.92 kg/h, respectively revealing a significant difference between the gears.

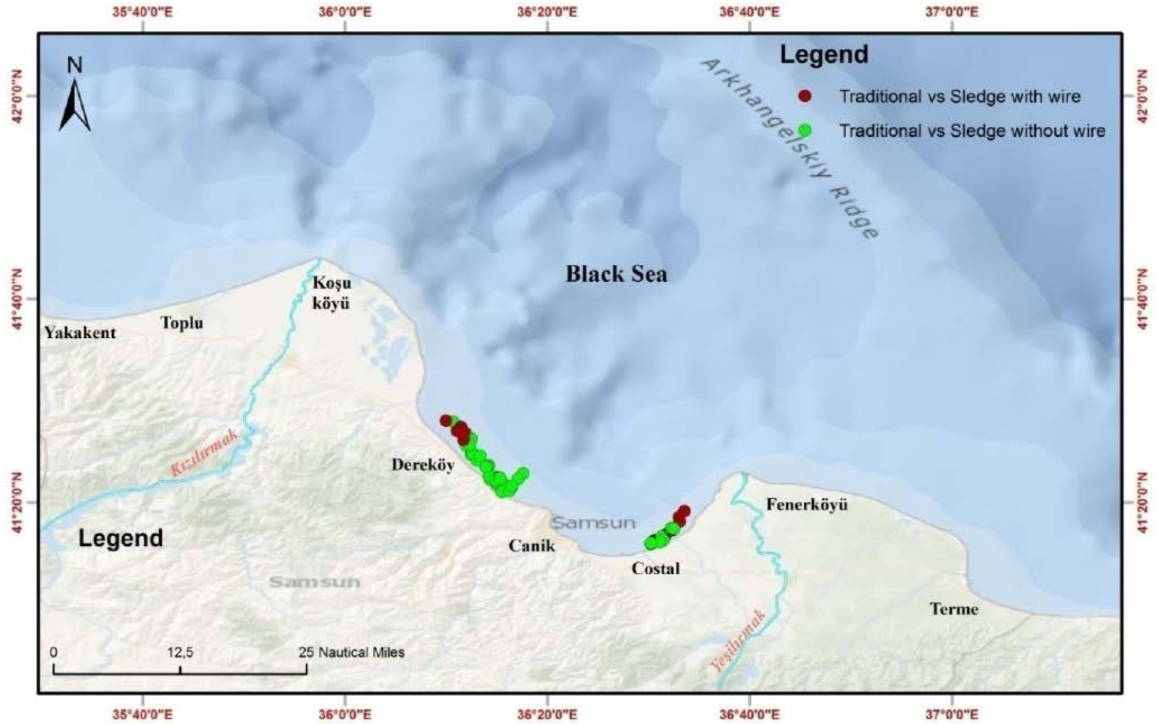


Figure 102. Study area. Dereköy and Costal localities in Samsun Shelf Area and the stations for experimental surveys for the trials of modified beam trawls on summer (July) 2014 period.

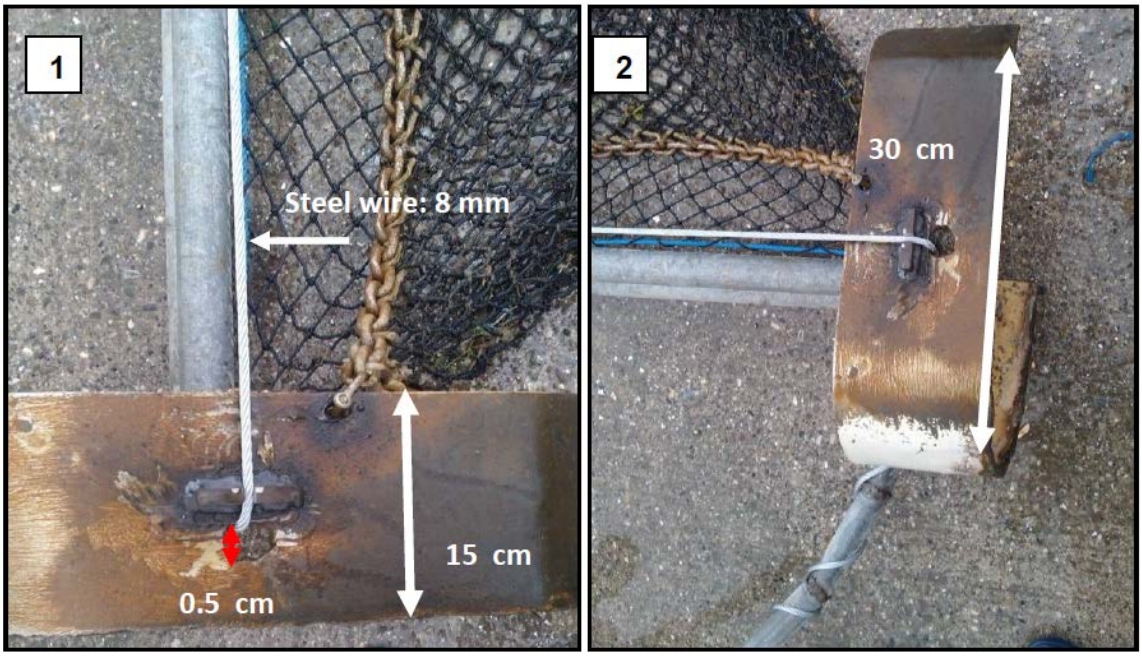


Figure 103. The modified beam trawl produced in Dereköy industrial plants. The modification; the shoes replaced by a sledge of 15 cm width and the steel wire attached the claw at 0.5 cm distance.

Table 41. The experimental surveys for the trials of the modified and traditional beam trawls in SSA in July and August 2014

Kind of survey	No of Survey	Date	Sampling period	Survey area	Name of vessel	Length-Engine power	Beam number	Mesh size (mm)	Number of operations	Substrat structure
I- Traditional /Modified (sledges with wire)	1	17.07.2014	Daylight	Dereköy	Remzi Baba	11,30 m- 135 HP	Twin	72	5	Sandy
	2	19.07.2014	Night	Dereköy	Remzi Baba	11,30 m- 135 HP	Twin	72	6	Sandy
	3	20.07.2014	Daylight	Costal	İki Kardeşler-2	11,75 m- 185 HP	Twin	76	7	Muddy-sandy
	4	21.07.2014	Daylight	Dereköy	Remzi Baba	11,30 m- 135 HP	Twin	72	5	Sandy
	5	22.07.2014	Daylight	Dereköy	Remzi Baba	11,30 m- 135 HP	Twin	72	5	Sandy
II- Traditional/Modified(sledges without steel wire)	6	20.07.2014	Daylight	Costal	İki Kardeşler-2	11,75 m- 185 HP	Twin	76	6	Muddy-sandy
	7	20.07.2014	Day-Night	Dereköy	Remzi Baba	11,30 m- 135 HP	Twin	72	9	Sandy
	8	22.07.2014	Night	Dereköy	Remzi Baba	11,30 m- 135 HP	Twin	72	10	Sandy
III-Fuel consumption (Traditional/sledges with and without steel wire)	9	22.07.2014	Daylight	Dereköy	Remzi Baba	11,30 m- 135 HP	Single	72	8	Sandy
	10	22.07.2014	Daylight	Dereköy	Remzi Baba	11,30 m- 135 HP	Single	72	8	Sandy
	11	23.08.2014	Daylight	Dereköy	Remzi Baba	11,30 m- 135 HP	Single	72	18	Sandy

Figure 104. The trials of the modified gear at sea. 16 July, 2014, Dereköy Port.

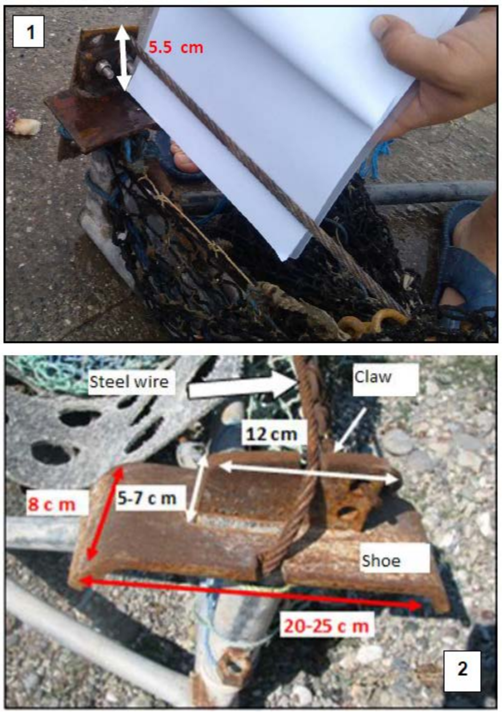


Figure 105. The parts of shoes in traditional beam trawl commonly used in SSA. 1: The distance where the steel wire attached the claws is about 5.0-5.5 cm. 2: The dimensions of a shoe which is the digging part of a beam trawl causing physical disturbance on substrate.

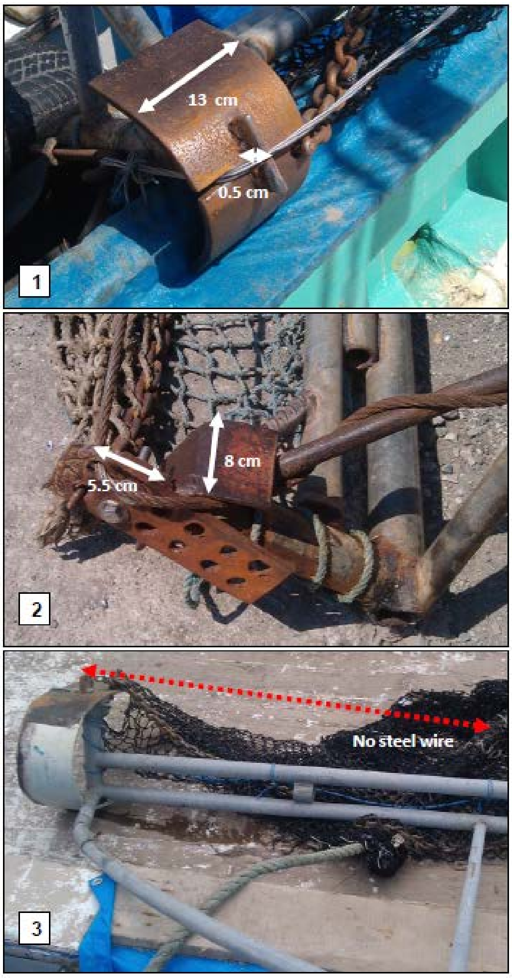


Figure 106. The sledge model commonly used in sandy-muddy and muddy substrates along Costal Yeşilırmak-Terme localities, 2: The traditional beam trawl used in Costal locality. 3: The modified gear without steel wire.

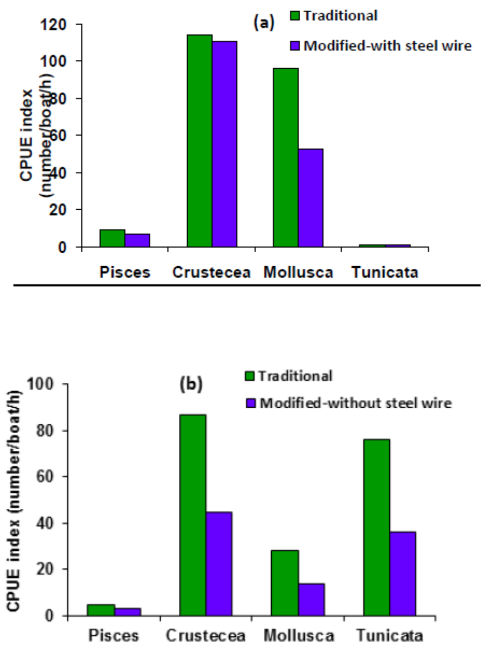


Figure 107. The CPUE index in number estimated for different organism groups of bycatch in; a) modified gear (sledges with steel wire) vs traditional gear and b) modified gear (sledges without steel wire) vs traditional gear in beam trawl fishery.

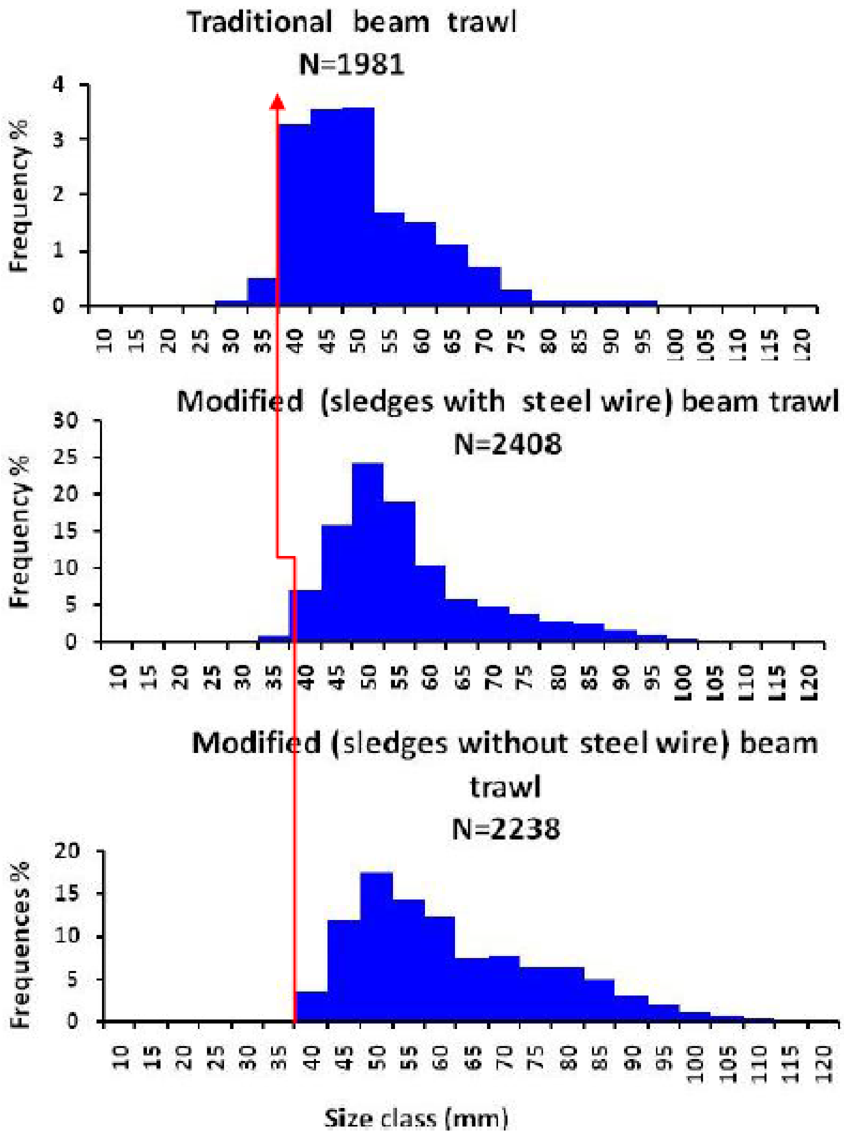


Figure 108. The size frequency distributions of rapa whelk catch (pooled by all operations) caught by traditional and the two type of modified beam trawls (The red line shows the mean length at first maturity in rapa whelk).

Table 42. The comparison of bycatch composition in number for any significant difference obtained in parallel hauls of traditional and modified gears

Organism group	Traditional gear vs Modified (sledges with steel wire) gear		Traditional gear vs Modified (sledges without steel wire) gear	
	X^2 test value	Sig.	X^2 test value	Sig.
Fish	5.194	**0.023**	6.333	**0.012**
Crustacean	0.692	0.405	93.545	**0.000**
Mollusc	223.536	**0.000**	31.680	**0.000**
Tunicate	0.027	0.869	99.492	**0.000**

Table 43. The presence of species in bycatch composition within parallel haulings of the traditional and modified gears in Dereköy station

	Traditional (T) vs Modified (Sledges with steel wire) (M1)																												Traditional (T) vs Modified (Sledges without steel wire) (M2)															
	20.07.2014								17.07.2014										19.07.2014										19.07.2014												22.07.2014			
	1		2		3		4		1		2		3		4		5		1		2		3		4		5		1		2		3		4		5		9		1		2	
	T	M_1	T	M_1	T	M_1	T	M_1	T	M_1	T	M_1	T	M_1	T	M_1	T	M_1	T	M_1	T	M_1	T	M_1	T	M_1	T	M_1	T	M_2	T	M_2	T	M_2	T	M_2	T	M_2	T	M_2	T	M_2	T	M_2
Pegusa nasuta	o						o		o							o							o																	o				
Diplogogaster sp.													o	o															o					o										
Uranoscopus scaber					o			o		o	o				o	o		o			o	o			o	o		o				o	o	o			o	o	o	o		o	o	
Parablennius tentacularis						o					o			o														o		o														
Hippocampus hippocampus	o		o	o	o		o	o				o	o	o	o		o		o	o	o	o		o			o	o	o		o	o			o	o	o	o	o	o	o	o	o	o
Psetta maxima															o																						o	o						
Arnoglossus kessleri														o			o							o	o					o						o	o	o						
Platichthyis flesus									o																									o			o	o				o		
Syngnathus sp.							o																																					
Scorpeana porcus																								o					o															
Callionymus sp.																																				o							o	
Dasyatis pastinaca																		o																										
Diogenes pugilator			o		o	o		o					o	o	o	o	o		o	o	o	o	o	o	o	o						o			o	o	o	o			o			
Liocarcinus depurator	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o			o	o	o	o	o	o	o	o
Carcinus aestuarii	o	o			o		o	o			o	o	o	o	o		o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o		o	o	o	o	o	o	o	o	o	o	o
Brachynotus sexdentatus	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o			o	o		o	o	o				o					o	o	o	o	o	o		o	o	o	o	o
Plimnus hirtellus																																												
Palaemon elegans																																												
Nerocilla sp.	o																						o																					
Eriphia verrucosa										o			o	o	o	o			o				o	o	o				o	o			o	o	o								o	o
Papillicardium papillosum														o																														
Cyclope nerita																						o																						
Nassarius reticulatus																						o			o											o	o							
Anadara cornea	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o		o	o	o	o		o	o	o	o		o		o	o	o		o	o			o	o	o		o	o
Mytilus galloprovincialis					o	o	o	o						o							o			o																				
Chamelea gallina				o	o	o	o	o	o		o		o	o	o		o		o	o	o	o	o	o	o	o	o	o		o	o	o	o	o	o	o	o	o		o	o		o	o
Ascidia sp.							o	o				o	o	o									o	o									o	o	o	o			o	o				

Table 44. The presence of species in bycatch composition within parallel haulings of the traditional and modified gears in Costal station.

	Traditional (T) vs Modified (Sledges with steel wire) (M1)								Traditional (T) vs Modified (Sledges without steel wire) (M2)					
	20.07.2014								20.07.2014					
	1		2		3		4		1		2		3	
	T	M_1	T	M_1	T	M_1	T	M_1	T	M_2	T	M_2	T	M_2
Pegusa nasuta	o	o						o						
Diplogogaster sp.		o												
Uranoscopus scaber	o		o			o	o	o			o		o	o
Parablennius tentacularis	o	o			o									
Hippocampus hippocampus	o		o	o	o	o			o				o	o
Psetta maxima													o	o
Arnoglossus kessleri									o					
Platichthyis flesus											o			
Syngnathus sp.														
Scorpeana porcus														
Callionymus sp.														
Dasyatis pastinaca														
Diogenes pugilator	o	o	o	o	o	o	o	o	o		o	o	o	o
Liocarcinus depurator	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Carcinus aestuarii	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Brachynotus sexdentatus	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Plimnus hirtellus	o					o	o	o				o		
Palaemon elegans				o							o			
Nerocilla sp.														
Eriphia verrucosa								o						
Papillicardium papillosum														
Cyclope nerita														
Nassarius reticulatus							o	o						
Anadara cornea	o	o	o	o	o	o	o	o		o	o	o	o	
Mytilus galloprovincialis	o	o	o	o				o						
Chamelea gallina	o	o	o	o	o	o	o	o	o	o	o	o	o	o
Ascidia sp.						o								

Table 45. The mean legth of the rapa whelk catches from traditional and modified gears in 11 operations and the comparison of size frequency distributions (α=0.05)

Date, Station	Substratum	Gear type				Size frequency distribution (K-S test sig.)
		Traditional beam trawl		Modified (sledges with steel wire)		
		N	Mean TL± s.e of the mean	N	Mean TL, s.e of the mean	
17 July, 2014, Dereköy	Sandy	330	51.15± 0.605	403	52.97±0.558	0.097
19 July, 2014, Dereköy	Sandy	191	56.91±1.112	233	52.88±0.899	0.026
19 July, 2014, Dereköy	Sandy	322	57.02±0.747	330	55.80±0.677	0.652
19 July, 2014, Dereköy	Sandy	317	56.05±0.700	267	58.93±0.871	0.034
19 July, 2014, Dereköy	Sandy	225	55.56±0,951	130	64.50±1.307	0.000
19 July, 2014, Dereköy	Sandy	209	62.85±1.083	278	60.27±0.954	0.037
21 July 2014, Dereköy	Sandy	234	66.03 ± 0957	160	70.81, ±0.822	0.001
		Traditional beam trawl		Modified (sledges without steel wire)		
20 July 2014, Costal	Muddy-sandy	227	52.8±0.698	246	58.27±0.629	0.000
20 July 2014, Dereköy	Sandy	314	61.02±0.609	403	58.49±0.471	0.030
20 July 2014, Dereköy	Sandy	295	58.41±0.865	204	57.99±1.035	0.939
22 July 2014, Dereköy	sandy	281	54.04±0.774	250	51.52±0.725	0.053

To reduce the fuel consumption:

Introduction

The potential effects of active fishing gears such as otter trawl; beam trawl etc. on the marine ecosystem is a worldwide problem (Rijnsdorp et al., 1998; Valdemarsen et al., 2007; Suuronen et al., 2012). Of these, beam trawl is used mainly for species such as flatfish (Groenwold and Fonds, 2000) and shrimp (Gamito and Cabral, 2003; Zengin and Tosunoğlu, 2006) in European waters. The gear is also responsible for rubbing and cultivating of the sea bottom, removing and destructing of some infaunal and epifaunal species (Groenwold and Fonds, 2000; Kaiser and Spencer, 1996; Rijnsdorp et al., 1998).

To measure seabed disturbance, the first experiments were conducted by Council for the Exploration of the Sea in 1970s and then direct underwater observations by divers, cameras and acoustic devices were used by scientists (Walsh et al., 2002).

In addition to studies of environmental effects of beam trawls, discard mortality of beam trawl (Kaiser and Spencer, 1995), codend selectivity (Zengin and Tosunoğlu, 2006) and gear modifications (Abookire and Rose, 2005; Suuronen et al., 2012), a small number of studies on energy saving and consumption (Sala, 2002; Schau et al., 2009; van Marlen and Salz, 2010; Balash and Sterling, 2012; FAO, 2012) were performed for towed gears.

Beam trawls have been identified as a gear towed from out rigger booms (EC, 356/2005). The horizontal opening of the net is provided by a rigid body (frame). A pair of shoes is welded to the ends of metal beam so that it can slide over the sea bottom (Valdemarsen et al., 2007).

In the Black Sea, traditional beam trawl (Rapana beam trawl) with shoes welded on a rigid frame had been used for sea snails since 1980s. Rapana beam trawl have 3 m mouth with 1 meter codend in 72 mm mesh size (Anonymous, 2012).

Both shoes have a claw to connect the steel wire has a penetration depth of 50-70 mm from one end to the other. Samsun is the most important region for the sea snail fisheries with the largest fishing fleet (>400 fishing vessels) (Zengin and Knudsen, 2006). However, fishing pressure on sea snails causes destructive environmental effects in the Black Sea. Fishing operations start from 5 m to 30 m depths (average; 10 m) in the Black Sea (Zengin et al., 2014).

In the study, we tested the modified and traditional beam trawls by measuring fuel consumption and towing tension during the fishing operation. In addition, underwater observations were carried out during the capture.

Materials and Methods

Study site and fishing gear

A total of 36 hauls were carried out on the commercial beam trawler (11.3 m length, 102.2 kW engine) from July to September 2015 in the coastal water of Samsun, the southern Black Sea (Turkey) (Figure 76). In the study, 12 different experiments were performed with 3 replicates (Table 46). Fishing operations conducted with the three types of beam trawl (Traditional and modified gears) on commercial fishing grounds (sandy and sandy/muddy) at depths between 7.5-11.5 m (target species; sea snail).

The fishing gear was a traditional beam trawl with 200 meshes around the mouth (Kaykaç et al., 2014).The traditional beam trawl with shoes had steel wire stretching between shoes at the mouth of the gear to scrapethe sea bottom. Modifications were made on shoes of traditional beam trawl (Figure 109).

In the study, beam trawls with different shoes (sledge) (T, M-1, and M-2) were used to determine towing resistance and fuel consumption of fishing vessel. Of these, traditional beam trawl (T) with small-size sledge had been used by local fishermen since 1980s (Figure 109). In addition, three replicates were performed for fuel consumption of beam trawl with and without wire between shoes on sandy bottom. Weight of the Rapana beam trawls are 55 kg in air.

Measurement of fuel consumption

Ultra-low flow (ULF) sensor (fuel flow meter) was used to measure the flow of fuel consumption (l/h) (Figure 110). Flow rate range was between 1.5 and 100 l/h. The flow meter was installed horizontally between fuel tank and main engine with pipe connection. Fuel flow meter with interface cable was supplied with electrical power from onboard vehicle power source (<15 m A, 24 VDC).

Measurements were performed for 10 min duration at a constant rpm (Revolutions per minute; 1100 min-1) or a constant speed (v) (Vessel speed during fishing, 2.4 knot) on SG and SMG (Table 46). Average flow consumption was recorded with 1 min interval by reading the digital display of the flow meter.

Measurement of towing resistance

Force gauge with S-type sensor was used to measure tension (N) on a steel wire of fishing gear during the fishing operation (Figure 111). The measurements were taken for 10 min duration at 1100 rpm or 2.4 knot on SG and SMG (Table 46). Force gauge was mounted on the steel wire of beam trawl by connecting with steel shackle, thimble, carabineer and clips without cutting the wire. Data were transferred to the computer after the measurement.

Underwater observations

The underwater observations were recorded by an underwater camera in the form of video clips. The digital camera (GoPro HERO4 Black Edition) with housing was mounted with plastic cable ties temporarily on steel frame of beam trawl at two different visual angels to monitor both a mouth of net and sledges. The recordings were transferred from the camera to the hard disk and captured to produce a picture using the Video Capture Software.

Statistical analysis

The statistical significance of differences between fuel consumption of beam trawls at constant rpm was determined with the One-way ANOVA. The difference between fuel consumption of beam trawls at constant speed was analysed by Kruskal-Wallis. The difference between tensions on wires of three different beam trawls was determined with Kruskal-Wallis.

Results

Fuel consumption

There was a significant difference between T, M-1 and M-2according to the results of experiments carried out on the sandy and sandymuddy ground with constant rpm.M-1 had the lowest fuel consumption on sandy bottom ($p<0.0001$) and sandymuddy bottom ($p<0.0001$) at constant rpm. The lowest fuel consumption was measured for M-1 at constant speed on both sandy and sandymuddy bottoms ($p<0.0001$) (Table 47).

Towing resistance

At a constant1100 rpm, while the lowest load was determined for T on sandy bottom ($p<0.0001$), M-1 had the lowest tension on sandymuddy bottom ($p<0.0001$) (Figure 112). On sandy bottom, it was determined that the lowest load measured for M-2 at constant speed ($p<0.0001$) (Figure 113). M-1 had the lowest value on sandymuddy bottom at constant speed ($p<0.0001$). According to the results, M-1 had the best average in terms of low fuel consumption and resistance during fishing operation (Table 48).

Monitoring

It was observed that sledges of traditional beam trawl sometimes get up off the ground up to 20 cm. Mostly, traditional beam trawl, which is towed on claw, penetrate at least 5 cm into the sediment. The bottom surface of sledge of beam trawl does not completely contact to ground due to penetration of claw. Underwater observations showed that the sledge of modified beam trawl (M-1) stayed stable and slipped on ground properly. The other modified sledge (M-2), that stay on the bottom or that are partly buried in the sediment. In addition, excluding the front of a sledge old M-2, whole body of sledge covered by sediment (Figure 114).

Discussion

In this study, we compared the fuel consumption and towing resistance of Rapana beam trawls have three different shoes on two different seafloors at constant speed and rpm. In addition, underwater observations of all the three experimental beam trawls were conducted.

Suuronen et al. (2012) stated that beam trawls were an effective and practical for capture, however they are responsible for seabed deformations, high fuel consumption and by-catch rate, need flat grounds and expensive for fishing. Fuel consumption depends on some essential factors as catch rate (Enerhaug et al., 1993), towing speed (Beare and Machiels, 2012, Poos et al., 2013), fishing vessel (technology, engine etc.) and sea state, habitat type and gear type (Sala et al., 2011).

Sala et al. (2011) used mass flow sensors for the measurement of fuel consumption of semi-pelagic trawlers during several fishing operations for different phases. We measured that average fuel consumption of beam trawler by fuel flow meter. The fuel consumption on sandy bottoms was lower than sandy/muddy bottoms for two experimental beam trawls (T and M-1).

The difference was between approximate 17% for T and M-1 at constant rpm. However, M-2 on mixed bottom had higher fuel consumption (3%) than sandy bottom at constant rpm. Likewise, those two beam trawls (T and M-1) had lower fuel consumption varied between 15.5% and 20.8% on sandy bottom than sandy/muddy bottom at constant speed. The other experimental beam trawl (M-2) had almost same consumption on both types of bottom at constant speed.

Fishing operation speed varies 2-2.5 knot for the capture of sea snails in that region. However, only we measured average fuel consumption at constant speed and rpm, previous studies showed that increasing towing speed cause high fuel consumption and total cost during the capture (Beare and Machiels, 2012; Suuronen et al., 2012; Poos et al., 2013).

Poos et al. (2013) developed a model for testing energy saving of beam trawl to find a correlation between towing speed, fuel consumption and catch. Beare and Machiels (2012) observed that increasing fuel price force fishers decrease average towing speed from year to years to reduce total fishing cost. In addition, if fuel prices rise continually, active fishing gears such as beam trawls may become uneconomical gears (Suuronen et al., 2012).

Environmental effects of towing gears (changes of seabed topography, penetration depth etc.) had been measured by various methods such as acoustic tool, underwater camera, and use of load cell (Fonteyne, 1999). In the study, we used force gauge and underwater camera to observe load on warp and penetration of sledges into the seabed during the capture.

Therefore, we modified sledges of beam trawl to decrease resistance to ensure both low fuel consumption and reducing destruction of seabed. In the experiments, loads on warp were 0.87, 1.1, and 1.1 kN for T, M-1, and M-2, respectively on sandy bottom at constant rpm. On sandymuddy bottom at constant rpm, these values were 1.08, 0.90, and 1.27 kN, respectively. In the constant speed, M-2 had the lowest load (0.99 kN) on sandy bottom and M-1 had the lowest load (0.90 kN) on mixed bottom, whereas T was high resistance (>1.1 kN) on both sea bottoms.

Hand held video and underwater camera systems mounted on fishing gears had been used to assess the seabed disturbance caused by towing gears by researchers (Currie and Parry, 1996; Smith et al., 2000). In some cases, divers counted and measured deformations of seabed after the fishing (Currie and Parry, 1996).In this study, we used two underwater camera systems to observe reactions of beam trawls to seabed during the fishing operation.

In most cases, underwater observations showed that M-1 stayed stable and slipped particularly on soft bottom properly due to design of sledge and low resistance during the fishing. However, sledges of traditional beam trawl (T) were observed unstable.

On the other hand, we monitored that sledges of M-2 were towed creating resistance on the ground. The shape of sledges, which are unsuitable for hydrodynamic, may cause the resistance and distributed sediments during the operation.

In our experiments, the shape of sledge and sediment type was the main factors influence the behaviour of fishing gear during the operation. Finally, we perceived that one of the modified Rapana beam trawls, is called M-1, was the most appropriate gear to reduce resistance and fuel consumption on both sea bottoms at constant rpm and towing speed.

In future, size and shape of sledges, use of beam trawl without steel wire stretching between shoes, lightweight construction should be studied to mitigate environmental effects of fishing gear, reduce carbon emission and sustain sea snail fishery.

Conclusion

All experimental studies carried out to test the modified beam trawl pointed out that it is possible to reduce the fishing impact on benthic ecosystem by using sledges and removing the steel wire stretched on the mouth of the gear in traditional beam trawl. Additionally, a fuel save is also can be achieved by this modified type of beam trawl. Therefore, a double benefit can be provided in terms of economy and ecology.

In Black Sea, the rapa whelk fishery by beam trawls is banned in summer period. Even though it is illegal, the fishermen continue to fish and obtained the highest catch throughout a year in this period. In case of the use of modified gears, the impact on benthic habitat will be reduced on this period which coincides with the reproduction and the recruitment period of some fish species.

It is determined that especially the modified gear of sledges without steel wire has a significant reduction in bycatch quantity. The modified gear did not reveal a significant effect in bycatch composition by means of species variety.

The rapa whelk being the target species in beam trawl fishery in this region is an invasive species and one of the major top predators on benthic fauna. It is reported that the length at first maturity is 40 mm for the rapa whelk inhabiting southern Black Sea coasts (Sağlam and Düzgüneş, 2007; Sağlam et al, 2009.). The fishery management on rapa whelk is crucial at this point.

The fishing pressure is important to control this well reproducing population. So, if the rapa whelk fishery is not allowed in summer, it would not be possible to control the high spawning and recruitment as this species can only be effectively fished in summer months. Therefore, a mutual solution can be offered as the allowance of rapa whelk fishery in summer by the use of the modified gears.

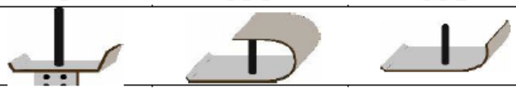
At least, it will be possible to reduce the negative ecological effect while the fishermen doing the rapa whelk fishery in any case. At this point, it is also be accounted that the modified gear have no significant effect on the individual size of the catch but a significantly lower CPUE. This result will make the fishermen unwilling to use the modified gear. So, it seems to be a new topic of argument between stakeholders (scientists, fishermen and government).

The most important result in the gear trials which also providing an advantage in negotiation with the fishermen for the adoption of the modified gears is the fuel save. The preliminary results of the repeated measurements carried out with the fuel meter showed that it is limited by 4-5%.

Even though, it is still an encouraging result to convince the fishermen for the use of modified gears. Because, it will provide a reasonable economic benefit for fishermen operating nearly 5 or 6 months specifically on rapa whelk fishery.

The future fishery management scenarios on rapa whelk will be based on this economical benefit of fuel save and the positive ecological effect withthe reduction of bycatch which is achieved by the use of modified gears.

Table 46. Experiments for the measurement of fuel consumption and towing resistance of beam trawls (36 hauls).

Exp.	Gear type			rpm (min^{-1})	v (knot)	Ground type	
	T	M-1	M-2	1100	2.4	SG	SGM
							
1	✓			✓		✓	
2		✓		✓		✓	
3			✓	✓		✓	
4	✓			✓			✓
5		✓		✓			✓
6			✓	✓			✓
7	✓				✓	✓	
8		✓			✓	✓	
9			✓		✓	✓	
10	✓				✓		✓
11		✓			✓		✓
12			✓		✓		✓

SG: Sandy ground, SMG: Sandy&muddy ground, v: Speed of fishing vessel, T: Traditional beam trawl, M-1 and M-2: Modified beam trawls

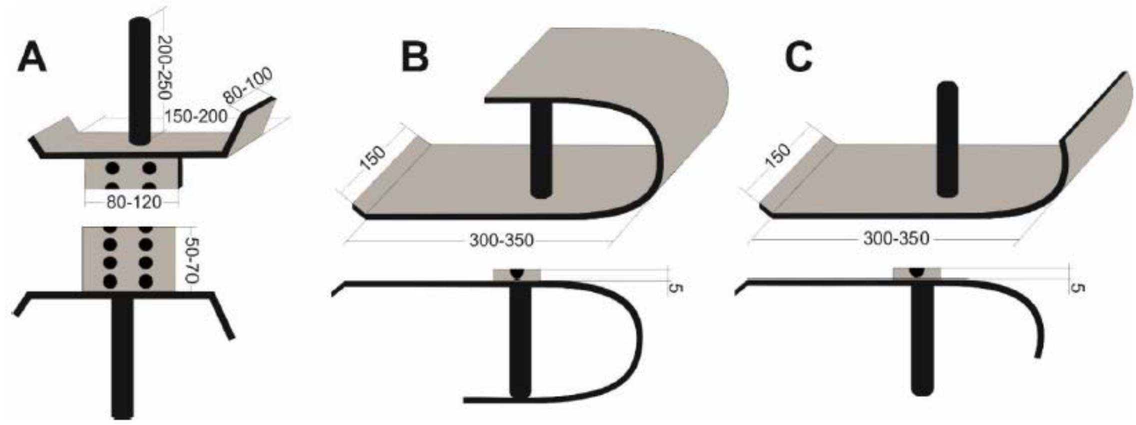


Figure 109. Shoe modifications of traditional beam trawl: A) Traditional shoe with 500-700 mm height of claw (T) B) Sledge type shoe with 5 mm claw (M-1) C) Cutting sledge type with 5 mm claw (M-2)

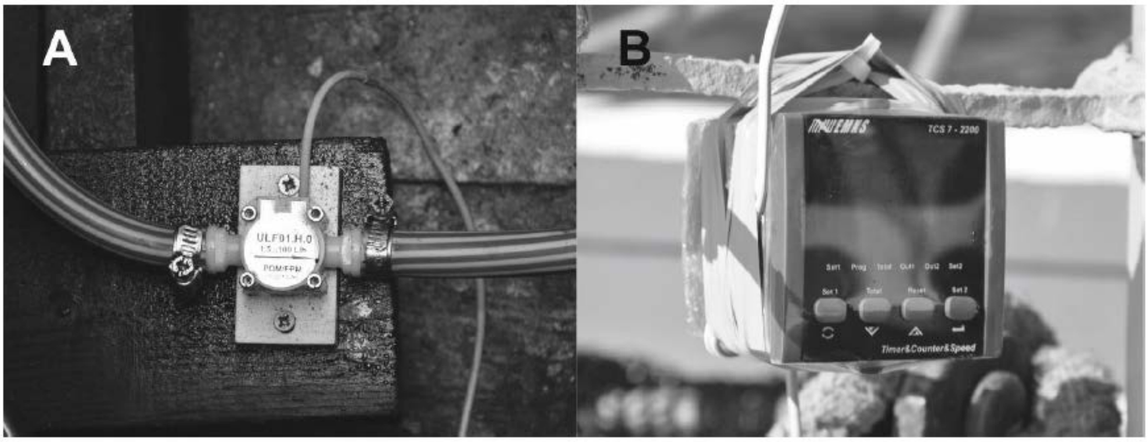


Figure 110. A) Installation of ultra-low flow (ULF) sensor and B)digital display

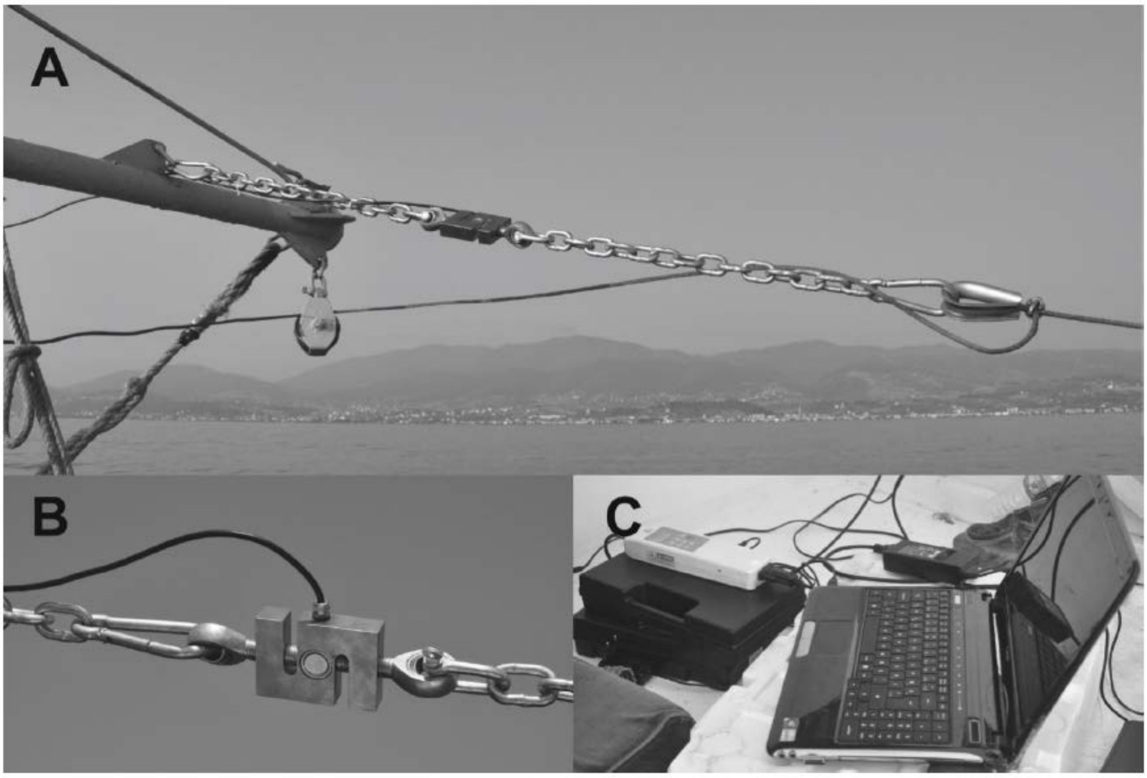


Figure 111. A-B) Installation of S-type sensor on a steel wire of beam trawl and C) force gauge connection with computer.

Table 47. Average fuel consumptions of three different beam trawls are working under various fishing conditions.

	Gear type			
	T	M-1	M-2	
Sandy	3.26	3.10	4.04	*Constant rpm*
Sandy&muddy	3.93	3.76	3.92	
Sandy	3.23	3.21	3.84	*Constant speed*
Sandy&muddy	4.08	3.80	3.85	

Table 48. Summary of fuel consumption and tension measurements of beam trawl

	Gear type			
Fuel consumption	T	M-1	M-2	
Sandy		✓		*Constant rpm*
Sandy&muddy		✓		
Sandy		✓		*Constant speed*
Sandy&muddy		✓	✓	
Tension				
Sandy	✓			*Constant rpm*
Sandy&muddy		✓		
Sandy			✓	*Constant speed*
Sandy&muddy		✓		

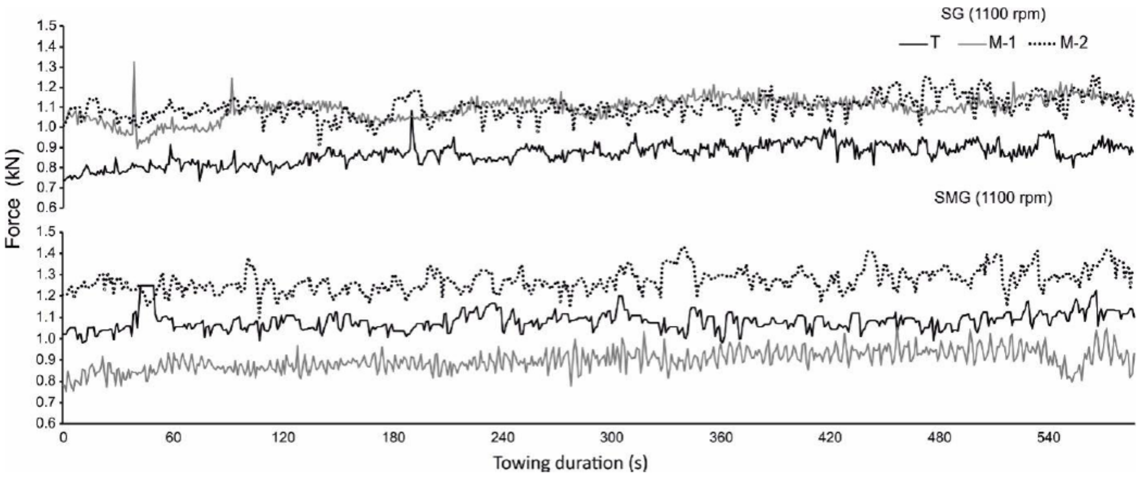


Figure 112. Measurements of force on beam trawl at 1100 rpm (SG: Sandy ground, SMG: Sandy-muddy ground, v: speed of fishing vessel, T: Traditional beam trawl, M-1 and M-2: Modified beam trawls)

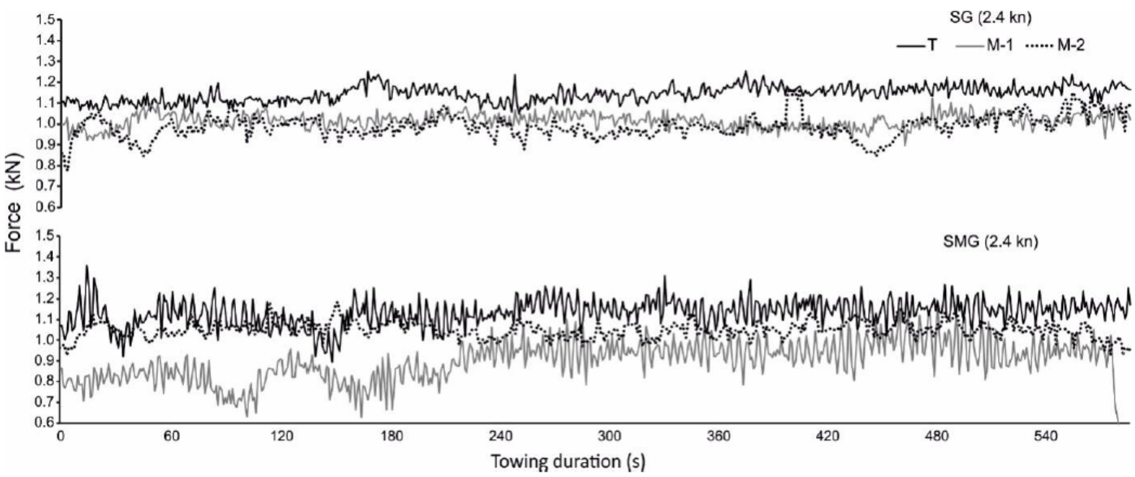


Figure 113. Measurements of force on beam trawl at 2.4 knot (SG: Sandy ground, SMG: Sandy-muddy ground, v: speed of fishing vessel, T: Traditional beam trawl, M-1 and M-2: Modified beam trawls).

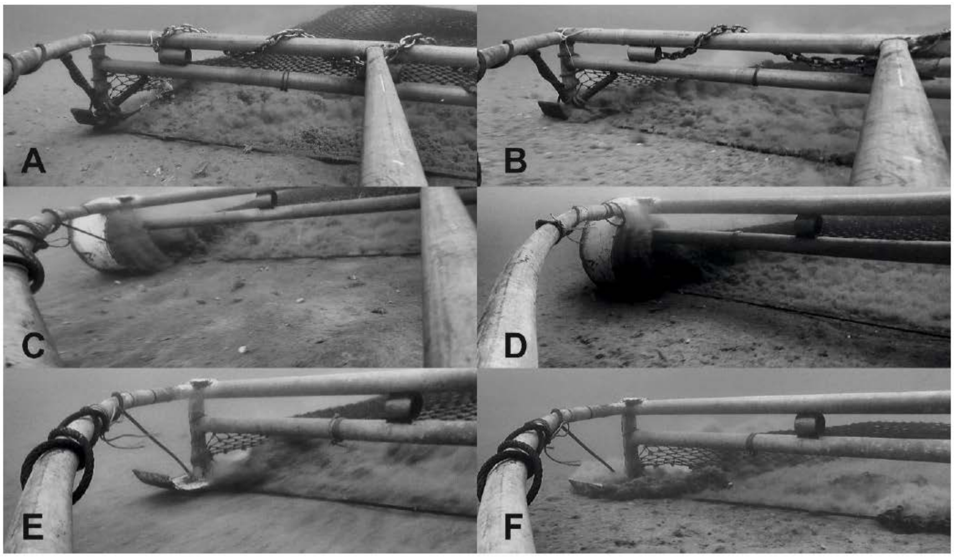


Figure 114. Underwater observations of Rapana beam trawls (T: Traditional beam trawl, M-1 and M-2: Modified beam trawls): A) T on sandy bottom B) T on sandy/muddy bottom C) M-1 on sandy bottom D) M-1 on sandy/muddy bottom E) M-2 on sandy bottom F) M-2 on sandy/muddy bottom.

Selectivity studies on the bottom trawl codend

Introduction

Samsun Shelf Area (SSA) is the most important fishing areas along the Turkish Black Sea coasts because SSA being discharged by two major river of Anatolia (Yeşilırmak and Kızılırmak) is a special ecosystem. In the bottom trawl fishery, the growing fleet and effort by 1980s raised a collapse in demersal fish stocks affecting all ecosystem components. Red mullet (Mullus barbatus) and whiting (Merlangus merlangus euxinus) stocks are affected by this situation. In monitoring studies on trawl fishery (2009-2013), the discard rate in bottom trawl fishing was determined high especially for red mullet and whiting in SSA (Zengin et al, 2013).

Mesh size of codend used bottom trawl nets in the Black Sea cannot be smaller than 40 mm. Increasing the selectivity of the fishing gear used in SSA is one of the main objectives of BENTHIS project (WP7). Seasonal discard rates in fishing period of 2013 for whiting were as 33.2%, 26.7% and 29.4% and 20.6%, 25.6 and 17.3% for red mullet respectively. The range of age groups for whiting discard was 0-2 yr and 0-1 yr for red mullet (Zengin et al, 2014).

This causes a great economic loss and has impacts on food web and indirectly on the benthic ecosystem. The high discard rate indicates that there is a heavy fishing pressure on red mullet and whiting populations in Southern Black Sea. The other reasons for the high discard rate may be the long operation durations and the low selectivity of trawl codend.

Material and Method

Selectivity trials were carried out onboard the commercial trawler 'Malkoç Bey' (31 LOA, 1300 HP main engine) from 20 to 27 August 2014. Towing duration varied between 60 and 90 min, and trawling is made at depths ranging from 15 to 55 m. Trawling was carried out between 15 and 30 m for Red mullet and the thermocline layer below 45-50 m for Whiting due to seasonal. Fishing was conducted using a conventional bottom trawl with 900 meshes around (Figure 77). All tows were made during daytime.

Trawling was carried out by using four different codend with a total of 21 valid hauls for red mullet and 20 valid hauls for whiting. A total of four codends were tested for selectivity trials. First one was the commercially used nominal 40 mm PE codend with 300 meshes on its circumference (three seems of 100 meshes panels) (40D). Second codend was made of nominal 40 mm. PE material and turned 90º T-90 with 300 meshes on its circumference (three seems of 100 meshes panels) (40T90). The third codend was constructed as constructed as 150 bars on its circumference full square mesh codend with nominal 36 mm PE netting (36S).

Finally, the fourth one was150 bars on its circumference full square mesh codend with nominal40 mm PE netting (40S) (Figure 115). All the codends were approximately 4-4.5 m in stretched lengths. They were attached to end of funnel which was 300 meshes in its circumference and made of 40 mm mesh size PE netting.

The hooped-covered codend method was used to collect selectivity data (Wileman et al., 1996). A 8.2 m long, and 24 mm mesh size knotless PA (polyamide) netting cover was used to collect the individuals that escaped. The cover was supported by two hoops (PVC Ø 1.6 m) to avoid the masking effect and to provide water flow between the codend and the cover. These hoops were mounted on the cover at distances of 2.2 and 5.2 meters from the attachment point at the end of the funnel (Figure 116).

The mesh opening of the codend netting was measured using a caliper rule. A 4 kg weight was tied vertically to the stationary jaw of the rule. A total of 60 meshes (3 lines of 20 meshes in the towing direction) near to the aft of each codend were measured (Figure 117). At the end of each tow the cover catch was first removed and sub-sampled in case of catching a lot of fish, target species separately sorted from the rest of the catch and weighed. After sub-sampling was performed and weighed on the codends catch for red mullet and whiting. For the species, length measurements were taken to the nearest cm. After each haul, the catch was taken on board and sorted by species. Then, full or sub-samples of the target species from the codend and cover were taken and weighted separately Figure 118.

Selectivity data were collected using the covered codend method and selection curves of the individual hauls were obtained by fitting a logistic function:

$$r(l) = \exp(v_1 + v_2 l) / [1 + \exp(v_1 + v_2 l)]$$

where r(l) is the retained proportion of length class l, given that it entered the codend (Wileman et al., 1996), and v=(v1, v2)T is the vector of the selectivity parameters. The values of L50 were estimated from the expressions:

$$L_{50} = \frac{-v_1}{v_2}$$

These parameters were calculated by maximum likelihood using the software CC 2000 (ConStat, 1995). For red mullet and whiting, mean selectivity curves using EC Model software (ConStat, 1995) were estimated by taking into account the between-haul variation of the selectivity parameters according to Fryer (1991).

Results

Table 49 shows the numbers of the measured meshes (when wet) and their results with Caliper rule for each codend. During the sea trails, 21 valid hauls for red mullet and 20 valid hauls for whiting were carried out the depths of 15 and 55 m for all codends in SSA (Table 50). Depth was noted only at starting and ending location for each tow. Towing duration (min 60 and max 90 minute) was the time during which the trawl net was on the sea bed as commercial trawl operations.

Red mullet and whiting communities are located at different depths in the Black Sea. Therefore, trawl operations were conducted about 15-30 m depth for the red mullet and about 45-55 m depth below the thermocline layer for whiting. Together both red mullet and whiting were rarely caught in the some hauls.

Raja clavata, Dasyatis pastinaca and Psetta maxima are the important flatfish species in bycatch of bottom trawl fishery in the Black Sea littoral. There are two common jellyfish in SSA; Rhizostoma pulmo and Aurelia aurita.

Red mullet

L_{50} and SR values were estimated for all codends (Table 51). The highest rate of discard (18.1 %) was determined in the conventional gear net (40 mm-diamond mesh 40D) still used by fishermen. The best selectivity results were obtained in the 40S codend. L_{50}values of 40D codend used by the fisherman were determined very low than others. This value is fairly bellowing the MLS value for the40D. Mean selectivity curves for all codends is shown in Figure 119. MLS and L_{M50} values for red mullet is 11 cm.

Whiting

L_{50} and SR values were estimated for all codends (Table 52). The highest rate of discard (29.5 %) was determined in the conventional gear net (40 mm-diamond mesh) still used by fishermen. The best selectivity results were obtained in the 40S codend. L_{50} values of 40D codend used by the fisherman were determined very low than others. This value is fairly bellow the MLS value for the 40D. Mean selectivity curves for all codends is shown in Figure 120. MLS and L_{M50} values for whiting are 14 cm.

Conclusion

In this study, we conducted selectivity experiments for trawl codend (40D) used by the commercial trawl fisherman and three different mesh shape and size (40S, 36S and 40T90) for two target species. Results of the selectivity analysis show that presently used commercial 40 mm nominal mesh size PE codend was rather unselective to release sufficient amount of juveniles. Mean selectivity value (L50) of 40D codend were quite below MLS and LM50 values of target species. Hanging ratios of the traditional codend meshes are quite low and the shape of mesh openings does not supply an effective escaping area for most of the undersized fish species. Many researchers emphasize that the commercial trawl codend used in Turkey are rather unselective for these species (Zengin et al, 1997; Zengin and Düzgüneş, 1999; Tokaç et al., 1998, 2004; Özbilgin and Tosunoğlu, 2003; Tosunoğlu et al., 2003; Özbilgin et al., 2005; Özdemir et al, 2012). Results of the experimental codends in the present study show higher mean L50 values than that of the commercial codend for red mullet and whiting.

Square mesh trawl codend had a positive effect on size selectivity of red mullet and whiting. The full square mesh codend in general improved the selectivity for round fish such as whiting and red mullet. The best result of selectivity values were obtained in the 40S codend. But trawl fisherman are not in favor of use this codend (40S) because of the high selectivity according to fisherman.

At the same time, the use of square mesh codend as a technical measure was strongly supported the size selectivity with small loss in marketable catch. Mesh shape is the most important factor for understanding the consequences of changes in mesh selectivity, because there are many varieties of fish shapes in the landings.

Tokaç et al. (2014) reported that T90 trawl codend (41 mm mesh size) significantly improved size selectivity of red mullet when compared to conventional diamond mesh codend. In our study, for the 40T90 codend was obtained positive result on the size selectivity for the red mullet.

Selectivity studies carried out on the Black Sea is very limited (Zengin et al, 1997; Aydın et al, 1998; Zengin and Düzgüneş, 1999; Özdemir et al, 2012). According to the results obtained in this study, square or T90 mesh shape used on the commercial trawl codend will contribute for sustainable fishing of these two species.

First, there is a need also to be made selectivity studies for other species. As stressed by many authors (Ordines et al., 2006; Sala et al., 2008; Düzbastılar et al., 2010a,b), knowing survival rate of the escaped individuals are very important to examine the selectivity study results. Therefore, we should encourage researchers about selectivity, behavioral underwater observation and survival studies on the bottom trawl nets in the Black Sea.

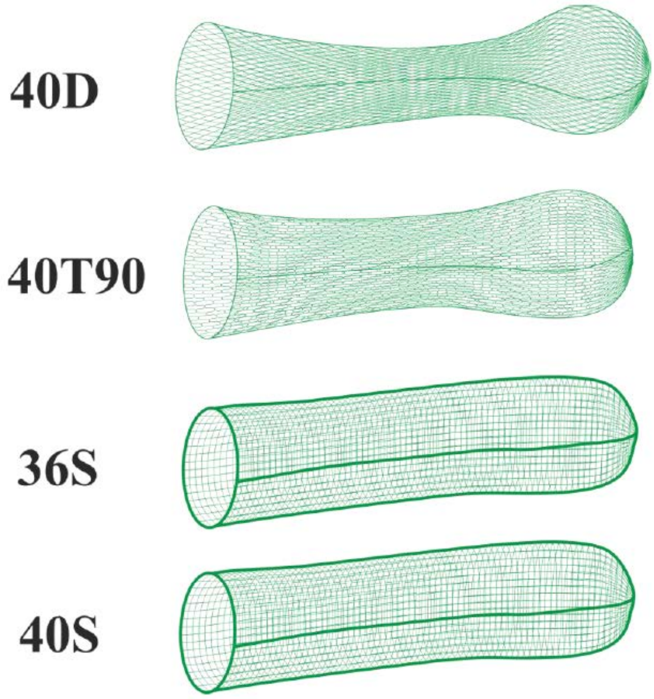


Figure 115. Illustration of the codend tested.

Table 49. Results of mesh measurements

	40S	40T90	36S	40D
Mean	39,85	39,47	35,95	44,29
SE	0,08	0,09	0,12	0,39
n	60	60	60	60
Min.-Max.	39-42	38-41	34-38	39-52

Table 50. Date and haul number of the codend used in the experiment. CMNC-circumferences number of mesh codends

Date	*Codend Type*	*CNMC*	*Haul no*	*Target species*
			1	Red mullet
			2	Red mullet-Whiting
20.08.2014		300	3	Red mullet-Whiting
			4	Red mullet
	40T90		5	Red mullet-Whiting
			6	Red mullet
21.08.2014		300	7	Whiting
			8	Red mullet
			9	Whiting
			1	Red mullet
21.08.2014		150	2	Red mullet
			3	Red mullet
			4	Red mullet
			5	Whiting
22.08.2014	**36S**	150	6	Whiting
			7	Whiting
			8	Red mullet
			9	Whiting
24.08.2014		150	10	Red mullet
			11	Whiting
			1	Whiting
			2	Red mullet
24.08.2014		150	3	Red mullet
			4	Red mullet
	40S		5	Red mullet
			6	Whiting
			7	Whiting
25.08.2014		150	8	Whiting
			9	Whiting
			10	Whiting
25.08.2014		300	1	Whiting
			2	Red mullet
			3	Whiting
			4	Whiting
	40D		5	Whiting
26.08.2014		300	6	Whiting
			7	Red mullet
			8	Red mullet
			9	Red mullet

Figure 116. Illustration of the hooped cover used to collect selectivity data.

Figure 117. Measuring of mesh openings by caliper rule.

Figure 118. Sub-sampling procedure and length measurements.

Table 51. Selectivity parameters for Red mullet. Selectivity parameter estimates [L50 (cm), length at 50% retention; SR (cm), selection range; SE, standard error; v1 and v2, maximum likelihood estimators of selectivity parameters; R11, R12, and R22, variance matrix measuring within-haul variation; d.f., degrees of freedom].

	Haul no	L_{50}	(SE)	SR	(SE)	v_1	v_2	R_{11}	R_{12}	R_{22}	Deviance	d.f.	p-value
36S	1	**10,19**	(0,07)	**1,08**	(0,09)	-20,771	2,038	3,2137	-0,2993	0,0280	31,78	19	0,03
	2	**10,37**	(0,10)	**1,21**	(0,09)	-18,852	1,818	2,2626	-0,1983	0,0175	75,39	21	0,00
	3	**10,29**	(0,08)	**1,49**	(0,12)	-15,191	1,476	1,7357	-0,1575	0,0144	47,42	18	0,00
	4	**11,57**	(0,05)	**0,97**	(0,07)	-26,189	2,264	3,3018	-0,2893	0,0254	34,38	15	0,00
	8	**10,17**	(0,04)	**1,00**	(0,06)	-22,348	2,197	1,7820	-0,1656	0,0154	41,34	21	0,01
	10	**10,79**	(0,08)	**1,02**	(0,12)	-23,257	2,155	7,8489	-0,7009	0,0628	80,81	16	0,00
	Mean (Fryer)	**10,59**	(0,09)	**1,11**	(0,03)	-20,893	1,972	2,6232	-0,2017	0,0167			
40T90	1	**8,92**	(0,16)	**1,62**	(0,12)	-12,143	1,361	0,9575	-0,0930	0,0094	46,21	20	0,00
	2	**8,68**	(0,73)	**4,14**	(1,10)	-4,605	0,531	2,5418	-0,2243	0,0199	22,55	11	0,02
	3	**11,07**	(0,07)	**1,83**	(0,11)	-13,275	1,199	0,6884	-0,0592	0,0051	9,63	12	0,65
	4	**10,07**	(0,53)	**3,96**	(0,93)	-5,582	0,555	2,2082	-0,1903	0,0169	727,35	23	0,00
	5	**10,45**	(0,13)	**1,88**	(0,17)	-12,250	1,172	1,5294	-0,1334	0,0117	4,53	12	0,97
	6	**10,61**	(0,09)	**1,28**	(0,10)	-18,163	1,712	2,3775	-0,2106	0,0188	56,39	24	0,00
	8	**11,56**	(0,15)	**2,58**	(0,27)	-9,864	0,853	1,0606	-0,0920	0,0081	109,42	20	0,00
	Mean (Fryer)	**10,29**	(0,12)	**1,92**	(0,08)	-10,851	1,055	2,9099	-0,2624	0,0250			
40D	2	**10,76**	(0,21)	**2,26**	(0,37)	-10,471	0,974	3,1706	-0,2856	0,0261	1265,32	22	0,00
	7	**10,83**	(0,10)	**1,84**	(0,16)	-12,938	1,194	1,3556	-0,1230	0,0113	232,99	22	0,00
	8	**9,01**	(0,20)	**2,14**	(0,32)	-9,243	1,026	2,2336	-0,2256	0,0231	460,26	20	0,00
	9	**7,97**	(0,23)	**2,75**	(0,25)	-6,370	0,799	0,4811	-0,0483	0,0051	1026,71	21	0,00
	Mean (Fryer)	**9,79**	(0,35)	**2,20**	(0,11)	-9,714	0,992	2,4339	-0,1478	0,0094			
40S	2	**12,36**	(0,12)	**1,81**	(0,19)	-14,998	1,213	2,1864	-0,1848	0,0157	174,47	18	0,00
	3	**11,93**	(0,03)	**0,35**	(0,03)	-74,935	6,284	38,8766	-3,2506	0,2720	46,63	18	0,00
	4	**11,60**	(0,06)	**1,65**	(0,10)	-15,471	1,335	0,9127	-0,0788	0,0068	119,69	20	0,00
	5	**11,67**	(0,10)	**1,33**	(0,11)	-19,279	1,652	2,1752	-0,1968	0,0179	480,1	16	0,00
	Mean (Fryer)	**11,89**	(0,08)	**1,26**	(0,17)	-30,625	2,575	204,6551	-17,1415	1,4361			

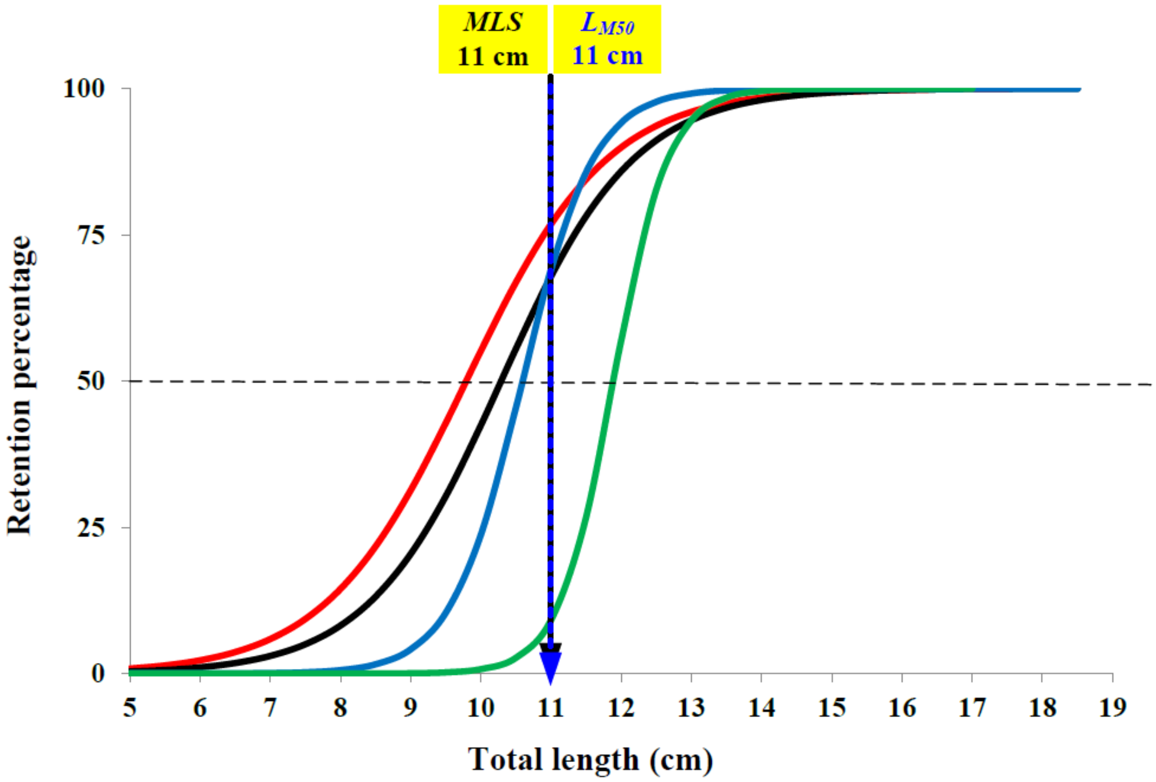


Figure 119. Mean selection curves in the all codend for red mullet (red line-40D, black line-40T90, blue line-36S and green line-40S)

Table 52. Selectivity parameters for whiting. Selectivity parameter estimates [L50 (cm), length at 50% retention; SR (cm), selection range; SE, standard error; v1 and v2, maximum likelihood estimators of selectivity parameters; R11, R12, and R22, variance matrix measuring within-haul variation; d.f., degrees of freedom].

	Haul no	L_{50} (SE)	SR (SE)	v_1	v_2	R_{11}	R_{12}	R_{22}	Deviance	d.f.	p-value
36S	5	**13,86** (0,12)	**1,81** (0,12)	-16,863	1,217	1,0190	-0,0807	0,0064	223,49	18	0,00
	6	**14,26** (0,23)	**1,76** (0,20)	-17,823	1,250	3,2546	-0,2547	0,0201	235,18	18	0,00
	7	**13,69** (0,10)	**1,27** (0,13)	-23,641	1,727	5,4488	-0,4069	0,0305	305,93	21	0,00
	9	**12,93** (0,12)	**1,78** (0,16)	-15,944	1,233	2,0620	-0,1622	0,0129	110,43	21	0,00
	11	**13,05** (0,11)	**1,55** (0,12)	-18,540	1,421	1,7709	-0,1416	0,0114	111,42	22	0,00
	Mean (Fryer)	**13,55** (0,11)	**1,61** (0,04)	-18,069	1,334	1,0508	-0,0729	0,0056			
40T90	2	**12,40** (0,21)	**2,23** (0,32)	-12,228	0,986	3,5341	-0,2641	0,0199	11,67	17	0,82
	3	**12,62** (0,26)	**4,09** (0,66)	-6,779	0,537	1,4140	-0,1033	0,0076	43,36	18	0,00
	5	**12,40** (0,38)	**1,50** (0,44)	-18,138	1,463	30,6534	-2,3574	0,1829	2,84	16	1,00
	9	**13,97** (0,42)	**5,39** (0,74)	-5,699	0,408	0,4798	-0,0381	0,0032	230,5	22	0,00
	Mean (Fryer)	**12,59** (0,18)	**3,08** (0,40)	-9,286	0,737	3,3297	-0,2914	0,0256			
40D	1	**9,92** (0,12)	**2,09** (0,19)	-10,412	1,050	1,0027	-0,0952	0,0092	333,17	21	0,00
	3	**10,04** (0,17)	**3,01** (0,27)	-7,321	0,729	0,5021	-0,0450	0,0041	1294,51	21	0,00
	4	**10,43** (0,13)	**3,72** (0,29)	-6,166	0,591	0,2522	-0,0225	0,0021	852,03	23	0,00
	5	**10,06** (0,10)	**1,62** (0,17)	-13,621	1,353	1,9849	-0,2003	0,0204	1960,99	24	0,00
	6	**10,53** (0,11)	**2,78** (0,20)	-8,338	0,792	0,3637	-0,0337	0,0032	473,44	21	0,00
	Mean (Fryer)	**10,18** (0,05)	**2,59** (0,16)	-9,047	0,889	1,5366	-0,1577	0,0162			
40S	1	**14,21** (0,21)	**1,58** (0,15)	-19,755	1,390	2,5960	-0,2053	0,0165	225,59	23	0,00
	6	**15,88** (0,16)	**2,01** (0,16)	-17,335	1,092	1,5965	-0,1088	0,0075	211,23	25	0,00
	7	**16,14** (0,21)	**1,64** (0,21)	-21,644	1,341	6,3561	-0,4239	0,0284	970,37	24	0,00
	8	**15,85** (0,21)	**2,70** (0,29)	-12,901	0,814	1,6592	-0,1127	0,0077	259,68	19	0,00
	9	**16,11** (0,10)	**1,20** (0,10)	-29,417	1,826	5,2799	-0,3427	0,0223	309,16	23	0,00
	10	**15,83** (0,08)	**1,94** (0,09)	-17,945	1,134	0,6669	-0,0449	0,0030	247,35	24	0,00
	Mean (Fryer)	**15,74** (0,29)	**1,81** (0,08)	-19,388	1,232	4,8587	-0,2938	0,0181			

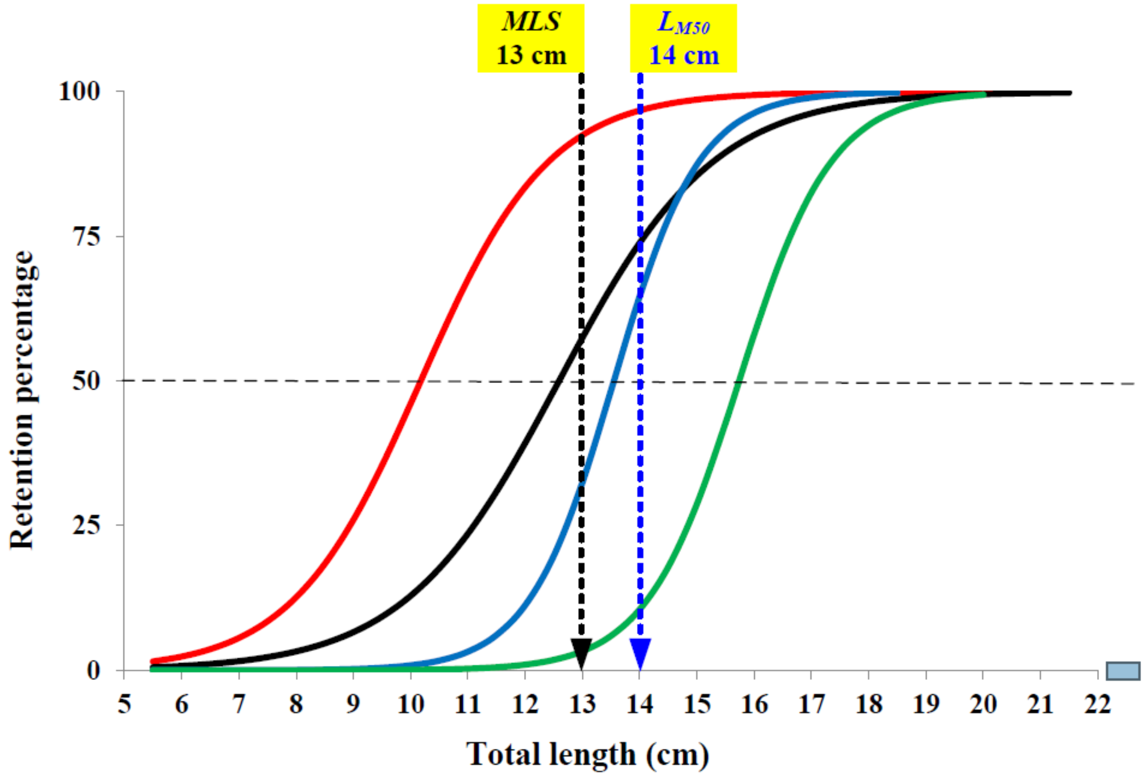


Figure 120. Mean selection curves in the all codend for whiting (red line-40D, black line-40T90, blue line-36S and green line-40S)

Management scenario's

Economic analysis of the new management measures and evaluating the management strategy for beam trawl fisheries

The study examined the economic and ecological effects of new management measures such as traditional (GT1), with sledge and steel wire (GT2), traditional without steel wire (GT3) and with sledge and without steel wire (GT4) and evaluated the economic and ecological consequences of alternative management strategy.

Data and methods

The study was conducted in Samsun (40o 50'- 41o 51' N latitudes and 37o 08'-34o 25' E longitudes), a province in northern Turkey. There have been 154 active vessels for snail. We used the variables of quantity of snail, quantity of discards, fuel consumption and some economic characteristics of vessel and fleet by using data generated from the trial conducted the Samsun shelf area.

The data collected by using face to face deep interview were also used. The brief results of the trial conducted in Samsun and some economic characteristics of fleet were presented in Table 53 and Table 54, respectively.

Eco-efficiency scores was used when examining the economic and ecological effects of new management measures such as traditional (GT1), with sledge and steel wire (GT2), traditional without steel wire (GT3) and with sledge and without steel wire (GT2).

Data envelopment analysis (DEA) was performed to estimate the scores of eco-efficiency of alternative management measures. DEA is one of the most popular methods for estimating the best practice production frontier and provides an analytical tool for determining efficient and inefficient behavior. Since DEA is less data-demanding, works with small sample sizes, and does not require knowledge of the proper functional form of the frontier, error, and inefficiency structures, it has been preferred over stochastic frontier analysis (SFA). Stochastic models such as SFA necessitate a large sample size to make reliable estimations (Coelli et al., 2005).

Efficiency is defined in a relative sense as the distance between observed input–output combinations and the best-practice frontier. The best-practice frontier represents the maximum output attainable from each input level. The Farrell output-orientated measure of efficiency was used as a measure of eco- efficiencies. The Farrell measure equals 1 for efficient measures, and then decreases with inefficiency (Farrell, 1957).

Based on the suggestion by Charnes et al. (1978), we constructed DEA models for management measures assuming that each decision making unit (DMU), which is alternative management measures in the research, quantity of snail, quantity of discards fish and other discards (yi) using the fuel inputs under the assumption of all the other inputs was fixed (xi). Using piecewise technology, an output-oriented measure of efficiency can be estimated by using linear programming.

$$
\begin{aligned}
& Minimize_{\theta,\lambda}\ \theta \\
& Subject\ to\ -y_i + Y\lambda \geq 0 \\
& \theta x_i - X\lambda \geq 0 \\
& \lambda \geq 0
\end{aligned}
$$

where□is the eco-efficiency score and the vector □is an N □vector of weights which defines the linear combination of the peers of the i -th management measures. When evaluating the economic and ecological consequences of alternative management strategies, scenario based partial budget analysis were used.

Partial budgeting is a method of organizing experimental data and information about the cost and benefits from some change in the technologies being used. The aim is to estimate the change that will occur in decision making unit profit or loss from some change in the decision making unit plan (Boehlje and Eidman, 1984). Partial budgets do not calculate the total income and expenses for each of the alternative plan but list only those items of income and expense that change. They measure changes in income and returns to limited-resources, provide a limited assessment of risk and, through sensitivity analysis, suggest a range of prices or costs at which a technology becomes profitable (Mutsaers et al, 1986).

The economic and ecological effects of new management measures

The brief results of the eco-efficiency analysis for alternative management measures were depicted in Table 54.The quantity of snail, discards and fuel reduction were given Table 55 and Table 56. It was clear based on the results of efficiency analysis, economically and environmentally the best management measures were GT3.

If the fishermen followed the research recommendation, they would get 33 kg of snail, approximately 8 kg of discard and 0,864 kg of discard fish per hour. It meant that this measures reduced the fuel consumption by 5,46%, discard fish by 76,44% and other discards by 55,90% comparing to traditional one (GT1).

However, fishermen scarified snail by 9,12%. The GT4 was the worst management measures. In spite of the fact that this measure was the most suitable management measures environmentally, it was not economically efficient management measures due to presence of high level snail reduction.

On the other hand, GT2 was the second order management measures. This measure was economically good option. It was better than GT3 in economic sense due to lesser snail reduction. However, GT2 was not good option in environment sense due to low level of discard reduction.

The effects of conversion on fishermen profitability

The results of the partial budget analysis were depicted in Table 57, Table 58 and Table 59. Results of the scenario based partial budget analysis revealed that ecologically and economically best option was the GT3. In first scenario, the traditional measure (GT1) was compared with the traditional without steel wire (GT3). This conversion was economically and environmentally efficient and economically viable.

Net change in profit of fishermen was €1850 per season in this scenario. Fishermen would have to scarify €1410 per season for ecological sustainability. The value of environmentally sustainability for fishermen was €3260 per season. Cost-Benefit ratio for environmentally sustainable fishing was 2,31. There is no refunding risk for conversion investment (Table 57).

The management strategy evaluation

Results of the economic analysis showed that this conversion (GT1 to GT3) was economically and environmentally efficient. Net change in profit of fishermen would be €50725 per season if the conversion completely dispersed the Samsun. Fishermen would have to scarify €210'669 per season for ecological sustainability. The value of environmentally sustainability for fishermen was €261'394 per season. Since the cost-benefit ratio for environmentally sustainable fishing was 1,24, this conversion would be economically and environmentally suitable in Samsun Shelf Area (Table 60).

Economic analysis of the new management measures and evaluating the management strategy for bottom trawl fisheries

The study examined the economic and ecological effects of new management measures such as traditional (40D), with square by 40 mm (40S), with square by 36 mm (36S), and with transformed 90 degrees by 40 mm (40T90) for both whiting and red mullet and evaluated the economic and ecological consequences of alternative management strategy.

Data and methods

There have been 129 active vessels for both whiting and red mullet. We used the variables of quantity of whiting, quantity of red mullet, quantity of discards, and some economic characteristics of vessel and fleet by using data generated from the trial conducted the Samsun shelf area. The data collected by using face to face deep interview were also used. The brief results of the trial conducted in Samsun for both whiting and red mullet and some economic characteristics of fleet were presented in Table 61, Table 62 and Table 63, respectively.

Eco-efficiency scores were used when examining the economic and ecological effects of new management measures such as traditional (40D), with square by 40 mm (40S), with square by 36 mm (36S), and with transformed by 90 degrees and by 40 mm (40T90) for both whiting and red mullets. Data envelopment analysis (DEA) was performed to estimate the scores of eco-efficiency of alternative management measures.

DEA is one of the most popular methods for estimating the best practice production frontier and provides an analytical tool for determining efficient and inefficient behavior. Since DEA is less data-demanding, works with small sample sizes, and does not require knowledge of the proper functional form of the frontier, error, and inefficiency structures, it has been preferred over stochastic frontier analysis (SFA).

Stochastic models such as SFA necessitate a large sample size to make reliable estimations (Coelli et al., 2005). Efficiency is defined in a relative sense as the distance between observed input–output combinations and the best-practice frontier. The best-practice frontier represents the maximum output attainable from each input level. The Farrell output-orientated measure of efficiency was used as a measure of eco- efficiencies. The Farrell measure equals 1 for efficient measures, and then decreases with inefficiency (Farrell, 1957).

Based on the suggestion by Charnes et al. (1978), we constructed DEA models for management measures assuming that each decision making unit (DMU), which is alternative management measures in the research, quantity of whiting, or red mullet, quantity of discards fish and L50 value (yi) using the fuel inputs under the assumption of all other inputs was fixed (xi). Using piecewise technology, an output-oriented measure of efficiency can be estimated by using linear programming.

Table 53. The results of the beam trawl trial in Samsun

Management measures	Sea snail catch (kg per hour)	Discard (kg per hour)	Discard fish (kg/ per hour)	Fuel (liter per hour)
GT1	36,310	18,149	3,667	3,48
GT2	36,142	17,361	3,508	3,38
GT3	33,000	8,003	0,864	3,29
GT4	12,000	4,881	0,671	3,19

Table 54. Beam trawl fisheries characteristics of fleet in Samsun

Variables	Mean
The length of the vessel (m)	10,87
Average motor power (HP)	169,50
The number of operation per day	20,00
Average operation time (hour)	0,50
Days in sea (days/year)	117,00
Average crew size (person)	2,00
Total asset (thousand €)	23,13
Quantity of snail captured per day (kg)	1142,00
Quantity of discards per day (kg)	58,00
Average fuel consumption per hour (liter)	10,50
Daily variable cost (€)	273,98
Daily fixed cost (€)	65,15
The price of snail per kg (€)	0,31
Daily revenue (€)	354,02
Net income per day (€)	63,04
Return on asset	0,11

Table 55. The results of the eco-efficiency analysis for alternative management measures

Management measures	Quantity of snail(kg/ per hour)	Discard (kg per hour)	Discard fish (kg/ per hour)	Fuel (liter per hour)	Eco-efficiency score
GT1	36,310	18,149	3,667	3,48	0,810
GT2	36,142	17,361	3,508	3,38	0,818
GT3	33,000	8,003	0,864	3,29	1,000
GT4	12,000	4,881	0,671	3,19	0,890

Table 56. The quantity of snail, discards and fuel reduction associated with alternative management measures

Management measures	Quantity of snail reduction		Discard reduction		Discard fish reduction		Fuel reduction		Eco-efficiency score
	kg	%	kg	%	kg	%	kg	%	
GT2	0,168	0,46	0,788	4,34	0,159	4,34	0,10	2,87	0,818
GT3	**3,310**	**9,12**	**10,146**	**55,90**	**2,803**	**76,44**	**0,19**	**5,46**	1,000
GT4	24,310	66,95	12,268	67,60	2,996	81,70	0,29	8,33	0,890

Table 57. Partial budgeting for conversion from traditional (GT1) to the traditional without steel wire (GT3) (For 2 vessels per season)

Positive impacts	*1000 TRY	*1000 Euro	Negative impacts	*1000TRY	*1000 Euro
Increased incomes			***Increased costs***		
Reduction in discard fish	8,53	2,55	Depreciation + interest cost [1]	-	-
Reduction in other discards	2,37	0,71			
Reduced costs			***Reduced incomes***		
Fuel reduction	3,42	1,02	Reduction in sea snail	8,13	2,43
			Interest loss	-	-
Total positive impacts	14,32	4,28	***Total negative impacts***	8,13	2,43

Table 58. Partial budgeting for conversion from traditional (GT1) to sledge and without steel wire (GT4) (For 2 vessels per season)

Positive impacts	Bin TL	1000 Euro	Negative impacts	Bin TL	1000 Euro
Increased incomes			***Increased costs***		
Reduction in discard fish	15,16	4,53	Depreciation + interest cost [1]	0,64	0,19
Reduction in other discards	2,37	0,71			
Reduced costs			***Reduced incomes***		
Fuel reduction	5,22	1,56	Reduction in sea snail	59,73	17,83
			Interest loss	0,05	0,01
Total positive impacts	22,75	6,80	***Total negative impacts***	60,42	18,03

Table 59. Partial budgeting for conversion from traditional (GT1) to with sledge and steel wire (GT2), (For 2 vessel per season)

Positive impacts	1000 TL	Euro	Negative impacts	Bin TL	Euro
Increased incomes			***Increased costs***		
Reduction in discard fish	1,12	0,33	Depreciation + interest cost [1]	1,49	0,44
Reduction in other discards	1,84	0,55			
Reduced costs			***Reduced incomes***		
Fuel reduction	1,80	0,54	Reduction in sea snail	0,41	0,12
			Interest loss	0,06	0,02
Total positive impacts	4,76	1,42	***Total negative impacts***	1,96	0,58

Table 60. Partial budgeting for conversion from traditional (GT1) to the traditional without steel wire (GT3) (For fleet per season)

Positive impacts	*1000 TL	1000 Euro	Negative impacts	1000 TL	1000 Euro
Increased incomes			***Increased costs***		
Reduction in discard fish	875,67	261,39	Depreciation + interest cost [1]	102,41	30,57
Reduced costs			***Reduced incomes***		
Fuel reduction	263,41	78,63	Reduction in sea snail	626,22	186,93
Support payment reduction	127,06	37,93	Interest loss	8,59	2,56
Total positive impacts	1266,14	377,95	***Total negative impacts***	1096,21	220,06

[1]*The cost of depreciation and interest for conversion was calculated by using the formula of "(amortization factor) (investment - Salvage value) + (Salvage value) (opportunity cost of Money)"*

Table 61. The changes in quantity of whiting and discards associated with alternative management measures

Management measures	Total captured whiting (kg)	Discards (kg)	L50 value
36S	42,6	3,4	13,55
40T90	38,1	8	12,59
40D	46,7	16,5	10,18
40S	14,6	0,9	15,74

Table 62. The changes in quantity of red mullet and discards associated with alternative management measures

Management measures	Total captured red mullet (kg)	Discards (kg)	L50 value
36S	36,310	18,149	10,59
40T90	36,142	17,361	10,29
40D	33,000	8,003	9,79
40S	12,000	4,881	11,89

Table 63. Fishery characteristics of fleet for whiting and red mullet in Samsun

Variables	**Whiting (Mean)**	**Red mullet (Mean)**
The length of the vessel (m)	20,5	20,5
Average motor power (HP)	483,5	483,5
The number of operation per day	5	5
Average operation time (hour)	7,5	7,5
Days in sea (days/year)	129	129
Average crew size (person)	5	5
Total asset (thousand €)	319,06	319,06
Quantity of captured per day (kg)	350,25	115,50
Quantity of discards per day (kg)	123,75	42,75
Average fuel consumption per hour (liter)	24,80	24,80
Daily variable cost (€)	268,96	268,96
Daily fixed cost (€)	100,84	100,84
The price per kg (€)	1,19	2,35
Daily revenue (€)	417,23	271,55
Net income per day (€)	47,43	-98,25
Return on asset (%)	1,93	-

$$Minimize_{\theta,\lambda}\ \theta$$
$$Subject\ to\ -y_i + Y\lambda \geq 0$$
$$\theta x_i - X\lambda \geq 0$$
$$\lambda \geq 0$$

Where θ is the eco-efficiency score and the vector λ is an N X 1 vector of weights which defines the linear combination of the peers of the i -th management measures. When evaluating the economic and ecological consequences of alternative management strategies, scenario based partial budget analysis were used. Partial budgeting is a method of organizing experimental data and information about the cost and benefits from some change in the technologies being used.

The aim is to estimate the change that will occur in decision making unit profit or loss from some change in the decision making unit plan (Boehlje and Eidman, 1984). Partial budgets do not calculate the total income and expenses for each of the alternative plan but list only those items of income and expense that change. They measure changes in income and returns to limited-resources, provide a limited assessment of risk and, through sensitivity analysis, suggest a range of prices or costs at which a technology becomes profitable (Mutsaers et al, 1986).

The economic and ecological effects of new management measures

The brief results of the eco-efficiency analysis associated with alternative management measures for whiting and red mullet were depicted in Table 64 and Table 65.The chancing quantity of whiting, red mullet, and discards were given Table 66 and Table 67. It was clear based on the results of efficiency analysis, economically and environmentally the best management measure for whiting and red mullet was40S.

When focusing on the whiting, if the fishermen followed the research recommendation, they would get 14,6 kg of whiting, approximately 0,9 kg of discard fish per hour. It meant that this measures reduced discard fish by 94,54% and increased the L50 value by 54,62% comparing to traditional one (40D). However, fishermen scarified from whiting by 68,74%.

When glancing at the red mullet, if the fishermen transformed from 49D to 40S, they would get 12 kg of red mullet, approximately 4,88 kg of discard fish per hour, indicating the reduction in discard fish by 39,01% and increased the L50 value by 21,45% comparing to traditional one (40D). However, fishermen scarified from red mullet by 63,64 %.The 40T90 was the worst management measures.

In spite of the fact that this measures was the moderately suitable management measures economically, but it was not environmentally efficient management measures due to low level discards reduction. On the other hand, 36S was the second order management measures.

This measure was economically good option. It was better than 40S in economic sense due to lesser whiting reduction in whiting and increasing in red mullet. However, 36S was not good option in environment sense due to increase in discard for red mullet.

The effects of conversion on fishermen profitability

The results of the partial budget analysis were depicted in Table Table 68, Table 69, Table 70 and Table 71. Results of the scenario based partial budget analysis revealed that ecologically and economically best option was the 40S.In first scenario, the traditional measure (40D) was compared with the square by 40 mm (40S) for whiting and red mullet, individually. This conversion was economically and environmentally efficient and economically viable for whiting. Net change in profit of fishermen was €17626 per season in this scenario.

Fishermen would have to scarify €35610 per season for ecological sustainability. The value of environmentally sustainability for fishermen was €53230 per season. Cost-Benefit ratio for environmentally sustainable fishing was 1,49. In addition, changes in selectiveness length was 54,62%. There is no refunding risk for conversion investment. However, the case was the reverse for red mullet. The conversion from 40D to 40S was economically inefficient and not economically viable, but environmentally efficient for red mullet.

There was a negative change in profit of fishermen by €27592 per season in this scenario. Fishermen would have to scarify €45980 per season for ecological sustainability. The value of environmentally sustainability for fishermen was €61940 per season. Cost-Benefit ratio for environmentally sustainable fishing was 0,40. Regarding the L50 value, changes in selectiveness length was 21,45% for red mullet (Table 69).

In the second scenario, the traditional measure (40D) was compared with square 36 mm (36S). Regarding whiting, this conversion was economically viable due to increase in net profit by $113330 per season. However, ecologically was lesser efficient than comparing to 40S even if it had lower fishermen sacrifice due to lower value of environmentally sustainability and changes in L50 value.

Cost-Benefit ratio for environmentally sustainable fishing was higher than 1 (Table 70). When focusing on the red mullet, the case was totally different. It was clear based on the results of economic analysis that this conversion was not economically and environmentally efficient due to negative changes in net profit and discards increase. Net change in profit of fishermen was negative (€42009) per season in this scenario.

Fishermen would have no scarify and the value of environmentally sustainability for fishermen was zero. In addition, the changes in selectiveness length (8,17%) was the unsatisfactory level comparing to 40S (33,10%) (Table 71).

In the third scenario, the traditional measure (40D) was 90 degree rotated by 40 mm (40T90). This conversion was economically viable for whiting. Net change in profit of fishermen was €30790 per season in this scenario. Fishermen would have to scarify €9539 per season for ecological sustainability. However, the value of environmentally sustainability for fishermen was €18760 per season.

Therefore this option was economically efficient, but ecologically lesser efficient than that of 40S (Table 72). Regarding red mullet, the reverse was the case. Conversion from 40D to 40T90 was economically and environmentally inefficient due to negative change in net profit (€38548), discards increase (9,358 kg) and lower level of increase in selectiveness length (5,11%) (Table 73).

The management strategy evaluation

Results of the economic analysis showed that this conversion was economically inefficient, but environmentally efficient under the assumption of catch pattern were %70 whiting and %30 red mullet. Net change in profit of fishermen would be €0,9431 million per season if the conversion completely dispersed the Samsun. Fishermen would have to scarify €6,92 million per season for ecological sustainability.

The value of environmentally sustainability for fishermen was €5,97 million per season. Since the cost-benefit ratio for environmentally sustainable fishing was 0,84, this conversion would be environmentally suitable in Samsun, but there is in need of economically supporting the fishermen (Table 68).

Table 64. The results of the eco-efficiency analysis for alternative management measures for whiting

Management measures	Total captured whiting (kg)	Discards (kg)	L50 value	TE
36S	42,6	3,4	13,55	0,772
40T90	38,1	8	12,59	0,294
40D	46,7	16,5	10,18	0,174
40S	**14,6**	**0,9**	**15,74**	**1,000**

Table 65. The chancing quantity of whiting and discards, and eco-efficiency scores associated with alternative management measures

Management measures	Changing in whiting quantity		Changing in discard		Changing in L50 value		Eco-efficiency score
	kg	%	kg	%	cm	%	
36S	-4,1	-8,78	-13,1	-79,39	+3,37	+33,10	0,772
40T90	-8,6	-18,42	-8,5	-51,51	+2,41	+23,67	0,294
40S	**-32,1**	**-68,74**	**-15,6**	**-94,54**	**+5,56**	**+54,62**	**1,000**

Table 66. The results of the eco-efficiency analysis for alternative management measures for red mullet

Management measures	Total captured red mullet (kg)	Discards (kg)	L50 value	TE
36S	36,310	18,149	10,59	0,365
40T90	36,142	17,361	10,29	0,179
40D	33,000	8,003	9,79	0,211
40S	12,000	4,881	11,89	1,000

Table 67. The chancing quantity of red mullet and discards, and eco-efficiency scores associated with alternative management measures

Management measures	Changing in red mullet quantity		Changing in discard		Changing in L50 value		Eco-efficiency score
	Kg	%	kg	%	cm	%	
36S	+3,31	+10,03	+10,146	+130,7	+0,8	+8,17	0,365
40T90	+3,142	+9,52	+9,358	+116,93	+0,5	+5,11	0,179
40S	**-21,00**	**-63,64**	**-3,122**	**-39,01**	**+2,1**	**+21,45**	**1,000**

Table 68. Partial budgeting for conversion from traditional (40D) to square by 40 mm (40S) for whiting, (For 1 vessel per season)

Positive impacts	Bin TL	1000 Euro	Negative impacts	Bin TL	1000 Euro
Increased incomes			***Increased costs***		
Reduction in discard fish	177,80	53,23	Depreciation + interest cost [1]	-	-
Reduced costs			***Reduced incomes***		
			Reduction in whiting	118,93	35,61
			Interest loss	-	-
Total positive impacts	177,80	53,23	***Total negative impacts***	118,93	35,61

Table 69. Partial budgeting for conversion from traditional (40D) to square by 40 mm (40S) for red mullet, (For 1 vessel per season)

Positive impacts	Bin TL	1000 Euro	Negative impacts	Bin TL	1000 Euro
Increased incomes			***Increased costs***		
Reduction in discard fish	61,44	18,40	Depreciation + interest cost [1]	-	-
Reduced costs			***Reduced incomes***		
			Reduction in red mullet	153,56	45,98
			Interest loss	-	-
Total positive impacts	61,44	18,40	***Total negative impacts***	153,56	45,98

Table 70. Partial budgeting for conversion from traditional (40D) to square by 36 mm (36S) for whiting (For 1 vessel per season)

Positive impacts	Bin TL	1000 Euro	Negative impacts	Bin TL	1000 Euro
Increased incomes			***Increased costs***		
Reduction in discard fish	128,52	38,48	Depreciation + interest cost [1]	-	-
Reduced costs			***Reduced incomes***		
			Reduction in whiting	15,19	4,55
			Interest loss	-	-
Total positive impacts	128,52	38,48	***Total negative impacts***	15,19	4,55

Table 71. Partial budgeting for conversion from traditional (40D) to square by 36 mm (36S) for red mullet (For 1 vessel per season)

Positive impacts	*1000 TL	1000 Euro	Negative impacts	Bin TL	1000 Euro
Increased incomes			***Increased costs***		
Increase in red mullet	24,20	7,25	Depreciation + interest cost [1]	-	-
			Increase in discards	164,51	49,25
Reduced costs			***Reduced incomes***		
			Interest loss	-	
Total positive impacts	24,20	7,25	***Total negative impacts***	164,51	49,25

Table 72. Partial budgeting for conversion from traditional (40D) to with transformed 90 degree by 40 mm for whiting (For 1 vessel per season)

Positive impacts	*1000 TL	*1000 Euro	Negative impacts	*1000 TRY	*1000 Euro
Increased incomes			***Increased costs***		
Reduction in discard fish	62,65	18,76	Depreciation + interest cost [1]	-	-
Reduced costs			***Reduced incomes***		
			Reduction in whiting	31,86	9,54
			Interest loss	-	-
Total positive impacts	62,65	18,76	***Total negative impacts***	31,86	9,54

Table 73. Partial budgeting for conversion from traditional (40D) to with transformed 90 degree by 40 mm for red mullet (For 1 vessel per season)

Positive impacts	*1000 TRY	*1000 Euro	Negative impacts	*1000 TRY	*1000 Euro
Increased incomes			***Increased costs***		
Increase in red mullet	22,98	6,88	Depreciation + interest cost [1]	-	-
			Increase in discards	151,73	45,43
Reduced costs			***Reduced incomes***		
			Interest loss	-	
Total positive impacts	22,98	6,88	***Total negative impacts***	151,73	45,43

Table 74. Partial budgeting for conversion from traditional (40D) to square by 40 mm (40S) (For fleet per season) (assuming the catch pattern was %70 whiting and %30 red mullet)

Positive impacts	*million TRY	*million Euro	Negative impacts	*million TL	*million Euro
Increased incomes			***Increased costs***		
Reduction in discard fish	19,95	5,97	Depreciation + interest cost [1]	-	-
Reduced costs			***Reduced incomes***		
			Reduction in whiting	23,10	6,92
			Interest loss	-	-
Total positive impacts	19,95	5,97	***Total negative impacts***	23,10	6,92

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ANNEXES

NORTH SEA

Appendix A: Economic performance of a transition to pulse trawling: two case studies in the North Sea flatfish fishery

Katell G. Hamon (Wageningen Economic Research), Katrien Verlé (ILVO)

Introduction

Bottom contact gears are controversial due to their impact on the sea bottom and their lack of selectivity (Løkkeborg, 2005). Scientists, NGOs and managers have sometimes pushed for alternative techniques, but a requirement for an alternative gear to be picked up is that it must be economically viable. In EU FP7 project BENTHIS, a set of alternative gears have been tested in different regions. To assess the economic performance of the alternative/innovative gears, we performed a simple static economic analysis to investigate the impact of the introduction of these gears on the economic performance of the fleets. In the North Sea case study, we focus on the beam trawlers for flatfish. Since the late 2000's and the increase of the fuel price, the fishery sector has actively sought alternatives to traditional beam trawlers. Furthermore, there exists a broad series of possible measures to improve selectivity and reduce the number of unwanted species and undersized fish.

These measures are often developed by the industry itself or in science-industry partnerships. Measures such as escape panels, lighter netting, replacement of the traditional beam with more hydrodynamic structures (e.g., *sumwing*), replacement of the trawl heads with rollers (e.g., *ecoroll beam*) have proven successful in reducing bycatch, fuel consumption or bottom impact (or a combination of these) (Depestele et al., 2007; Polet et al., 2010; Poos et al., 2013). The sumwing technique has been introduced in the Dutch and Belgian fisheries. Furthermore, the Dutch fishery has been experimenting with electric fishing by using a "pulse trawl". Here the heavy tickler chains or chain mats are replaced by lightweight electrodes. This alternative stimulation is based on producing a low energetic electric pulse field at the seabed that either startles shrimp or induces a cramp reaction in flatfish (Verschueren et al. 2014).

If applied correctly, there is less intense seafloor contact and hence less disturbance of the benthic ecosystem and lower fuel usage. Preliminary studies showed high economic potential and evidence of ecological advantages over traditional trawling methods (Renders et al., 2011, Soetaert et al., 2015). This technique has not been adopted in Belgium.

In this analysis we look at the situation of selected fleets in 2012 and estimate the effort distribution based on economic profitability and evaluate the impact of fuel price on the metier choice. In the case of Belgium, the possible introduction of the pulse was explored.

Material and methods

Dutch Data

The Dutch data was extracted from several sources:

- Panel data: detailed catch, effort, costs and earnings data at the fishing trip level for a subset of the fleet. This dataset is created from the data collected by Wageningen Economic Research from *panel* fishers.
- Logbook data: containing the catch and effort of all Dutch vessels
- Fleet registry: containing the characteristics of all active vessels
- Regulation data: days at sea limitation for specific gears (from the Informatiebulletin, Ministry from Economic affairs), species specific quotas (after trade from agrimatie.nl)

For the analysis the fleet targeting mostly flatfish was selected. The segmentation used for EU data collection framework (DCF) was also used here and the fleet TBB_40XX of vessels larger than 40m mainly using beam trawlers (or a variant of) was selected. In 2012, this fleet represented 40% of the total effort of the Dutch fleet (in kWdays), accounting for 11% of weight and 31% of value of landings (the large pelagic trawlers represent 75% of the volume of landings) and 23% of employment in the Dutch fisheries (STECF, 2016).

Because the transition to pulse trawl started in 2009 and that by 2012 hardly any traditional beam trawlers were left in the panel, we calculated catch, fuel consumption and costs per unit of effort per metier on the average of 2010-2012 data. The number of vessel, effort and fish and fuel prices were used as of 2012.

Belgian Data

The Belgian data was extracted from several sources:

- Data collected for the Data Collection Framework: costs and earnings data at the vessel level for the fleet.
- Logbook data: containing the catch and effort of all Belgian vessels
- Fleet registry: containing the characteristics of all active vessels
- Regulation data: days at sea limitation for specific gears, species specific quotas (from *De Belgische zeevisserij: Aanvoer en besomming: Vloot, quota, vangsten, visserijmethoden en activiteit*, Flemish government, department of agriculture and fisheries), yearly publication
- Dutch panel data to introduce the pulse trawl

For this analysis, only observations of beam trawlers with mesh sizes between 70 and 99 mm and a vessel length between 24 and 40 m were considered (TBB_DEF_70-99). These vessels are the larger beam trawlers in the Belgian fleet. Belgium does not have any vessels of more than 40 m. In 2012, this fleet represented 41% of the total active Belgian fleet, accounting for 70% of the weight and value of landings and 55% of employment (Tessens & Velghe, 2013).

Method

The data was used as an input for the Senseco model (Merzéreaud et al. 2014, Deliverable 5.2, this project). The model works with data on effort, catch composition per metier, prices and variable and fixed costs. Then using the GUI developed in BENTHIS, the user can change parameters (for example effort allocation in each metier), look at how it impacts the fleets and export the results. One option to change the effort allocation in the model is to use the *Report2* function:

The total effort is also kept constant at initial level and we consider a situation where a redistribution of effort per métier is based on a weighting of tradition (original distribution) and profit. The weights are defined using one parameter α, between 0 and 1, (1 - α) is the weight of the initial distribution of effort by métier on the one hand, and α the weight of the profit distribution generated by métier (denoted profit as in Marchal et al. 2011). Everything is relative to the total effort. One can thus formalize the effort by métier using the following equation:

$$E_{m_i} = \left[\alpha \frac{Profit_{m_i}}{\sum_i Profit_{m_i}} + (1-\alpha)\frac{Eini_{m_i}}{\sum_i Eini_{m_i}}\right] \times Etot, \forall i \qquad 1$$

This report is potentially controlled with the alpha variable on the right side of the sheet. Several expressions of profit per métier $Profit_m$ are then possible: in the current version of the tool, a rest to be shared by unit of effort was considered, dynamic towards parameters modification.

Introducing a new gear (which had 0 effort before) was currently not possible when using the effort reporting function "report2" in Senseco. Because of the way the $Profit_m$ variable was calculated, the model necessitated to have initial effort in each metier to allocate any effort to it. Initial effort of 0, remained 0.

So we recoded the function externally for the North Sea case where we wanted to introduce the pulse metier in the Belgian fleet. Instead of using the rest to be shared by unit of effort we used the short term profit as an indicator of profit:

$$Profit_m = RTBS_m(1 - cshr) - vCosts_m \qquad 2$$

Where $RTBS_m$ is the theoretical rest to be shared per unit of effort per metier. For the Belgian fleet it corresponds to the sum of value of landings per day for each metier. For the Dutch one it corresponds to the value of landings per day for each metier minus the fuel cost per day. $cshr$ is the crew share i.e. the percentage of the rest to be shared used as wages. Belgian $cshr$ is 29.5% and Dutch $cshr$ is 33.2%. $vCosts_m$ represents the rest of the variable costs not taken into account in the calculation of $RTBS_m$ expressed per day for each metier. A negative effort as a result of a negative profit for a given metier was prevented and resulted in 0 days at sea, under the assumption that the metier would not be used if it generated a loss.

This function can take into account different fuel prices and it is possible to set effort restriction on one or several metiers. If an effort limitation is reached, the extra effort is reallocated to the non-restricted metiers following the same distribution function as in equation 1. The newly allocated effort were then manually input into the model to generate the scenarios. A number of assumptions and choices were made to generate the needed data. The average number of days at sea for each metier was calculated on the fleet level, that is, it was assumed that all vessels used all the metiers. One should therefore look at the fleet as an average fleet. The base fuel price was 0.66 euro/l.

To introduce the "pulse trawl" in the selected Belgian fleet, factors were calculated based on data from 2010-2012 for Dutch vessels of over 40m. In the Netherlands, fuel consumption, gear costs and catch composition were different when using the pulse compared to the traditional beam trawlers or compared to the sumwing.

To take into account the fact that sumwing was introduced in the Belgian fleet in 2010, a percentage of time spent using the sumwing in 2012 was allocated to each vessel within the selected fleet. This was based on expert knowledge. This lead to a weighted factor that attempts to take into account the fact that the Belgian fleet does not purely consist of traditional beam trawlers.

The model required a number of variables by metier and fishing effort. However, for Belgium not all variables were available at a metier level and only available yearly on a vessel level (for e.g. costs). In this case, variables were allocated equally across metiers. For example, it was assumed that the number of crew members remained constant, regardless of the metier. In general this is a plausible assumption in the Belgian case. However, this is not likely to be true for fuel consumption. It is likely that while fishing, certain gears will consume less fuel per day at sea than others. Unfortunately, the data did not allow to make this distinction.

Scenario description

Vessel owners are limited by the yearly quota of their target species as well as by effort regulations (e.g. under the cod management plan). Therefore, different scenarios were explored to take into account some of these limitations. The Senseco model allow to set effort allocation to two different extremes: either very conservative (alpha =0) or either by fishing as much as you can to achieve maximum profitability (alpha=1).

Fuel price is furthermore an important factor for these fisheries. Fuel prices are volatile and it is expected that the high variability affects decisions made by the fleet. Therefore, scenarios were considered with a low fuel price (0.58 euro/l) and with a high fuel price (0.80 euro/l). The fuel prices were that occurred between 2008 and 2014 are illustrated in Figure 6. The following effort constraints were used to reallocate effort for scenarios 7 and 8. In the Netherlands, an effort restriction for beam trawlers with a mesh size ≥120 mm (BT1) was 999,808 kW*days at sea. With an average vessel power in the selected Dutch fleet of 1560kW and considering the 60 vessels, the limit corresponded to 10 days at sea for each vessel. For Belgium, the authorities decided to use a system of collective use for fishing effort in the areas of the cod recovery plan. Specifically, for vessels of the large-fleet segment (>221 Kw) a maximum of 150 days was set in the North Sea and VIId in 2012.

The following scenarios were explored with Senseco:

1. Status quo scenario based on the data with a traditional effort allocation (alpha =0)
2. Scenario with an effort allocation that aims for economic profitability, that is, fishing to earn as much as possible (alpha =1)
3. Status quo scenario if fuel prices are low
4. Status quo scenario if fuel prices are high
5. Scenario 2. (alpha =1) If fuel prices are low
6. Scenario 2. (alpha =1) If fuel prices are high
7. Same scenario as in 2. (alpha =1), however, it will be explored how effort is constrained by regulation and how this will affect profitability
8. Same scenario as in 7., however, with a high fuel price

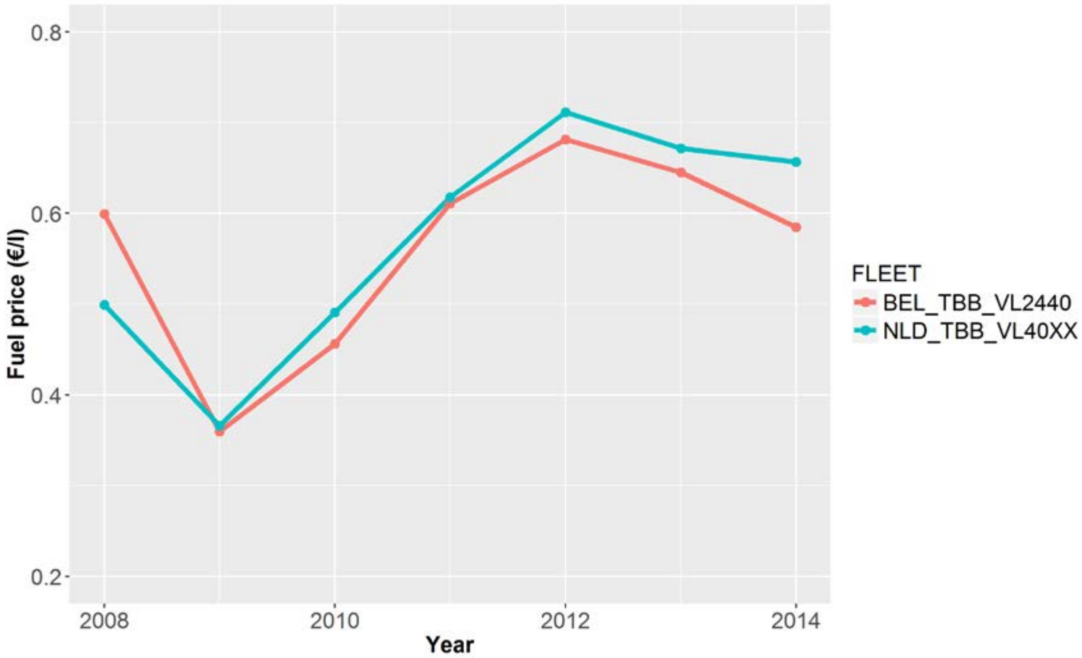

Figure 121. Fuel prices between 2008-2014 for the Belgian beam trawler fleet with a length of 24-40m and for the Dutch beam trawler fleet with a length over 40 m (Data source: STECF 2016).

Results

<u>Dutch case study description</u>

In 2012, the Dutch fleet selected for this study was composed of 60 vessels. Their landings are mainly composed of plaice and sole (Figure 122). Plaice represents the main part of the volume (about 60%) but only 26% of the value of landings while sole represents 19% of the volume and 54% of the value. The main fishing grounds of the fleet are located in the

North Sea and the metiers operated are all types of beam trawlers:

- PUL_70-99_NS : pulse (electric) trawlers with mesh sizes between 70 and 99 mm operating in the North Sea.
- TBB_70-99_NS : traditional beam trawlers with mesh sizes between 70 and 99 mm operating in the North Sea.
- SUM_70-99_NS : beam trawlers with a sumwing with mesh sizes between 70 and 99 mm operating in the North Sea.

- TBB_≥120_NS : traditional (59%) and sumwing (41%) beam trawlers with mesh sizes above 120 mm operating in the North Sea
- OTHER : metier composed of the rest of the activity, mainly traditional(51%) and sumwing (32%) beam trawlers with mesh sizes between 100 and 119 mm operating in the North Sea.

In 2012 the main metier for the fleet was already the pulse trawl, followed by the traditional beam trawl and sumwing (Figure 123). Those three metiers target mainly sole (Figure 124), while the other two metiers with larger mesh sizes target plaice. The value of landings per day of the different metiers range to 7.9k€ for the SUM_70-99_NS and OTHER metiers to 8.8 k€ for the TBB_70-99_NS metier (Figure 124) while the variable costs per day range from 6.1k€ for the OTHER metier to 7.9k€ for TBB_70-99_NS metier (Figure 125). The cost structure of the metiers shows differences in terms of fuel costs (fuelc_f_m), gear costs (gc_f_m) and labour costs (persc_f_m).

The pulse trawl metier, PUL_70-99_NS, has lower fuel costs (41% of variable costs) but higher gear costs (15%) than other metiers. Lower fuel costs have a direct impact on the rest to be shared used to calculate the labour costs, meaning that lower fuel prices lead to higher wages. For the other metiers, the fuel costs represent more than half the operating costs of fishing. The fuel costs of the traditional beam trawl is higher than in any other metier (66% of variable costs), for the SUM_70-99_NS and TBB_≥120_NS fuel costs represent 62% of the variable costs and for the OTHER metier 52%. Change in fuel prices have obviously large impact on the economic performances of this fleet.

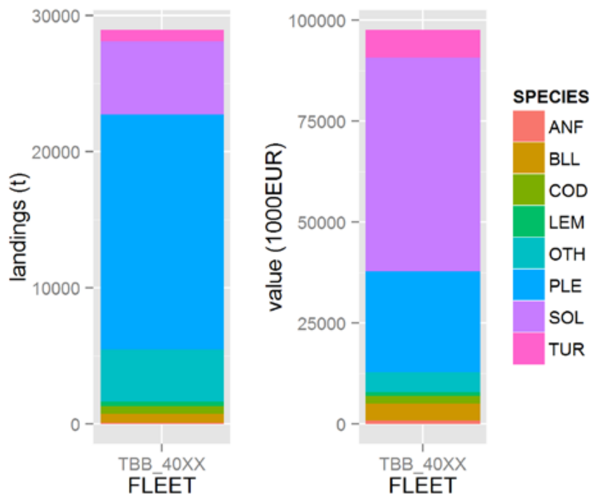

Figure 122. Landings composition for the Dutch TBB 40XX fleet in volume (left) and in value (right).

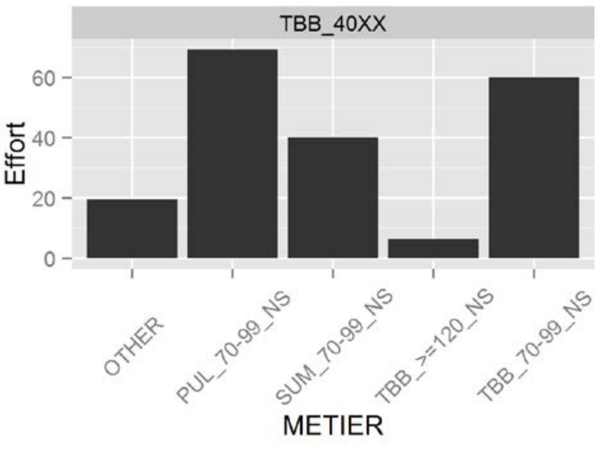

Figure 123. Average effort composition of the Dutch TBB 40XX per metier in days at sea

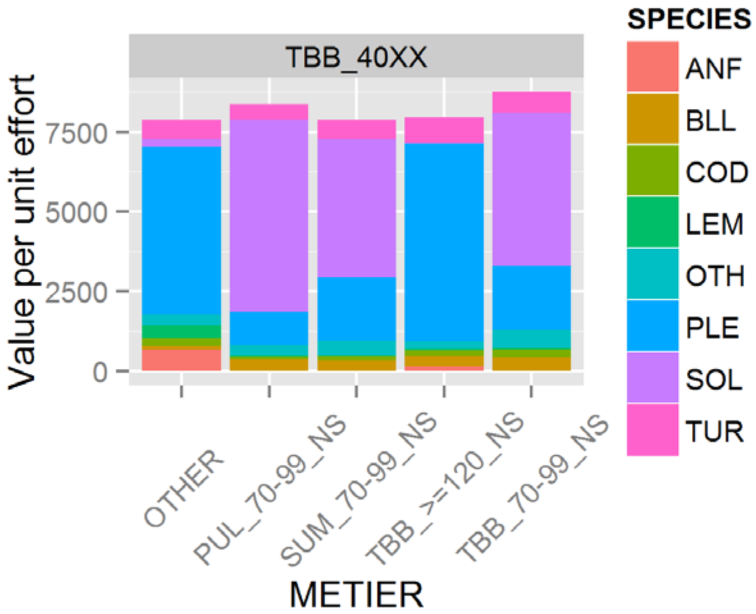

Figure 124. Landings composition in value per metier per day

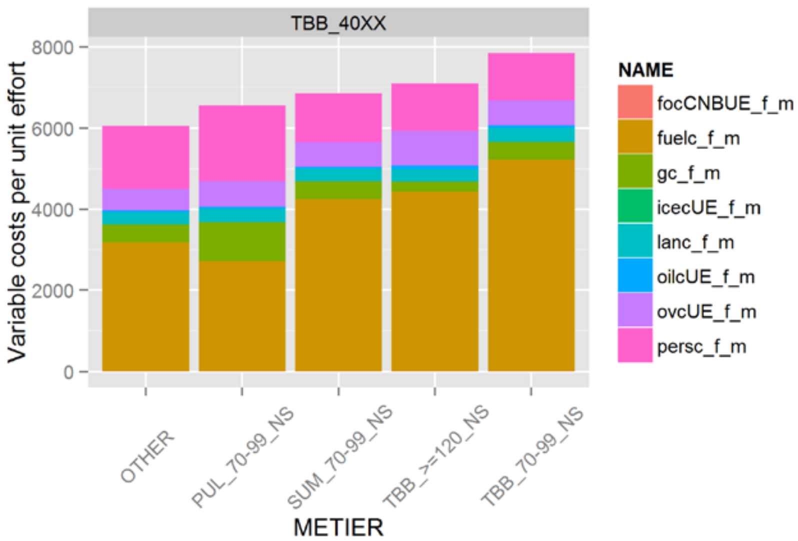

Figure 125 Variable costs per metier.

Belgian Case study description

In 2012, there were 32 vessels in the selected fleet. They mainly targeted sole, the most important species in terms of value of landings. During the year, these vessels also switch to other fishing activities. The most prominent alternative activity involves targeting plaice with beam trawlers with mesh size of more than 120 mm. More rarely, these vessels use otter trawlers targeting sole, plaice, lemon sole and Norway lobster, and seiners targeting cuttlefish, gurnard and surmullet. Overall, the most important species for this fleet in terms of the value of landings other than sole and plaice are turbot, cod, lemon sole, angler fish and brill.

Besides fishing activities in the North Sea, Belgium has fishing rights for sole (and other species) in the English Channel (VIId, VIIe) and the North Atlantic (VIIa, VIIg, VIIk, VIIh, VIIj, VIIIa, VIIIb). These “distant waters” are accessible to the vessels described above (Figure 126). In addition, these vessels are not allowed to fish within 12 nm from the coast (Devogel & Velghe, 2015). For this exercise, beam trawling with a mesh size of 70-99 in the North Sea, the English Channel and the North Atlantic were considered as separate activities or metiers.

The main current metiers within the fleet were identified, taking area into account (North Sea, North Atlantic, Channel). The remaining were grouped in a category others. The metiers considered were:

- TBB_DEF_70-99_NA : traditional beam trawlers with mesh sizes between 70 and 99 mm operating in the North Atlantic (VII and VIII except VIId and VIIe)
- TBB_DEF_70-99_NS : traditional beam trawlers with mesh sizes between 70 and 99 mm operating in the North Sea.
- TBB_DEF_70-99_CH : traditional beam trawlers with mesh sizes between 70 and 99 mm operating in the Channel (VIId and VIIe)
- TBB_DEF_≥120_NS : traditional beam trawlers with mesh sizes above 120 mm operating in the North Sea
- PUL_70-99_NS : pulse (electric) trawlers with mesh sizes between 70 and 99 mm operating in the North Sea.
- Others

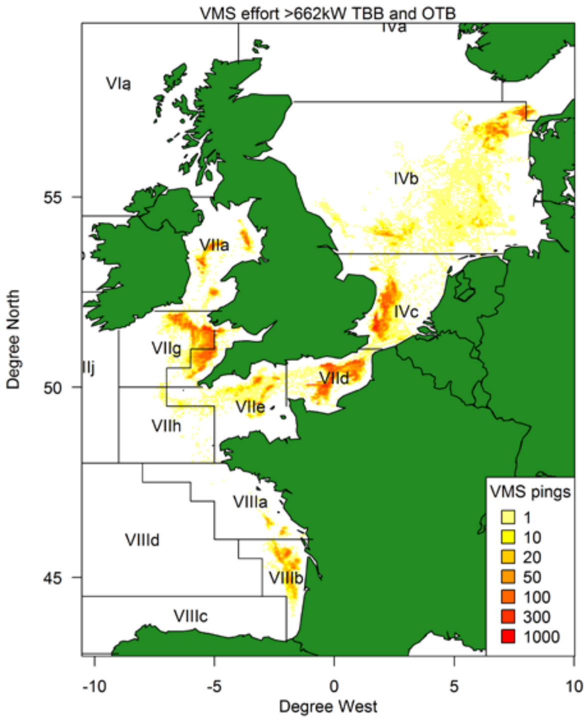

Figure 126. Fishing effort of beam trawlers and otter trawlers (≥ 662 Kw) with a vessel length between 24 and 40m (2009-2015).

Between 2010 and 2012, subsidies were granted for sumwing investments. In the selected fleet, 15/32 vessels applied and received subsidies for sumwing. It is likely that these vessels were at least partly using the sumwing in 2012. Therefore, although the sumwing metier is not appearing in the fleet, it is included in some of the traditional beam trawlers.

Figure 127 depicts the initial effort of these different metiers. The days at sea were calculated as hours at sea divided by 24 hours without rounding up at a trip level. This allowed for comparison with the Netherlands. However, effort constraints set nationally slightly differ. Days at sea under the cod management plan are allocated per trip per 24 hours to the area were the vessel spent most of its time. From 2013 onwards, a maximum of 160 days was set in the North Sea and VIId. Effort restrictions in area VII and VIII (NA) do not seem to be constraining. A long existing national rule in Belgium limits the number of "sea-going days" ("*vaartdagen*") per vessel. A "sea-going day" is any started period of 24 hours of more than 4 hours (meaning that a 5 hour trip is 1 "sea-going day"). In 2012, this limit was set to 265 days for all vessels in the Belgian fleet. This rule allowed to exchange "sea-going days" for catch possibilities except for sole, plaice and cod.

In 2013, this limit was 270 days. This measure does not appear to be constraining in this analyses, however it must be noted that the units of effort are slightly different. The Catch per Unit of effort per metier for the most important species are shown in Figure 128. Plaice, cod and lemon sole are mainly caught with TBB_>=120_NS. This metier receives the highest revenue per unit of effort, originating mainly from these species (Figure 129). Plaice is also important for TBB_70-99_NS.

In the other metiers, sol is the main contributor to the revenue. The sole CPUE is highest in the North Atlantic and higher with the pulse trawl in the North Sea, compared to TBB_70-99 in the North Sea. Furthermore, the pulse catches less plaice, cod and other species compared to TBB_70-99_NS. Anglerfish are mainly caught in the North Atlantic (VII and VIII) and are important for TBB_70-99_NA.

Crew cost and fuel costs are the two major expenses (Figure 130). In 2013, fuel costs represented around 35% of the value of landings for this fleet (STECF, 2015). Rising fuel prices, leading to a peak in 2008 and then again in 2012 (Figure 121) led to difficult times for this fleet, making losses in 2008, 2009, 2012 and 2013 (STECF 2015).

On average, 6 crew members were on board the vessel per trip. Usually vessel owners work with the same crew members under a "rotation system", so they would create more job opportunities than reflected in the number of crew members on board. However, long-term contracts do not exist and each fisherman is contracted per fishing trip. In a European context, Belgium stands out for high wages and low profits. In 2012, the average wage for the entire Belgian fleet was estimated at 94'537 € (STECF economic indicators, found on:

- https://datacollection.jrc.ec.europa.eu/dd/indicators/economic/graphs).

Crew members earn a percentage of profits from the sale of the landed value on top of a base salary. More specifically, the crew receive a fixed percentage of the value of landings before the variable costs are subtracted. If the value of landings is lower than a certain minimum wage, the employer has to pay a minimum wage. Usually the crew share is around 30% of the value of landings in total.

This income insurance for all vessels was introduced by the law of 3 May 2003 and put an end to the 'no catch, no pay' principle (RD 2005). This is unique in Europe (Van Bogaert et al. 2014). The trade-off of such a system is that more of the revenue goes to wages and therefore less to profits. On the other hand this is considered reasonable given that fishing remains a dangerous profession.

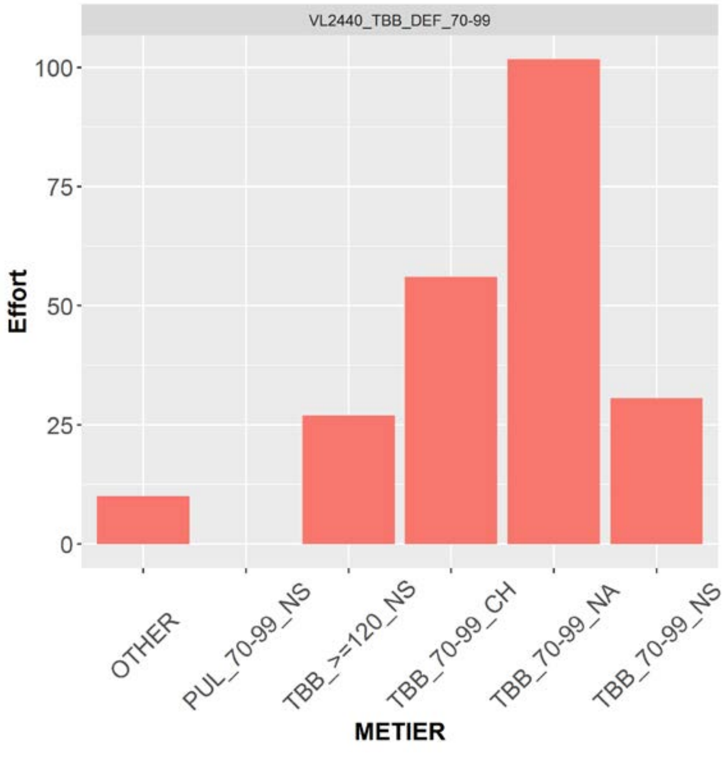

Figure 127. Initial effort for each metier

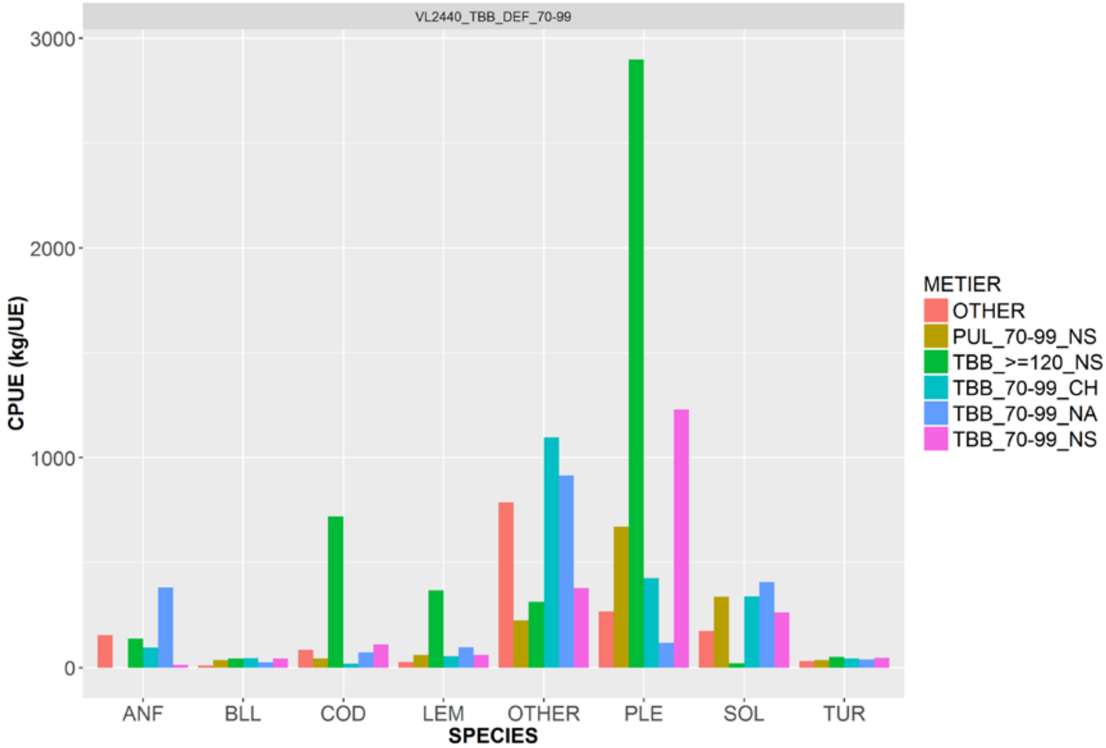

Figure 128. CPUE (kg per day at sea) for the selected species and different metiers

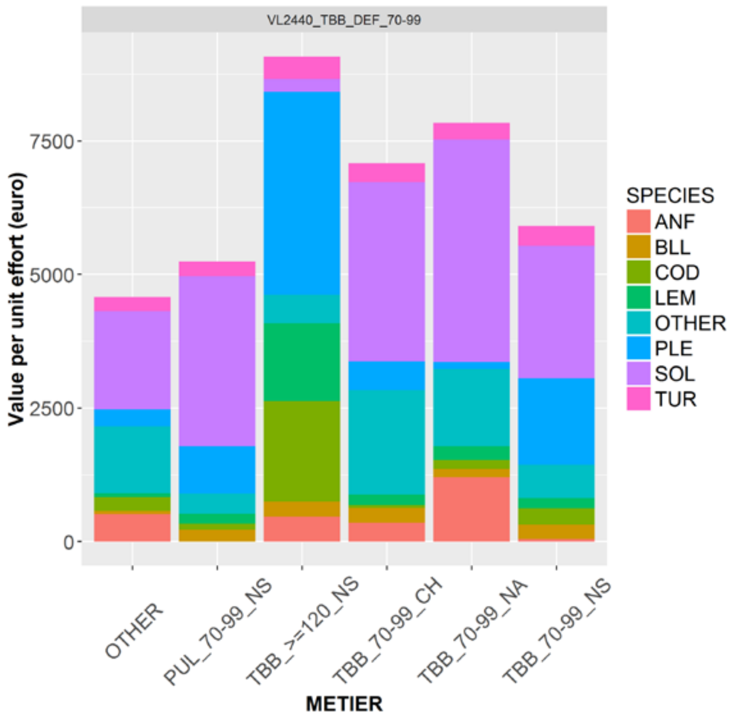

Figure 129. Revenue (euro per day at sea) for each metier for each species

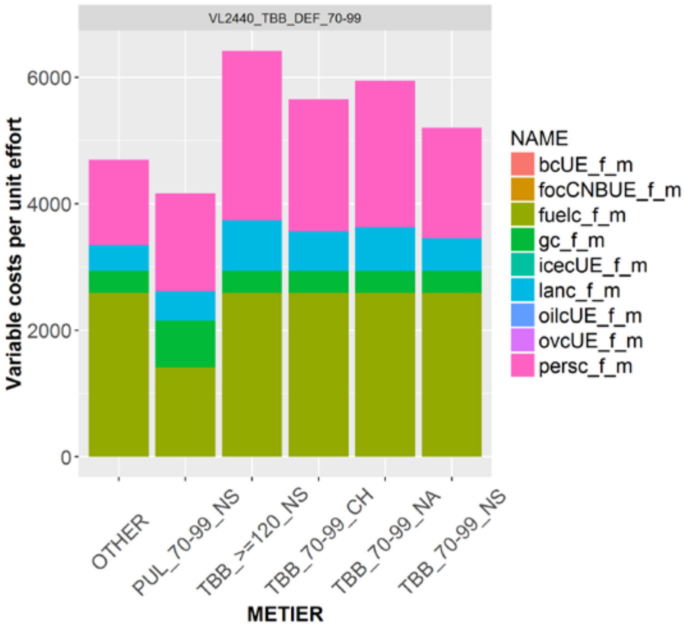

Figure 130. Variable costs per day at sea for each metier for each species

Tradition vs profit

The first scenario investigated with the Senseco model was the effect of using an effort allocation method that took profit into account. Figure 131 shows that by allocating the effort proportionally to the short-term profit, the effort decreases in all TBB_70-99 metiers, targeting sole. For the Dutch fleet, the effort in the sumwing and pulse metiers also decreases and is reallocated to the larger mesh-sized metiers, TBB_>=120_NS and OTHER. For the Belgian fleet, the effort also increases in the larger mesh-sized metier and effort is also allocated to pulse. This results in an increased profitability for both fleets (see Figure 132). The increase in profitability is higher for the Belgian fleet because the "traditional" allocation of effort of the Dutch fleet favored the most profitable metier (pulse) more than by applying a proportional distribution. The change in effort distribution also affects the catch composition of the fleets (Figure 133). In the "profit" scenario the Dutch fleet considerably increases its landings of plaice (50% higher than in the "tradition" scenario) while the landings of sole decrease by 30%. The landings of some minor species, such as lemon sole and anglerfish also double. The Belgian fleet increases its plaice and cod landings (respectively +88% and +95% in the "profit" scenario compared to the "tradition" scenario), sole and anglerfish decrease by 23 and 26%.

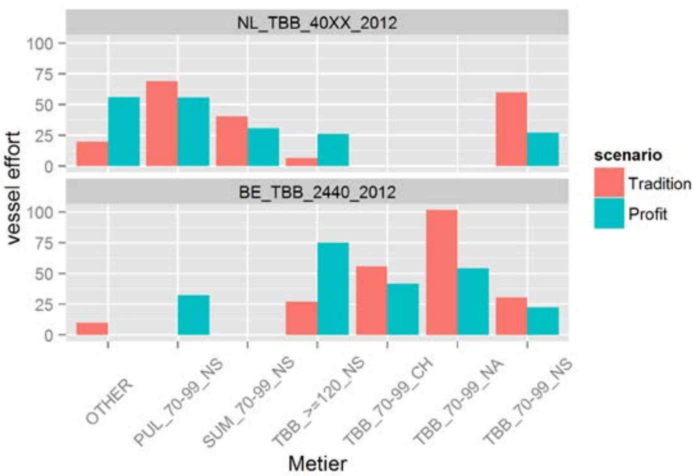

Figure 131. Effort distribution for the two fleets for the scenario "Tradition" (base data, status quo) and "Profit" for which effort is allocated proportionally to the short-term profit in each metier. Average effort per vessel in each fleet. Metiers TBB_70-99_CH and TBB_70-99_NA are not available for the Dutch fleet and metier SUM_70-99_NS is not available for the Belgian fleet.

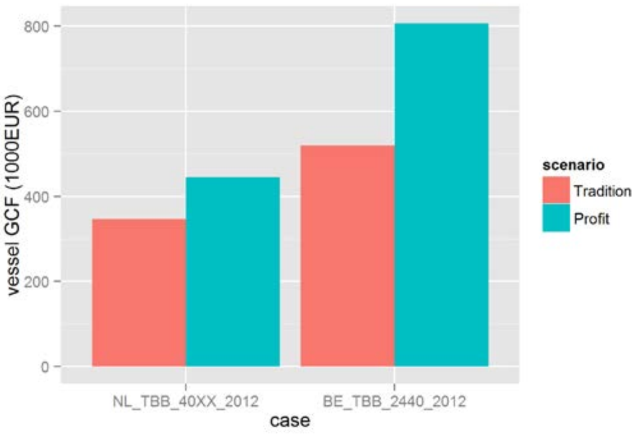

Figure 132. Gross cash flow for the two fleets for the scenarios "Tradition" and "Profit".

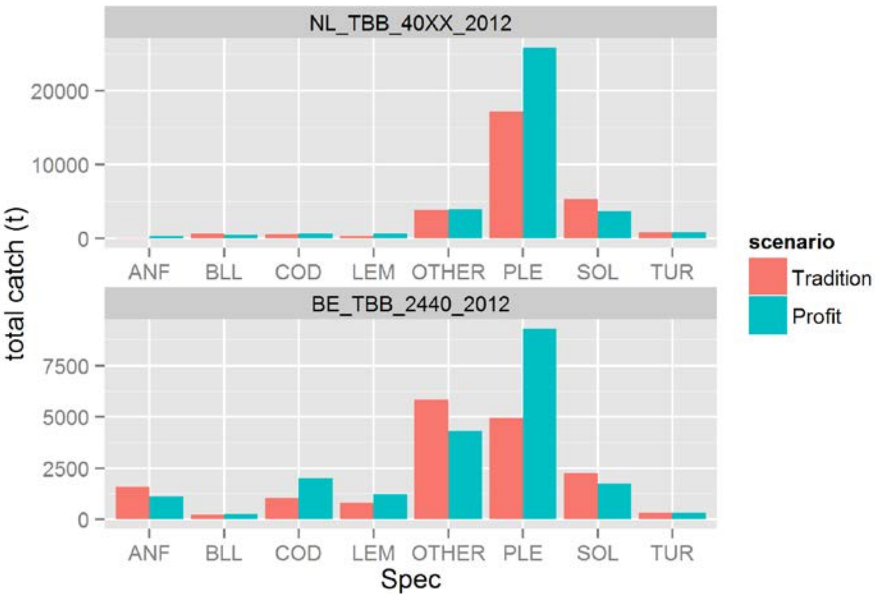

Figure 133. Catch composition for both fleets with the "tradition" and "profit" scenarios.

Impact of fuel price

It has been argued that the main reason why fishers switched to pulse was the increasing fuel price. The impact of fuel price on the fleets is investigated with scenarios with lower and higher fuel prices than the base price. For each fuel price, the effort is allocated according to tradition (same as in the base data) or to profitability (see resulting effort on Figure 134). As a result of the design of the model, the "tradition" scenarios display exactly the same effort allocation. But if the fleets adapt their effort allocation based on more economic motives ("Profit" scenarios), we can see that with low fuel prices, the TBB_70-99_NS is more economically attractive for both fleets while sumwing and large mesh size metiers are also more profitable for the Dutch fleet, while the Belgian fleet would fish slightly more in the Channel (TBB_70-99_CH). Inversely when fuel prices are high, the pulse technique becomes more attractive and for the Dutch case so does the "OTHER" metier (mainly mesh sizes between 100 and 119 mm).

Unsurprisingly, the resulting profitability shows that the price of fuel greatly impacts the economic performances of both fleets (Figure 135). High fuel prices lead to a drop in gross cash flow, especially if the fleets do not change their effort allocation (Trad_hifuel). If the fleets adapt, the gross cash flow becomes positive. It can be noted that the difference in profitability between the "tradition" and "profit" scenarios increases with fuel price.

At low fuel price, changes in effort allocation has less impact than at high fuel prices. This could explain why alternative gears are especially preferred when fuel prices are increasing. Profitability can also be looked at from the point of view of the crew. On Figure 136 the average crew wages (including the skipper) show that the wages depend on the metier operated. For the Dutch fleet the metier with the highest daily wage is the pulse metier PUL_70-99_NS, whereas pulse would deliver the lowest wages in the Belgian fleet (the pulse in Belgium remains hypothetical).

Given how the wages are calculated in the two fleets (as a share of income minus fuel cost for the Dutch and directly as a share of income for the Belgian), fuel price has only an impact on the Dutch wages. On the top panel of Figure 136, we can observe that not only the pulse metier has the highest wage of the selected metiers, but also that the variability of wage due to change in fuel prices is smaller than for the other metiers.

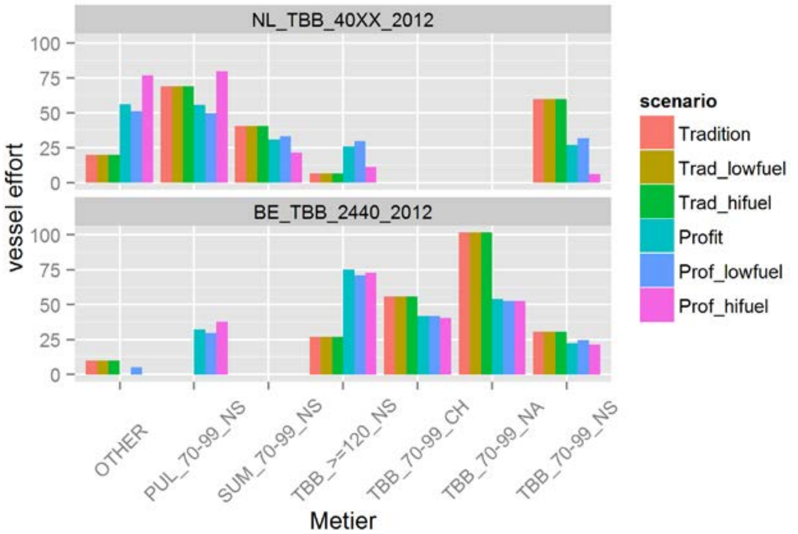

Figure 134. Effort distribution for the two fleets for the fuel price scenarios. Average effort per vessel in each fleet. Metiers TBB_70-99_CH and TBB_70-99_NA are not available for the Dutch fleet and metier SUM_70-99_NS is not available for the Belgian fleet.

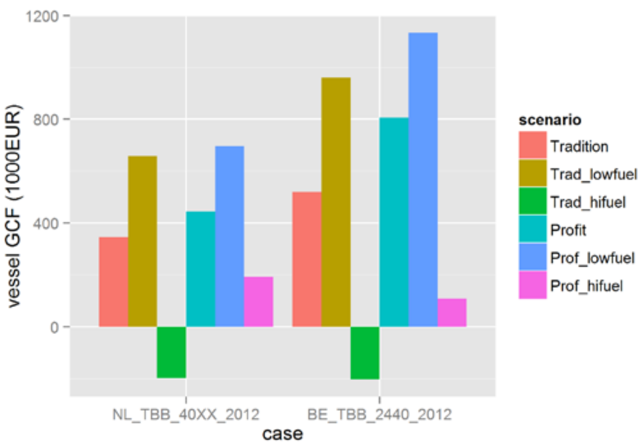

Figure 135. Average gross cash flow per vessel for the two fleets for the fuel price scenarios.

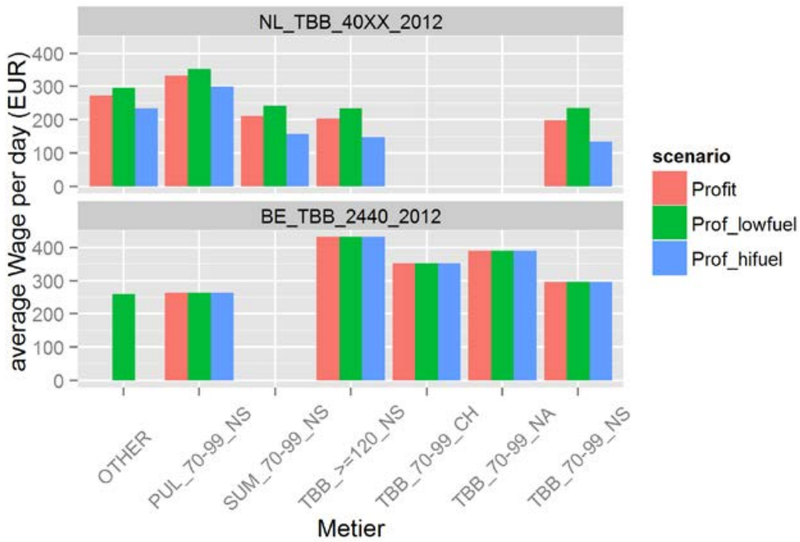

Figure 136 Average wage per day at sea per crew member of the two fleets by metier for different fuel prices. Wages are the same regardless the fishing strategy (tradition or profit).

Regulatory constraints

To investigate the effect of effort restriction on the effort allocation in metier we applied different effort restriction to the two fleets. In the Dutch fleet the total effort allowed to BT1 (TBB_DEF_≥120_NS) is allocated to the fleet amounting to about 10 days at sea per year for the metier. For the Belgian fleet, the total effort in the North Sea and VIId (eastern Channel) is limited to 150 days a year.

The constraint on TBB_DEF_≥120_NS effort (scenario Prof_effortCons) in the Dutch fleet results in an effort distribution closer to the "tradition" or observed distribution than to the profit scenario (Figure 137). This is valid for the effort in PUL_70-99_NS, SUM_70-99_NS and TBB_DEF_≥120_NS metiers, but not for the metier OTHER (more than twice as much as for the tradition scenario) and TBB_70-99_NS (about half the effort of the tradition scenario). For the Belgian case the effort restriction leads to higher effort in the North Atlantic TBB_70-99_NA. The entire effort in the Channel TBB_70-99_CH was constrained while in reality only part of the Channel falls under this effort restriction and could explain why the effort there is lower than without constraint (no extra effort can be allocated to the western Channel).

In case of high fuel costs, the restriction has no effect on the Dutch fleet because the effort in the only metier restricted is already around the limitation when fuel prices are high. This could come from the fact that the fishing grounds with this metier are further North and the steaming costs become too high. The high fuel prices have an impact on the reallocation of the effort within the North Sea and the Channel for the Belgian fleet who reallocates extra effort to the pulse metier.

Surprisingly, the effort restriction results in small gains in profitability for both fleets (Figure 138). This is because they restrict access to metiers that are not the most profitable. With higher fuel prices the change in profitability is negligible.

Figure 137. Effort distribution for the two fleets for the effort restriction scenarios. Average effort per vessel in each fleet. Metiers TBB_70-99_CH and TBB_70-99_NA are not available for the Dutch fleet and metier SUM_70-99_NS is not available for the Belgian fleet.

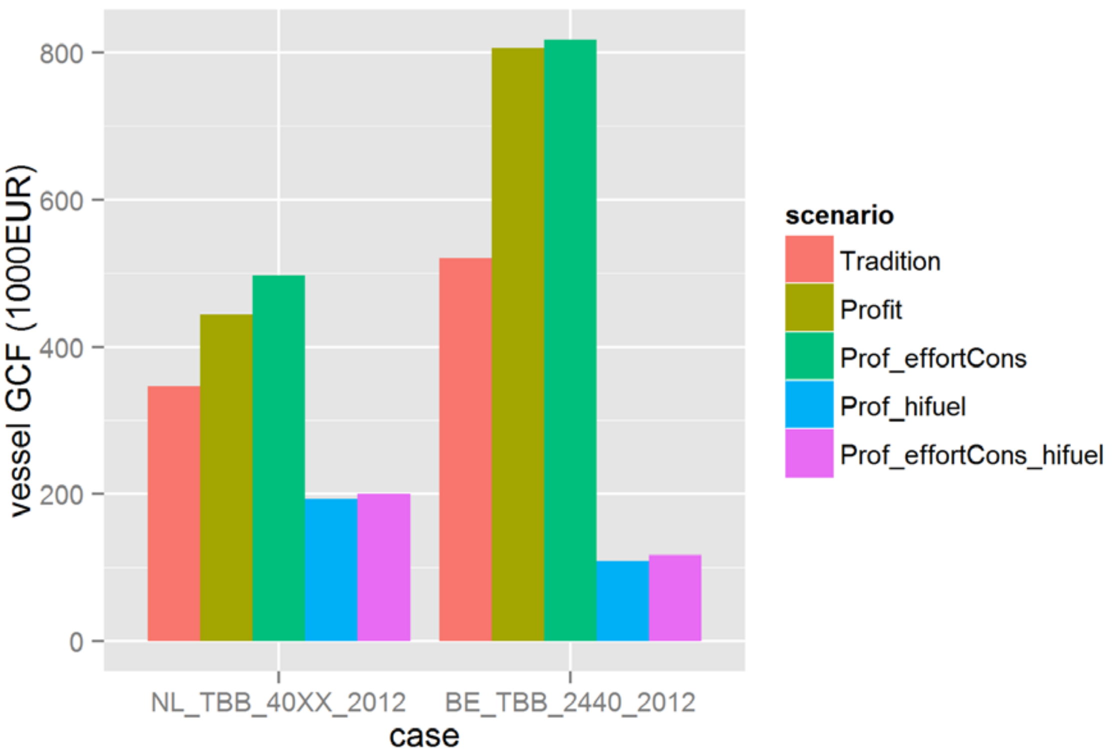

Figure 138. Average gross cash flow per vessel for the two fleets for the effort restriction scenarios.

Conclusion

In this study we looked at the economic performances of two beam trawl fleets, one Dutch and one Belgian. Both those fleets were highly dependent on fuel prices because fuel costs represent the main part of their operating costs. Looking at two ways to distribute effort based on tradition or on profitability, it appears that if vessel owners were more driven by profit, they would fish more with pulse (for sole) and large mesh sizes (targeting plaice).

Allocating effort proportionally to the profitability of the metiers would improve the economic performances of the fleets. However, it would also lead to a change in catch composition with higher landings of plaice and cod and lower landings of sole. In the Netherlands it seems that the fleet has already transitioned to pulse trawl beyond our projection, but that in 2012 they were not using as much large mesh sizes as would be projected. This could come from the fact that the beam trawlers target principally the high value sole while low value plaice was historically more of a bycatch species.

Therefore, to remain fishing for sole while trying to increase profitability would lead to a transition towards pulse. In addition, the quota for sole was higher in 2012 than the years before or after explaining why a lot of effort would be allocated to "sole metiers" such as the pulse, sumwing and small mesh size beam trawlers. For the selected fleets, the price of fuel can have a dramatic impact on the economic viability of the fleet. At 0.80€/l both fleets make a loss. To counter the increasing fuel prices of the late 2000's the fisheries had to innovate and adapt their fishing behavior. Larger mesh-sizes and innovative techniques such as pulse trawls seem to be good alternatives to the traditional beam trawlers. However, switching is not simple.

First, the use of pulse is still only based on a temporary derogation and the controversy surrounding the use of electricity to fish hasn't convinced the Belgian fleet. This could be partly due to the mode of remuneration of the crew. In the Dutch fleet, fuel costs are subtracted from the income to calculate the salaries. So indeed, lower fuel costs is an advantage for everyone on board not only the owner. In the Belgian fleet, decreasing the fuel costs only benefit the vessel owner, while the lower catch, and therefore the lower revenue associated with pulse fishing are harming everyone. Second, the switch to larger mesh sizes is complicated in the North Sea where the cod management plan has been limiting the effort in the North Sea (with large mesh sizes) to avoid cod catch.

Effort restrictions in the North Sea prevent fishers to allocate their effort as they wish. The limitation of effort for Belgian vessels to 150 days in the North Sea (160 days since 2013) restrict fishers to invest in innovative gear that can only be used in the North Sea. To be viable, Belgian vessels would have to switch gear within the year to go fish outside the North Sea, taking longer to pay their investment back. It is currently not possible to trade the days at sea between vessels so specialisation of vessels into "North Sea – VIId" (pulse?) and "outside North Sea - VIId" fleets is not possible.

The effort restrictions explain some of the differences between the tradition and profit effort allocation, but not all of them. Fishing fleets are also limited in their access to quota (either national or individual quota). Almost doubling the landings of cod and plaice would have been complicated for the Belgian fleet in 2012. Similarly, the Dutch fleet would have trouble to switch from sole to plaice because quota is owned individually and changing activity would mean having to lease quota in/out. This wasn't seen in 2012, but with the introduction of additional pulse licences in 2014, the demand for sole quota has increased and more and more fishers have started fishing separately for sole with 70-99 mm mesh sizes or for plaice with >100mm mesh sizes as the model suggested.

Pulse as an innovative gear would be economically performant for both the Dutch and Belgian fleets. However additional restrictions on days at sea in the North Sea (while the pulse trawl is currently only allowed in the North Sea area southern of 55°) and limiting sole quota are barriers to its wider adoption in the Belgian fleet. In addition, beyond the purely economic arguments, there is still uncertainty around the effect of pulse on the ecosystem on a longer term making the gear highly controversial for NGOs and society. Finally, with the Belgian remuneration system, only the vessel owners would benefit from the reduced fuel costs while the crew would earn less because the revenue per day with the pulse trawl is lower than with traditional beam trawl. It is therefore interesting to ask ourselves who take investment decisions on board, the vessel owner/skipper alone or does the crew have any influence?

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Appendix B: Comparing the costs of the landing obligation for traditional beam trawl gears and pulse trawling in the Dutch cutter fleet

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Introduction

Since the 1960s the beam trawl gear has been the dominant gear used for fishing flatfish by the Dutch cutter fleet. Due to increasing criticism on the damage done to benthic ecosystems by the beam trawl gears and stimulated by high fuel prices there has been a transition from beam trawl to pulse trawl over the period 2010-2015. Now pulse trawling has become the main gear in the cutter fleet and only a minority of the vessels is still using the relatively fuel intensive beam trawl gears.

The main advantage for fishers is that pulse trawling is relatively fuel extensive so fuel costs are much lower in pulse trawling than in beam trawl fisheries. Another advantage is that the discard rates of pulse trawling are also lower than in beam trawling. Now that the cutter fleet is confronted with the Landing Obligation which is being gradually introduced between 2015 and 2019 (Regulation (EU) No 1380/2013) this raises the question how this will affect the economic results in the Dutch cutter fleet and particularly whether the economic effects differ for pulse trawling and beam trawling. This question is discussed in section 4.

Effects of the Landing obligation on economic results of the Dutch cutter fleet

A first estimation of the economic effects of the LO for the Dutch fleet was made by Buisman et al (2013). The study assumed that fishing activities would remain unchanged compared to the base year (2011) and calculated the economic effects that the LO would have had if it had been in force in that year. The study concluded that, under the condition that quota would be lifted to a level where all discards of quota species and all marketable fish could be landed within the quota, the total estimated additional costs of the LO for the Dutch fleet would amount to 21.4 million euros of which 19 million euros for the cutter fleet after complete introduction of the LO in 2019. The potential benefits from selling the landed discards were estimated between 6.7 and 13.4 million euros for the cutter fleet which would result in total net costs of 5.6 to 12.3 million euros for the cutter fleet. This result is of course to a large extent dependent on the price obtained for landed undersized fish which was considered very uncertain. The extra costs for the fleet would consist mainly of labour costs on board due the higher volumes of fish that will have to be landed and extra sorting costs on land. For the small cutters some of the anticipated extra costs are caused by lack of capacity for storing the increased volume of fish that has to be landed.

In 2015 five pilot trips were carried out in which the cutters kept the discards of quota species on board in order to test how much extra labour time it took to handle the discards on board and to sort the landed discards on shore. Three large pulse trawlers (over 300 hp) and one small (under 300 hp) pulse trawler fishing for flatfish were involved on these pilot trips. Baarssen et al (2015) analysed the results in terms of extra labour costs and used average discard rates from the Dutch discard monitoring programme (Verkempynck et al (2015) to make a new estimation of costs of the Landing Obligation for the cutter fleet[6] following the same method as in Buisman et al 2013. Extra costs for the fleet were estimated between 12.9 million euro and 26.5 million euro depending on how many extra crew will be taken on board to deal with the extra workload. The revenues from selling the undersized fish landed in the pilot trips generally were disappointing but also varied considerably from case to case. Therefore no new conclusions were drawn on potential benefits from selling undersized fish although the results from the pilot trips suggest that the estimation of potential benefits made by Buisman et al (2013) which was based on prices of 0.15 to 0.30 €/kg were possibly too high.

[6] excluding fly-shoot and demersal trawl other than Nephrops fishery. This means that in terms of days at sea app. 80% of the Dutch cutter fleet is included in the estimation.

Economic results of beam trawlers and pulse trawlers in 2014

The costs and revenues for an average large beam trawler and an average large pulse trawler in 2014 are presented in table 1. Economic results for pulse trawlers were much better than for beam trawlers which is why a large part of the cutter fleet has made the transition from beam trawling to pulse trawling. The main cause for these better economic results of pulse trawlers is lower fuel costs. Together with higher revenues of pulse trawlers the lower fuel costs lead to higher net revenues and therefore also to higher wages for the crew and higher crew costs and a better net result.

Table 75. Costs and revenues (€) for an average large pulse trawler and an average large beam trawler: >300 hp. Year 2014. Source: LEI BIN.

	Beam trawl[7]	Pulse trawl
Revenues	1,676,000	1,904,400
Fuel costs	708,200	424,400
Crew costs	359,600	520,200
Other costs	460,800	560,200
Depreciation	84,200	104,000
Interest	11,800	15,000
Total costs	1,624,600	1,623,800
Net result	51,400	280,600

Economic effects of introduction of the Landings Obligation

The landing obligation is being introduced gradually in EU fisheries between 2015 and 2019. Here the economic impact of the Landing Obligation on Dutch beam trawl and pulse trawlers is analysed for a situation where the landing obligation has been fully implemented (situation 2019).

In this analysis we use economic data for the cutter fleet from 2014 (LEI Bin,2015 agrimatie.nl), discard monitoring data of the same year (Verkempeijk et al, 2015) and data collected during the pilot discard trips on the extra labour involved in handling and sorting the landed discards (Baarssen et al, 2015).

Assumptions made in this analysis:

- All quota species have to be landed from 2019. Possible de minimis exemptions or exemptions for high survival are not taken into account.
- Fishing operations are exactly the same as in the base year (2014). This means that all costs and revenues are exactly equal to the base year except for the costs due to handling the discards on board and on shore, costs caused by capacity problems and possible revenues from previously discarded bycatches.
- Over the past few years beam trawling has been replaced by pulse trawling to quite a large extent. Now the majority of the Dutch flat fish fleet is fishing with pulse trawl. There are still some large cutters fishing with beam trawl (or a modern version called sum wing) but hardly any small cutters (<=300 hp) were fishing with beam trawl gear in 2014. Therefore in the comparison of beam trawl (including sum wing) and pulse trawl we focus on the large cutters (> 300pk)

[7] Beam trawl here is taken as a combination of traditional beam trawl and sum wing. Sum wing is an innovation in beam trawl gear that causes lower fuel costs although fuel costs are still higher than for pulse trawl

Discard rates

The volume of discards of an average beam trawl cutter and a pulse trawler has been calculated on the basis of discard monitoring data (Verkempeijk et al, 2015) and landings data from the LEI panel for economic data collection. The discard rate of beam trawlers as well as the volume of discards is considerably higher than the discard rate of pulse trawlers (60% vs 50%, Table 11) where discard rate is defined as discards of quota species divided by total landings (quota species and non-quota species).

This means that the extra volume of fish to be handled on board and to be sorted on land under the LO is much bigger for beam trawlers (151%) than for pulse trawlers (100%). The extra labour time on board measured during three pilot trips for pulse trawlers was 50% (Turenhout et al, 2015).

There were no beam trawlers involved in these pilot trips but here we assume that the extra labour time on board is proportional to the extra volume of fish to be handled[8] resulting in 75% extra labour time on board spent on handling the fish by the crew for beam trawlers.

Table 76. Discards of and average beam trawl cutter and an average pulse trawl cutter (> 300pk). Sources: Verkempynck, et al, 2015, and LEI BIN: http://www.agrimatie.nl/SectorResultaat.aspx?subpubID=2232&sectorID=2860

	Beam trawl	Pulse trawl
Volume of landings (quota and non-quota species)	581,977	454,475
Volume of discards(quota species) (kg)	876,870	454,306
Discard rate	60%	50%
Extra volume of fish to be handled under LO	151%	100%
Extra labour time on board handling fish	75%	50%
Average crew on-board	6	6

Comparison of costs and benefits of the landing obligation for beam trawlers and pulse trawlers

In this section the costs and benefits of the LO for beam trawlers and pulse trawlers from the segment of large cutters (>300 hp) are compared. For the cutters of this segment the main extra costs caused by the LO are the extra costs of sorting undersized fish on land and the costs of extra crew on board to handle extra volume of fish that has to be landed.

Costs of sorting discards on land

The extra costs of sorting discards on land for the 5 pilot trips amounted on average to 305 €/ton of discards landed (Baarssen et al, 2015). Although the number of trips is limited we use this number to calculate the extra costs for sorting on land of an average beam trawler and an average pulse trawler. Due to the higher volume of discards the costs of sorting on land for a beam trawler (267 k€) are almost twice as high as for a pulse trawler (139 k€) (Table 12).

[8] The extra labour time is probably more dependent on numbers of fish to be handled than on the volume of fish. There could be a difference because of different catch composition of beam trawlers compared to pulse trawlers

Costs of handling discards on board

For the crew on pulse trawlers extra labour time on board for handling the discards was measured to be 50% during the pilot trips for the best practices project. On basis of the extra volume of fish to be handled on beam trawlers the extra labour time is estimated at 75% (table 1). Before the Landing obligation there are on average 6 crew members per trip on board of a pulse trawler and a beam trawler (Table 12).

Scenarios

Following Turenhout and Buisman (2015) two scenarios for calculating the extra labour costs on board are distinguished. In scenario 1 we assume that no extra crew is hired for the extra workload which means considerable extra work pressure (50% extra work per crew member on a beam trawler and 75% on a pulse trawler) on the existing crew and no extra labour costs for the owner. In scenario 2 it is assumed that 2 extra crew members per trip (ca. 33% extra crew) are hired to deal with the extra fish to be handled on board.

This reduces the workload for the crew but still the work pressure will be much higher than before the Landing Obligation. However, on most cutters it would not be possible to take more crew on board. Moreover, we assume that the two extra crew members are hired for the same wage as the original crew, meaning that the extra costs are born by the owner and directly diminish the net result.

Alternatively, we could have assumed that the original crew share has to be shared with two extra crew (8 crew members instead of 6) and the extra costs are born by the original crew members. Their crew wage would decrease 25%. In reality, the costs will probably be shared between the owner and the crew in a way that would depend on the labour market situation and other factors.

Revenues from selling undersized fish

According to the EU regulations undersized fish cannot be used for direct human consumption which means that prices are much lower than for marketable fish. The prices obtained for undersized fish from the pilot trips in the best Practices project varied considerably and amounted on average to 0.08 €/kg. Here we assume this as the average price for undersized fish for all cutters although we have to bear in mind the price is quite uncertain because it is based on just a few trips.

Economic results after introduction of the landing obligation

The economic results of beam trawlers and pulse trawlers for both scenarios are presented in Table 13. The costs of sorting discards are almost twice as high for beam trawlers compared to for pulse trawlers due to a much higher volume of discards to be sorted. On the other hand the costs of taking two extra crew members on a beam trawler are lower than for a pulse trawler because labour costs per crew member are lower due to worse economic results of beam trawlers[9].

This results in 93% higher total costs due to the landing obligation for beam trawlers than for pulse trawlers in scenario 1 and 25% higher costs in scenario 2. Because of the higher volume of discards the revenues from selling undersized fish are also 93% higher for beam trawlers than for pulse trawlers (but much lower than the costs).

This results for an average beam trawler in total net extra costs per year due to the LO of 201 k€ and 104 k€ for a pulse trawler in scenario 1 (no extra crew) (93 % higher for a beam trawler than for a pulse trawler). In scenario 2 (2 extra crew members) the total net extra costs are 318 k€ and 273 k€ respectively (15% higher for a beam trawler). The overall net result remains positive for a pulse trawler but becomes negative for beam trawlers in both scenarios.

[9] In Dutch cutter fisheries crew share is calculated as a percentage of revenues minus direct costs (e.g. fuel costs, technical costs and auction costs).

Table 77. Economic results per year of an average large pulse trawler and an average large beam trawler (>300 hp) after introduction of the Landing Obligation.

Source: LEI BIN: http://www.agrimatie.nl/SectorResultaat.aspx?subpubID=2232&sectorID=2860

	Beam trawl		Pulse trawl	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2
Extra labour on board	0 FTE	2 FTE	0 FTE	2 FTE
Net result before discard ban	51,400	51,400	280,600	280,600
Extra labour costs on-board		116,917		169,133
Extra costs on shore	267,445	267,445	138,563	138,563
Total extra costs (a)	267,445	384,362	138,563	307,696
Result (incl. extra costs discard ban)	-216,045	-332,962	142,037	-27,096
Revenues from undersized fish (0.076 €/kg) (b)	66,642	66,642	34,527	34,527
Total net extra costs (a-b)	200,803	317,720	104,036	273,169
Result (incl. costs and revenues discard ban)	-149,403	-266,320	176,564	7,431

Conclusion

This study shows that the extra costs caused by the landing obligation are much lower for a pulse trawler than for a beam trawler. An important limitation of this study are that the data on extra labour costs for sorting and handling fish on board and on shore are based on just a few pilot trips. Similarly, the data on prices for selling of undersized fish is based on just a few transactions. Nevertheless, the analysis in this study shows quite convincingly that a pulse trawler will probably suffer much less from the extra costs incurred by the landing obligation than a beam trawler. Besides the lower fuel costs for pulse trawlers this can be seen as an additional economic advantage of pulse trawling over beam trawling under the new CFP.

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Appendix C Capital Utilization and Investment decisions: a case study for the Netherlands

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Introduction

Dutch fleets are making transition from fishing with traditional beamtrawl gear to fishing with innovative gears like pulse or sumwing. In this paper we will explore which vessels are likely to switch to innovative gears and whether this switch makes the Dutch beamtrawl fleet more efficient. To answer this question we will analyse how short run profit drives investments in innovative gears and show how data envelopment analysis can be used to determine the optimal level of capital use and determine how investment innovative gears can optimize the output of the industry.

A standard tool for evaluating the available capacity and potential output in the fleet is Data Envelopment Analysis (DEA). DEA methodology uses information on physical inputs, to provide multi-output distance functions/frontiers to determine how these inputs relate to the capacity level of output. With the help of a DEA analysis the overall efficiency level of the fleet can be determined and it can be shown which factors contribute to a less than optimal production.

With a DEA analysis, the total capital utilization of the fleet can be determined. Capital utilization can be seen as a measure of whether firms should invest or disinvest in their capital assets. Capital utilization also measures to which extent idle and excess capacity is present in a firm. Differences in capital utilization mainly depend on the inability of a firm to adjust fixed capital in the short run, thus creating a structural inefficiency. It therefore should be a key economic parameter to evaluate the performance of a sector.

We will measure the physical capital utilization for the Dutch beam trawl and demersal fleet in this paper and decompose the capacity utilization into technical efficiency, economic capital utilization and optimal capacity idleness. Furthermore we will illustrate how the economic capacity measure can be used to predict investment decisions in the fleet.

Material and methods

Capital utilization and idleness

Capital utilization is normally defined as the ratio between actual output and maximum potential output. There are two dominant approaches toward defining the potential output: a technological approach and an economic approach (Sahoo and Tone, 2009). The technological approach was first defined by Johansson (1968) as the maximum potential output that could be produced per unit of time with existing plant and equipment, provided that the availability of variable inputs is not restricted. This definition of capacity utilization was first made operational in a DEA setting by Färe et al (1989).

The economic approach is based on the concept that the maximum potential output should take into account maximizing profits as fully using available capital will not necessary lead to maximum profits. Coelli et al (2002) showed that it is almost always optimal for firms to have some capacity idle. They decompose using different variations of data envelopment analysis (DEA) models, the physical measure of capital utilization in terms of outputs into three components: output technical efficiency, economic capital utilization and optimal capacity idleness.

Idle capacity in general can arise because of indivisibilities in inputs (i.e. fixed inputs), a fluctuating demand for an existing product or uncertainties in the expected demand for an existing product. Idle capacity is of great importance to investment decisions as a large amount of existing idle capacity can be used to diversify in other products, without investing into new capital.

In this paper we will use data envelopment analysis (DEA) to determine the available idle capital in the Dutch fishing fleet and based on these measures we will be able to determine whether capital utilization can be used to predict investment decisions in the fishing fleet. To do this we will follow the decomposition of the capital utilization as presented by Coelli at al (2002).

Formal definitions of capacity

Before introducing the DEA models used some definitions about capital and capital utilization are useful.

1. The capacity of a vessel, y_c, is defined as the maximum possible production given technology S and fixed input vector x_f; the variable input xv can take any positive value.
2. Capacity utilization θ can be defined as the ratio between observed output y and the maximum capacity of the vessel yc. That is θ= y/yc.

Capital utilization can take a value between 0 and 1. A value of 1 indicates that the vessel is operating at full capacity.

In the case that multiple outputs are considered, the capacity of the vessel should be redefined. Eilon and Soesan (1976) showed that in the case of multiple outputs and inputs a radial expansion of the output vector can be used. That is by how much the output vector can be proportionally expanded given the current technology and the fixed input vector.

1. The ray capacity yc can be defined as y/ θ. Where 1/ θ is the largest scalar amount the output vector y can be radially expanded using technology S and fixed input xf when the variable input vector xv may take any non-negative value.
2. The ray capacity utilization θ is defined as the inverse of the largest scalar amount by which the output vector can be expanded.

The ray capacity utilization will be same as the capacity utilization if the number of output is equal to one.

Simple two-output example

The definitions of the previous section are illustrated in Figure 139. Suppose there are m firms that produce two outputs y1 and y2. $P(x_v,x_f)$ illustrates the production curve if vessels are operating on a technical efficient level. The technical efficiency indicates whether vessels are producing optimal when both fixed inputs and variable inputs are kept at their current levels. $P(x_c^v, x_f)$ illustrates the production frontier if vessels are operating on capital utilization maximizing level, which indicates whether a vessel is operating at full capacity while only keeping its fixed inputs at its current level.

Vessel A produces a level of output y1 and y2 that is clearly inefficient. This vessel should be able to produce at a level B is it was operating at a technical efficient level. If vessel A was maximizing their capital utilization it would even be able to produce on level D.

To test whether a vessel is operating on the ray economic efficient level we need to determine whether the vessel is maximizing the short term profit. To do this we add a slope determined by the prices of the 2 outputs G' (-p1/p2) to Figure 139. Point F represents the point where a vessel is operating in a technical efficient manner and is also maximizing its short term profits.

However the output mix is changed in point F, if it is assumed that the 2 outputs are linked and the outputs can only be radial expanded, the economic efficient technical output would be equal to Point C. The same analysis can be done for the capital utilization.

A vessel maximizing short run profit and operating at capital utilization level would be able to produce at level E. Point E represents the ray economic capital utilization. In the remainder of this paper this will be shortened to economic capital utilization.

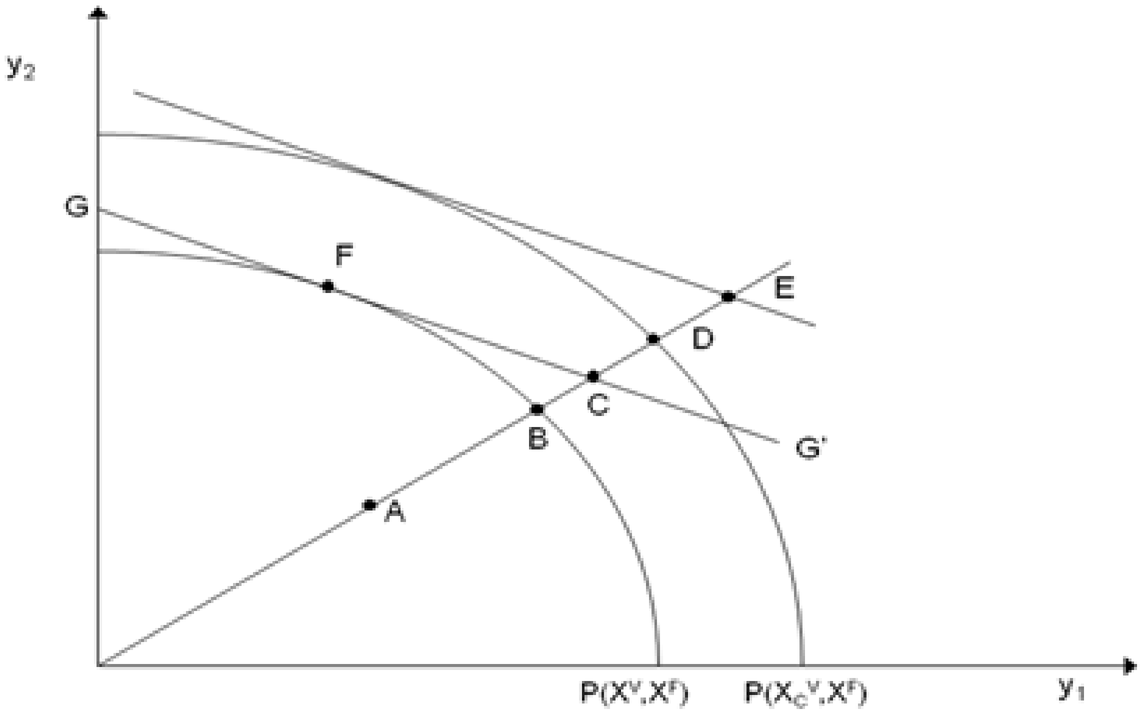

Figure 139. A two output example of efficiency scores.

Model

To calculate the possible capacity of a vessel we need to estimate the unknown production frontier on which a vessel is operating a maximum capacity. For this we have chosen to apply data envelopment analysis and need to solve three linear programs.

1. Technical efficiency

First of all we can calculate the technical efficiency that is how much a vessel should be able to produce given both the current level of fixed and variable inputs. To calculate the technical efficiency of the vessel we use a standard DEA LP model as can be found in Färe et al (1994).

$$
\begin{aligned}
&Max\theta_{TE} \\
&\text{subject to :} \\
&\sum z_i y_{im} \geq \theta_{TE} y_{jm} && \forall m \\
&\sum z_i x_{in} \leq x_{jn} && n \in F_x \cup V_x \\
&\sum z_i = 1 \\
&z_i \geq 0 \quad \forall i,
\end{aligned}
$$

Where θ_{TE} is the efficiency score of firm *i*, y_{jm} is the amount of output m produced by firm *j*, F_x and V_x are the sets of fixed and variable inputs respectively, x_{jn} is the amount of input *n* used by firm *j* and z_i is the intensity variable for firm *i*. The technical efficiency score is equal to:

$$TE = \frac{1}{\theta_{TE}}$$

2. Capital utilization

While calculating the technical efficiency, we assume that the variable inputs should remain on their observed level. If instead we would assume that a firm can adjust its variable inputs to increase its output, we can calculate the capital utilization. The model is changed to:

$$
\begin{aligned}
& Max\,\theta_{CU} \\
& \text{subject to:} \\
& \sum z_i y_{im} \geq \theta_{CU} y_{jm} \qquad \forall m \\
& \sum z_i x_{in} \leq x_{jn} \qquad \mathrm{n} \in F_x \\
& \sum z_i x_{in} \leq \lambda_{jn} x_{jn} \qquad \mathrm{n} \in V_x \\
& \sum z_i = 1 \\
& z_i \geq 0 \quad \forall i, \qquad \lambda_{jn} \geq 0 \quad \forall j,n
\end{aligned}
$$

Where λ_{jn} is the input utilization rate by firm j of variable input n. Note that the fixed inputs, like size or engine power are assumed fixed on the short run and can not be changed. Variable inputs, like fuel consumption, are allowed to vary in the model.

The capital utilization score is defined by:

$$
CU = \frac{1}{\theta_{CU}}
$$

3. Economic capital utilization

Following Coelli et al (2002), the economic capital utilization can be calculated by maximizing the short run profits, given that the outputs can only be radially expanded. The model used to calculate the economic capital utilization looks as follows:

$$
\begin{aligned}
& Max \sum_m p_m \beta_i y_{im} - \sum_v w_{vi} x_{vi}^{rec} \\
& \text{subject to:} \\
& \sum z_i y_{im} \geq \beta_i y_{jm} \qquad \forall m \\
& \sum z_i x_{in} \leq x_{vi}^{rec} \qquad n \in V_x \\
& \sum z_i x_{in} \leq x_{fi} \qquad n \in V_f \\
& \sum z_i = 1 \\
& z_i \geq 0 \quad \forall i, \qquad \lambda_{jn} \geq 0 \quad \forall j,n
\end{aligned}
$$

Where β is the factor by which output can be radially expanded.

The economic capital utilization is calculated by:

$$CU_{econ} = \frac{1}{\beta_i}$$

4. Optimal level of idleness

The idea of optimal idleness of capital is hinged on the idea that the short term profit curve is downward sloping. Up till certain point it will not be beneficial anymore to increase production as the marginal costs of producing an extra product exceed the profit gained by it. This idea is shown in Figure 140.

A firm with an idleness score of unity, should use its capital to the fullest extent. A firm with an idleness score of less than unity will earn more short profits by decreasing production.

The optimal level of idleness is defined as the ratio between the optimal production considering economic capital utilization and the optimal production considering capital utilization.

$$Idle = \frac{\beta_i y_i}{\theta_{CU} y_i} = \frac{CU}{CU_{econ}}$$

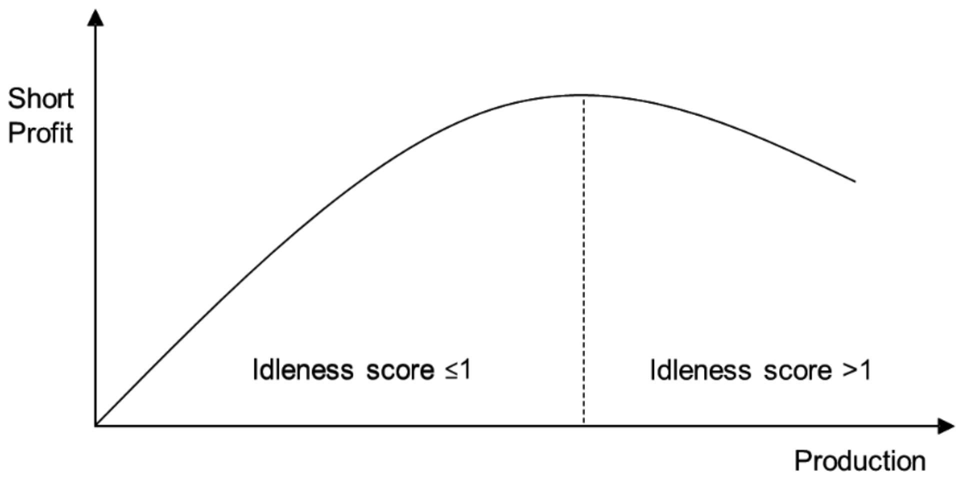

Figure 140. An illustration of idleness scores.

Calculation of capital price based on data envelopment analysis

The relationship between measures of economic capacity utilization and investment can be explained in terms of incentives to invest in physical capital. An economic capital utilization score of less than unity suggests that the company is not using their available capital to the maximum.

This may mean that they either could increase their variable inputs to increase production or that they have too much capital and thus a reason to disinvest. The shadow price of capital in this case is higher than the actual price of capital. We are using the economic capital utilization measure here as this measure does not include the optimal idleness anymore in contrast to the physical capital utilization. A firm with an economic capital utilization of more than unity is overusing its available capital. This means that it has an incentive to invest in its capital because that would increase short term profits. In this case the shadow price of capital is lower than the actual price of capital. A firm with an economic capital utilization of 1 has no reason to either invest or disinvest.

Results

Introduction

We estimated the three models described in the previous section using length and age of the hull as fixed input; gear cost, fuel costs and personnel cost as variable inputs and sole, plaice, other species with a low price and other species with a high price as outputs. As this paper focuses on short term profits and investments, these variables were chosen because of their strong link to profits and investments.

Although there is some autocorrelation and heteroscedasticity between the variables used, especially between length and employment, data envelopment analysis is not affected by this. Moreover research has shown that DEA-based estimators are the best estimators of efficient output under heteroscedasticity (Banker et al, 2003).

The models will only be applied to the beam trawl and demersal fleet. To ensure that vessels are comparable we selected only vessels that catch at least 5 tonnes of sole and plaice per year. This means that vessels only targeting shrimp will be left out of the analysis as these are significantly different from the other vessels in the analysis.

This analysis has been done using cost and revenue data based on panel maintained by LEI and vessel characteristics collected from the official vessel registry. LEI collects yearly data about cost and revenue from for about one third of the Dutch fleet. As the Dutch fleet is reduced over the time period 2001-2013, the survey size becomes smaller over time. In 2001 we had 71 suitable vessels in the survey, in 2013 only 39 suitable vessels were left.

While selecting the variables included in the models it is important to make sure the rule of thumb hold. The rule of thumb states that:

$$n \geq \max\{m \times k, 3 \times (m + k)\}$$

n= number of observations, *m*=number of outputs, *k*=number of inputs

While the number of vessels decline in the survey, for all years the rule of thumb holds true.

Data

Figure 141 shows the average revenues and landing of the vessels in the sample used for the time period, 2001-2013. On average, the total catch is increasing. Especially the catch of plaice has increased significantly. However, the revenue of plaice has hardly increased indicating that the price of plaice decreased over the years. The impact of the financial crisis is clearly visible in the year 2009. In 2009, the average revenue drops breaking the increasing trend in revenue that can be observed in the period 2004-2008.

In 2009, the revenue of other high priced fish almost disappears. On average, the vessels have become slightly older indicating that only few owners have been investing in their fixed capital as Table 14 shows. Both the average length of a vessel and the number of FTE has remained fairly constant over the years. Investment in gear has sharply increased in the later years. In 2013, the gear costs are more than twice as much as in 2001.

Both fuel consumption and horsepower steadily declined in the early years (2001-2004) as Figure 142 shows. After 2005 fuel consumption and average horse power increases again. The average fuel costs in 2013 are more than twice as high compared to period 2001-2004. Surprisingly the average horsepower of the vessel also increases. Vessels do not seem to reduce average horsepower due to high fuel costs.

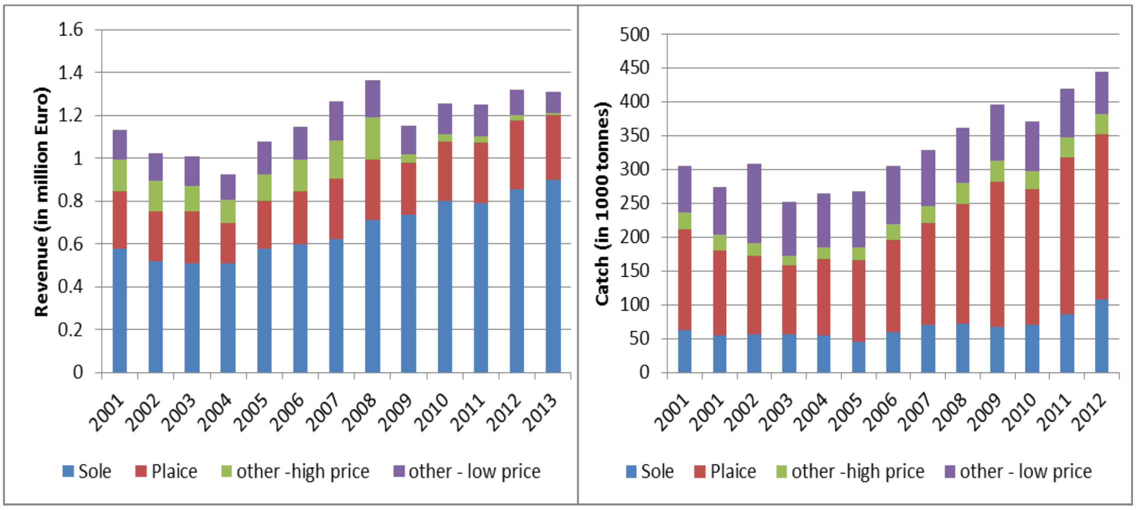

Figure 141. Average revenue and catch of the Dutch beamtrawl fleet (2001-2013).

Table 78. Average use of fixed and variable inputs in the period 2001-2013.

	Age	Length	FTE	gear cost (1000 euro)
2001	15.8	35.5	7.5	55.1
2002	15.4	34.9	7.5	53.5
2003	16.0	34.1	5.8	49.5
2004	16.5	33.4	5.5	42.8
2005	15.3	34.4	5.7	47.8
2006	16.9	34.4	5.4	53.8
2007	17.3	35.3	5.6	58.2
2008	19.3	36.1	5.1	55.4
2009	18.9	36.5	5.7	69.3
2010	20.5	36.5	5.8	75.0
2011	21.2	35.0	6.0	100.7
2012	20.6	37.1	6.0	115.5
2013	20.6	36.6	6.1	123.1

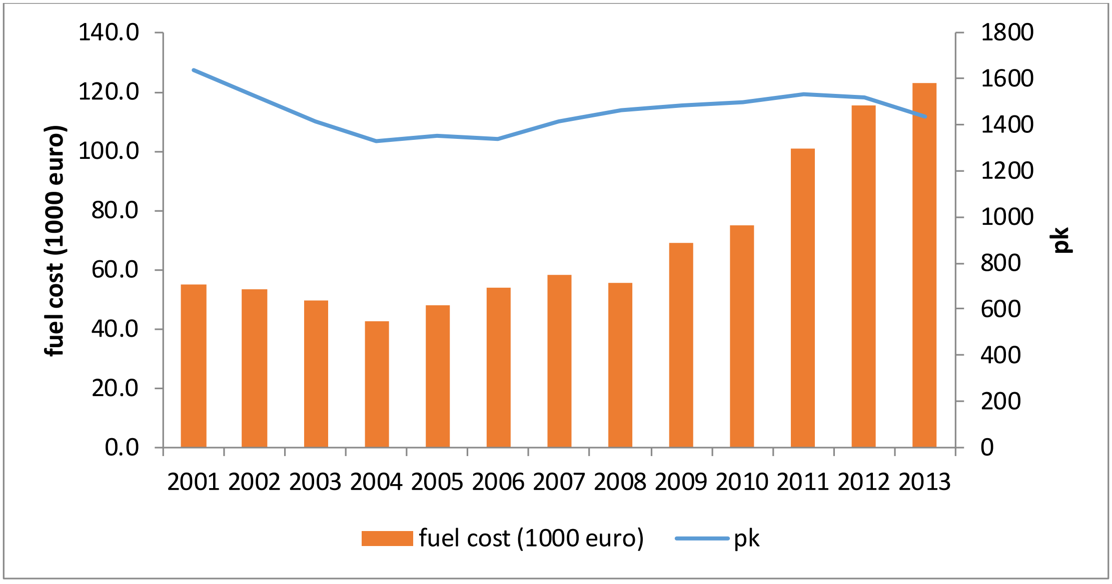

Figure 142. Fuel cost in 1000 euros and horsepower in pk Dutch beam trawl fleet (period 2001-2013).

<u>Innovative gears</u>

In the period 2003-2013 many vessels switched from traditional beam-trawling to innovative gears, like sum-wing and pulse fishing. Figure 143 shows how many vessels in the panel switched to innovative gears. While in the first years, only few vessels tried out the new gears, since 2009 the number of vessels fishing with innovative gears increased rapidly. In 2013 almost 70% of all the vessels switched to innovative gears.

Some data about investments is available for the years 2008 to 2013 as shown in Figure 144 . Apart from the years 2009 and 2011 the average investment costs are fairly low. This is surprising considering the amount of vessels switching to innovative gears. This may indicate that the investment data does not cover all investments done in the fishing segment.

Figure 145 shows the amount of investments in both vessels switching to innovative gears and vessels fishing with traditional gears. In both groups some investments took place although the timing is different. In the group fishing with traditional gears, a peak is visible in 2009 in which several vessels changed engines.

In the group fishing with innovative gears the main investment came in 2011 where several vessels invested in the hull of the vessel. Considering that the increase of innovative gears already started in 2009 this is a clear indication that the investment data is not covering all investments. Therefore, in the rest of the DEA analysis this data will not be used.

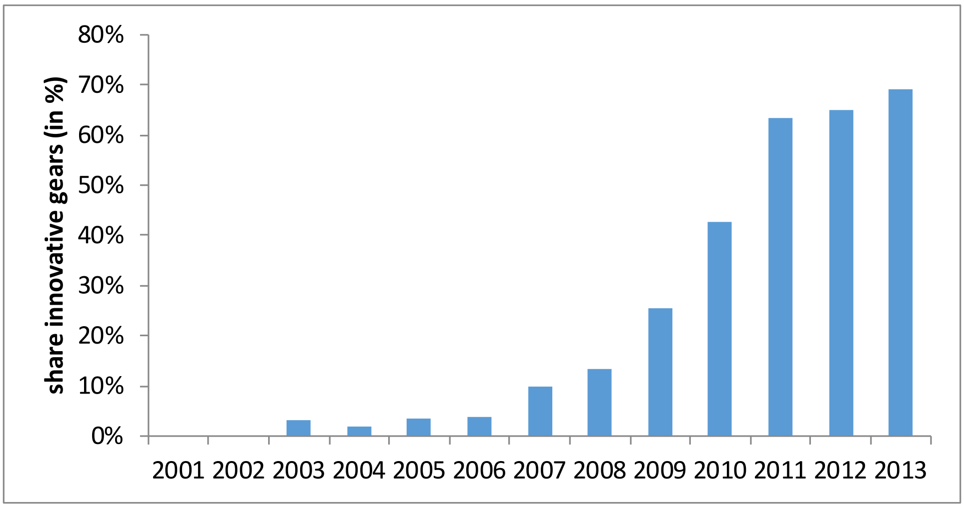

Figure 143. Percentage of vessels fishing with innovative gears

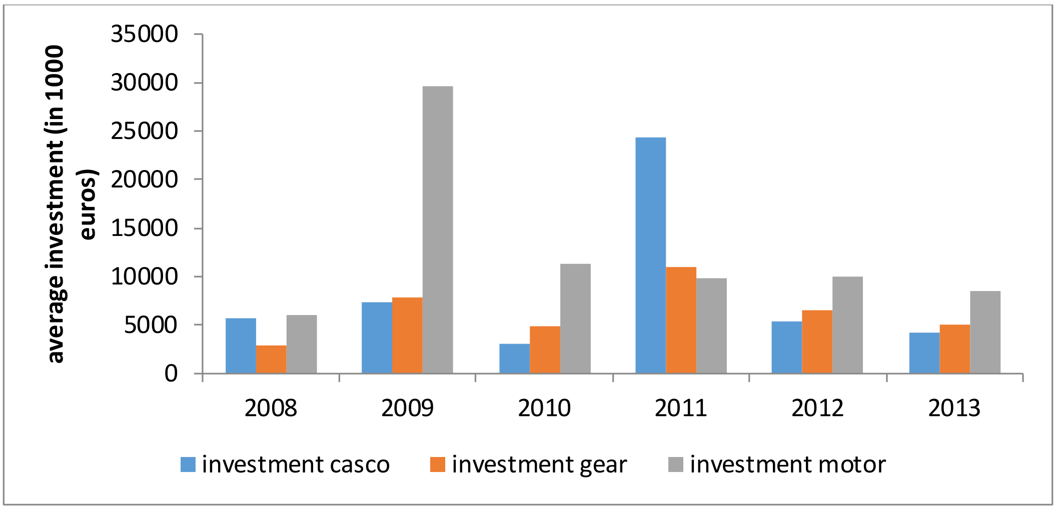

Figure 144. Average investment costs in 1000 euros for the period 2008-2013

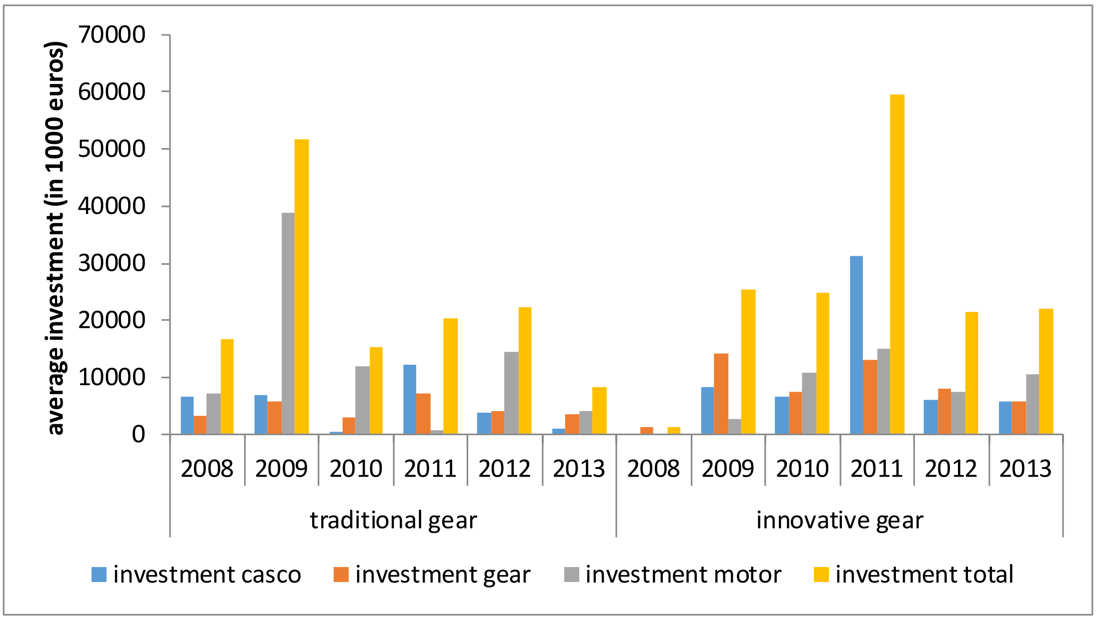

Figure 145. Average investment costs for the group of vessels fishing with traditional gear and group of vessels fishing with innovative gears (1000 euros period 2008-2013)

Description results DEA analysis

The various efficiency scores calculated by the models are shown in Figure 146. Many of the vessels were considered technical efficient. This means that many vessels are producing optimal given the available fixed and variable inputs. Or in other words they produce the maximum output given the level of inputs employed. Vessels that are operating a maximum efficiency are considered peer vessels. Vessels that are operating at a lower level then the peer vessels are considered to be non-peer vessels.

The average technical efficiency score in 2013 was 0.98 indicating that total outputs could be increased by only 2% if all vessels in the fleet were operating technically efficient. The capital utilization indicates whether a vessel could make better use of its fixed capital by employing their variable inputs more efficiently. Compared to the technical efficiency it is clear that fewer vessels are optimizing their capital utilization.

Vessels could improve output if more variable inputs were available or used. However the overall capital utilization of the fleet is still relatively high, indicating that the variance in the fleet is low and many vessels are producing close to optimal. The average capital utilization was equal to 0.87 in 2013.

The economic capital utilization, takes into account short term profits while maximizing output. Several vessels have an economic capital utilization of more than 1. These vessels are overusing their available capital and could increase profits by reducing their production. The average economic capital utilization has been increasing significantly over the years and was equal to 0.94 in 2013.

The optimal level of capital idleness indicates whether it is optimal to fully use the available capital. A score of unity indicates that it is optimal for that vessel to fully use their capital. A score less than 1 indicates that it is optimal for that vessel to leave part of its capital idle if the vessel wants to maximize short term profits. For most of the vessels in the fleet it is optimal to fully use their capital, only for a small number of vessels the optimal level of idleness is less than unity. The average idleness score is 0.92 in 2013. To investigate why some vessels are considered to be more efficient than others, we will compare how the efficient peer vessels compare to the non-efficient non-peer vessels on the variables used in the analysis.

Figure 147 shows that the peer vessels are on average younger than the non-peer vessels. This trend is noticeable in the entire time period. The peer vessels are also on average slightly smaller than the non-peer vessels, however the difference in this regard is not very large.

The peer vessels have on average higher or similar variable costs as Figure 148 shows. Especially fuel costs are significantly higher for the peer vessels (25% higher) compared to the non-peer vessels. The fixed costs are also on average higher for the peer vessels (Figure 149). Especially the depreciation costs are much higher for the peer vessels, which is not surprising as the age of the peer vessels is lower. The maintenance costs are lower for the peer vessels probably also due to the fact that the vessels are younger.

While the average costs of the peer vessels are higher, the average revenue of the peer vessels is also quite a bit higher as shown in Figure 150. Up to 2010 the peer vessels mostly catch more sole compared to the non-peer vessels; Figure 150 only show results from 2007 and upwards but this also holds true for the early years.

After 2010, the peer vessels distinguish themselves mainly in a significant increase in plaice catches compared to the non-peer vessels. The peer vessels catch about 50% more plaice then the non-peer vessels in 2013.

In almost all years the optimal level of idleness is very close to unity for the peer vessels, the optimal idleness score is almost 0.98 in 2013. This means that peer vessels are kept idle for only 2% of the year (Figure 151).

However for the non-peer vessels it is optimal to leave part of their capital idle in the period 2011-2013 (about 12% of the fleet is kept idle part of the time).

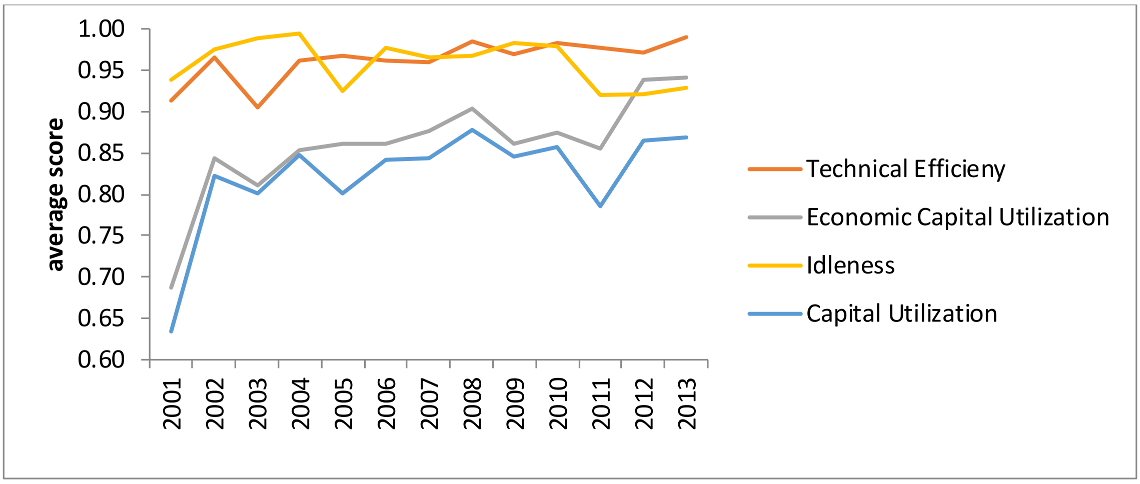

Figure 146. Average efficiency scores (period 2001-2013).

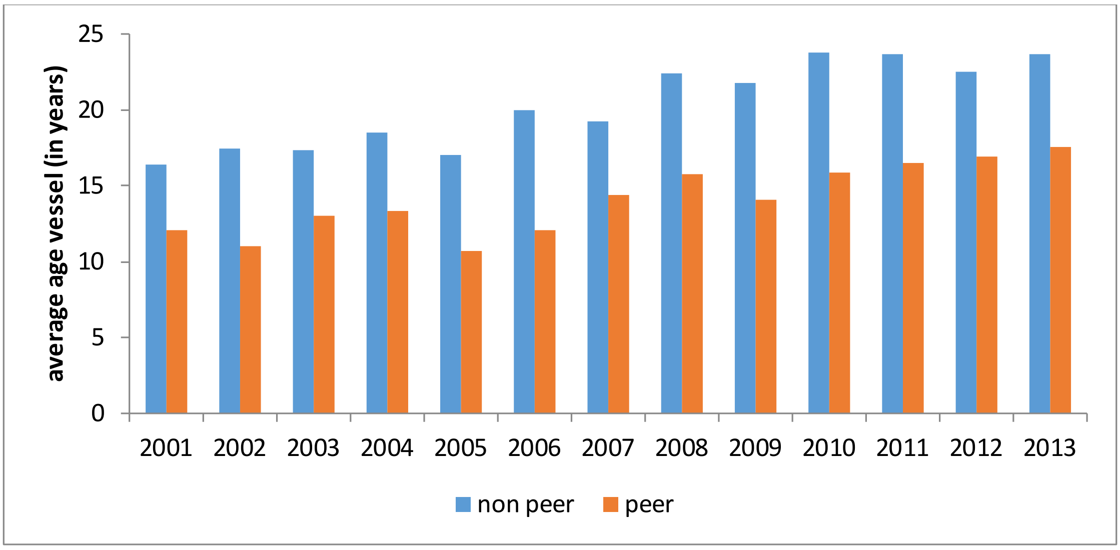

Figure 147. Average age peer and non-peer vessels (in years for the period 2001-2013).

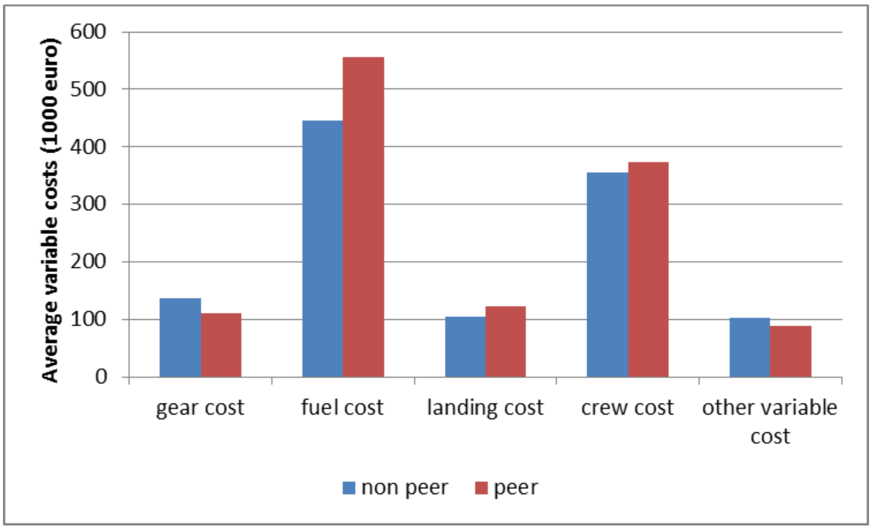

Figure 148. Average variable costs peer and non-peer vessels (in 1000 euros for the year 2013).

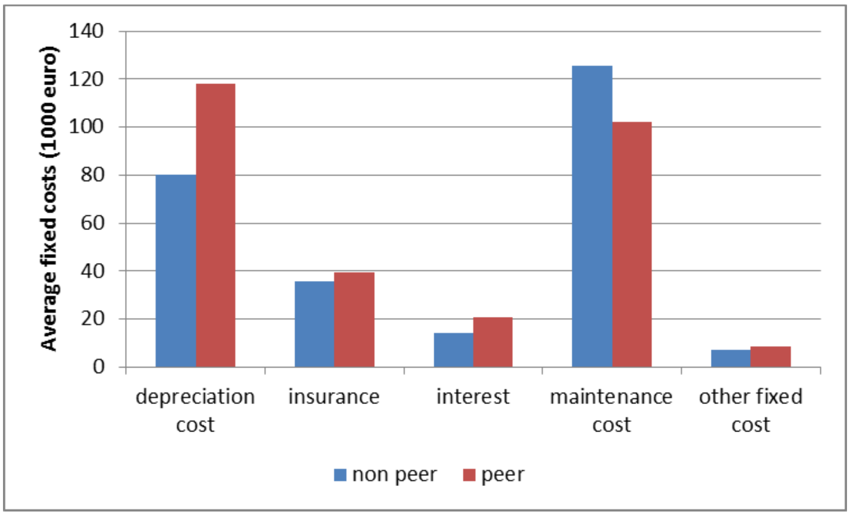

Figure 149. Average fixed costs peer and non-peer vessels (in 1000 euros for the year 2013).

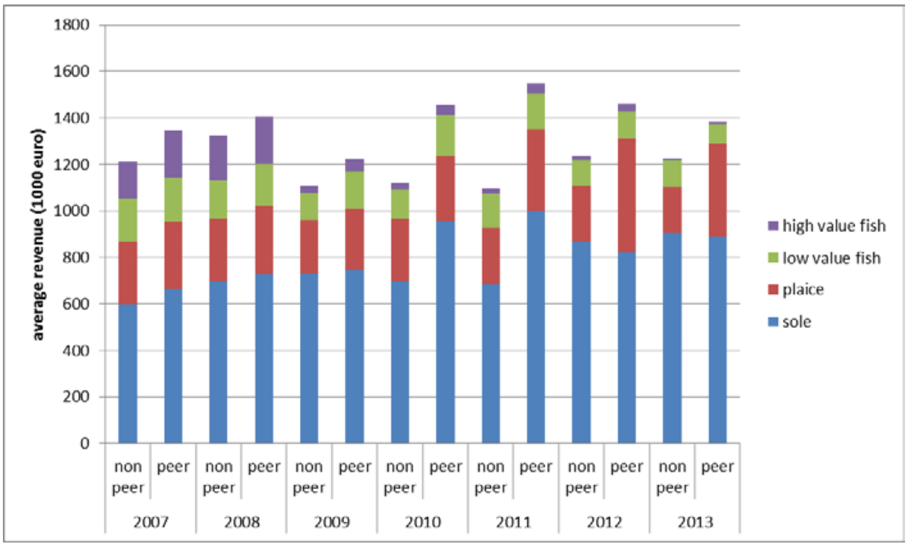

Figure 150 Average revenue peer and non-peer vessels (in 100 Euros for the period 2007-2013).

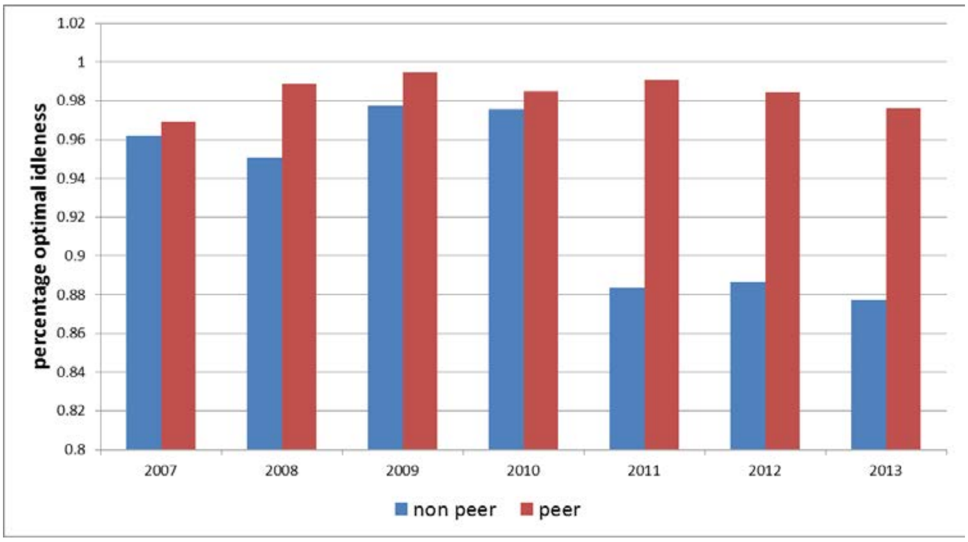

Figure 151 Optimal idleness fleet (in percentages for peer and non-peer vessels).

Predicting investment decisions based on economic capital utilization

Economic capital utilization can be used to predict investment decisions. Like shown in the model section, if the economic capital utilization is higher than unity, that vessel will have an incentive to invest because the shadow price of capital is higher than the actual price of capital. Likewise, a vessel with a low economic capital utilization will have an incentive to disinvest because the shadow price of capital is lower than the actual price of capital.

Figure 152 shows how many peer and non-peers vessels have invested in innovative gears. In 2013, about 90% of the peer vessels were fishing with innovative gears. While a percentage of the non-peer vessels are also investing in innovative gears, this percentage is much smaller, about 45%.

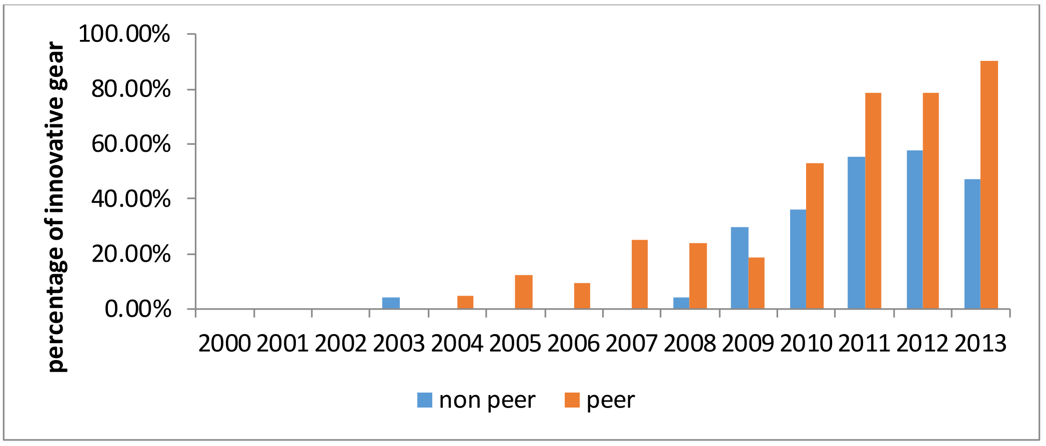

Figure 152. Percentage of peer and non-peer vessels fishing with innovative gears.

To determine whether the economic capital utilization can be used to predict investment decisions in innovative gears we have plotted the economic capital utilization of two years back versus the decision whether to invest in innovative gears or not. The results are shown in Figure 153.

This figure shows that in most years the average economic capital for vessels that chose to keep fishing with traditional gears is lower than that of vessels that chose to invest in innovative gears. Almost all vessels that had an economic capital utilization of above unity choose to invest in innovative gears.

The Figure 153 shows that the variance of results is high. The economic capital utilization is not the only reason vessels decide to invest in innovative gears. However, in Table 79 it is tested whether the mean of the capital valuation is different between the group of vessels and a two-tailed T-test shows that for most years the difference is indeed significant.

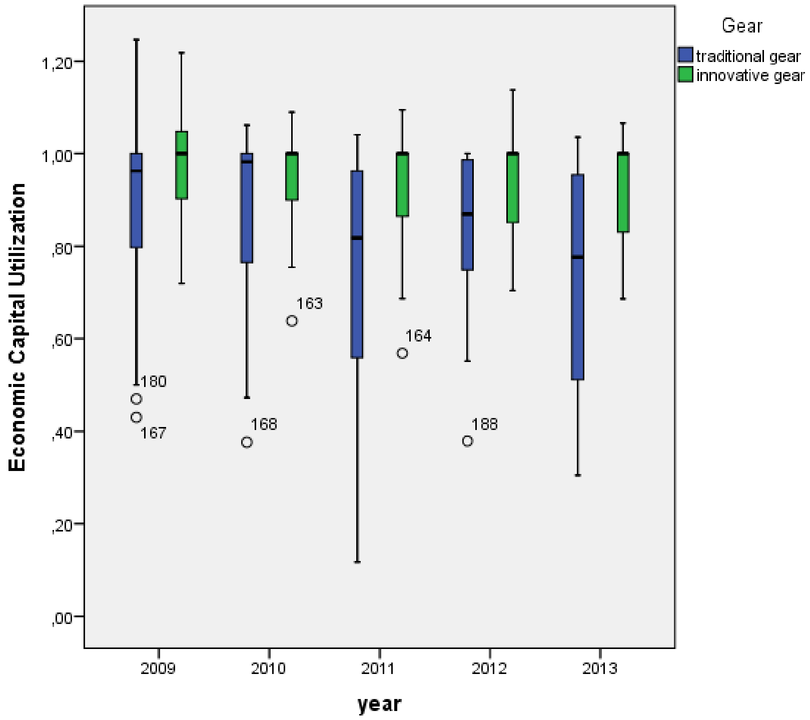

Figure 153 Economic capital efficiency versus choice of fishing with innovative gears.

Table 79. Statistical difference between investment decisions.

Year	Investment	N	Mean economic CU	Std. Deviation	Std. Error Mean	Sig. (2-tailed)
2009	Traditional gear	30	0.87	0.21	0.04	0.21
	Innovative gear	10	0.97	0.14	0.04	
2010	Traditional gear	23	0.87	0.21	0.04	0.23
	Innovative gear	18	0.94	0.12	0.03	
2011	Traditional gear	14	0.75	0.27	0.07	0.01
	Innovative gear	25	0.92	0.12	0.02	
2012	Traditional gear	11	0.82	0.20	0.06	0.03
	Innovative gear	25	0.94	0.12	0.02	
2013	Traditional gear	8	0.73	0.27	0.09	0.01
	Innovative gear	25	0.93	0.11	0.02	

Conclusions

Based on the results presented above it is striking that the average capacity utilization of the fleet is rather high for all years in the analysis. However, on average the fleet could increase production by about 16% in 2013 if the capacity utilization is maximized. About 8% of the capacity utilization inefficiency is caused by idle/excess capacity. The remaining 8% can be attributed to economic capacity inefficiency (6%) and technical inefficiency (2%).

It is optimal to leave about 8% of the fleet capacity idle. Peer vessels are less likely to remain idle (2%) then non-peer vessels (12%). This low idleness score indicates that there are few indivisibilities in the input (i.e. fixed variables) for the Dutch beam trawl and demersal fleet. Based on short term profit maximization it is clear that it is optimal to make as much use of the available capital as possible. It also shows that the capacity of the fleet is almost fully used in 2013 and it can be expected that a reduction of capacity will have an immediate effect on the output of the sector.

The results also show that efficient vessels are on average younger, smaller and have on average both higher fixed and variable costs. The revenue of the efficient vessels is also significantly higher. Efficient vessels are especially catching more plaice. Catch of sole is similar between efficient and non-efficient vessels.

The economic capital utilization can be used to predict investments. Results show that vessels with a low capital utilization are far less likely to invest in innovative gears than vessels with a high capital utilization. Vessels with a capital utilization that is higher than unity almost always will choose to invest in innovative gears.

While it is difficult to provide real quantitative investment decisions based on a data envelopment analysis, this study has shown that data envelopment analysis can be a useful tool in estimating potential investment opportunities in the fishing sector. The substantial differences between efficiency levels of vessels and difference in the optimal levels of idleness demonstrate to amount of information that can be generated by using data envelopment analyses in this field.

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WESTERN WATERS

Appendix Sub-case study 1

Appendix 1: Evolution of Nephrops trawlers <12 m and 12-24 m over 2000-2014

Nephrops bottom trawlers (specialized) < 12 m

Nephrops bottom trawlers (specialized) with overall size under 12m is the second main fleet in terms of *Nephrops* landings with 10% contribution to total landings in 2014. The number of vessel involved in this fleet has not changed a lot over the period. Total landing fluctuated between 700 and 1000 tons without specific trend.

Nephrops landings remained quite stable around 300 tons. Other main landings species are monkfishes, European hake and Common sole. Gross revenue in constant Euros ranged from 4 to 6 M€ between 2000 and 2014 with lowest values in 2000 and 2012.

Total landings per vessel fluctuated between 35 and 42 tons except for 2008 when landings peaked at 50 tons. Average landings of *Nephrops* are around 13 tons over the period with a minimum of 9 tons in 2000 and a maximum of 17 tons in 2008. It is difficult to establish a significant trend in *Nephrops* landings per vessel considered the probable data improvements over the period.

Other main landings species are monkfishes, European hake and Common sole. Globally, *Nephrops* dependency increased over the period, from 47% to 62%. The share of monkfish also increased over the period, from 1.5% to 7%. European hake decreased from 14% to 5% and the share of the group of other also declined from 19% to 12%.

Except the period 2000-2002, gross revenue per vessel remained quite stable with 230 k€ over the period (base 100:2014). The gross revenue is sensitive to *Nephrops* revenue considering the high dependency of the fleet to *Nephrops* (see section on contribution-dependency).

Nephrops bottom trawlers (specialized) 12-24 m

This is the main fleet in terms of *Nephrops* landings with 70% contribution to total landings in 2014. Except the year 2000, total landings of this fleet decreased significantly from 10000 tons to 7000 between the beginning of the 2000s and the most recent years. *Nephrops* landings also decreased from about 2600 tons to 1300 tons.

Other main landings species are monkfishes, European hake and Common sole. Gross revenue in constant Euros peaked between 2002 and 2005 with around 55 M€ when it ranged at lower values, between 30 and 40 M€ over the last five years.

If total *Nephrops* landings fell over the period, no significant trend is observed for *Nephrops* landings per vessel and year. *Nephrops* landings per vessel and year were around 24 tons over the period with a minimum of 19 tons in 2000 and a maximum of 30 tons in 2014. Total landings per vessel fluctuated between 75 and 10 tons. Globally *Nephrops* dependency increased over the period, from 50% to 58%.

The share of monkfish also increased over the period, from 6% to 12% but no significant changes are observed for individual species, except the group of other species which decreased. As a consequence, the gross revenue per vessel is sensitive to *Nephrops* revenue with a value in constant euros oscillating between 400 k€ and 450k€ between 2000 and 2014.

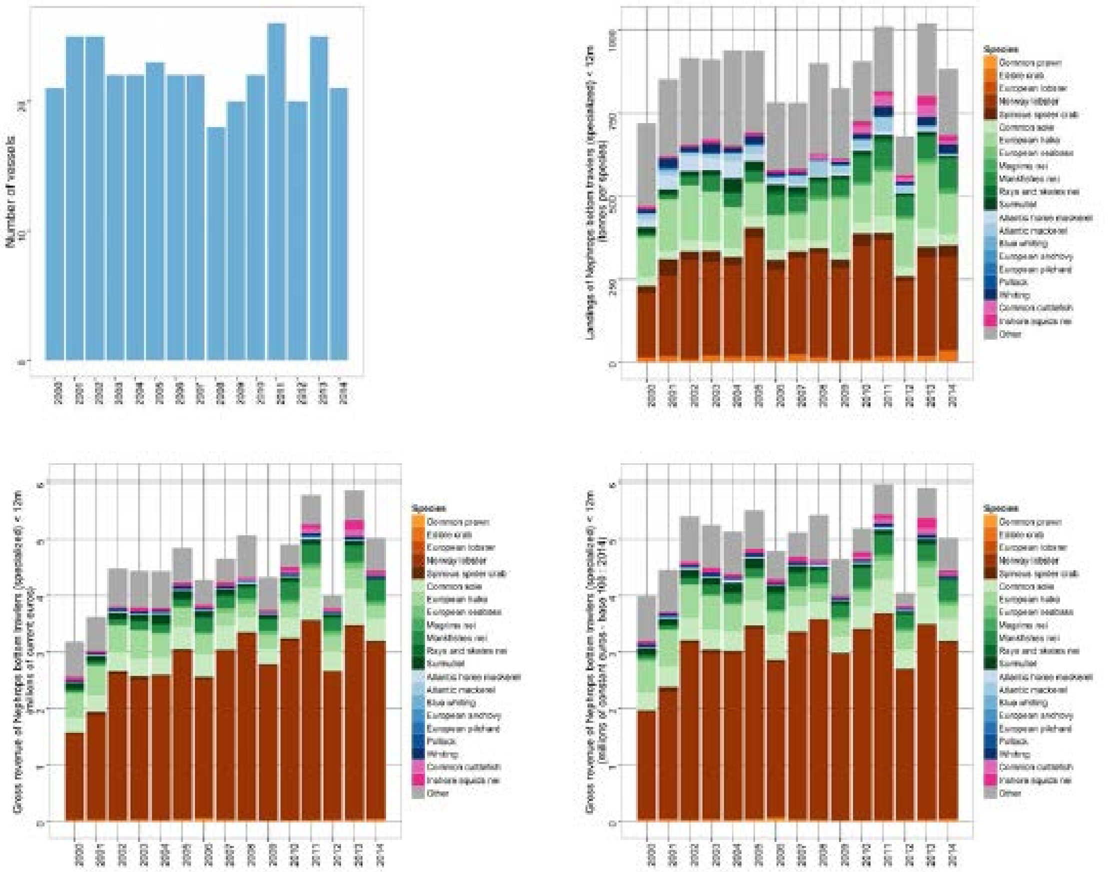

Figure 154. Landings and total gross revenue for the Nephrops bottom trawlers (specialized) <12 m.

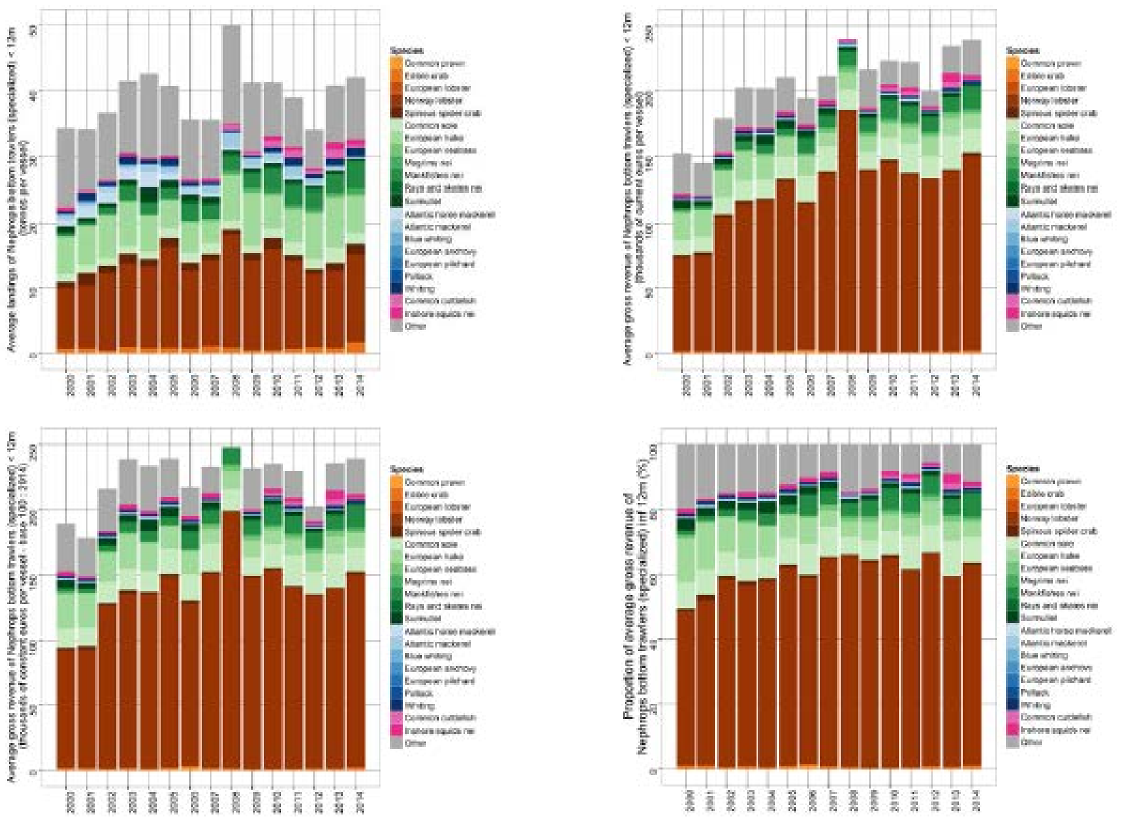

Figure 155. Landings, gross revenue per vessel for the Nephrops bottom trawlers (specialized) <12m.

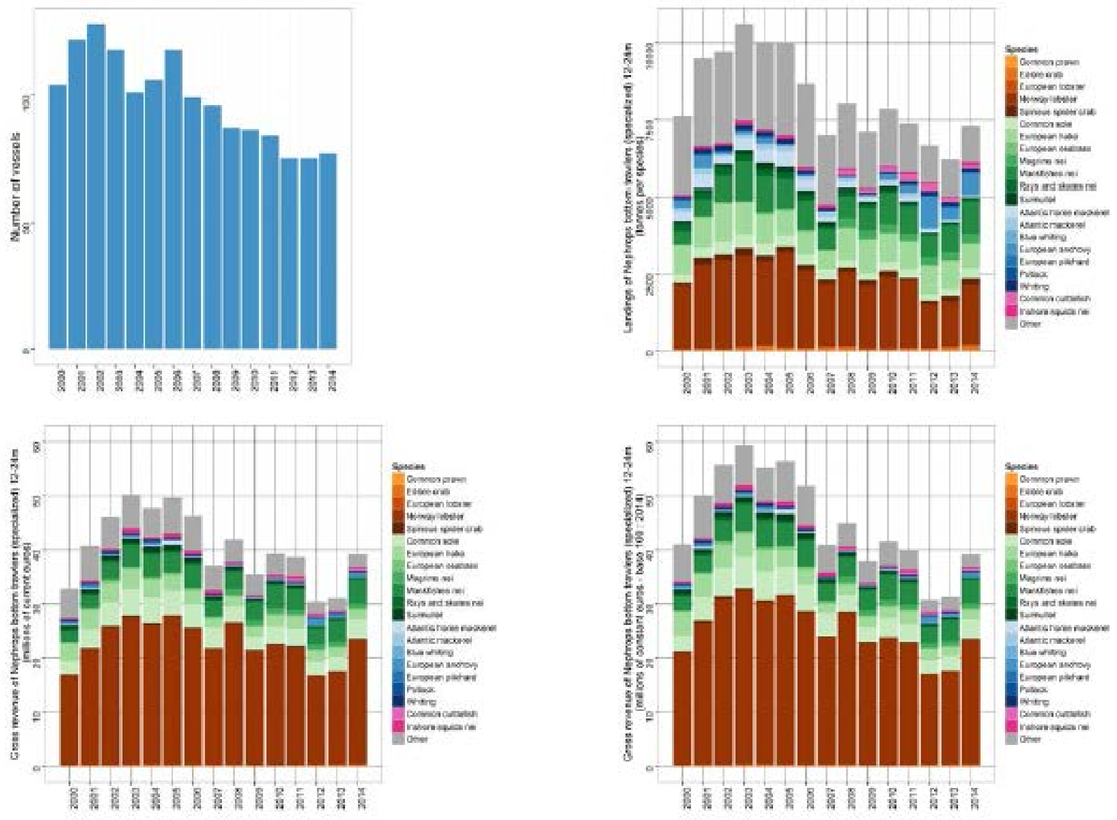

Figure 156. Landings and total gross revenue for the Nephrops bottom trawlers (specialized) 12-24 m.

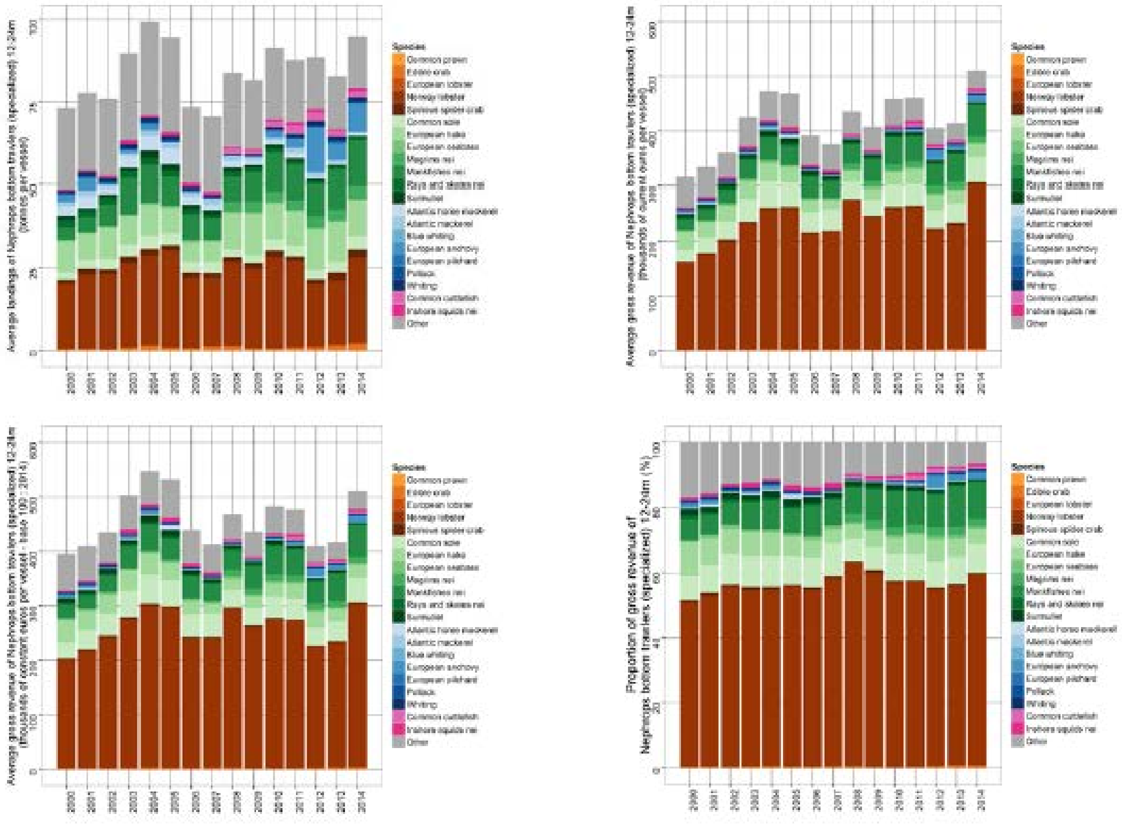

Figure 157. Landings, gross revenue per vessel for the Nephrops bottom trawlers (specialized) 12-24 m.