Final Report

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SUMMARY

BENTHIS developed the scientific basis to quantify the impact of bottom trawling on the seafloor and the benthic ecosystem. Based on insight in how fishing gear affects the seafloor, an assessment framework was developed that provide indicators of impact and seafloor status on a continuous scale that can be applied in the context of the MSFD. The mechanistic approach allows us to set reference values of impact (status) to estimate the proportion of a region or habitat where the impact is below (status is above) the threshold. The methodology combines estimates of trawling intensity with the depth to which the fishing gear penetrates into the sea bed (penetration profile) and the sensitivity of the habitat. Habitat sensitivity is estimated from the longevity composition of the benthic community that is related to the recovery rate. The mortality imposed by trawling was shown to be related to penetration depth of the fishing gear. The framework was applied to explore which fisheries had the greatest impact and which habitats were impacted the most.

Fishers concentrate their activities in only a part of their total fishing area. These core fishing grounds are characterised by a relative low status (high impact). Additional fishing in these core grounds have only a small impact. In the peripheral areas where fishing intensity is low, additional fishing will have a much larger impact. Hence, shifting trawling activities from the core fishing grounds to the peripheral areas will increase the overall impact. Shifting activities from the peripheral grounds to the core will reduce the overall impact. This asymmetry provides the possibility to reduce the impact at a minimal cost. It was shown that implementing a habitat credit management system can provide incentives to reduce fishing in peripheral areas at minimal cost.

In collaboration with the fishing industry and gear manufacturers, technological innovations were studied to reduce the impact of trawling. Promising results were obtained showing that (semi-) pelagic otter doors can be applied to reduce bottom impact and at the same time reduce the fuel cost without affecting the catch rate of the target species. Replacing mechanical stimulation by tickler chains with electrical stimulation In the beam trawl fishery for sole, reduced footprint and penetration depth as well as the fuel cost. Electrical stimulation is also a promising innovation to reduce the bycatch and bottom contact in the beam trawl fishery for brown shrimps. Sea trials to replace bottom trawls with pots were inconclusive. Results suggest that creels may offer an alternative for small Nephrops fishers in the Kattegat. In waters off Greece, the catch rates were very low. Sea trials with the blue mussel fishery showed that fishers could reduce their footprint by deploying acoustic equipment to detect mussel concentrations that allow the fishers to more precisely target the mussel beds and hence reduce fishing in areas with low mussel density.

A review of the various case studies carried out in BENTHIS revealed the critical success factors for implementing technological innovations to mitigate trawling impact. While economic investment theory predict that economic profitability should lead to investment in innovative gears, it appeared that many other factors play a role in the successful uptake of new technology such as social, regulatory, technological and environmental factors. For the successful development and implementation of gear innovations, collaboration between fishers, gear manufacturers, policy makers, scientist and society is important.

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INTRODUCTION

Benthic ecosystems provide important goods and services, such as fisheries products and supporting, regulation and cultural services. There is serious concern about the adverse impact of fisheries on benthic ecosystem which may negatively affect the fisheries yield and integrity of the sea bed. To develop an integrated approach to the management of human activities in the marine environment, in particular fishing, there is a need to develop quantitative tools to assess the impact of fisheries on the benthic ecosystem and at the same time collaborate with the fishing industry to develop innovative technologies and new management approaches to reduce the impact on benthic ecosystems.

The FP7-project BENTHIS was developed to provide the knowledge and tools required to apply the ecosystem approach to fisheries management within the context of the Common Fisheries Policy and the Marine Strategy Framework Directive. The objectives of the project are given in Table 1. BENTHIS studied which benthic ecosystems and habitats are most sensitive for fishing impacts; which fishing gears have the biggest impact upon benthic systems; how does the impact of fishing compare to the impact of natural disturbance. In consultation with stakeholders, options to mitigate the adverse impacts of fishing were explored. Field trials were conducted with fishing industry partners to explore how innovative technology can contribute to mitigate the impact, and desk studies were conducted to explore the potential contribution of innovative management. Finally, the socio-economic implications of mitigation measures were studied.

BENTHIS covered the major regional EU-seas, including the Baltic Sea, North Sea, Western Waters, Mediterranean Sea and Black Sea, and studied the major bottom fishing gears used in Europe (Table 2). BENTHIS adopted a multi-disciplinary approach, including fisheries ecologists, benthic ecologists, theoretical ecologists, gear scientists, economists and social scientists. The BENTHIS consortium included 33 partners representing research institutes (applied research institutes and academic institutes) as well as fishing companies and gear manufacturers. Particular attention was paid to organise stakeholder consultation.

This report summarises the main results.

Table 1. Objectives of BENTHIS

Provide the knowledge base to

- assess status of benthic ecosystems on a regional basis
- support indicators of Seafloor Integrity

Develop tools to

- assess impact of bottom trawling on the structure and functioning of benthic ecosystems.

Study and test in close collaboration with the fishing industry

- innovative technologies to reduce the impact on a regional basis (Baltic, North Sea, western waters, Mediterranean and Black Sea)

Develop in consultation with the fishing industry and other stakeholders

- sustainable management plans that reduce the impact of fishing and quantify its ecological and socio-economic consequences

Table 2. Fishing gears studied in the five case study areas

	Baltic Sea	North Sea	Western waters	Mediterranean	BlackSea
Otter trawl	X		X	X	
Beam trawl		X			X
Nephrops trawl	X		X		
Shellfish dredge	X		X		
Pots			X	X	X

TRAWLING IMPACT AND STATUS OF THE SEA FLOOR

BENTHIS developed an methodology to assess the impact of bottom trawling on the sea floor. The methodology is mechanistic and builds on how bottom trawling gear affects the seafloor and the benthic community. The BENTHIS approach, illustrated in Figure 1, combines information on the fishing pressure with information on the sensitivity of the seafloor habitats to estimate the impact of bottom trawling.

Fishing pressure estimates includes an estimate of the gear footprint (swept area per fishing hour) of each fishing gear and the corresponding penetration profile (percentages of the footprint where the gear penetrates less than or at least 2 cm into the sediment). Gear penetration appeared to be a crucial factor as it was shown to determine the mortality imposed on the benthos. The sensitivity of the seafloor is estimated from the longevity composition of the habitat, which was found to influence the recovery rate of the organisms. The impact was estimated by combining the fishing pressure and longevity composition at a resolution of grid cells of 1x1 minute latitude and longitude (approximately 2 km^2 at 56°N). The impact estimates at the level of the grid cell were then combined at the level of the region or habitat, based on the spatial distribution of seafloor habitats and the extent of trawling (footprint) and the intensity profile. BENTHIS developed three different methods that combine the fishing pressure and the habitat sensitivity to estimate the impact on a continuous scale. In the following sections, the different steps in the impact assessment will be described in more detail.

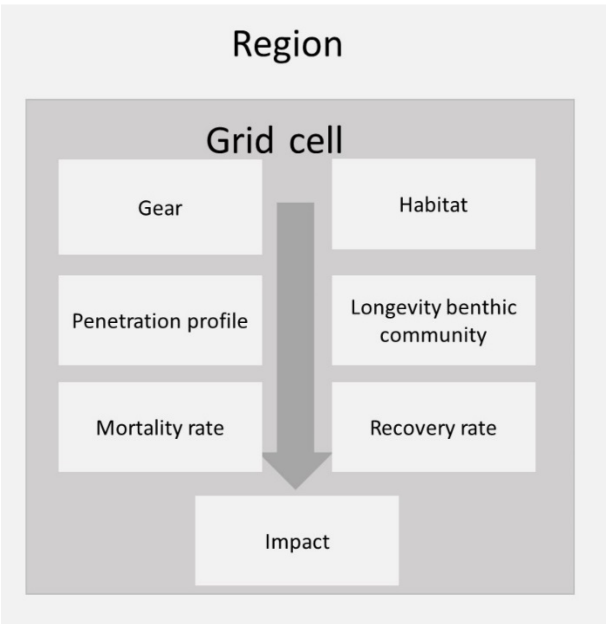

Figure 1. The BENTHIS approach

Gear type and fishing intensity

BENTHIS compiled critical information about the dimensions of the gear components of the different European fisheries (metiers) to estimate the footprint of each metier (seafloor area trawled per hour of fishing) and to estimate the trawling intensity (Eigaard et al., 2016, 2017). Metiers greatly differ in their footprint (Figure 2). Scottish seining has the largest footprint of 1.6 km^2 of which 0.08 km^2 has an impact at the subsurface level (sediment penetration ≥ 2 cm). Beam trawling for flatfish ranks low when comparing overall footprint size/hour but ranks substantially higher when comparing only impact at the subsurface level (0.19 km^2).

Trawling intensity maps were estimated by combining the fishing position recorded by VMS with the metier information of the vessel from the EU-logbooks and the estimate of the typical footprint for each metier (Figure 3). Mean trawling intensity ranged between 0.5 and 8.5 times per year in waters down to 200m depth, but was slightly less in the deeper water (200-1000m). Highest intensities were recorded in the Skagerrak-Kattegat, Celtic Sea, Bay of Biscay, Iberian Portuguese area, Tyrrhenian Sea and Adriatic Sea. The analysis further showed that only parts of the management areas (or habitats) were trawled. Between 15% and 72% of the seabed area within the management areas examined was untrawled (Eigaard et al., 2017). This estimate applies to the 3-year study period (2010-2012). It is unlikely, however, that the untrawled seafloor in the study period will remain untrawled when studied over a longer time period. A more cautious estimate of the untrawled seafloor is given by the proportion of the grid cells without trawling activities, which ranged between 1 and 47%. Within the total area trawled, trawling is highly aggregated with 90% of the effort occurring in around 50% of the grid cells. This implies room for a significant reduction of trawling impact at a minimal cost for the fishery. Because of the aggregated nature of trawling, the footprint estimates are scale (grid cell size) dependent.

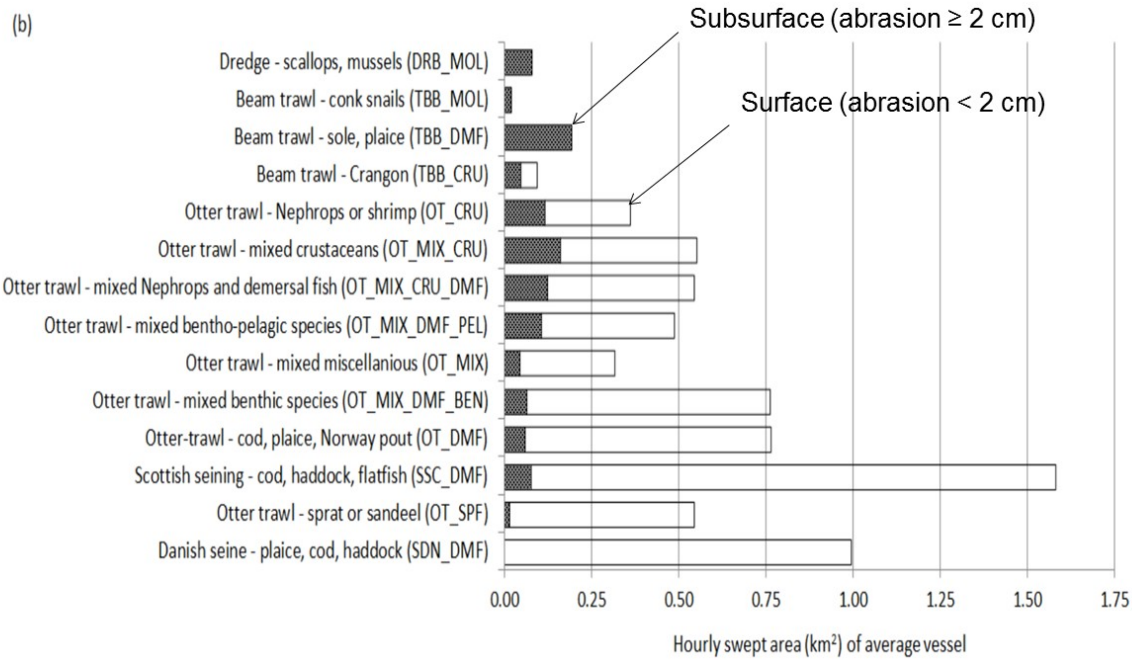

Figure 2. Footprint of an average vessel of the 14 European bottom trawling metiers (Eigaard et al. 2016)

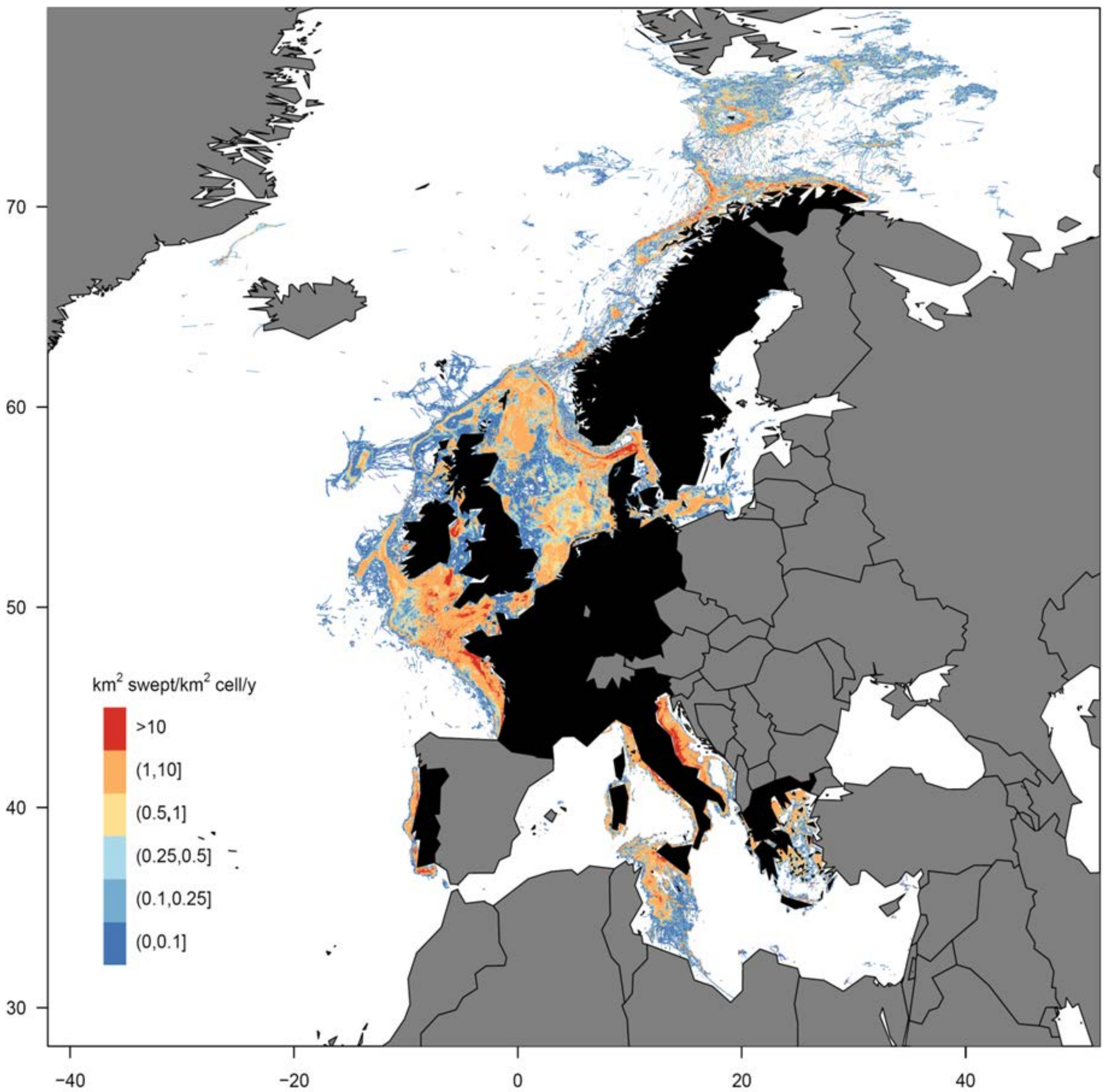

Figure 3. Mean annual trawling intensity at the seabed surface at a scale of 1x1 minutes latitude and longitude. Results are based on VMS recordings of fishing activities and logbook data for the period 2010-2012 from countries indicated in black.

Habitat sensitivity

The sensitivity of the benthic community can be estimated from the biological traits of their constituent species. The analysis of a broad spatial data set on the biological trait composition from a wide range of study areas representing different habitats and regions ranging from northern Norway to the Mediterranean Sea revealed that body size and longevity (= life span) were the most important traits when considering the impacts of bottom fishing on seabed integrity (Bolam et al., 2017). The relevance of longevity is due to its relation with the recovery rate of the organism (Hiddink et al., in prep). Hence, once we know the longevity composition of the community, we can estimate the recovery rate of the community.

The longevity composition of the community differed across habitats (Figure 4) (Rijnsdorp et al., 2016b). Coarse sediments with gravel were characterised by a larger proportion of long-lived organisms. The proportion of long-lived taxa was high in stable habitats with a low level of natural disturbance. Habitats exposed to a high natural disturbance due to tides or waves, were characterised by a low proportion of long-lived species.

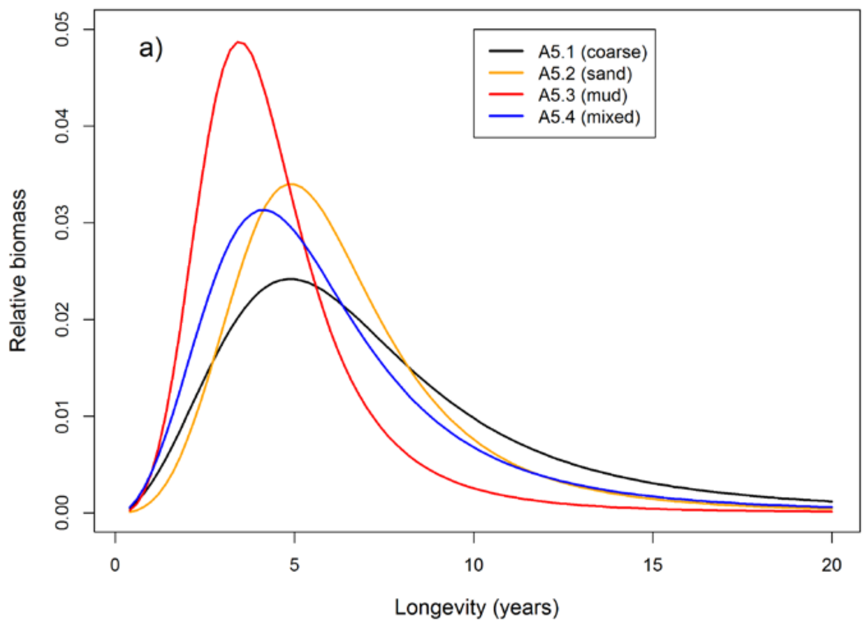

Figure 4. Longevity (life span, years) composition of the benthos in the four main seafloor habitats.

Estimating trawling impact

Three methods were developed to estimate the impact of trawling. All three methods produces an estimate of the impact on a continuous scale ranging from 0 (no impact) to 1 (maximum impact). The 1st method (LL1, Longevity 1) assumes that benthos with a longevity of more than the average interval between two successive trawling events will be potentially affected by bottom trawling. Hence the impact can be estimated as the proportion of biomass of those taxa that have a longevity of less than the reciprocal trawling intensity (Rijnsdorp et al., 2016a). The 2nd method (LL2, Longevity 2) builds on the observation that bottom trawling shifts the longevity composition of the community towards shorter lived species and estimates impact as the change in the median longevity of the community relative to the median longevity of the untrawled sea floor (D1.2, Rijnsdorp et al., 2016). The 3rd method (PD2, population dynamic method) estimates the impact of bottom trawling in terms of the reduction in the benthic biomass relative to the carrying capacity of the habitat (Pitcher et al., 2017) given a gear specific depletion rate and a longevity specific recovery rate (Hiddink et al., 2017; in prep). Meta-analysis provided estimates of the depletion rate imposed by trawling for different fishing gears and for the recovery rate of different types of benthos after a fishing event. Depletion rate increased with the penetration depth of the gear, while the recovery rate decreased with longevity of the benthos (Figure 5). The differences in the recovery rates of the community were estimated from the habitat-specific longevity composition of the benthos.

Sediment resuspension

(O'Neill and Ivanović, 2016) developed models to estimate the resuspension of sediments of various gear components. BENTHIS has elaborated these studies to derive predictive relationships which can be linked to the gear dimensions collated by Eigaard et al (2016) to map the sediment resuspension by bottom trawling. These models can be incorporated in the trawling impact assessment methodology described below.

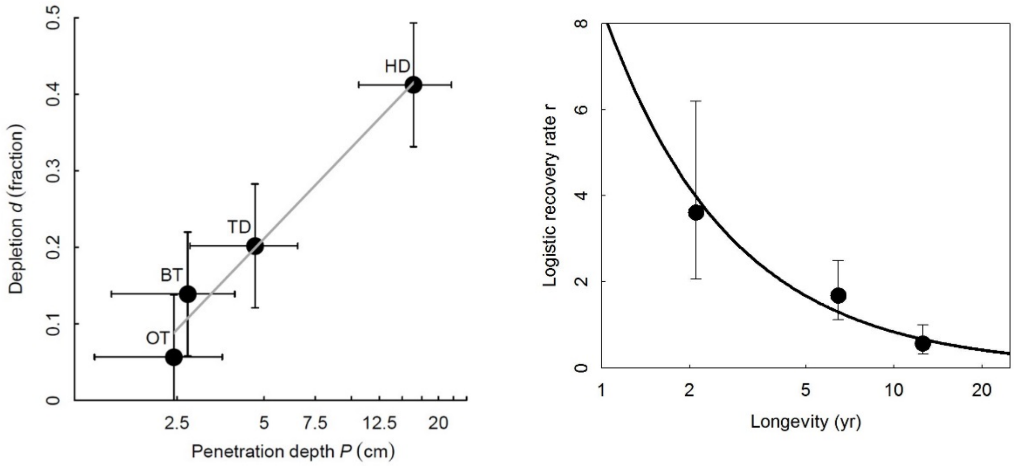

Figure 5. Results of the meta-analysis on the depletion and recovery rates of benthos. Left panel: Relationship between the depletion rate (mortality) caused by a trawling event and the penetration depth of otter trawls (OT), beam trawls (BT), dredges (TD) and hydraulic dredges (HD) (Hiddink et al., 2017); right panel: relationship between r and longevity estimated and longevity estimated from gradient studies. The points and error bars are r estimates and their 95% confidence intervals, while the line and they grey polygon are the fitted regression line and its 95% confidence interval (Hiddink et al., in prep).

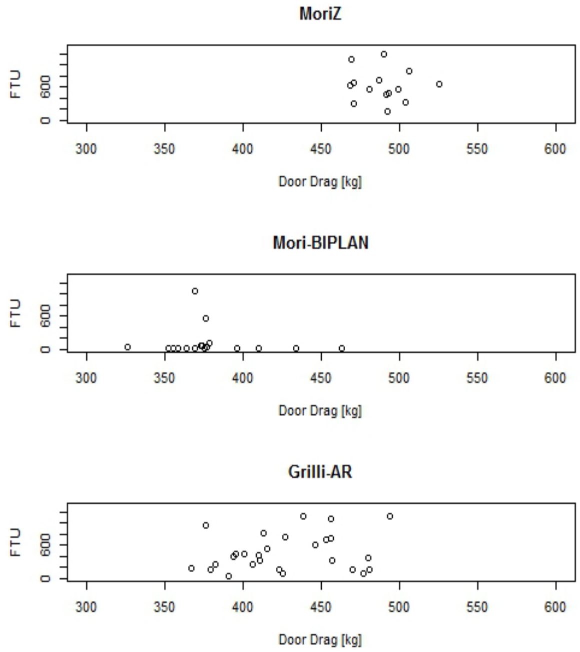

Figure 1. Comparison of sediment resuspension (FTU) against the advance resistance (drag) for a traditional otterboard (MoriZ) used as a reference, and two innovative otterboards (Mori-BIPLAN and Grilli-AR).

A methodology deriving from O'Neill and Ivanović (2016) was adopted to evaluate the physical impact of bottom otter-boards (Notti et al., in prep.). The sediment resuspension generated by the otter-board and the drag of the door were measured for traditional end innovative otter-boards order to define a assessment methodology relating typology and size of the otter-board to the physical disturbance of the sea bed (Figure 6).

The resuspension of the plumb was measured also with Side-scan sonar and a geometric evaluation of the size of the plumb was obtained, as a cross section area. The summarized evaluation, reported in Table 3, showed that the traditional-reference door (MoriZ) generated the largest section of plumb (S[m2]) with the highest resuspension density (FTU), while the MoriBIPLAN, one of the innovative doors developed within BENTHIS project, showed the lowest overall impact.

Table 1.

DoorType	W[m]	H[m]	S[m^2]	FTU	Resuspension [FTU*m2]	Rank	
MoriZ	2.44	2.10	5.12	556.24	2850.17	1	Highest impact
MoriZ	1.80	1.90	3.42	250.19	855.65	2	Highest impact
Grilli-AR	1.50	1.70	2.55	101.30	258.32	3	Medium impact
Grilli-AR	1.20	1.00	1.20	126.90	152.28	4	Medium impact
Mori-BIPLAN	1.90	1.50	2.85	19.44	55.40	5	Lowest impact
Mori-BIPLAN	1.54	1.94	2.99	6.85	20.47	6	Lowest impact

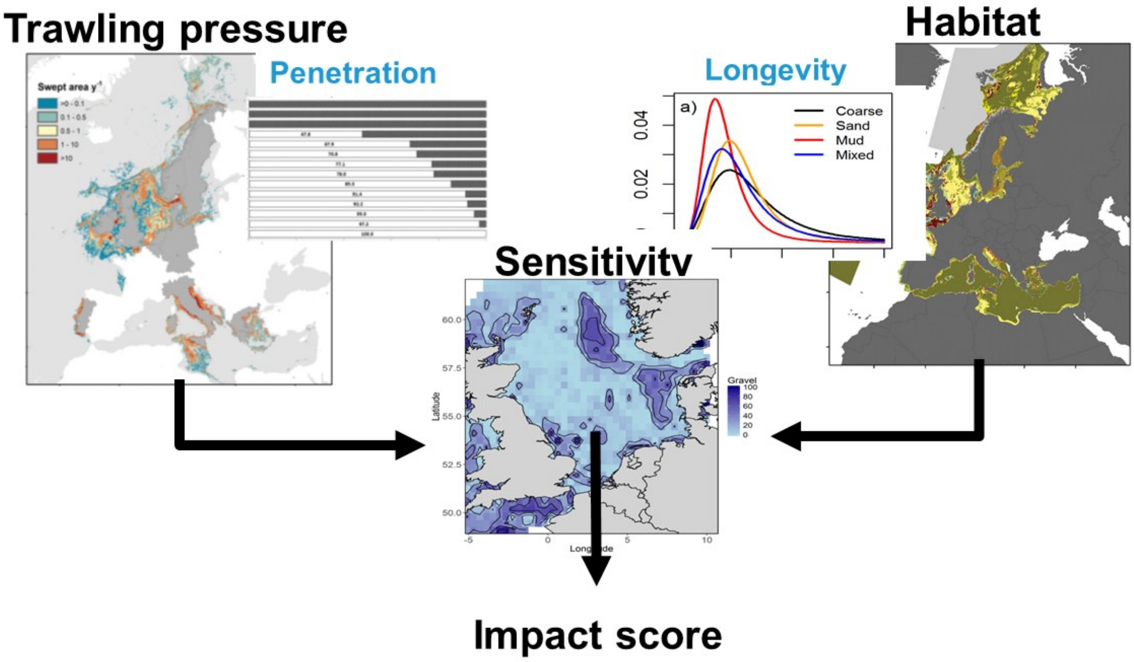

Figure 7. Schematic illustration of the procedure to estimate the impact score from the trawling intensity and penetration profile of the fishing gears and the different habitat sensitivity of the benthos

Impact assessment and indicators

The impact assessment methodology developed is generic and can be applied to any region and bottom contacting fishing gear if information on the penetration profile of gear elements and habitat characteristics (sediment grain size, bottom shear stress) is available. Because the method provides continuous driver – state relationships, it is particularly suitable to set reference levels for GES and critical trawling intensity and to address trade-off questions between impact and landings or value of the fish methodology can be updated each MSFD cycle and tested by field studies. Further work is needed to validate the assumptions and improve the parameterisation.

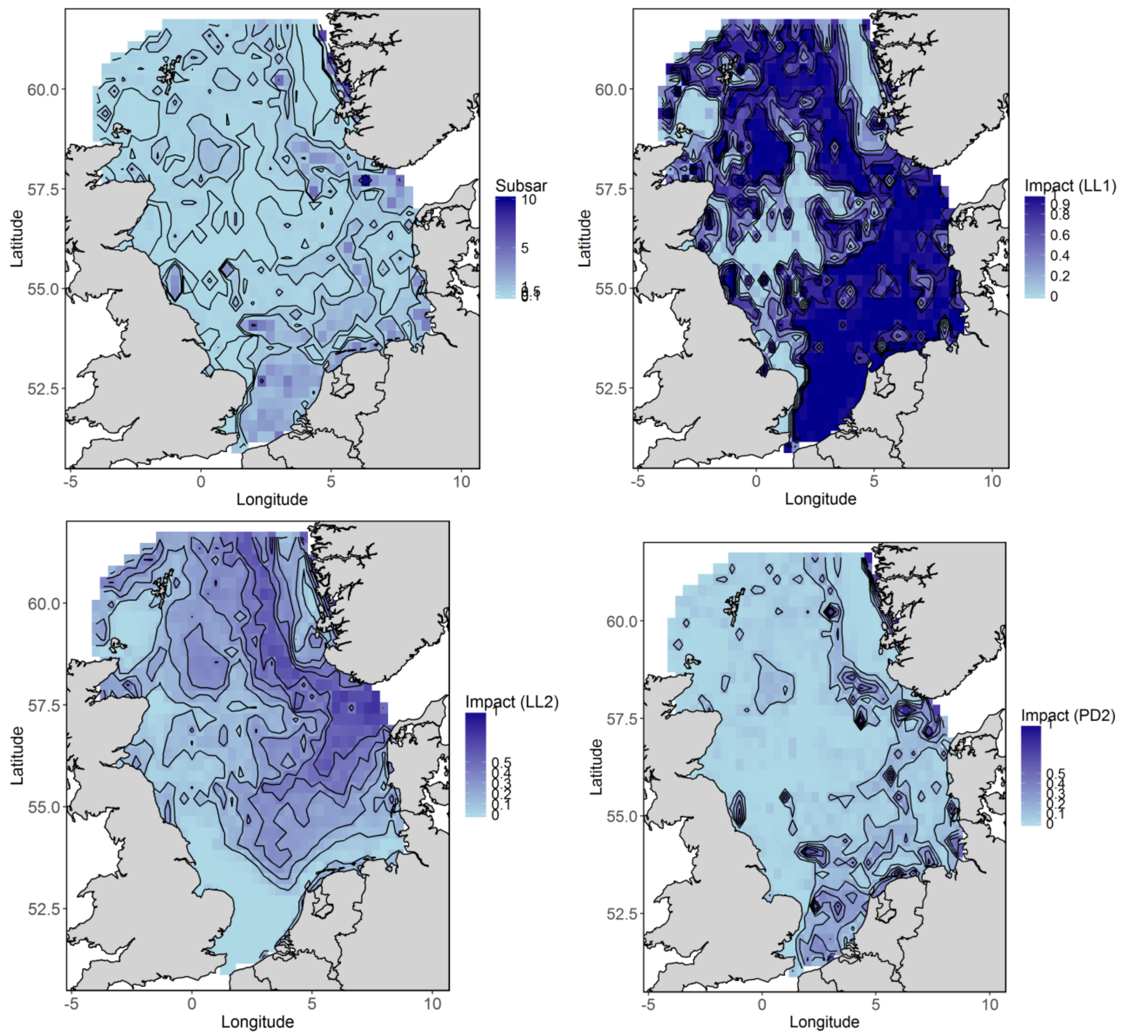

Figure 8. Maps of the subsurface trawling intensity and trawling impact scores estimated by the three assessment methodologies (LL1, LL2, PD2).

Impact assessment example for the North Sea

The three assessment methods developed were used to assess the impact of the bottom trawl fishery in the North Sea given the mean annual trawling intensities observed in the period 2010-2012 (Figure 8). Although the maps of the trawling impact scores appear to be very different, the impact scores are significantly correlated. The differences are mainly due to the different responsiveness of the methods. LL1 is particularly sensitive for trawling intensities between 0 – 1 $year^{-1}$, while LL2 and PD2 respond to changes in trawling up to 4 $year^{-1}$ and 10 $year^{-1}$, respectively. A true difference is between LL2 and the others because it takes account of the effect of natural disturbance that reduces the effect of bottom trawling.

All three methods showed higher impact in muddy (A5.3) and mixed sediments (A5.4) as compared to sand (A5.2) and coarse (A5.1) sediments (Figure 9). The high impact coincided with the higher trawling intensity and the larger proportion of the habitat trawled. The difference in the absolute level of the impact scores is related to the difference in responsiveness of the methods. LL1 already responds to fishing pressure at low trawling intensities, whereas LL2 and PD2 are more responsive to higher levels of trawling intensity.

The impact of each metiers was assessed by taking account of the size of their footprint. When assessed against the untrawled reference (top panels of Figure 8), OT_CRU, OT_MIX and OT_DMF showed the highest impact, followed by OT_MIX_2, TBB_DMF and SSC. DRB_MOL, SDN, OT_SPF and TBB_CRU showed the lowest impact. Impact scores are substantially lower when assessed against the trawled reference (bottom panels of Figure 10). This particularly applies to LL1 which shows the highest responsiveness to low levels of trawling intensity, but the effect is relatively small for the PD2 method. By changing the reference, the rank of the impact score changes across the metiers. Using the trawled reference raises the relative impact of TBB_DMF (LL1, LL2) and OT_MIX_1 (LL1), while it lowers the impact of OT_DMF (LL2). The difference in impact scores between the untrawled and trawled reference is due to the degree of overlap between the footprint of the metier and the footprint of the other metiers..

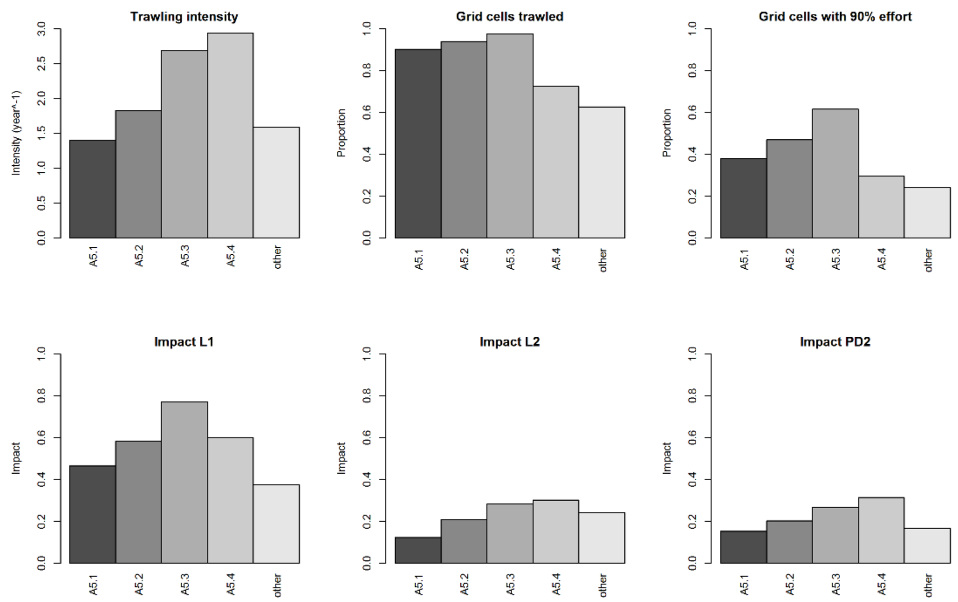

Figure 9. Pressure and impact indicators of all bottom trawling activities by main sea floor habitat (A5.1 – coarse; A5.2 – sand; A5.3 – mud; A5.4 – mixed sediments).

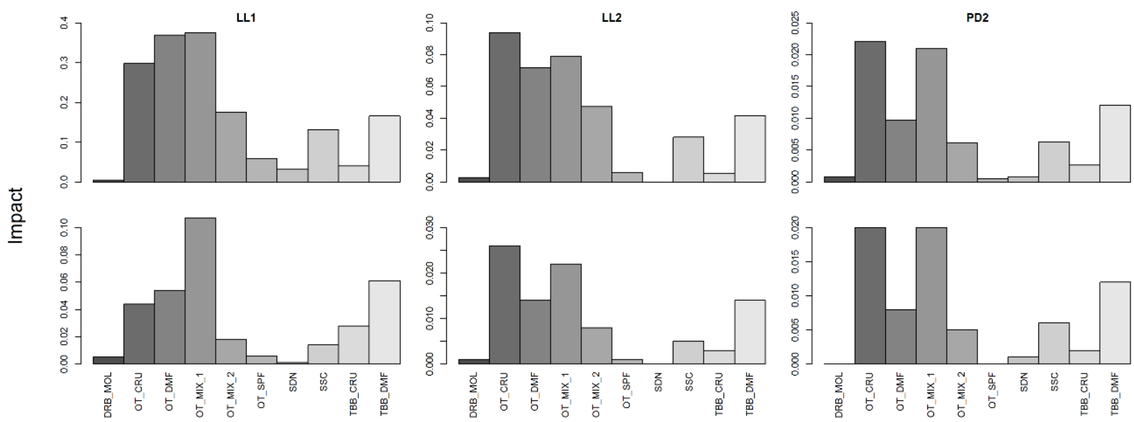

Figure 10. Impact score by metier assessed against the untrawled reference (top panels) and the trawled reference (bottom panels) with LL1 (left panels), LL2 (middle panels) and PD2 (right panels). Impact scores refer to total North Sea (0-1000 m). DRB – dredge fisheries for molluscs; OT_CRU – otter trawl fishery targeting crustaceans (Nephrops, pandalus); OT_DMF otter trawl targeting demersal fish; OT_MIX_1: otter trawl targeting Nephrops and demersal fish; OT_MIX_2: otter trawl targeting roundfish; OT_SPF: otter trawl targeting industrial species; SDN: danish (anchor) seine; SSC: Scottish seine; TBB_CRU: beam trawl fishery for brown shrimp; TBB_DMF: beam trawl fishery for flatfish.

Indirect effects of fishing

Fishermen claim that bottom trawling may increase the food for fish by increasing local productivity. This hypothesis, however, is controversial as others claim that bottom trawling may reduce the food availability (Kaiser et al., 2016). BENTHIS explored the effect of bottom trawling on the food of fish under a range of conditions (van Denderen et al., 2013). It was shown that the effect of trawling depended on the importance of top-down or bottom-up processes regulating the benthic community and prey preferences of the fish. Under certain conditions trawling will decrease the food for fish, but under other conditions trawling may increase the food for fish. A review of the literature showed that the latter may occur in benthivorous fish living in sandy sediments (Collie et al., 2016). A field study carried out in the Kattegat provided support for the hypothesis. It was shown that the condition of plaice was highest at intermediate trawling intensity (Hiddink et al., 2016). BENTHIS concluded that: (1) indirect effects will be subtle in existing empirical data; (2) understanding the benthic ecosystem is essential for choosing sensible management measures; (3) indirect effects are most apparent at low fishing intensity, hence we may expect more and stronger indirect effects in the future in areas where fishing pressure has been reduced.

SUSTAINABLE MANAGEMENT AND MITIGATION MEASURES

BENTHIS has explored a number of technological innovations to reduce the impact on the benthic ecosystem. The innovations studied were supported by the results of a questionnaire survey among stakeholders carried out at the beginning of the project to prioritise the options for mitigation. Sea trials were carried out in close collaboration with the fishing industry.

From active to passive gears

The use of passive gears instead of active gears is one of the options to reduce the impact of fishing on the seafloor and the benthic ecosystem. Experiments with creels, pots and traps have been conducted in the Kattegat and the Mediterranean. The Kattegat creel experiments showed that creels can be an economically viable and ecologically sustainable alternative to trawl fishery for certain (smaller) vessels in certain areas. The creels are highly selective and have a low by-catch. In the Mediterranean pot/trap experiments the viability was questionable and might only be viable in an artisanal fishery. The viability will also depend on the history of the fishing ground. If the area is a prior trawl ground, before trap fishery may be viable, areas may need a recovery plan.

From demersal to (semi-) pelagic otter boards

Otter trawls is the dominant fishing gear used in European Seas and the boards are the gear components having the deepest penetration into the sediment (Eigaard et al., 2016). A series of innovative otter boards were studied Mediterranean and the Bay of Biscay. A series of engineering tests were carried out in wind tunnel and flume tank, for a deeper analysis of otter-boards behaviour and performances. A complete assessment of the performances of the otter-boards, discussed by Mellibowksy et al. (2015) allowed for the mapping of efficiency and of centre of pressure the otter-board (Figure 11), which is a primary technical specification to achieve highest performances and reduced drag of the otter-boards. The results show that a shift from traditional demersal otter boards to novel (semi-) pelagic otter boards will reduce the penetration of the gear, and will reduce the drag and resuspension of sediments. The overall footprint (surface area of the seafloor swept by the gear per unit of time), which is mainly affected by the ground rope and sweeps, will not be affected. Although the catch efficiency (catch per unit of effort) appears to be unaffected and the fuel consumption is reduced, the uptake of the innovation is hampered by the investment costs and the operational demands of handling the (semi-) pelagic doors. Some of the otter-boards tested and developed within BENTHIS project entered in the Mediterranean market of bottom otter trawling segment (Figure 12).

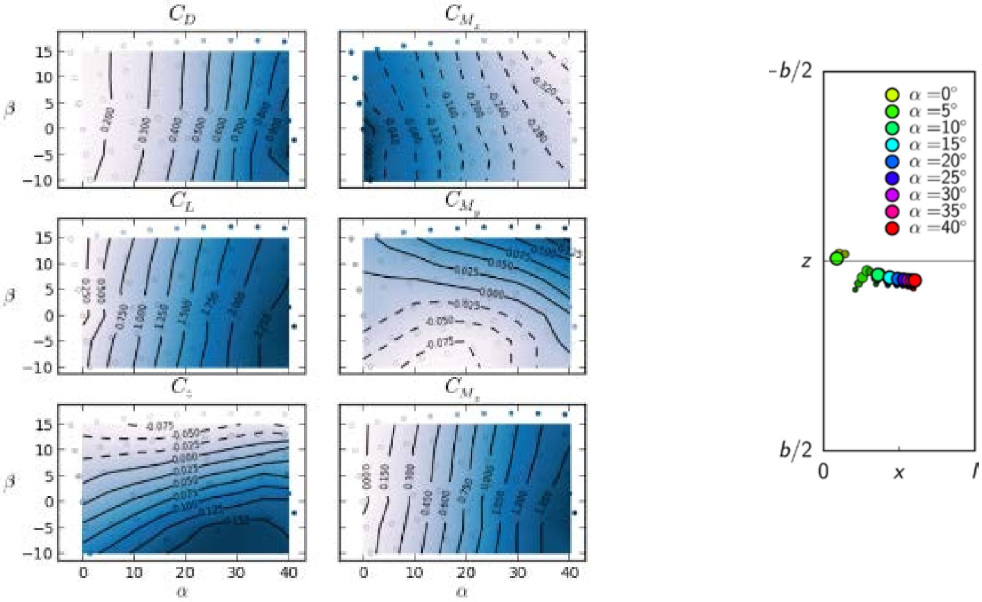

Figure 11. Analysis of data collected from wind tunnel tests. The picture on the left shows the drag coefficient (C_D), the spread coefficient (C_L) and the lift coefficient (C_Z), the momentum coefficients ($CM_{X,Y,Z}$), against the attack angle (a) and roll angle (b). On the right the position of the centre of pressure for different attack angles.

Figure 12. Novel otter-boards developed within the project BENTHIS. On the left Grilli-AR, on the right Mori-BIPLAN.

From mechanical stimulation to electrical stimulation

Mechanical disturbance by heavy gear components is responsible for the adverse effect of bottom trawling on the seafloor. In the flatfish fishery, beam trawls are used towing a series of tickler chains over the seafloor to startle flatfish, in particular sole, out of the sediment. Electrical stimulation is a promising alternative for mechanical stimulation. In the North Sea beam trawlers targeting sole have successfully shifted to electrical stimulation using pulse trawls. The electrical stimulus invokes a cramp response which immobilises the fish. In collaboration with the fishing industry two field experiments were conducted to measure the sediment penetration and direct benthos mortality induced by the traditional tickler chain beam trawl and the novel pulse trawl. The results show that the pulse trawls are lighter and are towed at a slower speed (5 knots or less) than the traditional tickler chain beam trawls (towing speed between 6 and 7 knots). As a consequence the pulse trawl has a smaller annual footprint. Pulse trawls show a reduced penetration into the sediment and a reduction in the bycatch of benthos. Although no significant differences in trawl path mortality of benthos was found, power analysis showed that a larger sample size would be required to detect a difference in mortality imposed by the pulse trawl as compared to the traditional beam trawl. Because pulse trawlers may be used in other habitats, the change in effort distribution over the habitats needs to be taken into account when estimating the change in impact of fishery for sole when the beam trawl is replaced by the pulse trawl.

Electrical stimulation may also be successfully applied in the fishery for brown shrimp to improve the selectivity and reduce the bycatch and the contact with the seafloor.

Innovative management

Scientific evidence supports the implementation of marine protected areas (MPAs) to protect vulnerable marine ecosystems (VMEs) such as cold water corals reefs and other biogenic habitats. For the soft sediment habitats dominating the continental shelf areas of Europe, the impact of bottom trawling can be reduced by introducing a habitat credit system, possibly in combination with technical measures. The catch efficiency indicators proposed to assess the performance of such management tools in terms of conserving the seafloor while maintaining the fishing opportunities of the fishery were defined as the ratio of the landings or revenue over the fishing disturbance (expressed as swept area multiplied by the recovery time of the benthic community). These indicators showed that catch efficiency is highest in the core fishing grounds. Hence a management tool such as a fisheries credit system which aims at reducing the trawling intensity in the areas outside the core fishing grounds should be able to mitigate trawling impact without compromising the fishing opportunities, i.e. landings or revenue.

Implementation of a habitat credit system was explored in a simulation study of the French mixed bottom fisheries using otter trawls or dredges in the eastern Channel (Batsleer et al., 2017). Habitat credits may reduce the benthic impacts of the trawl fisheries at minimal loss of landings and revenue as vessels are still able to reallocate their effort to less vulnerable fishing grounds while allowing the fishery to catch their catch quota and maintain their revenue. Only if reduced extremely, habitat credits may constrain fishing activities to levels that prevent the fisheries to uptake the catch quota of the target species.

Socio-economic issues

BENTHIS studied the socio-economic aspects of technological innovation and the conditions to successfully develop and introduce innovative gears. With the input from all the case studies, three main types of innovations were studied: from active to passive gears; from demersal to pelagic otter boards; from mechanic to electric stimulation. For the development phase of gear innovations, a number of factors are important. For the successful development of innovative technology the involvement of the industry is necessary. This will warrant user-friendliness and will bridge the gap with current gears. It is also important to give the industry the means to think out of the box (allow testing of “illegal” gears). To develop gears that fit both the goals of policy makers and of the industry, objectives must be reconciled, for example that a reduction in benthic impact will also lead to a reduction in fuel use, or the reduction in bycatch will reduce the sorting time.

While economic investment theory predict that economic profitability should lead to investment in innovative gears, it appeared that many other factors play a role in the successful uptake of new technology. Those factors could be categorised as economic, social, regulatory, technological and environmental drivers. Economic factors include the fuel prices, the wage of the crew and how it changes with the new gear, and access to funding (subsidies or bank loans). Social factors that influence investment decisions in innovative technology are the sharing of information and the long term perspective on the future of the company. Technological factors are related to the possible constraints of the vessel to implement the innovation. Regulatory factors comprise for instance the room for experimentation, legal support, access to the fishery, better selectivity and tighter controls. Finally, environmental factors may stimulate innovations. For instance the criteria set by MSC may stimulate fishers to adopt more environmentally innovative techniques and the perception of fishers to fish more sustainably may be important for his self-image.

In conclusion, it was recognised that to successfully develop and adopt sustainable innovative gears, collaboration between fishers, scientist, gear manufacturers, policy makers and society was important.

STAKEHOLDER INVOLVEMENT

To involve the fishing industry and other stakeholder, a two level approach was adopted. Regional Stakeholder Events were organised in each region to discuss the options for mitigation and to discuss the results of the field trials with stakeholders including the fishing industry, gear manufacturers and NGO's. The regional focus avoided language problems. EU-wide stakeholder meetings were organised at the beginning and end of the project to integrate the findings of the regional stakeholder events. Finally a stakeholder advisory board was established to provide feed-back on the workplan and interpretation of the results.

DISSEMINATION

By 28 November 2017, BENTHIS results were published in 60 peer reviewed publications, while 6 papers are under review and more papers are expected in the coming years. Over 10% of the papers were published in the high impact journals such as PNAS (1), Fish and Fisheries (3), Proceedings of the Royal Society B (2), Journal of Applied Ecology (2). The paper on the trawling footprint of European metiers (Eigaard et al., 2016) was selected as the editor's choice and is classified by Thomson Reuters as a high impact paper. Results have been presented at international scientific meetings and symposia (88 presentations or posters) and numerous national meetings.

BENTHIS results have been input directly in the ICES Advisory process around the development of indicators from the MSFD. The assessment methodology developed in BENTHIS in collaboration with the Trawling Best Practice project (see below) was favourably reviewed by ICES in 2016. And further applied in 2017. BENTHIS developed R-scripts to calculate indicators, provided back-ground documents explaining the methodology and its biological basis and prepared a series of analysis exploring the trade–off between conservation and fish production. Results of the two complementary BENTHIS methods (longevity approach, population dynamic approach) were used by ICES in the draft impact assessment for the North Sea.

Two activities focussed at dissemination and collaboration with researchers outside Europe are worth mentioning. In June 2015, BENTHIS co-organised a twinning meeting to discuss their methods and results with scientist from New Zeeland and Australia. A 2nd global level platform is given by the Trawling Best Practice project led by Ray Hilborn, Simon Jennings and Mike Kaiser. BENTHIS partners (Bangor University, CEFAS, and Wageningen Marine Research) participated in this project. This collaboration has enhanced the dissemination of the BENTHIS results through the joint publications in high impact journals (PNAS, Fish and Fisheries).

The BENTHIS methodology has been applied in the Baltic Sea through the Baltic Boost project.

A BENTHIS newsletter was produced, of which the single news items were distributed through Facebook, LinkedIn and Twitter. BENTHIS fieldwork photos were stored in the digital photo library of IMARES (http://images.wur.nl/cdm/search/collection/coll18/searchterm/benthis/order/nosort) and posted on Instagram.

To enhance the dissemination of the main results of BENTHIS to a wider audience, a series of 5 animation videos (1 -1.5 minute) were produced which summarised the different steps in the assessment methodology. The animation videos were disseminated using social media and made available on the BENTHIS website and youtube.

1. Fishing footprint https://www.youtube.com/watch?v=LR7CC1XGMTc
2. Benthic biological traits https://www.youtube.com/watch?v= tM-jg1RrNQ
3. Sensitivity of seafloor habitats https://www.youtube.com/watch?v=iAghyCWJ4Q0
4. Reducing trawling impacts https://www.youtube.com/watch?v=mDV_Y02Xyao
5. Assessing the impact of trawling https://www.youtube.com/watch?v=JTbYo2An_S0

In the Mediterranean Case Study, novel otterboards were developed by two SMEs and tested in the BENTHIS project. These have been well received in the Italian bottom trawl fisheries. None of the two door manufacturers requested any subsidies, in Italy or elsewhere. This was a clear case where the collaboration between scientists and industry has stimulated technological innovations and economic developments. None of the SMEs decided to patent their design. The main reason is that they did not consider a beneficial strategy against any form of potential plagiarism of fisheries products. Nevertheless, both the SMEs recently commenced the processes for obtaining the trademarks and unambiguously to distinguish their door design properties. Despite they are aware that a trademark does not protect their companies from another company that produces a similar product or uses a similar name.

EPILOGUE

When the project plan of BENTIS was conceived the following salient questions were formulated:

- Which benthic ecosystems and habitats are most sensitive to fishing impacts?
- Which fishing gears have the biggest impact on benthic systems?
- How does the impact of fishing compare to the impact of natural disturbance?
- What options are available to mitigate the adverse impacts of fishing, and how can these options be converted into effective management?
- How can science and the fishing industry be brought together to collaborate on innovative technology and management approaches to mitigate the impact?
- What are the socio-economic implications of changes induced in benthic systems by fishing and of the proposed management actions to mitigate these effects?

Now that the project has almost finished, we can tick off a number of them. We have developed tools to assess the sensitivity of sea floor habitats to trawling impacts and to assess which fishing gears have the biggest impact. A simplified trait based approach using the longevity trait provided the key to develop a quantitative framework. With this framework we could estimate the trawling impact and corresponding state of the sea floor on a continuous scale. This methodological achievement also allows the setting of ecologically meaningful reference levels.

The knowledge base has been improved considerably, mainly by the meta-analysis of existing data using novel approaches. Nevertheless, further work is required to test the assumptions and validate our assessment methodology and to improve the parameterisation by extending the analysis to other regions and a wider range of environmental conditions.

BENTHIS developed in parallel with the Trawling Best Practice project led by Hilborn, Jennings and Kaiser, which addressed similar questions on a global scale with participation from Australia, North America, South America and Europe. Both projects have collaborated intensively and inspired each other.

The BENTHIS methodology developed to estimate footprints at the surface and subsurface level has been adopted by ICES. Two quantitative benthic impact assessment methodologies (PD2, LL2) developed by BENTHIS have been used as a basis for the ICES Advice on benthic pressure and impact indicators (ICES, 2017). The developed impact assessment methodologies are based on a mechanistic understanding of the ecological effects of trawling, parameterised based on the best available empirical data, and are applicable over large spatial scales.

Impact assessments critically depend on how we deal with the interaction of trawling and natural disturbance. Natural disturbance may override the effect of trawling disturbance on the community composition, but this process was only partly captured by one of our impact assessment methodologies. Further work is required to evaluate whether including this interaction between trawling and natural disturbance is essential for an accurate assessment of trawling impacts.

Large differences exist in space in trawling intensity and fisheries landings, and there are large areas with substantial trawling impacts but only small landing. This potentially opens avenues to reduce the trawling impact at a minimal cost to the fishery. Habitat credit systems may be a tool to creative incentives to a fishery to concentrate their activities in the core fishing grounds and reduce the trawling in peripheral fishing grounds.

During BENTHIS, we collaborated with partners from the fishing industry. Language and the high level of abstraction of the scientific presentations and discussions proved a barrier for communication at general project meetings. This did however not play a role at the level of the case study work. The series of regional stakeholder meetings in which we also invited representatives of stakeholders not participating in BENTHIS, enhanced the dissemination of results to a wider audience and provided critical feedback.

Among the technical innovations investigated, the lifting of otter boards and the replacement of mechanical stimulation by electrical stimulation provide promising avenues to mitigate trawling impact. Replacing towed gear by static gear may have potential in specific cases, but is not applicable in all bottom trawl fisheries.

Trawling impact was assessed on the level of all mobile bottom contacting gears and on the level of metiers. The socio-economic consequences, however, will be experienced at the level of the individual fisher. Our current models provide insight in the likely cost and benefits at the level of a fishery. For the assessment of the consequences for individual fishers more detailed models are required.

The adoption of technical innovations critically depend on the economic performances of the innovative gears. Several technological innovations may reduce the fuel consumption and reduce cost, which may enhance the uptake by the fishery. However, in BENTHIS we also identified a number of other factors that have direct consequences on the development and adoption of innovation. Those factors are social (e.g. information sharing between vessels/fisheries), regulatory (e.g. being given the means to explore out of the legal boundaries), technological (the gap between the utilisation of traditional and innovative gears can be large, think going from trawl to traps, which completely changes the fishing practices of the fishers on-board) and environmental (the perception to fish in a more sustainable way is increasingly important for fishers). Better understanding those factors that affect investment behaviour can lead to better management measures designed to facilitate the adoption of more sustainable fishing practices.

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