BENTHIS

Deliverable 9.16

Minutes of the ICES Symposium "Effects of fishing on benthic fauna, habitat and ecosystem functioning", 16-19 June 2014, Tromsø, Norway

Due date of deliverable: month 21 (June 2014)
Actual submission date: month 23 (August 2014)

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

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 312088

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The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 312088

DOCUMENT CHANGE RECORD

Authors	Modification	Issue	Date
Buhl-Mortensen & Rijnsdorp		1	25 August 2014

SUMMARY

This report provides a brief summary of the ICES Symposium on the Effects of fishing on benthic fauna, habitat and ecosystem functioning organised by Institute of Marine Research in Norway. Topics covered (in order of the number of presentations) included: trawling impacts on the benthic community composition and ecological functioning; technological innovations to mitigate the trawling impact; modelling trawling impacts; indicators of trawling impact. The gears covered were otter trawls targeting crustaceans and roundfish, dredges targeting scallops, beam trawls targeting flatfish, and long lines. Specific attention is given to the contributions of BENTHIS partners.

1. INTRODUCTION

An international ICES symposium on the Effects of fishing on benthic fauna, habitat and ecosystem functioning was held on 17 – 19 June 2014 in Tromsø, Norway. The Symposium was organised by Institute of Marine Research (IMR-Norway) and attended by more than 100 scientist from 18 countries including Europe, New Zealand, Australia and North America. The objectives of the symposium was to review the physical and biological effects of fishing activities to sea bottom ecosystems, look at various technical conservation measures designed to mitigate these effects and ultimately try to quantify the overall ecosystem impact. The symposium was structured around fisheries impacts on different seabed types and communities with sessions divided into the following themes:

- Soft bottom/infauna (macrobenthos) community composition
- Mixed bottom/epifauna and habitat forming megafauna
- Gear effects and development.

Members of organising committee were: Lene Buhl-Mortensen, head of committee (IMR-Norway), Børge Holte (IMR-Norway), Carsten Hvingel (IMR-Norway), Mariano Koen-Alonso (DFO-Canada), Francis Neat (Marlab-Scotland). Technical support was delivered by the ICES Secretariat and IMR. The symposium was sponsored by ICES, Northwest Fisheries Organisation (NAFO) and IMR.

Directly following the Symposium, a 2-day Twinning Workshop was organised by the coordinator of BENTHIS in collaboration with Roland Pitcher (CSIRO, Australia) and Ian Tuck (NIWA, New Zealand). The logistics of the meeting were organised by Patricia Groo-Nagy (BIO-Triangle project). The Twinning Meeting will be reported separately.

This report summarises the topics that were covered at the ICES symposium and the key findings of the symposium relevant from the BENTHIS perspective, and presents the contributions of the BENTHIS partners.

2. HIGHLIGHTS OF THE SYMPOSIUM

The Symposium covered a wide variety of topics and approaches in 44 oral presentations (including 7 key note papers) and 28 posters,. Thirty papers dealt with trawling impacts on the benthic community composition and ecological functioning and 14 papers dealt with technological innovations to mitigate the trawling impact. Four papers used a modelling approach to explore trawling impacts and 2 dealt with indicators for trawling impact. The six key note papers reviewed the session topics: effects on soft bottom communities with main focus on shallow North Sea, effects on mixed bottom communities covering VMEs (e.g. coral and sponge communities) from continental shelf to deep sea mounts, bottom impact from fishing gear and gear development. The gears covered were otter trawls targeting crustaceans and roundfish, dredges targeting scallops, beam trawls targeting flatfish, and long lines.

Trawling impact

The majority of papers reported on field studies dealt with changes in benthos that was studied along a trawling intensity gradient The studies showed that the effect of trawling was context dependent and differed between habitats. Trawling impacts were generally less in areas of high natural disturbance. Although there are difficulties around confidentiality issues and data access for VMS data they were widely used to quantify the trawling gradients. Problems related to the use of VMS data as proxy for pressure were discussed. Depending on depth, gear and bottom type quantification of pressure on the seafloor and benthos from VMS data can be a major challenge. However, results of studies attempting to collate VMS data across large geographic areas and countries were presented and looked promising.

Recovery

Relatively few studies dealt with the recovery of the benthic ecosystem, however re-growth in a protected coral reef was presented in a poster.

Ecosystem functioning

Key note papers emphasized the importance of biodiversity in the functioning and resilience of benthic ecosystems. The number of papers dealing with ecosystem functioning were relatively few, in particular experimental studies in the field. Only one paper studied the effect of bioturbation on the nutrient dynamics and the benthic-pelagic coupling. Two papers used a modelling approach to study the impact of trawling on ecosystem functioning. Most other papers tackled the problem by relating the community composition in terms of functional traits (bioturbation, biodeposition, etc) with the trawling intensity. Two papers addressed the question how trawling may influence the food of benthivorous fishes.

Tool development for ecosystem based management

Few papers dealt with the development of tools to be used in fisheries management.

Gear innovations

Five papers dealt with gear innovations and studied how these may mitigate the adverse impacts on the benthic ecosystem. Promising results were reported on reducing sea bed contact by using (semi-) pelagic otter boards. Four papers studied the effect of pulse trawls tested in the North Sea flatfish and brown shrimp fisheries, either in field experiments or in laboratory experiments.

Seventeen of the oral presentations and five of the posters were provided by partners that are presently involved in the BENTHIS project. The abstracts of the oral presentations and posters are included in the Appendix of this report.

Overall, the following observations can be made.

- The trait based approach to estimate the effect of trawling on ecosystem functioning is adopted globally with great expectations.

- Studies on mixed bottoms and large long-lived organisms are few in Europe.

- There is a need for empirical studies on ecosystem functioning to test the assumptions that are inherent in traits analysis due to lack of ecological information on species level.

- VMS data analysis needs further standardisation and more detailed quantitative descriptions of the major fishing gears used are required to estimate trawling impact at a comparable scale across regions and across fishing gears.

- There is a need to develop tools to be used in integrating the benthic ecosystem in the ecosystem approach to fisheries management. First explorations were presented at the Symposium.

- BENTHIS contributions were well received. The research questions addressed and the approach taken are relevant and state of the art.

APPENDIX 1. ORAL PRESENTATIONS. KEY NOTES INDICATED IN BOLD

Title	**name**	**BENTHIS related**
Future challenges in understanding and managing fisheries impacts on marine ecosystems	**Poul Degnbol**	
Effects on soft bottom communities		
Implications of fisheries impacts to seafloor biodiversity and Ecosystem-Based Management	**Simon F. Thrush**	
Habitat-specific effects of fishing disturbance on benthic species richness in marine soft sediments	P. D. van Denderen	x
Bottom trawling impacts on the deep-sea benthic communities from the SW Portuguese continental slope (NE Atlantic)	Sofia P. Ramalho	
The effects of commercial dredging and trawling on epifaunal benthic communities associated with weathervane scallops in Alaska	Jessica Glass	
Predicting benthic community patterns using environmental gradients and the significance of fishing intensity: a case study in the English Channel	Claire Catherall	
Determining the impacts of trawling on benthic function in European waters: a biological traits approach	Andrew Kenny	x
Evaluation of chronic bottom trawling disturbance on continental shelf benthic communities in the Southern Tyrrhenian Sea, a Mediterranean case study	M. Cristina Mangano	
Effects of towed bottom fishing gear on benthic biota; current knowledge and future research priorities	**Michel J. Kaiser**	x
Ecological significant effects of bottom trawling revealed by functional trait analysis of macrobenthic communities	Paul Whomersley	
Indirect effects of otter trawling on the condition and trophic level of *Nephrops* and flatfish in the Kattegat	Jan Geert Hiddink	x
Fishing effects on distribution and trophic guild structure of the benthic assemblages in the South of Portugal (NE Atlantic)	Clara F. Rodrigues	
Fishing impacts on benthic-pelagic coupling - the scaling up of ecological functioning experiments	Drew Lohrer	
Community consequences of bottom trawl fisheries in demersal food webs	Tobias van Kooten	x
Benthic habitats of the West Greenland shelf. What is the impact of shrimp trawling?	Kirsty Kemp	
Effects on mixed bottom communities		
Assessment of trawling impacts on benthic ecosystems with particular reference to mixed sediment bottom fauna on shelf ecosystems	**Adriaan D. Rijnsdorp**	x
The impact of trawling on the functional composition of coastal and shelf macrofaunal and megafaunal benthic assemblages in the Eastern Mediterranean	Chris Smith	x
Context dependency of the magnitude of fishing impact on temperate epibenthic assemblages. Implications for fisheries closed areas	Marija Sciberras	x

Deep-sea suprabenthic assemblages in the Blanes canyon and adjacent open slope (NW Mediterranean). Diversity and spatio-temporal variations in important fishing grounds	Clara Rodrigues	
Development of a model of disturbance and recovery dynamics for marine benthic ecosystems	Carolyn Lundquist	
Developing an indicator of the state of offshore habitats. a UK case study using a spatially explicit vulnerability model	Ana Jesus	
Bottom fisheries closures introduced by Atlantic high-seas bottom fisheries and regulatory frameworks to facilitate sustainable resource utilization and conserve vulnerable marine ecosystems	Odd Aksel Bergstad	
The impacts of deep-sea fisheries their effects on the megabenthos, and lessons for sustainability	**Malcolm Clark**	
Effects of trawling on sessile megafauna and evaluation of the efficacy of management strategies	C. Roland Pitcher	
Trawling impact on megabenthos and sediment in the Barents Sea - use of satellite vessel monitoring and video	Lene Buhl-Mortensen	x
The Bottom Line on Bottom Trawling - A Review of the Scientific Literature	Les Watling	
Quantifying recovery rates and resilience of seabed habitats impacted by bottom fishing	Gwladys Lambert	x
Indicator species of the vulnerable marine ecosystems in the Barents Sea	Denis Zakharov	
Quantitative risk assessment of benthos & bycatch sustainability in a tropical shelf trawl fishery	C. Roland Pitcher	
An approach to link changes in benthic community structure with the delivery of ecosystem services in trawling grounds	Alba Muntadas	
Bottom impact from fishing gear		
The physical impact of towed demersal fishing gears on soft sediments	**Barry O'Neill**	x
Physical impact of beam trawling revisited. Sediment resuspension and disturbance of tickler chain and pulse beam trawling	Jochen Depestele	x
Estimation of seafloor impact from demersal trawls, seines and dredges based on gear design and dimensions	Ole R. Eigaard	x
The impact of electrical pulses on benthic invertebrates	Maarten Soetaert	
Comparing apples and oranges. A statistical approach to compare the impact of active and passive fishing gears on epibenthic communities	Kris Hostens	
The impact of deep-sea bottom longline and handline on Vulnerable Marine Ecosystems	Selmo Morato	
Reducing seabed impact of trawling - Can off-bottom floating bridles be used to reduce seabed contact and flounder by catch in shrimp and haddock trawls?	Pingguo He	
Mitigation options to reduce impact of trawling on benthos	**J. W. Valdemarsen**	
Gear modifications to a shrimp trawl to reduce seabed	Paul Winger	

impacts in the Atlantic Canada inshore shrimp fishery		
Do semi-demersal trawls catch cod? A comparison of a semi-demersal and demersal trawl, and how density/visibility may play a role	Melanie Underwood	
Performance and seabed impact of new fishing gears alternative to boat seine fisheries	Antonello Sala	x
Biological impact of beam trawling revisited - A comparison of direct mortality of benthic fauna between tickler chain and pulse beam	Lorna Teal	x
High-resolution mapping of European fishing pressure on the benthic habitats	Ole R. Eigaard	x
A systematic review and meta-analysis on the effects of mobile bottom fishing on the benthos	Kathryn Hughes	x

APPENDIX 2. ABSTRACTS OF ORAL PRESENTATION FROM BENTHIS PARTNERS

Habitat-specific effects of fishing disturbance on benthic species richness in marine soft sediments

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Abstract: Around the globe, marine soft sediments on continental shelves are affected by bottom trawl fisheries. In this study we explore the effect of this widespread anthropogenic disturbance on the species richness of a benthic ecosystem, along a gradient of bottom trawling intensities. We use data from 80 annually sampled benthic stations in the Dutch part of the North Sea, over a period of 6 years. Trawl disturbance intensity at each sampled location was reconstructed from satellite tracking of fishing vessels. Using a structural equation model, we studied how trawl disturbance intensity relates to benthic species richness, and how the relationship is mediated by total benthic biomass, primary productivity, water depth, and median sediment grain size. Our results show a negative relationship between trawling intensity and species richness, which is also negatively related to sediment grain size and primary productivity, and positively related to biomass. Further analysis of our data shows that the negative effects of trawling on richness are limited to relatively speciose, deep areas with fine sediments. We find no effect of bottom trawling in shallow areas with coarse bottoms. These condition-dependent effects of trawling suggest that conservation of benthic biodiversity might be achieved by reducing trawling intensity only in a strategically chosen fraction of space, while allowing bottom trawl fisheries to continue in areas where there is limited effect on species richness.

Determining the impacts of trawling on benthic function in European waters : a biological traits approach

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Abstract: One of the most widespread yet manageable pressures we impose on the seabed is disturbance of the substrate by towed demersal fishing gear (bottom trawling and dredging). Over the past forty to fifty years, many studies have been conducted specifically aiming to understand the impacts of such fishing gear on the seabed communities. Their outcomes have demonstrated dramatic effects of bottom trawling on the structure of marine ecosystems although impacts tend to be wide-ranging, depending upon the gear, intensity, spatial area and the nature of the seabed habitats. However, understanding the functional impacts of this activity (as opposed to impacts on the structure of benthic assemblages) has only recently been attempted. Advances in the application of biological traits analysis (BTA) wherein the assemblages are described in terms of their life history, behavioural and morphological characteristics, have allowed us to better understand the interactions between the benthic fauna and their environment at a functional level. We present the initial findings of work conducted under the auspices of the EU-funded project 'BENTHIS' which aims to improve our understanding of the impacts of trawling on benthic ecosystem functioning over much larger spatial scales than previously undertaken. Biological traits information from 887 stations across European waters (Norwegian, UK, Belgian, Dutch, Danish waters, the Mediterranean and Black Sea) were analysed to: i) quantify the relationships between infaunal trait composition and environmental variables (depth, sediment granulometry); ii) determine the relationship between traits and habitat type (EUNIS level 4); and iii) assess the relationships between trawling pressure (using data derived under BENTHIS; see Eigaard et al., this volume) and traits composition.

Keynote: Assessment of trawling impacts on benthic ecosystems with particular reference to mixed sediment bottom fauna on shelf ecosystems

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Abstract: A generic framework to quantify the impact of bottom trawling on benthic fauna is presented. The framework will be illustrated for mixed-sediment habitats and associated biota on shelf ecosystems. Trawling impacts will be determined by (1) the characteristics of the fishing gear used and the intensity and temporal pattern, and (2) the sensitivity of the habitats and biota and their relationship with other biota. Key mechanisms involved in this interaction will be reviewed and key metrics relevant for the integrated analysis will be discussed.

Context dependency of the magnitude of fishing impact on temperate epibenthic assemblages: Implications for fisheries closed areas

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Abstract: Fisheries closed areas Fishing with bottom towed gear is widely considered an invasive form of fishing in terms of its impacts upon seabed habitats and fauna. The fishing grounds around the Isle of Man and Cardigan Bay in the Irish Sea have been extensively exploited by scallop dredgers for over 30 years. To examine the effects of scallop dredging on target species (*Pecten maximus* and *Aequipecten opercularis*) and the epi-benthos, we conducted underwater camera surveys within these two fishing grounds and in nearby closed areas to scallop dredging. The abundance of *P. maximus* and taxa such as hydroids, bryozoans and anthozoans were on average two to three times lower in the fishing ground relative to the closed area in the Isle of Man. In contrast, no differences were detected between the fished and closed area at Cardigan Bay. Examination of modelled wave-induced bed shear stress across the Irish Sea and of side scan sonar images, suggested a highly dynamic environment strongly influenced by both tides and waves at Cardigan Bay. Unquestionably, dredges disturb the seabed and the communities that they support. However, results indicate that the magnitude and extent of fishing impact is influenced by background levels of natural disturbance. Gauging the impact of mobile fishing gear therefore requires an understanding of how natural disturbance affects benthic communities. Furthermore, the effect of protection from mobile fishing gear on the habitat structure and biological communities must be scaled against the magnitude and frequency of seabed disturbance due to natural causes. The imposition of fisheries closed areas without due consideration of the natural environmental conditions and the biology of species concerned may result in negative effects on fisheries and limited conservation benefits, particularly if fishing effort is displaced to previously non-fished areas.

Keynote: The physical impact of towed demersal fishing gears on soft sediments

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Abstract: An improved understanding of the physical interaction of towed demersal fishing gears with the seabed has been developed in recent years, and there is a clearer view of the underpinning mechanical processes that lead to the modification and alteration of the benthic

environment. The physical impact of these gears on soft sediments can be classified broadly as being either geotechnical or hydrodynamic in nature: penetration and piercing of the substrate, lateral displacement of sediment and the influence of the pressure field transmitted through the sediment can be considered geotechnical; whereas the mobilisation of sediment into the water column can be considered hydrodynamic. A number of experimental and numerical approaches have been used to gain better insights of these physical processes. These include small-scale modeling in towing tanks and sand channels; large-scale modeling in the field; measurements behind full-scale towed gears at sea; numerical/mathematical modeling of sediment mechanics; and numerical/mathematical modeling of hydrodynamics. Here we will briefly review this research, and that in associated fields, and show how it can form the basis of predictive models of the benthic impact of trawl gears.

Physical impact of beam trawling revisited: sediment resuspension and disturbance of tickler chain and pulse beam trawling

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Abstract: Beam trawling uses heavy gear combined with tickler chains that are dragged across the seabed disturbing the upper layers of sediment and causing damage or mortality to benthic organisms. Recently, Dutch fishermen have replaced the tickler chains of the beam trawls by electrodes as alternative stimulation for catching flatfish. The pulse is claimed to have less of an in impact on benthic organisms than the traditional beam. In June 2013, sea trials were conducted in Dutch coastal waters to compare and quantify the direct mortality of the traditional beam and the pulse gear on benthic fauna. Fauna was sampled using a triple-D sledge before and after trawling by beam and pulse trawls with a non-fished area for comparison (BACI). Densities were calculated before and 48 hours after trawling. Boxcore samples measured the depth distribution of infauna. As individual species showed no particular patterns of impact in relation to the two trawling types, all species were combined into one analysis and categorised by traits. Each species was assigned to one of the groups based on a traits database: Resistant, intermediate or susceptible to trawling. Results showed that the area was populated by a community of mostly resistant species prior to the experiment, which may explain the difficulty in identifying direct mortality effects. However, overall a decrease in densities was observed following trawling, mostly due to a decrease in the group categorised as susceptible. Although the pulse trawl not show a lower impact than the beam trawl, the beam trawl area had been fished with a lower intensity and it may be concluded therefore that the beam has a larger impact. Nevertheless, it is also evident that impacts of trawling in an area with mostly resistant species appear minimal. The context-dependency of trawling impacts should therefore always be taking into account."

Estimation of seafloor impact from demersal trawls, seines and dredges based on gear design and dimensions

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Abstract: This study estimates the seafloor impact of towed fishing gears from a bottom-up perspective. Traditionally fishing pressure, often in terms of indicators, is calculated topdown

using the fishing effort information available in large-scale statistics such as logbook and VMS data. Here we take a different approach using the gear itself (design and dimensions) for understanding and estimation of the physical interactions with the seafloor at the individual fishing operation level. With reference to the métier groupings of EU logbooks, we defined 17 distinct towed gear groups in European waters (11 otter trawl groups, 3 beam trawl groups, 2 demersal seine groups, and 1 dredge group), for which we established seafloor "footprints". The footprint of a gear was defined as the relative contribution from individual larger gear components, such as the trawl doors, sweeps and ground gear, to the total area and severity of the gear impact. An industry-based vessel and gear survey covering 13 different countries provided the basis for estimating the relative impact-area contributions from individual gear components, whereas seafloor penetration and resuspension was estimated for different sediment types based on a review of the scientific literature. For each defined gear group a vessel-size (kW or total length) – gear size (total gear width or circumference) relationship was estimated to enable the prediction of gear footprint area and sediment penetration from vessel size. The implications for the definition and monitoring of fishing pressure indicators are far-reaching, and are discussed in context of an ecosystem approach to fisheries management (EAFM).

Performance and seabed impact of new fishing gears alternative to boat seine fisheries

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Abstract: Ligurian Sea commercial fishery is mainly represented by the small-scale coastal fishery, operated basically with traditional fishing gears as boat seine. Since June 2010, EC Regulation 1967/2006 identified boat seine as a towed gear, leading to this fishing gear the same restrictions applied to bottom trawls. These restrictions have effectively crippled boat seines fishery, as this fishery is operated at short distance from the coast, shallow waters and by very small mesh size net. Considering the existing difficulties to obtain local management plans for this fishery, in this study alternative fishing gears have been assessed and experimented at sea. An experimental surrounding net without purse line and particular fish pots have been compared to the traditional fishing gear in terms of performance and physical seabed impact. Boat seine has been the most efficient fishing gear in catch quantities (estimated in kilograms per hour) with an average of 70 kg/h, significantly higher than that obtained with the experimental gears, ranging from 8 (purse seine) to 18 kg/h (fish pots). Catch Comparison analysis have shown how the traditional fishing gear was also the most efficient gear regardless of species captured, resulting however, less selective. The experimental purse seine was more species-selective and the most abundant catch has been recorded for the saddled seabream (*Oblada melanura*), a mid-water living species. The fish pots were highly selective, mainly targeting eel species with low commercial value as Mediterranean moray (*Muraena helena*) and the European conger (*Conger conger*). Physical impact on the seabed has been monitored by underwater video observations which showed furrows left by leadline of boat seine on sandy bottoms. Regarding the impact on *Posidonia* mats, the boat seine leadline lightly brush meadows, even if seagrass tufts were frequently observed on board after hauling operations. On the other hand, experimental purse seine showed no physical impact on the seabed, because of positive buoyancy of the gear did not allow leadline to touch the bottom. Physical impact of fish pots on the sea bed was also negligible.

Instantaneous and physical changes to the benthic ecosystem caused by fishing activity

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Abstract: Beam trawling causes physical disruption to the seafloor through physical contact of the gear components on the sediment and the resuspension of sediment into the water column in the turbulent wake of the gear. Recently Dutch beam trawlers have replaced tickler chains by electrodes as alternative stimulation for catching flatfish. It is claimed that benthic impacts are reduced. Here we report on trials in a medium sand fishing ground to compare the physical impact of a conventional 4m commercial tickler chain beam trawl with that of the new commercial “Delmeco” pulse trawl. We use a Kongsberg EM2040 multibeam echo sounder (MBES) to measure the extent to which the beam trawls modify the topography of the substrate and a particle size analyser (LISST 100X) to measure the concentration and particle size distribution of the sediment mobilized into the water column. MBES measurements reveal that the disturbed sediment in the trawl track was on average located at a centimetre deeper after trawling of the conventional beam trawl than after pulse trawling. Particle size distributions of the sediment plumes were measured at 25m, 45m and 65m behind the gear and did not reveal any differences in concentrations between the two trawls. Whereas the empirical data serve comparative purposes, their lack of predictive capacity limits extrapolation to fleet level. Finite element (FE) models have shown to overcome this for otter trawls by predicting the penetration depth and sediment displacement associated with each gear component in different sediment types. In this study, FE models were developed for the conventional tickler chain beam trawl and the pulse trawl. Predictions were validated by results obtained during sea trials. As such, this study attempts to provide the basis for future predictions of physical impacts of beam trawling and its technical advances on a larger spatial scale.

High-resolution mapping of European fishing pressure on the benthic habitats

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Abstract: Mapping and monitoring of pressure from fishery on the marine benthic environment is necessary to support an ecosystem approach to fisheries management (EAFM). In many cases this need is not reflected in official fisheries statistics and logbooks, where focus typically is on catch rather than effort. Consequently, most logbook information is not well suited for quantitative estimation of seafloor impact (swept area and impact severity) of the different gears and trips. We present a method to overcome this information deficiency of official statistics and develop high-resolution large-scale maps of benthic fishing pressure covering the EU, Norwegian and Turkish waters. First individual logbook observations from 13 countries were assigned to 17 different functional gear groups (métiers) based on target species and gear type information. Secondly, relationships between gear width and vessel size (e.g. trawl door spread and vessel kW) for each métier were used to assign quantitative information of bottom contact to each logbook trip by translating vessel size information into measures of

gear size. Thirdly the extended logbook data was merged with high resolution activity data (VMS) and gear width estimates were assigned to individual interpolated vessel tracks based on VMS data. The outcome was European wide high resolution fishing intensity maps (total yearly swept area within grid cells of 1*1 minutes
longitude and latitude) for 2010, 2011 and 2012. Finally the high-resolution fishing pressure maps were overlaid with existing marine habitat maps to identify areas of potential ecosystem service conflicts.

The MSC's Consequence Spatial Analysis: A risk-based approach for assessing habitat impacts Effects of seabed protection measures; total or partial fishing gear modification and technical conservation measures.

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Abstract: Current best practice fisheries management requires a comprehensive ecosystem based
understanding of the short, medium and long term impacts and effects of bottom fishing practices for sustainable exploitation. Moreover, there exists a complex interaction between gear type, habitat, the degree of natural disturbance as well as a specific response between biotic groups or taxa. There is a need for an up to date and comprehensive review of bottom fishing impacts on the benthos considering: new publications in the scientific literature since the last review; the increased availability of effort data such as vessel monitoring system (VMS) data and an increase in the amount of seabed habitat mapping data, since the last review. The up-to-date global systematic review and meta-analysis presented here will be used to underpin best practice in fisheries management as part of the "Trawling best practices" group led by Ray Hilborn, Mike Kaiser and Simon Jennings. The aim of this systematic review is to assemble a comprehensive database on the impacts of bottom fishing on benthic biota from primary published and grey literature. Meta-analysis includes investigation into the effects of different gear types and different habitats (as well as the gear x habitat interaction), on the response of marine benthos to bottom fishing impacts using a mixed effects model.

Keynote: Effects of towed bottom fishing gear on benthic biota: current knowledge and future research priorities

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The impact of towed bottom fishing gear on the seabed is a ubiquitous source of human distance to global benthic ecosystems. This disturbance occurs against a background of natural disturbance regimes that vary with the environmental context at each location. Similarly, the variety of different fishing methods used mean that each potential gear-type x habitat interaction could lead to different outcomes and recovery trajectories for the impacted benthic community. This complexity has spawned considerable research effort focused on experimental manipulations of fishing impact leading to >120 published studies to date. These individual specific studies can be synthesised using systematic review and meta-analysis to derive general predictions about the response of benthos to different gear types in different environmental settings. Validation of these predictions has been undertaken using small-scale controlled experiments and larger-scale comparative studies undertaken at the scale of commercial fleets. In general both approaches support the earlier inferences derived from experimental manipulations. Moving forward from this solid baseline of understanding, current policy needs demand that the science community
consider more closely the impacts of fishing on the provision of ecosystem processes such as nutrient cycling that are closely coupled with the benthos and microbial community within sediments. Key gaps in our knowledge relate to limitations in the extent of our knowledge of fishing impacts for some habitat types and the functional relationship between key benthic descriptors and ecosystem processes.

Indirect effects of otter trawling on the condition and trophic level of Nephrops and flatfish in the Kattegat

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Abstract: The fishing gear used in bottom trawl fisheries cause mortality of benthic invertebrates and this can decrease the long-term availability of prey to exploited fish species by reducing the
abundance of benthic invertebrates. Alternatively, low trawling levels could increase food production for species that feed on small invertebrates that are released from competition with large invertebrates by trawling. Both outcomes may have consequences for biodiversity, the food-web and the sustainability of fisheries. We assessed the impact of bottom trawling on the food availability of fish by comparing the condition (as weight-atlength) and trophic level of the fish Pleuronectes platessa, *Limanda limanda*, *Hippoglossoides platessoides* and the crustacean *Nephrops norvegicus* in an area with strong variation in commercial otter-trawling effort owing to the presence of MPAs with different levels of protection in the Kattegat (Sweden and Denmark). The results show that the abundance and body size of *Nephrops* was much higher in the fully closed areas, whereas that of the flatfish was less affected. The condition and trophic level for *Nephrops* were highest on intensively trawled areas suggesting that trawling reduces competition and increases food availability for *Nephrops*. In contrast, the condition of the flatfish species was the highest at low levels of trawling. This study therefore suggests that high effort levels of bottom trawling have a negative effect on the prey availability and thus on the condition of some of the target species, but not others, and that low levels of trawling might positively affect food availability for some flatfish species. Alternatively, flatfishes might avoid areas with high densities of large *Nephrops*.

Community consequences of bottom trawl fisheries in demersal food webs

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Abstract: Bottom trawls are a globally used fishing gear that physically disturb the seabed and kill non-target organisms, including those that are food for the targeted fish species. There are indications that ensuing changes to the benthic invertebrate community may increase the availability of food and promote growth and even fisheries yield of target fish species. If and how this occurs is the subject of ongoing debate, with evidence both in favour and against. We model the effects of trawling on a simple ecosystem of benthivorous fish and two food populations (benthos), susceptible and resistant to trawling. We show that the ecosystem response to trawling depends on whether the abundance of benthos is top-down or bottom-up controlled. Fishing may result in higher fish abundance, higher (maximum sustainable) yield and increased persistence of fish when the benthos which is the best quality fish food is also more resistant to trawling. These positive effects occur in bottom-up controlled systems and systems with limited impact of fish feeding on benthos, resembling bottom-up control. Fishing leads to lower yields and fish persistence in all configurations where susceptible benthos are more profitable prey. Our results highlight the importance of mechanistic ecosystem knowledge as a requirement for successful management.

Trawling impact on megabenthos and sediment in the Barents Sea: use of satellite vessel monitoring and video

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Abstract: Bottom-trawl fisheries expand into deeper habitats and high latitude ecosystems but few documentations of impact in these areas exists. The ecological importance of habitat forming megafauna and their vulnerability to fisheries is acknowledged but studies on effects from fisheries are few. This study presents an investigation of chronic effects of otter-trawl fishery on substratum and megabenthos in the southern Barents Sea, at 50-400 meters depth. In total 154 video-transects were inspected for trawl marks, substratum composition, and megabenthos (> 2 cm). Yearly mean number of recorded trawling vessels (hourly VMS-

records) with in a 2 km radius of the video station was used as proxy for fisheries intensity (FI). Density of trawl marks and megafauna composition was compared with FI using linear regression, generalized linear model and ordination. Abundance of trawl marks was not directly related to FI but reflected substratum softness. Megafauna density and diversity decreased significantly with increased FI and effects was indicated even for low FIs 2-3 recorded trawling vessels per year. On hard bottom and sand megafauna density was < 40 individuals per 100 m2 and diversity < 30 taxa per video where more than 15 trawling vessels were recorded yearly. Particularly vulnerable were the sponges: *Antho dichotoma, Craniella zetlandica*, and *Phakellia/Axinella* while scavenging large gastropods and some asteroids increased with FI. Redfish showed a negative relationship to FI, while cod showed a positive relation. These results are discussed in relation to the descriptors "Biological diversity" and "Seafloor integrity" in the EU Marine strategic framework directive (MSFD).

Quantifying recovery rates and resilience of seabed habitats impacted by bottom fishing

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Abstract: The Ecosystem Approach to Fisheries requires that managers take account of the environmental impacts of fishing. Towed bottom-fishing gears disturb seabed habitats and cause mortality of benthic invertebrates. Measurements of recovery rates of marine habitats after fishing disturbance can provide insight into spatial variations in resilience and may be used to assess the sustainability of these fishing impacts and inform the development of appropriate management strategies. 2. To measure recovery on real fishing grounds at fishery- and management- relevant scales we measured the post-disturbance recovery rates of epifaunal marine benthic communities on coarse and hard substrata across >4000 km² of seabed where the patchy distribution of bottom fishing in space and time creates a mosaic of habitat patches at different stages of recovery.
3. The history of fishing events at each location was described using satellite vessel monitoring system (VMS) data. Recovery rates were extrapolated from the relationship between time since the last fishing event and abundance of epifaunal benthic invertebrates with life history traits that are expected to make them sensitive to fishing. 4. Recovery of abundance of all species and functional groups (medium-large size, medium to long life span, low mobility and suspension feeding species) was estimated to take 10 years, with faster recovery in areas with faster tidal currents. 5. The recovery of large species and species with high body flexibility was faster when conspecifics were abundant within a radius of 6 km suggesting an important role for maintaining a source of recruits to repopulate impacted areas. 6. Synthesis and applications: We used a new method to show that multiple site-specific recovery trajectories can be used to estimate the recovery rate of benthic communities and to describe spatial differences in sensitivity to fishing. Bottom fishing in areas that facilitate fast recovery will minimise overall fishing impacts, while a pattern of fishing that leaves unfished patches of seabed will enhance recovery rates of benthos in fished areas. We conclude that management plans which limit bottom trawls and dredge fisheries to more resilient areas and maintain unfished patches in these areas will minimise the collective impacts of a given amount of fishing effort on seabed habitats.

APPENDIX 3. ABSTRACTS OF POSTERS PRESENTED BY BENTHIS PARTNERS

Development of indicators of ecological and community change

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Abstract: Fisheries discards generate a major food source for scavenging seabirds and have been shown to significantly affect seabird ecology. Seabirds scavenge mainly on specific types of discards. Roundfish for instance are more easily swallowed than benthic invertebrates with protrusions. This implies that the amount of discards that becomes available to other marine scavengers, notably benthic communities, substantially depends on seabird consumption. Given that discard composition varies greatly amongst fisheries and spatiotemporal factors, the provision of edible discards shows great variability in space and time. So far, most studies estimated the consumption of discards by seabirds over vast areas such as the North Sea. Local effects were generally levelled off. This study developed an approach whereby the finest spatial and temporal resolution was determined for discard and seabird distribution in a single region, i.e. the Bay of Biscay (ICES Division VIIIa/b). The French fisheries that contributed the major part of discards in this area in 2009-2011 were included, namely fish bottom trawlers, *Nephrops* trawlers, gill netters, longliners and pelagic fisheries. The attraction of scavenging seabirds to fishing vessels was assessed by the seabird scavenging index, relating seabird densities to the number of ship followers. Attraction was highest for large gulls in April to September, followed by northern gannets during the rest of the year. Discard consumption rates of ship followers were estimated through an experimental trial on-board the RV Thalassa. Data gaps were resolved with estimates from literature, which served as a validation of our experimental estimates as well. Northern gannets consumed the highest proportions of discards with a strong preference for roundfish. The mechanistic model applied in this study highlights that food subsidies to benthic communities follow a spatio-temporal pattern. Our understanding of these patterns is a key aspect in the improvement of the management of discards and benthic habitats.

Fishery Restricted Areas and Marine Protected Areas – is trawling a major pressure and how much of the Mediterranean is protected?

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Abstract: The ecosystem approach and marine conservation are high on the Mediterranean regional agenda as seen through recent targeted data calls and directives. For the EU Member States, obligations arising from the Habitats Directive (e.g. for the protection of regional priority habitats) and the recent Marine Strategy Framework Directive (e.g. for the achievement of GEnS) are significant additional drivers for mapping the status, as well as the extent and frequency of pressures acting on predominant and sensitive habitats. Within the framework of the DG MARE MEDISEH Mediterranean Sensitive Habitats project and the MAREA Consortium, regional experts have worked together to review and map a) existing marine NATURA 2000 and other MPAs, b) MPA network proposals, and c) Mediterranean Fishery Restricted Areas (FRAs). FRAs include applied EU and national gear specific closures (e.g. for trawl, purse seines) and measures with a spatio-temporal dimension aiming to protect marine species and habitats from fishing activities in the Mediterranean basin. The overarching aim was to relate findings to sensitive and priority Mediterranean habitats and the CBD objective (Aichi target 11) to protect 10% of coastal and marine areas by 2020, with well-connected systems of protected areas and other effective area-based conservation measures. Our review highlights the still limited extent and mainly coastal nature of MPAs, the considerably larger extent of FRAs that mainly protect very deep grounds from trawling, and the still limited and geographically patchy efforts to map sensitive and essential fish
habitats. In the Mediterranean, where spatial control is the one of the key pillars of an effort-based management system, we discuss the difficulties in accessing national management measures that cover existing fishing gear spatial restrictions in an area with a large variety of species, gears, economies, cultures and languages.

Discard trends of bottom trawl fishery along the Samsun Shelf Area of the Turkish Black Sea Coast

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Abstract: Trawl fishery is the major fishing method in the Turkish Black Sea. One of the most important problems with bottom trawl fishery is by-catch and discard in the Samsun Shelf Region. A large proportion of the catch on board is sent back to the sea after the removal of the target species. The thrown part of this yield creates great losses by two ways; the first is bio-economical and the second is ecological. Considering the fishery economy; the fisherman is not satisfied with the catch per unit effort. And reputedly, this unsatisfaction induces illegal fishing methods. The littoral zone of the Black Sea including Samsun shelf area (SSA) discharged by two big rivers Kızılırmak and Yeşilırmak was treated with intense trawling for a long periods. The destroying effect of bottom trawling on commercial and non-commercial benthic and demersal fauna has always been a matter of debate in Turkey. It is aimed to identify how to gain the basic fishery data in our country and to improve a basic monitoring programme with a methodology peculiar to conditions of Turkey. This study aimed to determine the basic fishery parameters for the target species of bottom trawling in the Samsun Shelf Region, to estimate the rate of landing and discard using data from a seasonally open commercial trawl fishery in the Turkish Black littoral, over a period of about last four years; 2010, 2011, 2012 and 2013. The period between the mid of April and the mid of September is the closed season for trawl fishery in Turkish Black Sea. The study area includes the near shore water of three miles where the fishermen operate illegally. Seasonal samplings Were carried out within the depth range of 30 and 120 m by using meshes varying between 400 and 900 and 40 mm diamond mesh size in codend in traditional bottom trawl. The monthly samplings were realized by two kind of vessels in size > 18 m (12-17 m) and <18 m (18-32 m) which are common for Black Sea trawl fishery fleet. In each sampling period, the catches were recorded on board from at least two commercial vessels representing the study area. Fieldwork included estimating the total catch and the relative fractions per haul and recording the faunal composition as standardized for per haul duration or per day. The rate of discard for two target species of bottom trawl fishery was estimated 17%, 24%, 35% and 40% for red mullet in 2010, 2011, 2012 and 2013, respectively. The rates were as 31%, 49%, 51% and 54% for whiting in these four successive years, respectively. The relatively low discard rate of red mullet may be due to its relatively high market price and almost whole of the catch is marketable. The reasons for the heavy pressure on red mullet and whiting populations were the low selectivity of meshes and the long operation durations. The high exploitation rate generally causes the catch of relatively small and immature individuals. Though the rate of discarded catch in weight is lower than the marketed catch, as it is considered in number of

individual the discarded portion is larger than the market. The age composition of red mullet was composed of 0 and 1 age groups and of whiting are 0, 1 and 2 age groups. The discard rates in relation to the marketed catch seemed to be an indicator of the exploitation state of the demersal species. The differences between the discarded and marketed fractions were high at the beginning of the fishing season (autumn) and winter, but they are getting decrease in winter and by the end of the fishing season (spring). These changes could be attributed to alternative discarding strategies for certain species in response to increased cumulative fishing mortality. According to results obtained from whiting and red mullet fishery, the factors specifying the targeted catch and discard trends can be outlined as; yearly fluctuations in population, fishing period, depth of operation, accurate/ideal time closures, net design and implementations of selective mesh size, duration of operation, market effects (supplydemand relations). Though the rate of discard by weight seems less than of landings, the rate of discard by individual number is significantly high and cause great bio-economic losses.

Assessment of hydrodynamic performance and impact of otterboards in wind tunnel trials

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Abstract: We present a methodology for exploiting wind tunnel facilities in otterboard testing. Flume tank tests are expensive and very restrictive in terms of what can be measured and the accuracy they can provide. Instead, wind tunnel tests allow for accurate control of velocity, angle of attack and sideslip, and for precise measurement of forces and moments in all three axes. This information is essential for a full understanding of the way otterboards, especially pelagic- and semipelagic-, but also bottom-doors, behave in real full scale conditions. Assessing and minimizing their impact on the seabed is tightly dependent on knowledge of their hydrodynamic behaviour which flume tank experiments do not provide in full. We exemplify the methodology and compare our wind tunnel measurements with available flume tank results.

An outlook of the sieving selection of striped venus clam (*Chamelea gallina*) in the Mediterranean hydraulic dredge fisheries

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Abstract: The infaunal bivalve striped venus clam (*Chamelea gallina*) is the target of a large fleet of hydraulic dredgers operating in the sandy coastal bottoms of the Northern and Central Adriatic Sea (Mediterranean). Despite the resource is now showing strong signs of depletion and overexploitation relatively little scientific work has been done to assess the selectivity of the hydraulic dredges. Selective process in the hydraulic dredge fisheries mostly occurs on board the vessel during sieving operations rather than at sea while fishing is in progress. We investigated the striped venus clam (*C. gallina*) selectivity occurring during the sieving process on board the hydraulic dredge in the Adriatic Sea fisheries. The sieving tool consists of sequential holed grids made with holes of different diameters that select clams on the basis of their size. This study was undertaken to analyse both the effect of sieve-diameter and the speed of sieving on the clam selectivity. Selectivity was measured using the same approach followed in the covered codend technique taking into account the between-haul variation in selectivity. The results attained in the present study can assist fisheries managers in the revision of current legislation.