EU request on indicators of the pressure and impact of bottom-contacting fishing gear on the seabed, and of trade-offs in the catch and the value of landings

Advice summary

ICES advises on a set of indicators for assessing pressure and impact on the seabed from mobile bottom-contacting fishing. These indicators are selected based on their ability to describe impacts on a continuous scale that can be used in the evaluation of trade-off between the fisheries and their impacts on the seabed.

The indicators for pressure include four indicators reflecting the annual pressure and one multiannual indicator representing the persistency in the geographical distribution of the pressure.

ICES advises on two impact indicators: one describes the average impact in an area and the other indicates the proportion of the area with impacts below a given threshold. In order to assess the impact on ecosystem functioning and the response to fishing pressure, ICES has developed and parameterized two methods, one for each of the seabed impact indicators, for those parts of the Greater North Sea that are shallower than 200 m.

Fishing pressure was found to be highly aggregated. In the Greater North Sea, a relatively high impact occurred in deeper waters and in muddy habitats. The two methods showed different results in shallow water areas with high natural disturbance.

The trade-off analysis indicated that landings in weight and value were also concentrated at the highly aggregated (core) fishing grounds. The relatively high landings per unit of impact at the core fishing grounds imply that an overall reduction of fishing impact on the seabed, achieved by reducing fishing at the peripheral grounds, may result in a smaller reduction in landings and a larger reduction in pressure than if the reduction were at the core fishing grounds.

A demonstration advice product for the Greater North Sea ecoregion, including maps, is provided in Annex 1 in order to illustrate possible future approaches to annual advice on this topic.

Request

This advice is in response to the following request from the European Commission (DG ENV):

Evaluate indicators for assessing pressure and impact on the seafloor from bottom-contacting fishing. Using this assessment, demonstrate trade-offs in catch/value of landings relative to impacts and recovery potential of the seafloor.

Elaboration on the advice

Pressure indicators

ICES advises the use of five indicators and maps for the pressure from mobile bottom-contacting fishing gear: four annual indicators and one multiple year indicator, as shown in the table below. The indicators can be applied by regional, subregional sea, or broadscale habitat type within that sea, and assessed by total bottom-contacting fishery, a métier, or a combination of métiers. Three of these indicators rely on gridding of the considered area. ICES has currently adopted a $0.05° × 0.05°$ grid, the c-square, for this purpose.

Annual pressure indicator	Description	Notes
1 – Intensity	Average number of times the area is swept by bottom-contacting fishing gears. Estimated as the sum of swept area for all vessels using bottom-contacting gears or by métier divided by the total area of the considered area (regional/ subregional sea, or broadscale habitat type within that sea).	'Swept area' is an estimate of the area of seabed in contact with the fishing gear and is a function of gear width, vessel speed, and fishing effort. This indicator is a proxy of the number of times the area is swept.
2 – Proportion of grid cells fished	The number of grid cells (c-squares) fished at least once (irrespective of the swept area within the cell), divided by the total number of grid cells (c-squares) within the considered area.	
3 – Proportion of area fished	The sum of swept area across all grid cells in a considered area, where swept area in a specific grid cell cannot be greater than the area of that grid cell, divided by the summed area of all grid cells.	This indicator provides the best estimate of the proportion of area fished.
4 – Aggregation of fishing pressure	The smallest proportion of the grid cells (c-squares) where 90% of the total swept area occurs.	

Multiple year indicator	Description
5 – Persistently unfished areas	In order to understand the length of time that grid cells remain unfished, Indicator 2 could be evaluated over six years.

In general, fishing pressure is highly aggregated. The proportion of grid cells at depths of less than 200 m that were fished in 2015 (Indicator 2) was 80% for the North Sea, while the proportion of the area fished (Indicator 3) was 54%. 90% of the fishing pressure in 2015 was aggregated (Indicator 4) into 36% of the grid cells. These percentages are scale dependent and depend on the current spatial resolution; should this resolution change, these percentages would change also.

Impact indicators

ICES advises the use of two annual impact indicators and maps for the impact from mobile bottom-contacting fishing gear as shown in the table below. These indicators can be applied by regional/subregional sea, or by broadscale habitat type within that sea and assessed by total bottom-contacting fishery, métier, or a combination of métiers.

ICES advises that the metrics used should reflect complementary aspects of the benthic community response: effect on ecosystem functioning, and response to fishing pressure. For each indicator, ICES therefore advises use of more than one quantitative methodology. ICES has developed and parameterized two methods for parts of the North Sea; the longevity (LL1) and the population dynamic (PD2). The longevity composition of a benthic community is a proxy for biodiversity and tracks the change in benthic community composition in response to trawling. The population dynamic method indicates how bottom trawling affects the biomass of the benthic community using the relative biomass as a proxy for the amount of functioning still remaining in the community (e.g. bioturbation, facilitation, nutrient cycling, reproductive output, secondary production). If present, this functioning helps maintain not only the local community as a whole, but the wider biodiversity (an important part of the integrity of the seabed) as well. These methods can be used in other regional and subregional seas, but have yet to be parameterized by ICES. However, for other regional/subregional seas, other methods may be more appropriate depending on available information.

Impact indicators	Method	Short description
1 – Impact	PD2 and LL1	Annual average fishing impact across grid cells in an area.
2 – Area below impact threshold	PD2 and LL1	The proportion of grid cells with an impact below a (chosen) impact threshold at a regional or subregional scale.

For the North Sea, both methods found a relative high impact (Impact Indicator 1) in deeper waters and in muddy habitats. In shallow habitats exposed to moderate to high shear stress, the two methods gave different results. The population dynamic method (PD2) found impact to be mainly determined by the level of fishing pressure and less by differences in seabed sensitivity. The longevity method (LL1) predicted low impact, despite high fishing pressures, in

shallow waters that are exposed to high natural disturbance. The underlying reasons for this difference require further investigation. The average impact of all bottom trawling in 2015 was 0.24 (0 = no impact, 1 = maximum possible impact), slightly lower than in 2009 and 2010. Impact varied between habitats, being highest in mud (0.33) and mixed sediment (0.31) and lowest in coarse sediment (0.26) and sand (0.22). Since 2009, the impact has shown a slight decrease in mud and coarse sediments, and a slight increase in mixed sediment.

The proportion of the grid cells in the North Sea (Impact Indicator 2) with a low impact (< 0.2) is around 0.5 in muddy sediments and 0.6 in other habitats.

Landings in weight/value indicators

ICES advises the use of four annual indicators to describe the landings or value of fish, as shown in the table below.

Annual landings/value indicators	Short description
Landings in weight	Total weight of landings (kg) within the assessed region, métier, or habitat.
Landings in value	Total value (Euros) of landings within the assessed region, métier, or habitat.
Landings in weight per c-square	Average weight (kg) of landings per c-square.
Landings in value per c-square	Average value (Euros) of landings per c-square.

Trade-off assessment

Landings in weight or value per unit area indicators can be used in assessing the trade-off in relation to the environmental impact and recovery potential of the seabed from mobile bottom-contacting fishing gear by area (regional/subregional sea, or broadscale habitat type within that sea).

The impact indicators can be compared with the landings/value indicators to assess trade-offs between the environmental impact and recovery potential of the seabed from fisheries using mobile bottom-contacting gears and the landings in weight and/or value of the fisheries. These trade-off assessments are informative at broad spatial scales. However, in assessment of impact of management measures, different trade-offs may be required depending on the management objectives and measures.

For the Greater North Sea (see Annex 1), the seabed within the core fishing grounds (high fishing intensity) was of lower status (higher impact score), but the landings (kg) per unit of impact were higher than in the peripheral fishing grounds (lower fishing intensity). Conversely, the seabed in the peripheral grounds had a higher status, but made a relatively small contribution to the overall landings and value.

The relatively high landings per unit of impact at the core fishing grounds imply that an overall reduction of fishing impact on the seabed, achieved by transfer of fishing pressure from the peripheral grounds to core grounds, might result in a smaller reduction in landings than if the transfer went the opposite way. The most sensitive species are affected at low trawling intensities, whereas only the more resilient species survive in the core fishing areas. A small increase in the pressure will therefore have little additional impact in the core fishing areas.

The general implications of management measures have been illustrated in this advice. Fisheries are by nature dynamic, responding to changes in management and in the environment. This advice used equilibrium relationships (steady-state models) between fishing pressure and impacts, and observed landings and value. It is possible to resolve the issues addressed in this advice and provide further advice, but all of the modelling approaches require that specific management objectives are defined (and potential management measures taken) and may be limited by availability of data.

A demonstration advice product for the Greater North Sea ecoregion is provided in Annex 1. The format of this product aims to make the spatial and temporal patterns of all of the indicators readily apparent to non-experts. Although the assessment in this demonstration was carried out with one (PD2) of two possible methods, this does not imply that ICES recommends that method above the other (LL1).

Suggestions

If these indicators are to be used to evaluate management strategies, ICES regards it as important that they be tested against realistic scenarios. These management scenarios will require management input and decisions.

Some management scenarios may require modelling at higher definitions of métier (e.g. DCF level 6). If these higher definitions are used, further exploration of trade-off scenarios will be needed. This will require increased involvement of the stakeholders affected by potential decisions.

The information underpinning the indicators could potentially be improved in a number of ways; testing might reveal which data or model require most improvement. For example, at present the broadscale habitat type assigned to each grid cell (c-square) is based on the habitat modelled for the centre of that grid cell. This potentially means that a relatively small area of a particularly sensitive habitat would be missed, or an area of apparent higher habitat heterogeneity would not be well described. Making relatively sparse habitats the focus of management will require improved knowledge of the location and extent of these areas and their benthic fauna as these are often poorly determined by the current methods, particularly for bottom types that are not readily sampled by box or grab sampling. Similarly, an increase in resolution and accuracy of fishing pressure will only improve habitat impact estimates if accompanied by a similar resolution and accuracy of the underlying habitat map. The actual fished area within a regional sea area will be different to the calculated c-square area (generally lower offshore, higher inshore). If this was to be improved, this would require vessel monitoring system (VMS) data at a higher spatial resolution and inshore would additionally require the use of a monitoring system for smaller (< 12 m) vessels. In all cases, the full supply of relevant VMS and logbook data from all countries fishing in an area is essential.

The outcome of the impact assessment [(fraction of (un)impacted habitat) / (fraction of habitat at a certain state)] is dependent on the assessment method used and the spatial resolution of the fishing pressure data layer (presently $0.05° × 0.05°$). A change in spatial resolution will result in an overall change in the assessed habitat state. This means that the setting of threshold values is method dependent. Therefore, a benchmarking process to formally agree on a methodology and parameterization, including threshold values, is required to harmonize the "good environmental status (GES) concept" across regions.

The impact models applied were parameterized for infaunal communities of those parts of the Greater North Sea shallower than 200 m. Further analysis of benthic community structure, in relation to habitat and including both infauna and epifauna, is required to improve the parameterization of the model and thus application in other regional or subregional seas, and in deeper waters.

The PD2 method can be used to estimate the time it takes a community to recover to an unimpacted state. This recovery time will vary as a function of fishing pressure and the longevity composition of the benthic community.

In evaluating overall regional seabed status from the effects of bottom fishing, context dependency of other significant region-specific pressures will need to be included in the models. This is for example evident in the Baltic Sea when evaluating the effects of bottom fishing, where both natural and anthropogenic oxygen deficiencies will need to be considered.

The models used in this advice have mainly examined the effects of mobile bottom-contacting gears on benthos quality. Other ecological consequences of this disturbance, such as foodweb consequences or the effects of sediment suspension, have not been explicitly modelled. The interconnectivity of all marine life through foodwebs means that every management decision will have an effect, sometimes in opposing directions, on every part of the system. It is important that these further ecological consequences are taken into account to reduce the risk that management produces unwanted results.

Basis of the advice

Background

ICES is requested to 1) propose a set of indicators for assessing physical disturbance pressures from bottom-contacting fishing gears and their environmental impacts on seabed habitats/sea-floor integrity, and 2) develop an approach on how to demonstrate the trade-off between catch/value of landings per unit area and the environmental impact and recovery potential of the seafloor (from the above assessments). The assessment scale should be suitable biogeographic subdivisions of the MSFD regions and subregions, and per MSFD broad habitat type (or more finely-defined habitat types). Within this context, maps and indicators (a-c, below) should include demonstration products for at least one MSFD (sub)region and take account of developments on these issues within the Regional Sea Conventions.

a) Map and indicator(s) of fishing intensity (physical disturbance), for the most recent 6-year period (and for earlier periods where possible);
b) Map and indicator(s) of the area impacted by bottom fishing (in same 6-year periods), and the percentage (%) of each MSFD broad habitat type impacted per subdivision;
c) Maps and indicator(s) assessing the benefits of the fishery (by weight and/or value) compared with its degree of impact on the seabed (taking account of the frequency of trawling and the ability of the habitat to recover after fishing), at the c-square scale (or other appropriate spatial resolution).

This advice is based on ICES (2016a) that recommended specific pressure and impact indicators and the use of a quantitative approach based on biological principles to provide continuous (rather than stepped) indicators. The outputs of the approaches taken are illustrated and described in the demonstration advice product for the Greater North Sea ecoregion (Annex 1).

Methods

Pressure indicators

ICES (2016b) defines the swept area as the cumulative area contacted by a fishing gear within a grid cell over one year. The swept area ratio (SAR, also defined as fishing intensity) is the swept area divided by the surface area of the grid cell. The area contacted by fishing gear is provided by geographically distinct vessel monitoring system (VMS) points for which speed and course are available at intervals of maximum 2 hours, coupled with information on vessel size and gear used derived from EU logbooks (ICES, 2017a; Eigaard *et al.*, 2016).

Vessel speeds representing fishing activity are assigned to a 0.05° × 0.05° grid, about 15 km² at 60°N latitude, which is the spatial resolution adopted by ICES: the c-square approach. ICES does not have access to information on vessel position at a finer scale than this, due to national confidentiality reasons.

Each c-square was assigned to a EUNIS level 3 habitat type using the habitat modelled at the centre point of the c-square.

Estimates on total SAR within each grid cell were calculated by métier and habitat. A total of four métiers (otter trawl, beam trawl, dredge, and demersal seine) and four broadscale habitat types (coarse, sand, mud, and mixed) were specifically considered. These habitat types were chosen as the new Commission decision on MSFD was not available when the expert work was undertaken.

The pressure and impact indicators are discussed in detail in ICES (2017a).

Impact indicators

ICES evaluated various impact indicators, of which two quantitative methods were derived from approaches that make use of the longevity composition of the benthic community (Rijnsdorp *et al.*, 2016), to assess habitat sensitivity to fishing.

The PD2 method is a mechanistic model that estimates the total reduction in community biomass (B) relative to carrying capacity (K), corresponding to the estimated fishing intensity. Total community biomass relative to carrying capacity

(B/K) describes the equilibrium state, i.e. the interaction between the depletion caused by fishing and the recovery of the benthic community. The impact is given by 1−B/K (Pitcher *et al.*, 2017). The depletion rates are estimated from a meta-analysis providing gear-specific depletion rates (Hiddink *et al.*, submitted), while recovery rates are derived from a longevity-specific meta-analysis (Hiddink *et al.*, in prep.). The biomass component of the PD2 method is a proxy for ecosystem (functioning) processes, for example, nutrient cycling or energy flow through foodwebs.

The LL1 method is a statistical model that estimates the habitat-specific longevity composition of the community and the effect of trawling on this composition (Rijnsdorp *et al.*, 2016). The basis of this relationship is that long-lived species, because of their lower growth rates and later age at maturity, have a lower recovery rate and they are therefore generally more sensitive to fishing mortality. The model includes an interaction of the effect of trawling and shear stress on the seabed as trawling has lower impacts in habitats with high shear stress (high natural disturbance). The indicator estimates the reduction in the proportion of long-lived taxa (maximum lifespan > 10 years) caused by trawling. The species-specific longevity traits were derived from a literature review (Bolam *et al.*, 2014).

Landings/value indicators

Landings values (Euros) and weights (kg) were calculated from logbook data, by countries submitting these data, prior to submission to ICES.

Trade-offs

As an example, ICES (2017b) used the PD2 assessment methodology (see above and ICES, 2017a) to examine the relationship between the pressure and impact of bottom-contacting fishing gear on the seabed, as well as the seabed status and the consequent catch and value of landings. The resultant landings and value metrics were aggregated across selected métiers, allowing impacts to be assessed at regional or subregional levels. Because trawling is aggregated at the regional sea scale, trade-offs between core and peripheral fishing grounds were examined.

Caveats

Several caveats, listed below, should be taken into account when considering the advice. These caveats relate to issues concerning the provision of vessel data and their interpretation, the scale at which the data are informative, and the biota used to assess impact.

- Data on the location of fishing by vessels smaller than 12 m are not available and therefore not included in the assessment. This introduces a bias in the assessment that is expected to be strongest in coastal areas.
- VMS data were not supplied from certain countries both within and outside the EU, introducing a bias in pressure in areas fished by these countries. In EU waters, the greatest bias will be in the Bay of Biscay, the southern Celtic Seas, and in Iberian waters.
- The calculation of fishing intensity, as well as of surface and subsurface abrasion, is inferred from a suite of VMS data, including vessel speed. However, fishing speed was not always supplied, and in such cases, estimates were based on average supplied fishing speed values.
- Fishing pressure indicators are dependent on the spatial resolution of the fishing pressure data. The indicators in the demonstration advice (Annex 1) are calculated at a resolution of $0.05^o \times 0.05^o$.
- It is possible that the valuation of landings has been treated differently by different countries, potentially introducing bias.
- Habitat maps at the regional scale may be both biased and uncertain, but the degree of this is usually unknown.
- The level of detail in benthic knowledge is variable by region and by habitat. Assessments at a regional sea scale do not encapsulate the consequences of this heterogeneity.
- Not all of benthos is included in the assessment, especially epifauna. Therefore, harder habitats in particular are omitted from the assessment.
- The relative lack of knowledge of biological features and species traits of the broadscale habitat types in deeper waters means that ICES can, at present, only advise on impacts on seabeds shallower than 200 m.

Additional information

ICES is confident that this advice can provide guidance for assessing the abrasion effects of bottom-fishing on broadscale habitats at the regional scale. However, in the longer term, a number of improvements to the underlying information used in this advice could be made that would likely help improve assessments on the smaller scale, or on more detailed habitat types.

There are several inputs to the assessment of the state of seabed habitats, most of which could be improved to reduce uncertainty and increase precision. Habitat maps could be improved and widened in their coverage with further surveys. The greatest gains can be achieved where fishing occurs; no (or only poor) habitat maps exist for areas that might contain more sensitive habitats than those mapped at present. Currently there is a mismatch between spatial resolution of pressure data (c-squares) and habitat data, and there is a need to develop methods for rationally assigning habitat types to spatial pressure units. Many of the c-square cells will have more than one broadscale habitat type and a range of sensitivities. Similarly, information about the prevailing benthic communities should be refined.

Fishing pressure maps could be improved in a number of ways; the greatest gains could be made by ensuring that all ICES Member Countries fully report their fishing activity (VMS data and logbook records) when requested. The lack of available information on the activities of fishing vessels under 12 m in length means that there will be underestimation of the pressure and impact in coastal areas. ICES (2016) estimated that the proportion of mobile bottom fisheries conducted by vessels under 12 m length in the North Atlantic (and adjacent seas) was 18% of fishing effort and 12% of the landings. Potential approaches to improve this situation would require further research. Further gain could also be made through studies to improve knowledge of the impacts of individual métiers on each broadscale habitat type.

Benthic datasets (infauna and epifauna) and associated traits need to be further analysed to determine the habitat-specific community compositions required to:

a) improve knowledge of the longevity composition of the benthic communities of different habitats;
b) make reasonable predictions for additional areas and habitats; and
c) ground-truth the outputs.

A prediction of fishing abrasion of different sediment layers for different habitats, more detailed than mere surface/subsurface abrasion, would greatly improve the PD2 impact indicator estimations.

The framework to evaluate trade-offs between fisheries and benthic impact used equilibrium relationships between the pressure and impact, and landings in weight and/or value at regional scales. Further improvements could be made by:

1. Developing the economic modelling methods to reveal the financial implications of spatial management measures, including the effects on vessel running costs as well as price flexibilities that lead to variation in the revenues arising from the sale of catches.
2. Modelling displacement of effort, taking into account technical interactions between fleet segments as well as the influence of other pressures such as wind farms, shipping lanes, gravel extraction, etc.
3. Increasing the understanding of spatial and temporal distributions of target fish populations based on, e.g. fishery-independent survey data time-series such as the International Bottom Trawl Survey. This would enable better modelling of displacement of effort and its consequences.

Improved models of the ecosystem effects of mobile bottom-contacting fishing should include:

1. Ecological consequences, in particular the cascading trophic effects on non-target species, e.g. charismatic top predators, species composition, and abundance of targeted resources.
2. Additional ecosystem functions of primary fishing grounds, i.e. functions not directly related to the benthic community such as spawning areas for fish stocks.
3. A framework/methodology to ensure that the different habitat types (common as well as rare and sensitive habitats) are equally represented in any areas with management-based effort reduction, to secure the integrity of biodiversity and ecosystem functions and services.

4.   Ecological processes at a regional scale (e.g. dispersal and connectivity across the seabed) in relation to habitat quality and patterns of fragmentation.

Sources and references

Bolam, S. G., Coggan, R. C., Eggleton, J., Diesing, M., and Stephens, D. 2014. Sensitivity of macrobenthic secondary production to trawling in the English sector of the Greater North Sea: A biological trait approach. Journal of Sea Research, 85: 162–177.

Eigaard, O. R., Bastardie, F., Breen, M., Dinesen, G. E., Hintzen, N. T., Laffargue, P., Mortensen, L. O., Nielsen, R., Nilsson, H. C., O'Neill, F. G., Polet, H., Reid, D. G., Sala, A., Skold, M., Smith, C., Sørensen, T. K., Tully, O., Zengin, M. and Rijnsdorp, A. D. 2016. Estimating seabed pressure from demersal trawls, seines, and dredges based on gear design and dimensions. ICES Journal of Marine Science, 73 (supplement 1): i27–i43.

Hiddink, J. G., *et al*. In prep. Longevity of benthic macroinvertebrates determines their sensitivity to bottom trawling impacts.

Hiddink, J. G., Jennings, S., Sciberras, M., Szostek, C. L., Hughes, K. M., Ellis, N., Rijnsdorp, A. D., McConnaughey, R. A., Mazor, T., Hilborn, R., Collie, J. S., Pitcher, R., Amoroso, R. O., Parma, A. M., Suuronen, P. and Kaiser, M. J. Submitted. Global analysis of depletion and recovery of seabed biota following bottom trawling disturbance.

ICES. 2016a. EU request for guidance on how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats. *In* Report of the ICES Advisory Committee, 2016. ICES Advice 2016, Book 1, Section 1.6.2.4. 5 pp.

ICES. 2016b. OSPAR request for further development of fishing intensity and pressure mapping. *In* Report of the ICES Advisory Committee, 2016. ICES Advice 2016, Book 1, Section 1.6.6.4. 27 pp.

ICES. 2017a. Report of the Workshop to evaluate regional benthic pressure and impact indicator(s) from bottom fishing (WKBENTH), 28 February–3 March 2017, Copenhagen, Denmark. ICES CM 2017/ACOM:40. 233 pp.

ICES. 2017b. Report of the Workshop to evaluate trade-offs between the impact on seafloor habitats and provisions of catch/value (WKTRADE), 28–31 March 2017, Copenhagen, Denmark. ICES CM 2017/ACOM:42. 109 pp.

ICES. 2017c. Report of the Workshop on scoping stakeholders on production of operational guidance on assessment of benthic pressure and impact from bottom fishing (WKSTAKE), 23 March 2017, ICES Headquarters, Copenhagen, Denmark. ICES CM 2017/ACOM:41. 31 pp.

Pitcher, C. R., Ellis, N., Jennings, S., Hiddink, J. G., Mazor, T., Kaiser, M. J., Kangas, M. I., McConnaughey, R. A., Parma, A. M., Rijnsdorp, A. D., Suuronen, P., Collie, J. S., Amoroso, R., Hughes, K. M., and Hilborn, R. 2017. Estimating the sustainability of towed fishing-gear impacts on seabed habitats: a simple quantitative risk assessment method applicable to data-limited fisheries. Methods in Ecology and Evolution, 8: 472–480.

Rijnsdorp, A. D., Bolam, S. G, Garcia, C. Hintzen, N., and van Denderen, P. D. 2016. Impact of Bottom Trawling on Sea Bed Integrity. BENTHIS Deliverable 1.2. 39 pp.

Annex 1

The demonstration advice is provided on the following pages.

Demonstration advice: Physical disturbance pressures from bottom-contacting fishing gears and their impacts on seabed habitats/seafloor integrity

Introduction

Note: This document is not actual ICES advice developed in response to a request from a client, but rather a demonstration of the type of advice ICES could provide if requested.

This demonstration advice provides information on MSFD descriptor 6 (Seafloor integrity), criterion 6.1 (Physical damage, having regard to substrate characteristics), using the Greater North Sea ecoregion as a case study. The Greater North Sea ecoregion is very similar to the Greater North Sea MSFD subregion. Sections where ICES could potentially add advice in the future are italicized; some of these additions depend on policy/management choices. Although the assessment was carried out with one (PD2) of two possible assessment methods, this does not imply that ICES recommends this method above the other (LL1). The section headed "Basis and methods" is provided for clarity of understanding, but would likely be published as a separate guidance note should future advice be requested.

Much of the work that this document derives from was undertaken before publication of a 2017 revision of the MSFD policy decision (Commission Decision 2017/848) and the associated revision of the EUNIS classification. ICES therefore used the Commission Decision (EU) 2010/477 and EUNIS level 3 habitats (JNCC, 2014). The methods and processes used to develop this demonstration advice are fully adaptable to the new set of criteria and habitat types, and to any spatial mananagement scale (≥ a c-square 0.05° × 0.05°).

Summary

Physical disturbance pressures from mobile bottom-contacting fishing gears varied spatially in the Greater North Sea ecoregion (Figure A.1). Within the depth zone of 0–200 m, 80% of the grid cells and 54% of the surface area were fished by mobile bottom-contacting gears in 2015. Fishing was highly aggregated, with 90% of the pressure occurring in 36% of the grid cells. Fishing pressure was lower at depths below 200 m. As shown in Table A.1, the average impact, estimated using the PD2 method for depths 0–200 m only, was 0.24. In the same way, 63% of the seabed had an impact factor *less than 0.2*. Impact was highest in deeper parts of the 0–200 m depth range and in muddy habitats. The spatial distribution of fishing pressure varied over time during the seven-year period of the assessment, without showing a trend. *Both pressure and impact indicators were/were not within thresholds (actual values pending decision on thresholds)*.

Table A.1 Indicator values for fishing pressure and seabed impact in the North Sea in 2015. Italicized items are chosen values and are subject to policy choices.

| Annual pressure indicators	Description	2015		Reference / threshold
		0–200 m	200–1000 m	
1. Intensity	Average number of times the North Sea is swept by bottom-contacting fishing gears. Estimated as the sum of swept area for all vessels using mobile bottom-contacting gears, divided by the total area of the North Sea.	1.68	0.64	*Not available*
2. Proportion of grid cells fished	The number of grid cells (c-squares) fished at least once (irrespective of the swept area within the cell), divided by the total number of grid cells (c-squares) within the North Sea.	80%	33%	*Not available*
3. Proportion of area fished	The sum of swept area across all grid cells in the North Sea, where swept area in a specific grid cell cannot be greater than the area of that grid cell, divided by the summed area of all grid cells.	54%	21%	*Not available*
4. Aggregation of fishing pressure	The smallest proportion of the grid cells (c-squares) in the North Sea where *90% of the total swept area* occurs.	36%	14%	*Not available*
Multi-annual pressure indicator				
Persistently unfished areas	Indicator 2 evaluated over six years.	*Not available*	*Not available*	*Not available*
Impact indicators				
Average impact	Annual average fishing impact across grid cells in the parts of the North Sea shallower than 200 m, PD2 method.	0.24	*Not available*	*Not available*
Average impact	*Annual average fishing impact across grid cells in the parts of the North Sea shallower than 200 m, LL1 method.*	*Not available*	*Not available*	*Not available*
Proportion of area with impact < *0.2*	The proportion of grid cells with an impact below a (*chosen, in this case 0.2) impact threshold* in the parts of the North Sea shallower than 200 m, PD2 method.	63%	*Not available*	*Not available*
Proportion of area with impact < 0.2	*The proportion of grid cells with an impact below a (chosen, in this case 0.2) impact threshold in the parts of the North Sea shallower than 200 m, LL1 method.*	*Not available*	*Not available*	*Not available*
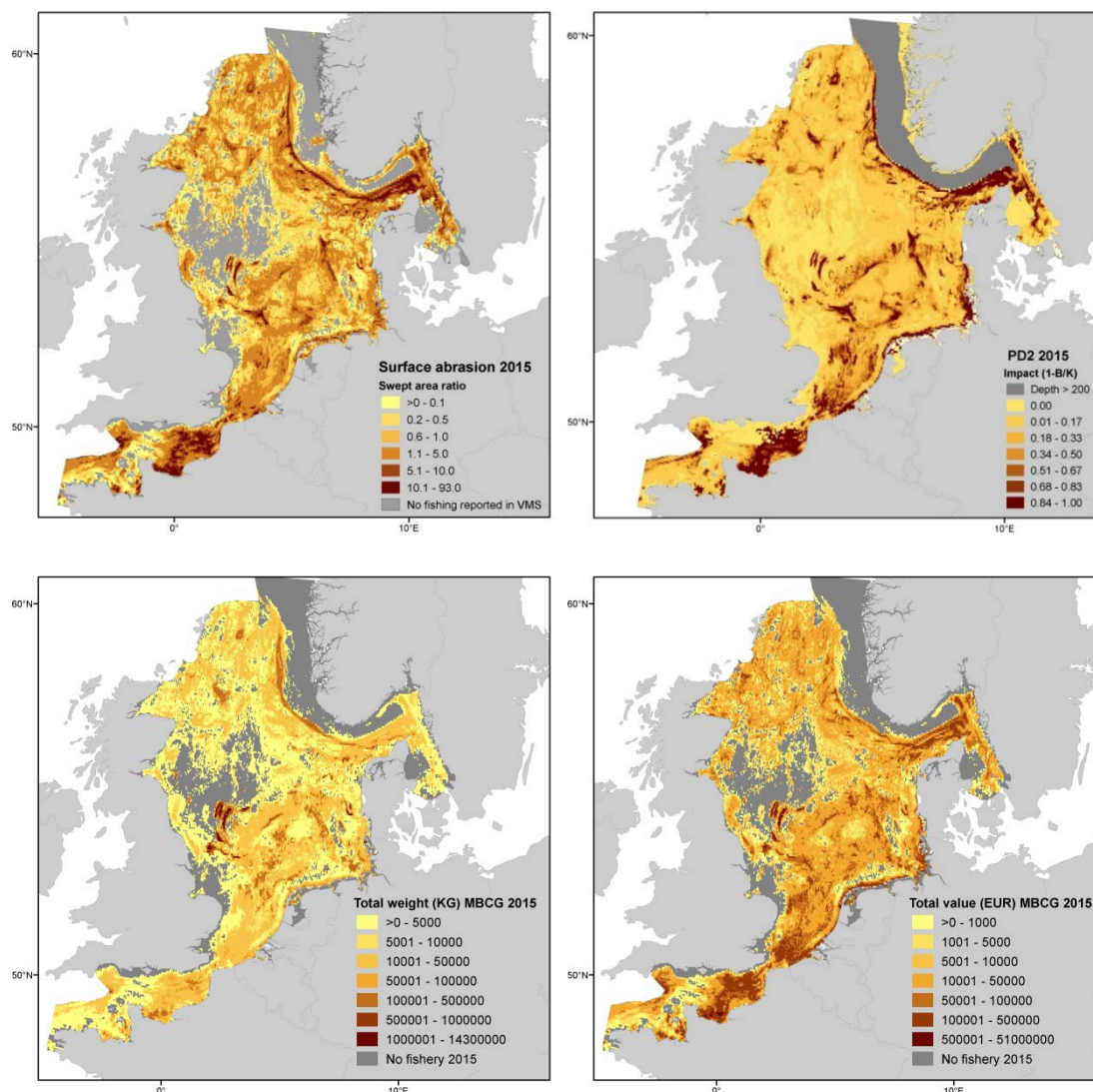
Figure A.1 Geographic distribution of surface abrasion, impact (PD2 indicator), total weight (kg) of fish caught, and total value (Euros) from mobile bottom-contacting gear in the Greater North Sea ecoregion in 2015. All figures in this demonstration advice are plotted on a 0.05° × 0.05° grid.

Basis and methods

ICES (2016a) advised that evaluation of seabed pressure and impact should use a quantitative approach based on biological principles to provide continuous (rather than stepped) indicators. This assessment is based on the fishing pressure estimated by métier following the approach of Eigaard *et al.* (2016) at a resolution of c-squares (0.05° × 0.05°). The impact is assessed using the PD2 method (Pitcher *et al.*, 2017; Hiddink *et al.*, submitted; ICES, 2017a), but could equally use the LL1 method. The PD2 method estimates the reduction in the biomass of the benthic community, taking into account the depletion rates by métier and recovery rates by species groups. Depletion and recovery rates (for the PD2 methods) are estimated by a structured meta-analysis of the literature (Hiddink *et al.*, submitted). The recovery rates are longevity class-specific (e.g. < 1, 1–3, 3–10, >10 years) and this can be translated into a habitat-specific recovery rate when the longevity composition at a specific location or habitat is known (Rijnsdorp *et al.*, 2016a; Hiddink *et al.*, in prep).
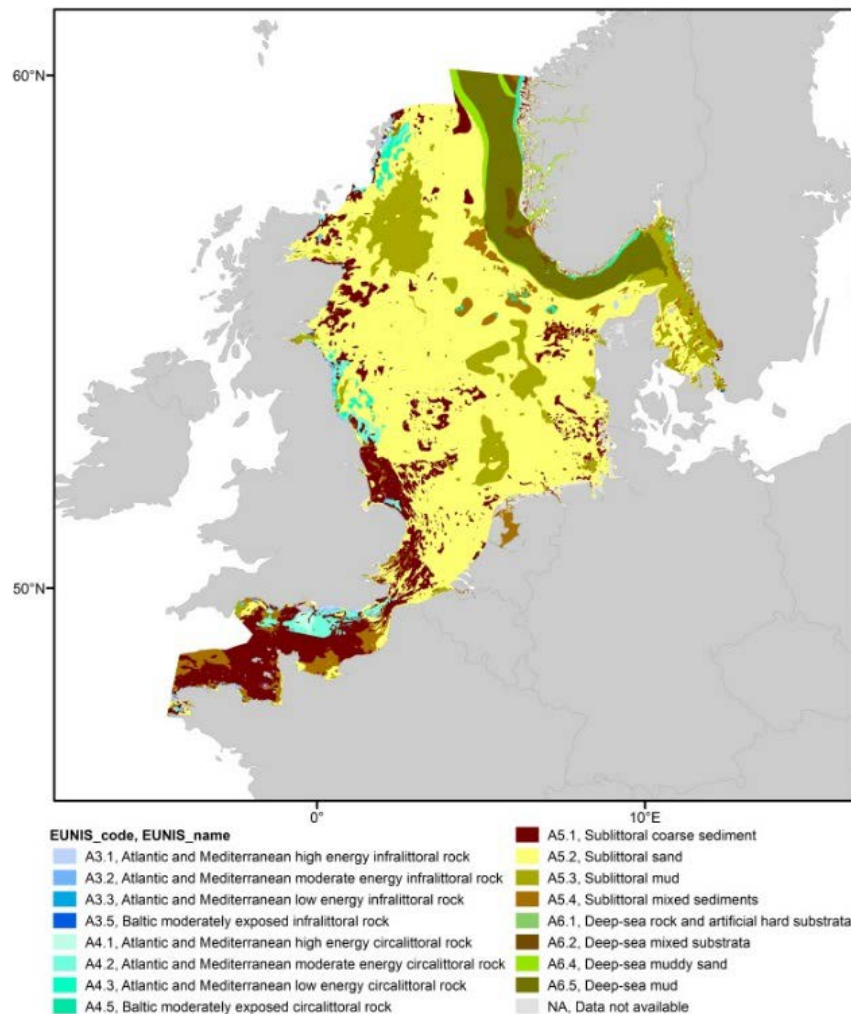
Habitats of the Greater North Sea ecoregion

EUNIS_code, EUNIS_name

- A3.1, Atlantic and Mediterranean high energy infralittoral rock
- A3.2, Atlantic and Mediterranean moderate energy infralittoral rock
- A3.3, Atlantic and Mediterranean low energy infralittoral rock
- A3.5, Baltic moderately exposed infralittoral rock
- A4.1, Atlantic and Mediterranean high energy circalittoral rock
- A4.2, Atlantic and Mediterranean moderate energy circalittoral rock
- A4.3, Atlantic and Mediterranean low energy circalittoral rock
- A4.5, Baltic moderately exposed circalittoral rock
- A5.1, Sublittoral coarse sediment
- A5.2, Sublittoral sand
- A5.3, Sublittoral mud
- A5.4, Sublittoral mixed sediments
- A6.1, Deep-sea rock and artificial hard substrata
- A6.2, Deep-sea mixed substrata
- A6.4, Deep-sea muddy sand
- A6.5, Deep-sea mud
- NA, Data not available

Figure A.2   Broadscale (2011 Level 3 EUNIS) habitats of the Greater North Sea ecoregion.

The seabed of the Greater North Sea is dominated by soft sediments (Figure A.1). The four main habitats (A5.1 – sublittoral coarse sediment, A5.2 – sublittoral sand, A5.3 – sublittoral mud, and A5.4 – sublittoral mixed sediment) comprise 93% of the total surface area between 0 and 200 m depth. Deeper waters are dominated by muddy sediments.

Indicators

Table A.2   Indicators of fishing pressure and seabed impact.

Annual pressure indicators	Description
1. Intensity	Average number of times the area is swept by bottom-contacting fishing gears. Estimated as the sum of swept area for all vessels using bottom-contacting gears or by métier, divided by the total area of the considered area (regional/subregional sea, or broadscale habitat type within that sea).
2. Proportion of grid cells fished	The number of grid cells (c-squares) fished at least once (irrespective of the swept area within the cell), divided by the total number of grid cells (c-squares) within the considered area.
3. Proportion of area fished	The sum of swept area across all grid cells in a considered area, but where swept area in a specific grid cell cannot be greater than the area of that grid cell, divided by the summed area of all grid cells.
4. Aggregation of fishing pressure	The smallest proportion of the grid cells (c-squares) where 90% of the total swept area occurs.
Multi-annual pressure indicator	
Persistently unfished areas	Indicator 2 evaluated over six years.
Annual impact indicators	
Average impact	Average fishing impact across grid cells in an area; PD2 method.
	Average fishing impact across grid cells in an area; LL1 method.
Proportion of area with impact < 0.2	The proportion of grid cells with an impact below a (chosen, in this case 0.2) impact threshold in an area; PD2 method.
	The proportion of grid cells with an impact below a (chosen, in this case 0.2) impact threshold in an area; LL1 method.

Methods

Pressure indicators

ICES (2016a) defines the swept area as the cumulative area of seabed contacted by a fishing gear within a grid cell over one year. The swept area ratio (SAR, also defined as fishing intensity) is the swept area divided by the surface area of the grid cell. Values above 1 indicate the area (c-square) is swept more than once per assessment period. The area contacted by fishing gear is calculated from geographically-distinct vessel monitoring system (VMS) points for which speed and course are available at intervals of maximum 2 hours, coupled with information on vessel size and the type of fishing gear used, derived from EU logbooks (ICES, 2017a; Eigaard *et al.*, 2016).

Vessel speeds representing fishing activity are assigned to a 0.05° × 0.05° grid which covers about 15 km² at 60°N latitude, the spatial resolution adopted by ICES: the c-square approach. This is the finest scale grid that it is possible to use in publicly available data products at present; should that situation change, finer grid scales may be possible.

Each c-square was assigned to a EUNIS level 3 habitat type using the habitat modelled at the centre point of the c-square.

Estimates of total SAR within each grid cell were calculated by métier and habitat type. A total of four métiers (otter trawl, beam trawl, dredge, and demersal seine) and four broad habitat types (sublittoral course sediment, sublittoral sand, sublittoral mud, and sublittoral mixed sediment) were specifically considered.

The pressure and impact indicators are discussed in detail in ICES (2017a).

Impact indicators

ICES evaluated different impact indicators derived from two approaches that make use of the longevity composition of the benthic community (Rijnsdorp *et al.*, 2016a, 2016b) to assess habitat sensitivity to fishing.

The PD2 method is a mechanistic model that estimates the total reduction in community biomass (B) relative to carrying capacity (K), corresponding to the estimated fishing intensity. Total community biomass relative to carrying capacity (B/K)

describes the equilibrium state (the interaction between the depletion caused by fishing and the recovery of the benthic community). The impact is given by 1−B/K (Pitcher *et al.*, 2017). The depletion rates are estimated from a meta-analysis that provided gear-specific depletion rates (Hiddink *et al.*, submitted). The recovery rates are derived from a meta-analysis that is longevity specific (Hiddink *et al.*, in prep.). The biomass component of the PD2 method is a proxy for energy flow through benthic (and associated) foodwebs, and for other ecosystem (functioning) processes.

The LL1 method is a statistical model that estimates the habitat-specific longevity composition of the community and the effect of trawling on this composition. The basis of this relationship is that long-lived species have a lower recovery rate because of their lower growth rates and later age-at-maturity; they are thus generally more sensitive to fishing mortality. The model includes an interaction of the effect of trawling and shear stress at the seabed as trawling has lower impacts on habitats with high shear stress (high natural disturbance). The indicator estimates the reduction in proportion of long-lived taxa (maximum lifespan > 10 years) due to trawling. The species-specific longevity traits were derived from a literature review (Bolam *et al.*, 2014).

Landings/value indicators

Landings values (Euros) and weights (kg) were calculated from logbook data by each country prior to submitting data to ICES.

Trade-offs

As an example, ICES (2017b) used the PD2 assessment methodology (see above and ICES, 2017a) to examine the relationship between the pressure and impact of bottom-contacting fishing gear on the seabed, as well as the seabed status and the consequent catch and value of landings. The resultant landings and value metrics were aggregated across selected métiers, allowing impacts to be assessed at regional or subregional levels. Because trawling is aggregated at the regional sea scale, trade-offs between core and peripheral fishing grounds were examined.

Quality of the advice

Data coverage for the estimation of fishing pressures is excellent in offshore waters in the North Sea. The VMS data cover all bottom trawling vessels above 12 m from all countries (ICES, 2017a).

Footprints of fishing pressure were estimated, assuming that trawling has a uniform distribution within each c-square. This assumption will apply when trawling is evaluated over longer time periods, but will lead to an overestimate of the proportion of the seabed trawled at shorter time scales because trawling is randomly distributed at small spatial scales (Rijnsdorp *et al.*, 1998; Ellis *et al.*, 2014; Eigaard *et al.*, 2017).

The PD2 method assesses the impact of trawling on the benthic biomass. The assessment of biomass gives due weight to recovery of body-size and age structure as well as numbers of individuals and takes account of energy flow through foodwebs and other ecosystem processes that are closely linked to biomass. The depletion and recovery rates are estimated by a meta-analysis, using a systematic review methodology (Hiddink *et al.*, submitted). The distribution of recovery rates of the benthic community is estimated from the longevity composition of the community derived in the LL1 method.

The LL1 method is based on a statistical analysis of the effect of bottom trawling on the longevity composition and showed that the effect of bottom trawling depends on the level of natural disturbance due to shear bed stress. Compared to the LL1 method, the PD2 method estimates higher impact of bottom trawling in areas exposed to higher levels of shear bed stress. LL1 is populated from grab and box core data taken in the main seabed habitats in the English Channel and the southern part of the North Sea (Rijnsdorp *et al.*, 2016b). It is unknown whether the longevity composition on the infauna is representative for the total benthic community (infauna and epifauna) and whether the estimated longevity composition applies beyond the English Channel and the southern part of the North Sea.

The PD2 method and the LL1 method gave different impact scores (ICES, 2017a). This is because the two methods measure different aspects of the seabed.

Additional information

Several caveats should be taken into account when considering the demonstration advice. The following caveats relate to issues concerning the provision of vessel data and its interpretation, the scale at which data is informative, and the biota used to assess impact. These caveats are:

- VMS data from vessels smaller than 12 m are lacking from the assessment. This introduces an underestimate in the assessment that is expected to be prominent in coastal areas. The degree of underestimate will vary along coasts.
- VMS data from certain countries both within and outside the EU are also lacking, introducing an underestimate in pressure in areas fished by these countries. This is not believed to be a large issue in the Greater North Sea.
- The calculation of fishing intensity, as well as of surface and subsurface abrasion, is inferred from a suite of vessel data, including vessel speed. However, fishing speed was not always supplied in such cases, estimates of fishing speed were based on an average of the fishing speed values that were supplied.
- It is possible that the valuation of landings has been treated differently by different countries, potentially introducing bias.
- Habitat maps at the regional scale may be both biased and uncertain, but the degree of this is usually unknown. ICES has not assessed the scale of this bias and uncertainty or how it varies at the regional sea scale.
- Benthic sample coverage is variable by region and by habitat. Consequences of this heterogeneity cannot be encapsulated in regional sea scale assessments.
- Not all of benthos is included in the assessment, especially epifauna, and harder habitats in particular are therefore omitted from the assessment.
- Owing to the relative lack of knowledge of biological features of the broad habitat types in deeper waters, ICES can at present only advise on impacts on seabeds shallower than 200 m.

Assessment

Fishing pressure, intensity, landings, and value

Fishing pressure in this context is defined as the fishing activities of all mobile bottom-contacting gears, including otter trawl, seines, beam trawls, and dredges and is described by the four annual (and one multi-annual) indicators shown in Table A.2.

Fishing intensity varies considerably across the Greater North Sea (Figure A.3). Areas of higher intensity (surface abrasion) occur in the northern North Sea along the edge of the Norwegian Trench, in the eastern English Channel, and in locations around the Dogger Bank. Areas with lower intensity occur in the western part of the North Sea, and in the deeper parts of the Norwegian trench. The distribution of fishing and its intensity in 2015 was similar to that seen during the period 2012–2015, but the non-fished area is smaller when assessed over this longer time period.

In the Greater North Sea most of the mobile bottom-contacting fishery operates in waters less than 200 m, with 54% of the seabed fished in 2015. In waters deeper than 200 m, 21% of the seabed was fished (but most of this at depths between 200 m and 300 m). The proportion of the area fished differs between the four most widespread habitat types in the Greater North Sea, being highest in sublittoral mud (EUNIS habitat code A5.3, 69%), followed by sublittoral mixed sediment (A5.4, 59%), sublittoral sand (A5.2, 54%) and sublittoral coarse sediment (A5.1, 49%) (Table A.1). Fishing intensity is highest in sublittoral mixed sediment (3.2 year^{-1}, i.e. this habitat was fished 3.2 times on average in 2015) and lowest in sublittoral sand (1.4 year^{-1}).

Fishing intensity shows some variation over time (Figure A.4a). Fishing intensity was slightly lower in 2015 than in previous years (2009–2014), except in sublittoral mixed sediment. The dip in fishing intensity in sublittoral mud observed in 2011 was due to reduced fishing for *Nephrops*; these crustaceans were difficult to catch in the early part of the season as water temperatures were lower in that year. The area (Figure A.4b) and main habitat types fished (Figure A.4c) showed similar variations in that year.

Fishing pressure is aggregated in a relatively small part of the total area fished, both at the regional level as well as at the level of each habitat type (Figure A.4c). 90% of the fishing effort with bottom-contacting gears occurred in about a third to half of the area; these most intensively fished areas represent the 'core fishing grounds'. The remainding 10% of the effort

is spread over a greater area that covers between half and two thirds of the total area fished; this area is thus less intensively fished and represents the 'peripheral fishing grounds'. The core fishing grounds contribute most of the landings of fish and shellfish by weight and value (Figure A.5). Almost 80% of the fishing effort and landings, and about 70% of the value, occur in only 20% of the surface area of the Greater North Sea ecoregion.

Table A.3   Overview of pressure and impact indicators for all mobile bottom-contacting gears per EUNIS habitat type in the Greater North Sea ecoregion in 2015 (0–200 m depth zone only), ordered by their habitat extent in the North Sea. The top four habitats are sublittoral sand (A5.2), sublittoral coarse sediment (A5.1), sublittoral mud (A5.3), and sublittoral mixed sediment (A5.4), representing 93% of the area of seabed in the Greater North Sea subregion. See Figure A.1 for other habitat codes. The deeper sea habitats (codes A6.x) all occurred along the 200 m depth contour on either side of the Norwegian Trench.

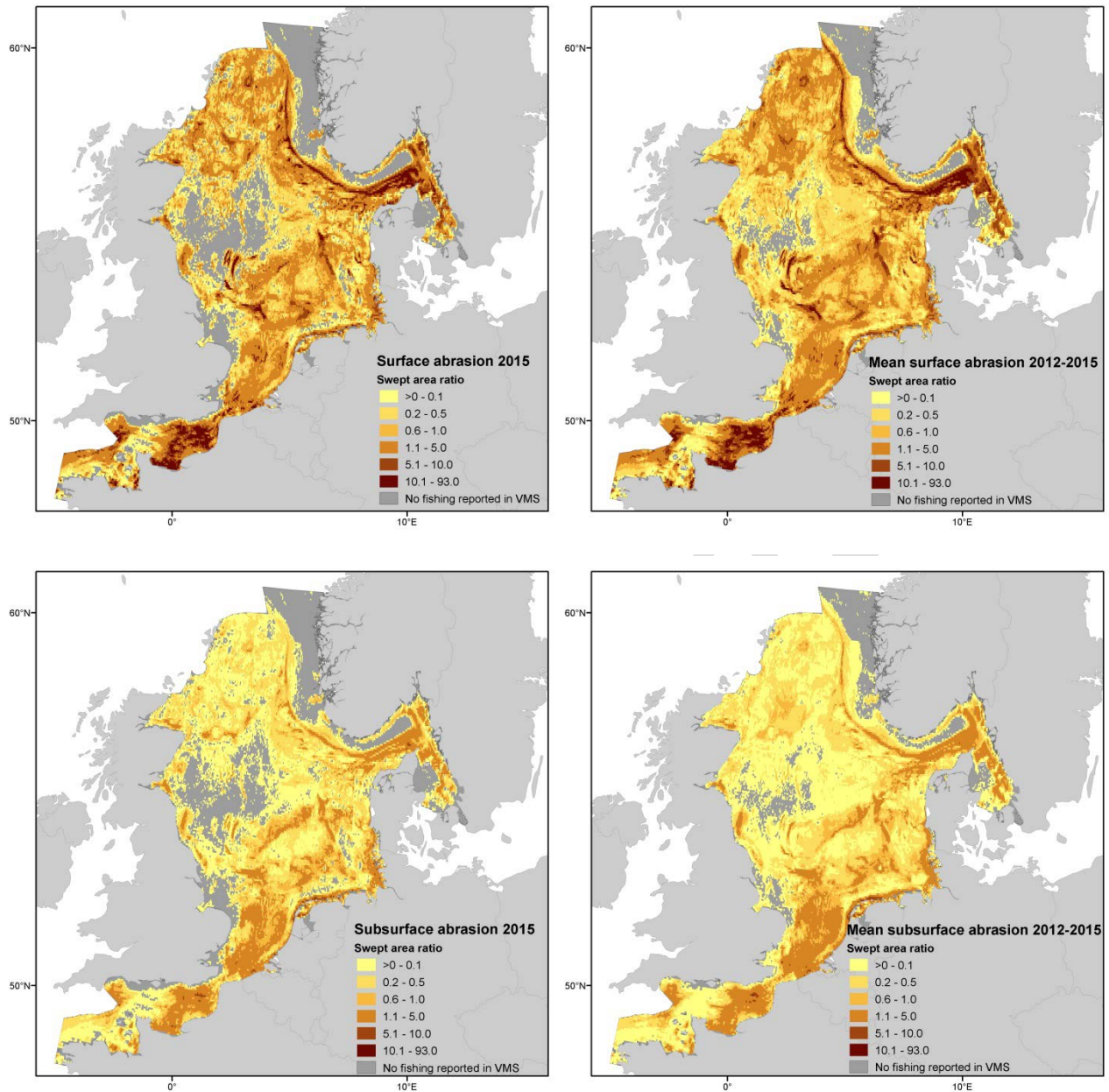| EUNIS Habitat code	Extent of habitat 10^3 km^2	number of grid cells	Swept area 10^3 km^2	Fishing intensity (year^{-1})	Proportion of North Sea (with relevant habitat) fished	Proportion of grid cells (with relevant habitat) fished	Proportion of habitat fished with 90% effort (grid cells)	Average impact (1–B/K)	Landings 10^3 tonnes	Value 10^6 Euro
A5.2	364.4	21218	512.4	1.41	54%	82%	40%	0.23	816.4	564.0
A5.1	90.3	4901	182.2	2.02	49%	78%	29%	0.26	86.9	158.9
A5.3	68.8	4108	166.7	2.42	69%	92%	46%	0.33	94.2	109.9
A5.4	31.8	1791	101.3	3.19	59%	75%	32%	0.31	36.2	86.7
A4.2	11.9	641	23.1	1.95	53%	84%	33%	0.27	6.1	17.2
A4.3	7.2	444	4.2	0.59	36%	70%	39%	0.09	2.0	3.8
A3.1	2.7	165	0.6	0.23	12%	33%	12%	0.06	0.4	0.6
A6.4	2.4	176	2.4	1.01	21%	20%	14%	0.12	3.4	0.9
A4.1	2.0	108	0.8	0.38	24%	71%	30%	0.05	0.2	0.5
A3.2	1.7	103	0.9	0.54	27%	54%	23%	0.08	0.5	1.3
A6.5	0.7	43	5.2	7.37	91%	93%	70%	0.83	3.7	2.7
A6.1	0.3	20	0.0	0.16	16%	30%	25%	0.07	0.0	0.0
A3.3	0.1	5	0.1	1.22	49%	100%	40%	0.18	0.0	0.1
A6.2	0.1	9	0.1	0.94	23%	33%	22%	0.13	0.5	0.1
Habitat unknown	10.3	684	1.3	0.12	5%	9%	3%	0.03	1.4	3.1

Figure A.3   Fishing intensity by mobile bottom-contacting gear (year⁻¹) in 2015 (left panels) and in the period 2012–2015 (right panels) for surface abrasion (top panels) and subsurface abrasion (bottom panels). Different gear types interact with the seabed in different ways and thus exert different levels of abrasive pressure, both in terms of the area of substrate affected and the penetration depth. Surface abrasion is defined as the damage to seabed surface features, subsurface abrasion as the penetration and/or disturbance of the substrate below the surface of the seabed.
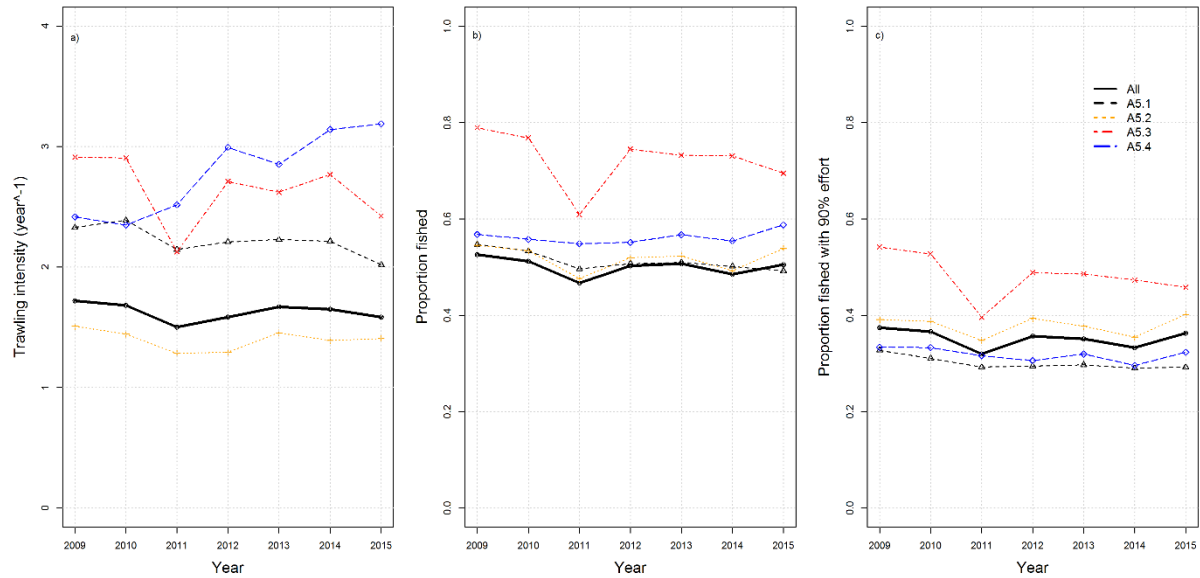
Figure A.4   Time-series of (left panel) average fishing intensity (surface abrasion), (middle panel) proportion of the surface area of the seabed fished, and (right panel) aggregation of fishing (proportion of the surface area with 90% of the fishing effort) by habitat for the depth zone 0–200 m in the Greater North Sea. Results represent vessels over 15 m (2009–2011) and vessels over 12 m (2012–2015).
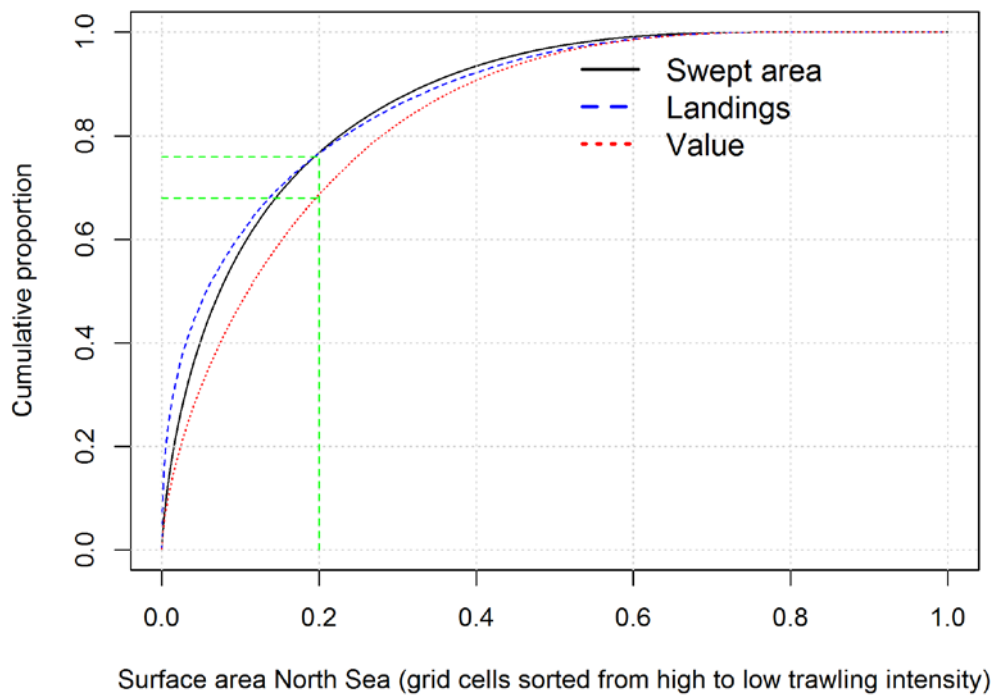

Figure A.5   Cumulative proportion of the swept area, landings, and value. Grid cells were sorted from highest to lowest fishing intensity and include non-fished cells. The results are for all mobile bottom-contacting gears in the North Sea. As an illustration, almost 80% of the fishing effort (swept area) and landings, and about 70% of the value, occur in only 20% of the surface area of the Greater North Sea ecoregion (green dashed lines).
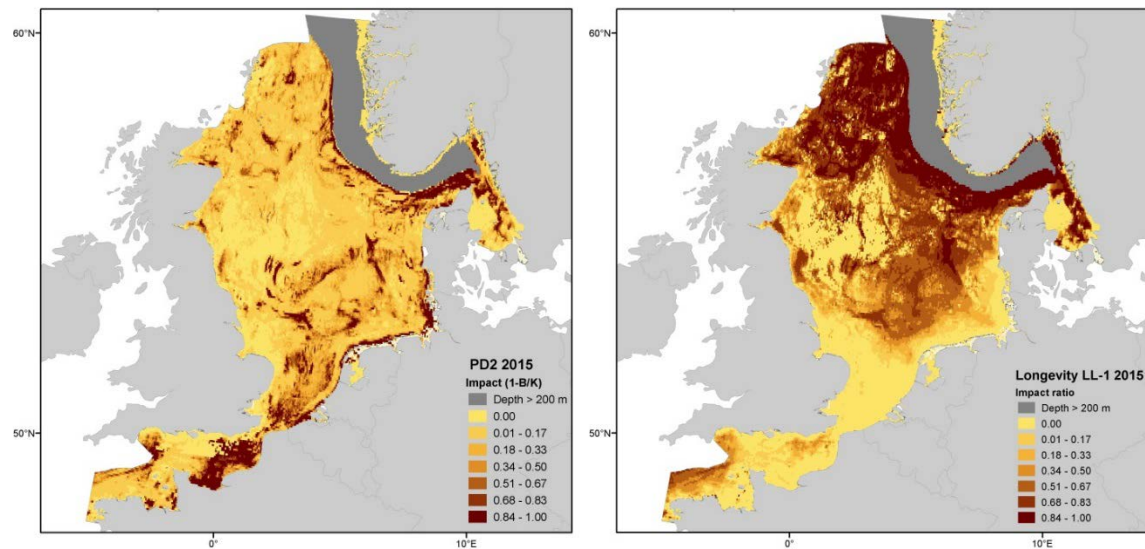
Impact

Figure A.6   Average annual Impact of all mobile bottom-contacting gears by c-square in 2015 according to the PD2 (left) and LL1 methods (right). Maps show only impacts in depths between 0 and 200 m. The colour scales are at equal-sized intervals between 0 and 1.

The impact of mobile bottom-contacting fishing assessed using the population dynamic approach (PD2) method shows the areas of highest fishing impact (in this example, > 0.84) along the slopes of the Norwegian trench in the Skagerrak and western Norway, and in the eastern English Channel (note the 200 m depth limit in this assessment; Figure A.6). Highly impacted areas are also seen along the continental coast of the North Sea, in the southern North Sea, and in areas around the Dogger Bank. The longevity method (LL1) shows a different pattern, in particular in the southern North Sea and eastern English Channel. In deeper waters the high impact areas correspond between the two methods, although LL1 gives overall higher impact scores. The difference between the methods results from the larger impact of depth and seabed shear stress (caused by tidal currents and wind-induced waves/currents) in shallow waters than in deep waters. This stress reduces the impact of fishing on the longevity distribution in shallow waters relatively more than on the biomass on which the PD2 method is based. Further research is needed to study whether the difference is due to the different response variable used in each model (population biomass versus the biomass proportion of long-lived species), or rather to the PD2 model being less sensitive to the effects of shear bed stress.

The average impact of all mobile bottom-contacting fishing in 2015 in the North Sea, using the population dynamic approach (PD2) method, was 0.24, which was slightly lower than in 2009 and 2010 (Figure A.7a). Impact varied between habitats. Impact is highest in mud (0.33) and mixed sediment (0.31) and lowest in coarse sediment (0.26) and sand (0.22). Since 2009, the impact showed a slight decrease in mud and coarse sediments, and a slight increase in mixed sediment. The proportion of the surface area fished with a *low impact (< 0.2)* is around 50% in muddy sediments and 60% in other habitat types (Figure A.7b). *The value of 0.2 has no particular significance and is chosen merely to illustrate the approach. Values could also be provided for the LL1 method, or for both. The choice of indicator depends greatly on policy priorities.*
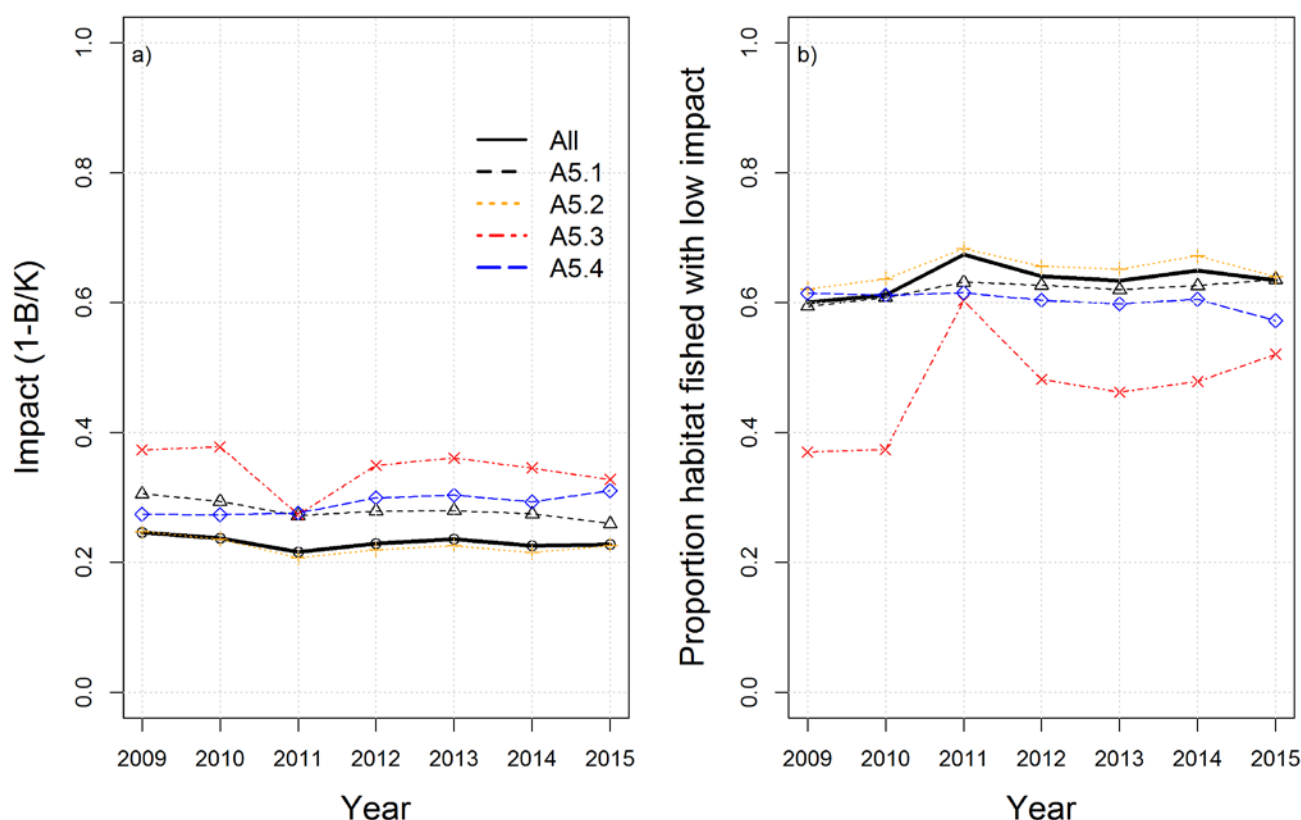
Figure A.7   The average impact in 2009–2015 by mobile bottom-contacting gears on four broadscale (EUNIS) habitat types at water depths less than 200 m in the Greater North Sea ecoregion, estimated using (a) the population dynamic (PD2) method (1–B/K) and (b) *the proportion of the fished area with an impact of less than 0.2.*

Impact of selected métiers, and the relationship with landings and value

The impact of four selected métiers using the population dynamic approach (PD2) method was assessed for the grid cells that were fished uniquely by these métiers, ignoring cells fished by other métiers (Table A.4). Métier-specific impact in 2015 varied between 0.10 and 0.17. Métier-specific impact was highest in the beam trawl fishery targeting flatfish (TBB_DEF_>70) and the otter trawl fishery for crustaceans, particularly *Nephrops* (OTB_CRU).

Métiers differ in their habitat association (Figure A.8). Fishing impact on coarse sediment and sand habitats is dominated by the beam trawl fishery on flatfish (TBB_DEF_>70). The impact on the mud habitat is dominated by the otter trawl fishery for crustaceans (OTB_CRU). The otter trawl fishery for mixed demersal fish had the highest impact on the mixed sediment habitat. The impact of the otter trawl fishery for industrial species (OTB_DEF_<70) is highest on sand habitat.

The impacts of these four métiers varied over time (2009–2015, Figure A.9). The impact of the otter trawl fishery for demersal fish decreased in the coarse sediment habitat, but not in other habitats. The impact of the beam trawl fishery decreased over time in all habitats, except in mixed sediment. The impact of the industrial fishery increased in mud and mixed sediment habitats and decreased in sand habitat. The cumulative impact of all métiers per habitat is shown in Figure A.7.

The weight of landings by each métier, and their value, were also calculated (Table A.4). The highest métier-specific impact relative to weight of landings was in the otter trawl fishery for crustaceans, particularly *Nephrops* (OTB_CRU), followed by the beam trawl fishery targeting flatfish (TBB_DEF_>70). OTB_CRU and the otter trawl fishery for industrial species (OTB_DEF<70) had the highest impact relative to the value of their landings.

Table A.4   Overview of pressure and impact indicators of four selected métiers in the Greater North Sea in 2015. The impact is estimated for the grid cells fished with these métiers only. OTB_CRU: otter trawl fishery for crustaceans; OTB_DEF<70: otter trawl fishery for industrial species; OTB_DEF_>70: otter trawl fishery for demersal fish; and TBB_DEF_>70: beam trawl fishery for flatfish.

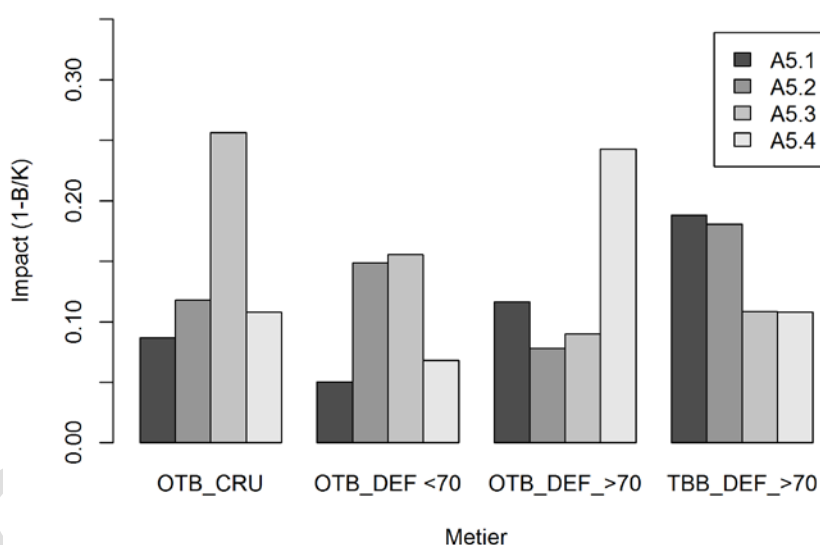| Métier	OTB_CRU	OTB_DEF<70	OTB_DEF_>70	TBB_DEF_>70
Area fished (10^3 km^2)	87.5	40.9	139.5	72.7
Intensity	1.23	1.06	0.79	0.55
Aggregation of fishing pressure, The smallest proportion of the grid cells (c-squares) in the area fished by each métier where 90% of the total swept area occurs.	39%	34%	46%	50%
Average impact (PD2 method)	0.16	0.12	0.10	0.17
Landings (10^3 tonnes)	40.8	584.2	86.6	70.2
Value (10^6 Euro)	128.3	112.8	173.6	235.9
Effort (10^3 km^2)	218.8	110.7	242.2	91.9
Average impact/landings ratio (10^{-2})	0.381	0.021	0.110	0.247
Average impact/value ratio (10^{-2})	0.121	0.108	0.055	0.074

Figure A.8   Impact of four selected métiers by habitat type for the Greater North Sea in 2015. OTB_CRU: otter trawl fishery for crustaceans; OTB_DEF<70: otter trawl fishery for industrial species; OTB_DEF_>70: otter trawl fishery for demersal fish; and TBB_DEF_>70: beam trawl fishery for flatfish.
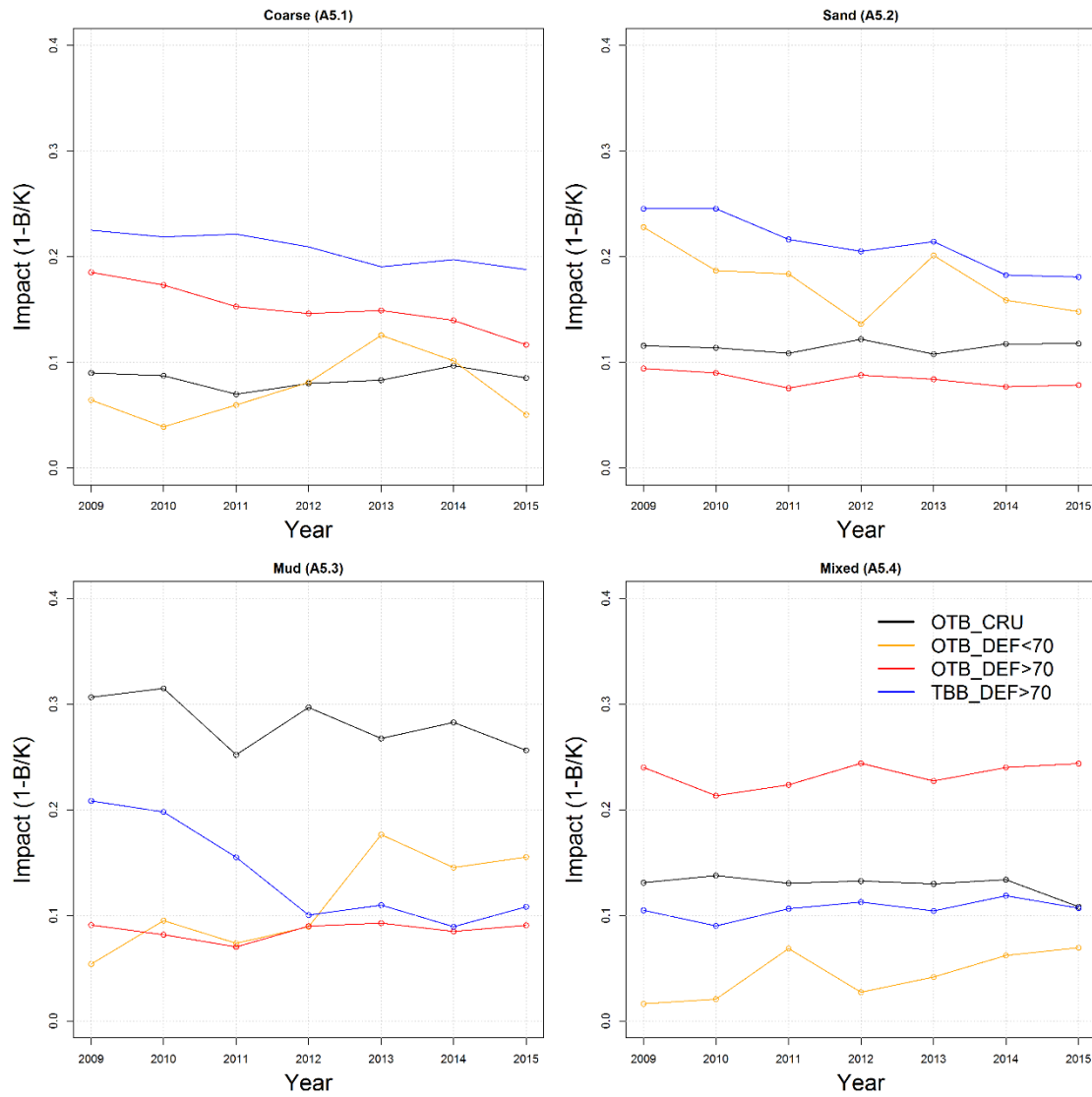
Figure A.9   Time trend in the impact of four separate métiers, by habitat type. OTB_CRU: otter trawl fishery for crustaceans; OTB_DEF<70: otter trawl fishery for industrial species; OTB_DEF_>70: otter trawl fishery for demersal fish; and TBB_DEF_>70: beam trawl fishery for flatfish.
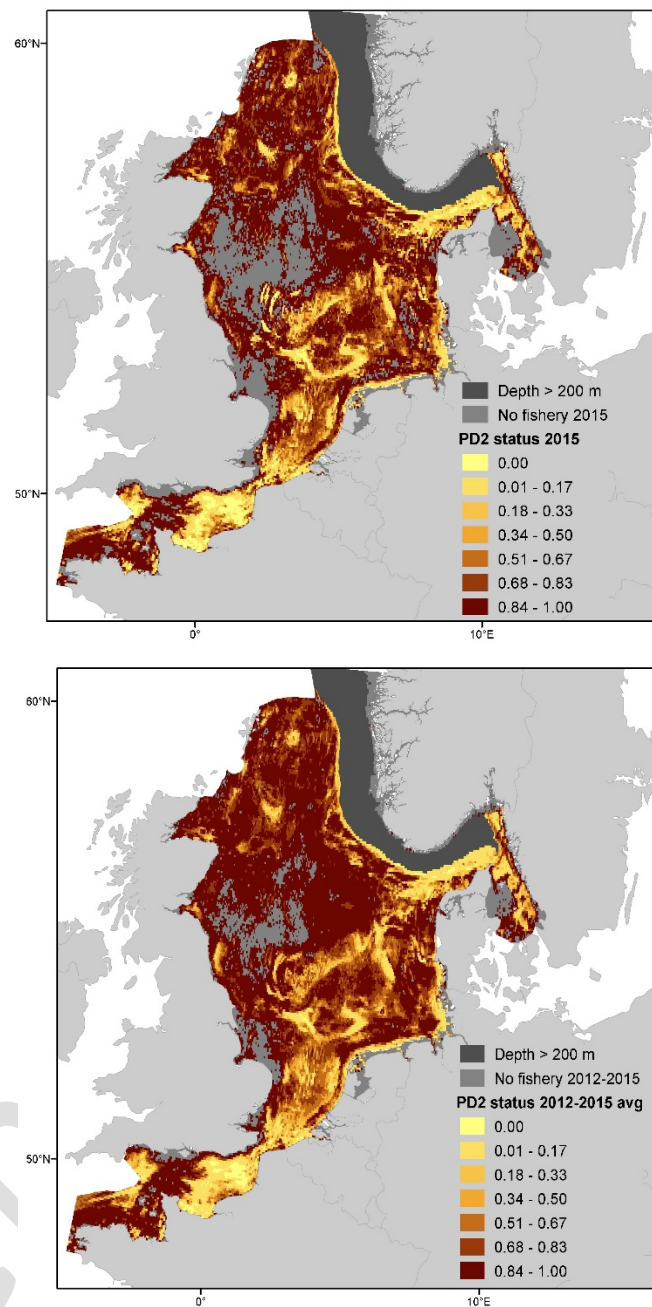
Status

Figure A.10   Status of the seabed in the Greater North Sea in relation to fishing pressure using the population dynamic approach (PD2) method: (a) in 2015, and (b) in the period 2012–2015. Note: status score is inverse of impact, i.e. 0 = not in good status (heavily impacted, yellow) and 1 = good status (unimpacted, brown).

Status can be mapped for each of the impact methods, taking 0 as being heavily impacted and therefore not in good status, and 1 as being unimpacted and in good status from the point of view of fishing pressure (Figure A.10). All widespread habitats exhibit the full range of possible state scores, from 0 to 1. A large fraction of habitats are in a state close to 1 for each of the assessment methods because a substantial fraction of most habitats is either not or only very lightly fished (Figure A.11).

At present there is no agreed method to determine where status is "good" in relation to fishing pressure. As noted above, the choice of method used to describe impact will also affect status. There is limited ecological basis for setting good environmental status (GES) threshold levels at different scales across a continuous landscape. If non-linear relationships exist between pressure and state of a habitat at a specific scale, the inflection point in these relationships (i.e. when a

significant change in the relationship occurs) could be used to help define thresholds. However, at the current time, such thresholds have not been identified. Figure A.11 indicates that for the PD2 method, there would be little difference in the choice of any value for a GES threshold at less than 1 in the major broadscale habitats of the North Sea, with the same applying to the LL1 method (except for sublittoral mud habitats). The spatial heterogeneity in 'good status' locations across the region may also affect recovery rates (e.g. habitat fragmentation, relative to dispersal and connectivity across the seabed).

If the population dynamic approach (PD2) method is used and GES was assessed to be *above 0.6*, then large parts of the Greater North Sea would be assessed as being in good status. Areas of low status *(< 0.50)* occur throughout the region and reflect the core fishing grounds. *As stated above, these values are chosen for illustration only, and are not ICES advice.*
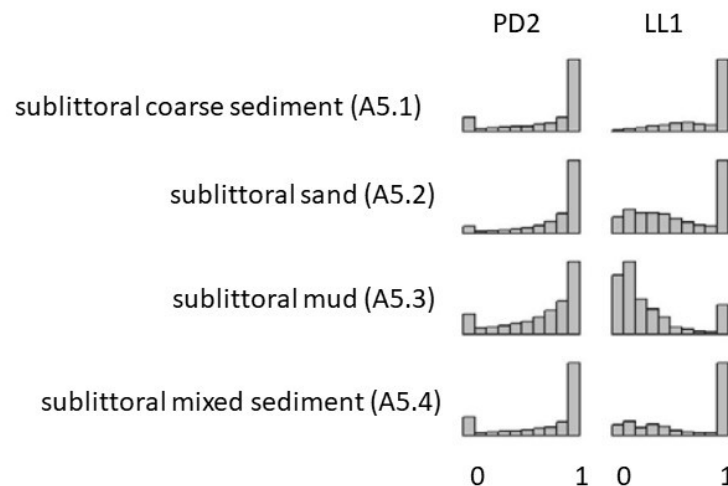

Figure A.11   Frequency of the relative state, in relation to fishing pressure, of the four main broadscale benthic habitats in the North Sea in 2015, using two methods for expressing impact (PD2 and LL1). 0 = not in good status, 1 = good status. The height of the columns indicate the relative proportion of that habitat in each state.

Management options

This section reflects on possibilities for management advice. This should not be interpreted as advice, it is purely for demonstration using one method to assess impact/state of the seabed, and confined only to the Greater North Sea at depths < 200 m, using only 2015 data.

Changes in fishing effort

Figure A.12 shows the effect of changes in fishing effort on the status of the seabed and the proportion of the area where the status of the seabed is above a certain threshold level, here chosen at 0.8 for demonstration purposes (the impact of trawling is less than a certain threshold value) using the PD2 method to assess state/impact. The heavy line shows how the proportion of the seabed with a status above the threshold level decreases with this threshold level. In this example, just over 60% of the seabed in the North Sea has a status of at least 0.8 (vertical dashed line). Decreasing the fishing effort will improve the status of the seabed, as reflected in the lines moving upward. A reduction of 50% in fishing effort (the overall amount of fishing occurring) will increase the proportion of the seabed having a status of 0.8 from about 65% to 80%, assuming that the same proportional decrease in effort is seen in all areas. Increasing fishing effort by a factor of 2 will reduce the proportion of the seabed having a status of 0.8 to around 45% if this increase leads to the same proportional increase in effort in all areas. These figures should be considered very uncertain as it is very unlikely that changes in effort would occur proportionally in all areas.
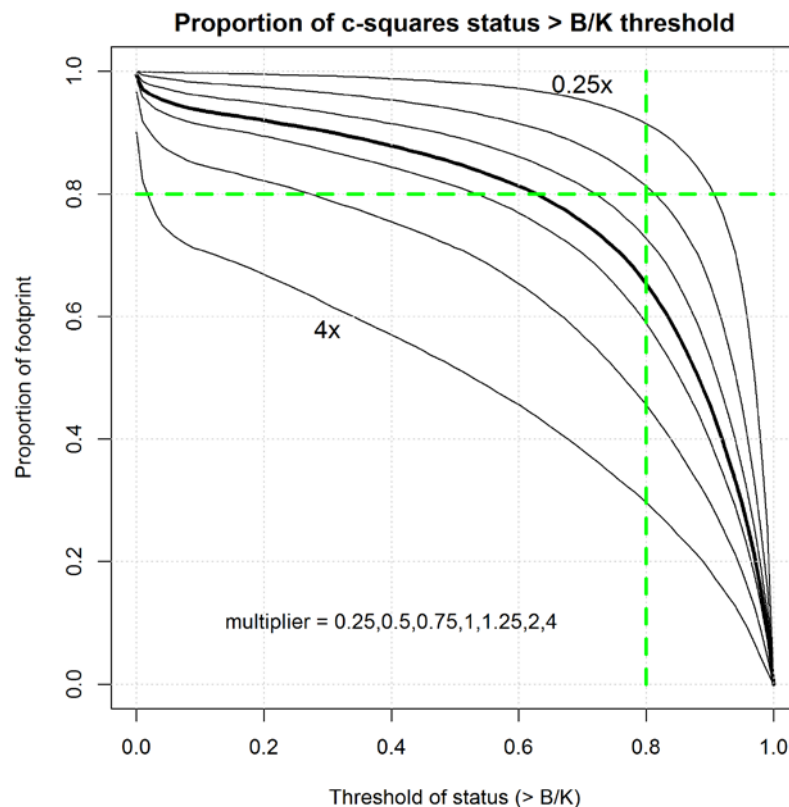
Proportion of c-squares status > B/K threshold

Figure A.12	Effect of a change in fishing effort on the proportion of the seabed of the Greater North Sea at depths < 200 m with a status above the threshold (B/K). The heavy line shows the situation for 2015. The area with a status above the threshold decreases when fishing pressure is increased (multipliers 1.25, 2, and 4) and increases when fishing pressure decreases (multipliers 0.75, 0.50, and 0.25). The status of the seabed can be assessed against reference levels for the status of the seabed (vertical dashed line) and for the proportion of the region or habitat with a status above the reference. *The reference levels shown in the graph are drawn for illustrative demonstration purposes only*.

Spatial management

The overall fishing impact could be reduced by minimizing fishing pressure in the areas of least importance to the industry, while at the same time minimizing the negative effect on the weight of landings and value. This is because fishing pressure is highly aggregated. Figure A.13 shows the average landings value of each c-square over the period 2012–2015. Data were sorted by EUNIS habitat type and value and those c-squares with the least value, constituting 5% and 10% of the swept area, were highlighted (Figure A.13). It should be noted that any spatial management limiting effort in selected areas is likely to lead to redistribution of this effort into other areas. To predict this effect, a specific evaluation of the suggested management measures is required.

The total area by EUNIS habitat type and the value of landings in these areas from fisheries using bottom-contacting gears are shown in Table A.5, together with the area of the c-squares that accounts for the lowest 5% and 10% of the cumulative swept area by habitat type and the associated value of landings. *Please note that these values are put in purely for demonstration purposes.*
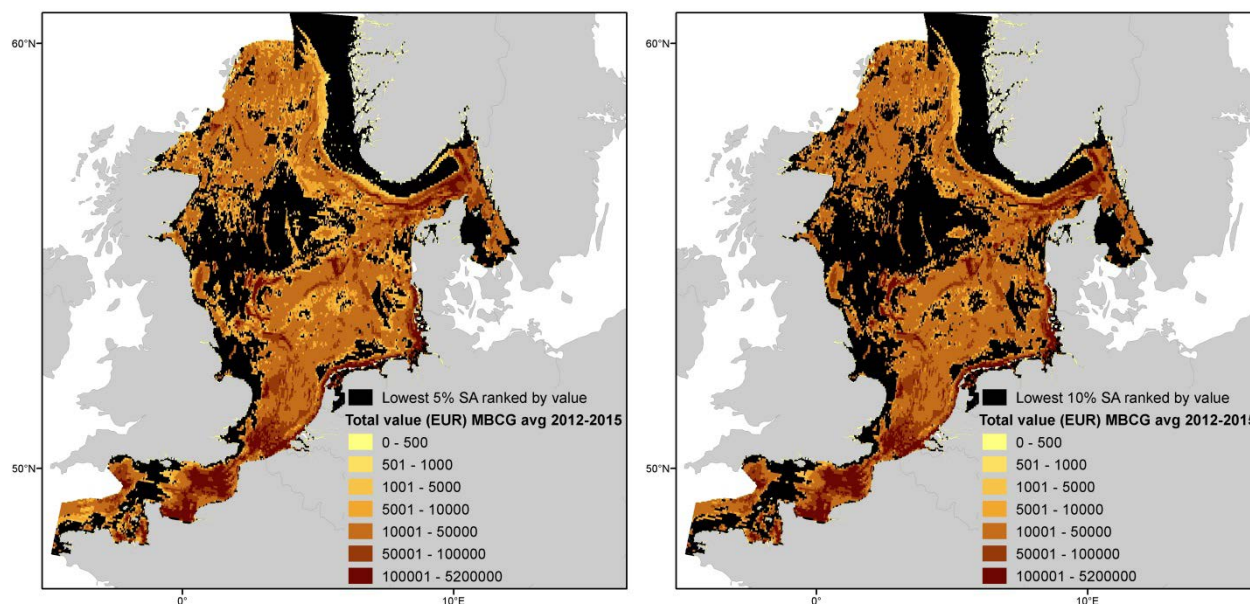
Figure A.13 The average value of each c-square over the period 2012–2015 in the Greater North Sea subregion. *Those c-squares with the least value constituting 5% (left panel) and 10% (right panel) of the swept area are highlighted.*

Table A.5 The area of c-squares representing the lowest 5% and 10%, respectively, of the total swept area of fisheries with bottom-impacting gears in the Greater North Sea ecoregion and the associated value of the landings from these fisheries. The proportions (%) of these areas compared to the total area of each habitat are also shown.

Habitat code	Total area (km²)	Total value (EUR)	Area (km²) of lowest *5% swept area* of c-squares. Percentage of total area in brackets	Value (EUR) of lowest *5% swept area* of c-squares. Percentage of total area in brackets	Area (km²) of *lowest 10%* swept area of c-squares. Percentage of total area in brackets	Value (EUR) of *lowest 10%* swept area of c-squares. Percentage of total area in brackets
A5.2	364508	491075026	114012 (31%)	6095548 (1.2%)	141987 (39%)	13234594 (2.7%)
A5.1	90256	156951314	33560 (37%)	1176371 (0.7%)	40307 (45%)	2822481 (1.8%)
A5.3	69236	111031176	13882 (20%)	1818299 (1.6%)	18398 (27%)	3949593 (3.6%)
A6.5	51998	23943246	37950 (73%)	69677 (0.3%)	40047 (77%)	170370 (0.7%)
A5.4	31944	79784400	12141 (38%)	432964 (0.5%)	14044 (44%)	944718 (1.2%)
A4.2	11862	15660868	4338 (37%)	162325 (1.0%)	5216 (44%)	329754 (2.1%)
A6.4	8078	2701046	4534 (56%)	20088 (0.7%)	4849 (60%)	48725 (1.8%)
A4.3	7482	4135990	3869 (52%)	83768 (2.0%)	4345 (58%)	179427 (4.3%)
A6.2	3932	55196	3772 (96%)	508 (0.9%)	3853 (98%)	3036 (5.5%)
A3.1	2740	1044324	1727 (63%)	10735 (1.0%)	1857 (68%)	23044 (2.2%)
A4.1	2004	634564	938 (47%)	8490 (1.3%)	1109 (55%)	18028 (2.8%)
A3.2	1740	1037846	989 (57%)	15098 (1.5%)	1096 (63%)	34748 (3.3%)
A6.1	920	1832	823 (89%)	67 (3.7%)	839 (91%)	137 (7.5%)

Sources and references (these include sources not cited in the text)

Bolam, S. G., Coggan, R. C., Eggleton, J., Diesing, M., and Stephens, D. 2014. Sensitivity of macrobenthic secondary production to trawling in the English sector of the Greater North Sea: A biological trait approach. Journal of Sea Research, 85: 162–177.

Bolam, S. G. Eggleton, J., Garcia, C., Kenny, A., Buhl-Mortensen, L., Gonzalez, G., van Kooten, T., Dinesen, G., Hansen, J., Hiddink, J. G., Sciberras, M., Smith, C., Papadopoulou, N., Gumus, A., van Hoey, G., Laffargue, P., Eigaard, O., and Bastardie, F. 2016. Biological traits as functional indicators to assess and predict (using statistical models) the status of different habitats. BENTHIS Deliverable D3.4. 127 pp.

Eigaard, O. R., Bastardie, F., Breen, M., Dinesen, G. E., Hintzen, N. T., Laffargue, P., Mortensen, L. O., Nielsen, R., Nilsson, H. C., O'Neill, F. G., Polet, H., Reid, D .G., Sala, A., Skold, M., Smith, C., Sørensen, T. K., Tully, O., Zengin, M., and Rijnsdorp, A. D. 2016. Estimating seabed pressure from demersal trawls, seines, and dredges based on gear design and dimensions. ICES Journal of Marine Science, 73 (supplement 1): i27-i43.

Eigaard, O. R., Bastardie, F., Hintzen, N., Buhl-Mortensen, L., Buhl-Mortensen, P., Catarino, R., Dinesen, G. E., Egekvist, J., Fock, H., Geitner, K., Gerritsen, H., Gonzalez, M. M., Jonsson, P., Kavadas, S., Lafargue, P., Lundy, M., Mirelis, G. G., Nielsen, J. R., Papadopoulou, N., Posen, P., Pulcinella, J., Russo, T., Sala, A., Silva, C., Smith, C., Vanelslander, B., and Rijnsdorp, A. D. 2017. The footprint of bottom trawling in European waters: distribution, intensity and seabed integrity. ICES Journal of Marine Science, 74: 847–865.

Ellis, N., Pantus, F., and Pitcher, C. R. 2014. Scaling up experimental trawl impact results to fishery management scales – a modelling approach for a "hot time". Canadian Journal of Fisheries and Aquatic Sciences, 71: 733–746.

EU. 2010. COMMISSION DECISION of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters (notified under document C(2010) 5956) (Text with EEA relevance) (2010/477/EU). Official Journal of the European Union, L 232/14. http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010D0477(01)&from=EN.

Hiddink, J. G., *et al*. In prep. Longevity of benthic macroinvertebrates determines their sensitivity to bottom trawling impacts.

Hiddink, J. G., Jennings, S., Sciberras, M., Szostek, C. L., Hughes, K. M., Ellis, N., Rijnsdorp, A. D., McConnaughey, R. A., Mazor, T., Hilborn, R., Collie, J. S., Pitcher, R., Amoroso, R. O., Parma, A. M., Suuronen, P., and Kaiser, M. J. Submitted. Global analysis of depletion and recovery of seabed biota following bottom trawling disturbance.

ICES. 2016a. EU request for guidance on how pressure maps of fishing intensity contribute to an assessment of the state of seabed habitats. *In* Report of the ICES Advisory Committee, 2016. ICES Advice 2016, Book 1, Section 1.6.2.4. 5 pp.

ICES. 2016b. Interim Report of the Working Group on Spatial Fisheries Data (WGSFD), 17–20 May 2016, Brest, France. ICES CM 2016/SSGEPI:18. 244 pp.

ICES. 2017a. Report of the Benchmark Workshop to evaluate regional benthic pressure and imapct indicator(s) from bottom fishing (WKBENTH), 28 February–3 March 2017, ICES Headquarters, Copenhagen, Denmark. ICES CM 2017/ACOM:40. 233 pp.

ICES. 2017b. Report on the Working Group to evaluate trade-offs between the impact on seafloor habitats and provisions of catch/value (WKTRADE), 28–31 March 2017, Copenhagen, Denmark. ICES CM 2017/ACOM:42. 109 pp.

Jennings, S., Lee, J., and Hiddink, J. G. 2012. Assessing fishery footprints and the trade-offs between landings value, habitat sensitivity, and fishing impacts to inform marine spatial planning and an ecosystem approach. ICES Journal of Marine Science, 69: 1053–1063.

JNCC. 2014. EUNIS level 3 seabed habitat map integrating data originating from maps from field surveys and the EUSeaMap model. Version 1.0, Released: 11/03/2014. Lead author: Helen Ellwood, JNCC.

http://jncc.defra.gov.uk/pdf/20140311_InformationSheet_combinedEUNISL3map_v1.pdf.

Pitcher, C. R., Ellis, N., Jennings, S., Hiddink, J. G., Mazor, T., Kaiser, M. J., Kangas, M. I., McConnaughey, R. A., Parma, A. M., Rijnsdorp, A. D., Suuronen, P., Collie, J. C., Amoroso, R., Hughes, K. M., and Hilborn, R. 2017. Estimating the sustainability of towed fishing-gear impacts on seabed habitats: a simple quantitative risk assessment method applicable to data-limited fisheries. Methods in Ecology and Evolution, 8: 472–480.

Rijnsdorp, A. D., Buys, A. M., Storbeck, F., and Visser, E. G. 1998. Micro-scale distribution of beam trawl effort in the southern North Sea between 1993 and 1996 in relation to the trawling frequency of the sea bed and the impact on benthic organisms. ICES Journal of Marine Science, 55: 403–419.

Rijnsdorp, A. D., Bastardie, F., Bolam, S. G., Buhl-Mortensen, L., Eigaard, O. R., Hamon, K. G., Hiddink, J. G., Hintzen, N. T., Ivanovic, A., Kenny, A., Laffargue, P., Nielsen, J. R., O'Neill, F. G., Piet, G. J., Polet, H., Sala, A., Smith, C., van Denderen, P. D., van Kooten, T., and Zengin, M. 2016a. Towards a framework for the quantitative assessment of trawling impact on the seabed and benthic ecosystem. ICES Journal of Marine Science: 73: 127–138.

Rijnsdorp, A. D., Bolam, S. G, Garcia, C. Hintzen, N., and van Denderen, P. D. 2016b. Impact of Bottom Trawling on Sea Bed Integrity. BENTHIS Deliverable 1.2. 39 pp.

van Denderen, P. D., Bolam, S. G., Hiddink, J. G., Jennings, S., Kenny, A., Rijnsdorp, A. D., and van Kooten, T. 2015. Similar effects of bottom trawling and natural disturbance on composition and function of benthic communities across habitats. Marine Ecology Progress Series, 541: 31–43.