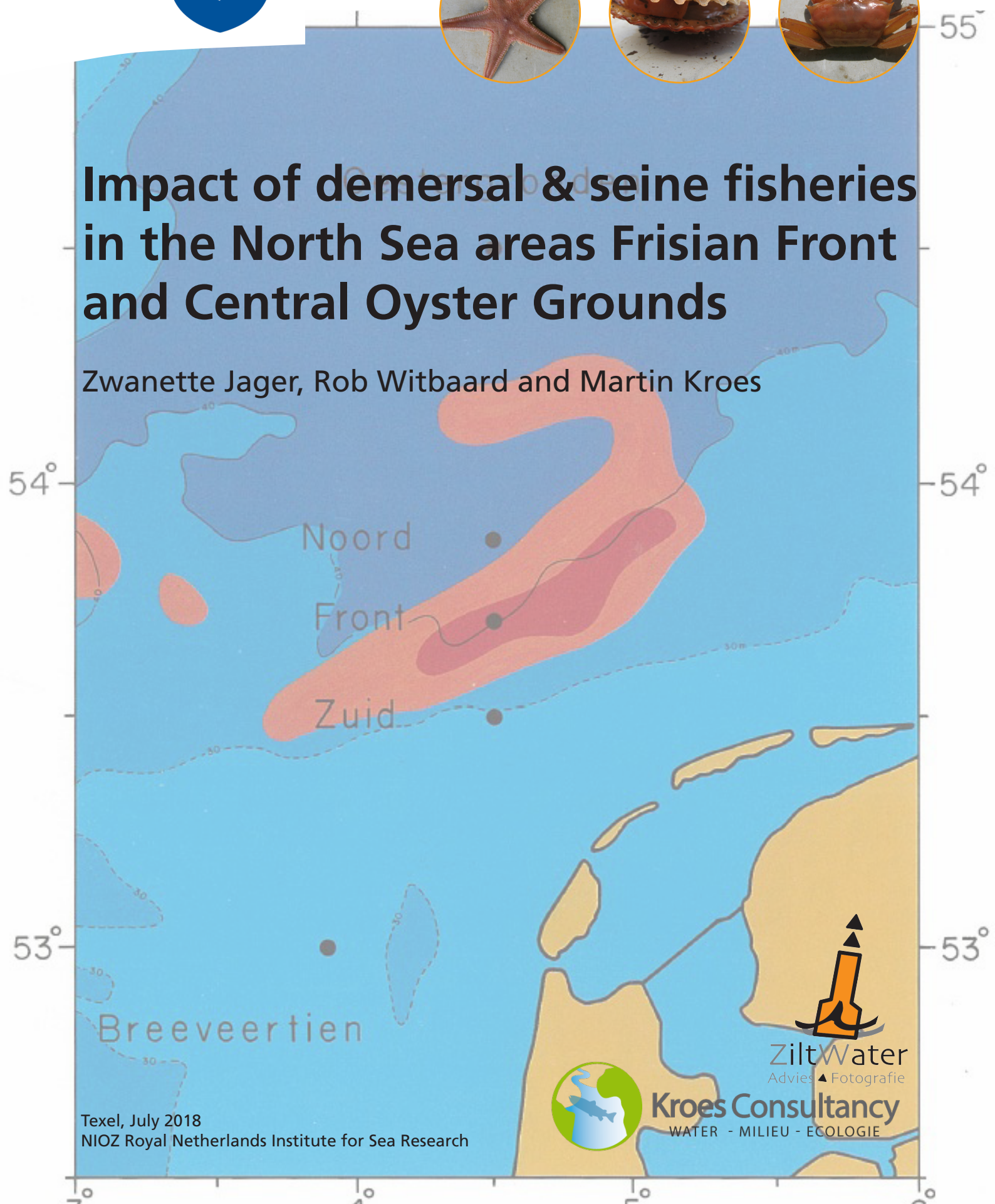




Impact of demersal & seine fisheries in the North Sea areas Frisian Front and Central Oyster Grounds

Zwanette Jager, Rob Witbaard and Martin Kroes



Impact of demersal & seine fisheries in the North Sea areas Frisian Front and Central Oyster Grounds

A review of literature and available data

Final version

16/07/2018 21:32:00

Colophon

Zwanette Jager

Rob Witbaard

Martin Kroes

Internal review:

Tom Ysebaert

1	Introduction	9
1.1	Background Document Frisian Front and Central Oyster Grounds	9
1.2	Aim of the assignment.....	10
1.3	Research question.....	10
2	Methodology	11
3	Conservation status	14
3.1	Description of typical values and species	14
3.1.1	Typical values.....	14
3.1.2	Typical or indicator species	15
3.2	Available surveys	16
3.3	Status of the Frisian Front and Central Oyster Grounds.....	17
3.3.1	Current situation.....	17
3.3.2	Regime shifts and habitat changes	18
3.3.3	Recent studies with high relevance	20
3.4	Traces of fishery and fishery intensity	22
4	Impact of demersal fisheries.....	27
4.1	Description of demersal gear types and footprint.....	27
4.2	Sensitivity of typical species to physical and biological pressures	30
4.3	Impacts of mobile demersal fishing gear	33
4.3.1	Beam trawl	33
4.3.2	Pulse trawl ('pulskor' & 'pulswing' bottom trawls).....	34
4.3.3	Otter board trawl.....	36
4.3.4	Fly-shoot/ Danish seines.....	37
4.3.5	Comparison of gear impact	37
4.4	Impact on conservation objectives	38
5	Cumulative effects	41
6	Discussion and recommendations.....	47
6.1	Scientific certainty	47
6.2	Is the best available knowledge applied?.....	48
6.3	Is the impact assessment complete?	50
6.4	In what way have knowledge gaps and uncertainties been dealt with?	51
6.5	Does the BD give sufficient insight in the activity?	52

6.6	Is the selection of activities considered in cumulation complete?	53
6.7	Recommendations	54
7	References.....	56
	Annex 1. List of consulted literature on impact of mobile bottom contacting fishing gear on the status of indicator species.....	62

Summary

The EU Marine Strategy Framework Directive (MSFD) requires the Member States to draw up a strategy for their marine waters to achieve a good environmental status (GES) by 2020 and to take the necessary measures to actually achieve or maintain the good status. Under article 13.4 of the MSFD Member States are required to include spatial protection targets in their programmes of measures, contributing to coherent and representative networks of marine protected areas. In the 'Marine Strategy for the Netherlands part of the North Sea 2012-2020' (the Dutch Marine Strategy), the Frisian Front and Central Oyster Grounds are considered search areas for spatial measures aiming at the protection of benthos in addition to sea bed protection in Natura 2000 areas on the Dutch part of the North Sea. These spatial measures are considered essential, in order to achieve the GES and the spatial protection targets of the MSFD.

To this end the Netherlands have drafted a proposal for fisheries measures (latest draft version joint recommendation is of 13 July 2017, attachment 2), which the Dutch government intends to submit to the European Commission as a joint recommendation under articles 11 and 18 of Regulation (EU) 1380/2013 of the Common Fisheries Policy.

According to the proposal, the realisation of the conservation objectives of the habitat should result from the following measures:

- A zoning system consisting of three management zones (see Annex I to the Joint recommendation for the coordinates, and Background Document, p. 5 for a map). The three management zones cover approx. 31,5% of the search areas of the Frisian front and Central Oyster Grounds.
- Closure of the management zones to mobile bottom-contacting gear types beam trawl, bottom otter board trawl, dredges and demersal seines (Scottish seines - also called fly-shoot - and Danish anchor seines).

In this literature review, carried out by ZiltWater Studies, Kroes Consultancy and NIOZ, the impact of the aforementioned demersal fishing gear types on the habitats of the Frisian Front and the Central Oyster Grounds and their conservation objectives is reviewed and briefly summarized in relation to the statements made in the draft background document.

For the MSFD-areas Frisian Front and Central Oyster Grounds, the main question that the commissioning party, WWF Netherlands, would like to have answered is:

ToR – Main question 1

Can it be concluded with certainty, leaving no reasonable scientific doubt, that in case mobile bottom contacting fishing gears would be allowed in the management zones of these areas, the delivery of the conservation objectives, as defined in the Dutch Marine Strategy, the Marine Strategy Framework Directive, and in compliance with the criteria of the Commission Decision (EU) 2017/848, will not be compromised?

ToR – Main question 2

Can it be concluded with certainty, leaving no reasonable scientific doubt, that allowing bottom-impacting fisheries in the remaining area outside the management

zones, would not jeopardize the delivery of the conservation objectives of these sites as defined in the Dutch Marine Strategy, the Marine Strategy Framework Directive, and in compliance with the criteria of the EU Commission Decision (EU) 2017/848?

With the outcome of the research, WWF Netherlands wants to anticipate the potential degradation of the current proposal if the use of certain bottom impacting fisheries are being permitted into the management zones on basis of the draft background document. The results of this study can be used as a second opinion on the draft Background Document to the Joint Recommendation for offshore fisheries management on the Natura 2000-sites Frisian Front and Central Oyster Grounds (BD, DRAFT version December 1, 2017; in preparation).

Regarding the **first question** (ToR – Main question 1) the conclusion of this literature review is that in case that mobile bottom contacting fishing gears would be allowed in the management zones of the Frisian Front and Central Oyster Grounds, the delivery of the conservation objectives (especially the improvement of biodiversity and bottom integrity) will be negatively impacted. This is the case for gears with a sub-surface impact, but even more so for gears with a shallow surface impact but larger area footprint, since several typical features of the Frisian Front and Central Oyster Grounds protected areas are the long-lived, filter-feeding, infauna, living in the upper sediment layer of the bottom substrate.

Regarding the **second question** (ToR – Main question 2), fishing in the areas outside the management zones can also jeopardize the goals in the Natura 2000 areas Frisian Front and Central Oyster Grounds. Bycatch outside the management zones in combination with mobility of fauna, attraction of scavengers and predators all might have effects on faunal densities and recovery inside the areas. Also resuspension of sediments, caused by fisheries, will certainly affect "downstream" areas with settling sedimentary material.

On basis of historical data it can even be argued that in the last century the area has changed from a biotic oyster reef into a soft sediment habitat. Therefore the observed effects of permitting bottom fisheries in the management zones will also depend on the reference situation that one takes into account. For the present day soft sediment community, additional effects of fishing might be small or undetectable due to the long history of bottom trawling in the area and the unpredictability of recovery.

The brief review given in this report shows that all mobile bottom contacting gears have a negative impact on the substratum or turbidity and thus on the vulnerable in- and epifauna and with that on the conservation goals. Effects of seabed disturbance by bottom contacting fishery were demonstrated in many studies and comprise increased mortality rates for non-target species (Bergman and Santbrink, 2000), increased scavenger abundance (Groenewold and Fonds, 2000), changed food web structures (Groenewold 2000, Hinz et al. 2017), changed size distributions (Van Kooten et al. 2015), and reduced abundances (Duineveld et al., 2007).

Thus despite certain scientific uncertainties, from all available literature it is evident that allowing bottom impacting fishery in and outside the management zones of the Frisian Front or the Central Oyster Grounds does not contribute to the ecological improvement of the sea bed ecosystem, but rather has a detrimental effect on seafloor

integrity and thus impairs its ecological improvement, which is the objective of the Marine Strategy Framework Directive.

To create opportunities for a natural development of the sea bed ecosystem in these areas, an impact reduction or exclusion of the bottom fishery appears crucial. This said, it should also be acknowledged that exclusion of mobile bottom trawl activities alone may not be sufficient for a full recovery of the areas as regime shifts that have occurred in the past are not easily reversed. Furthermore, recovery is also highly dependent on climatological and hydrological conditions that are changing. In absence of bottom disturbance the bottom communities can at least develop in a natural way within the prevalent hydrographical and climatological forcing.

Therefore, is it likely that closure of the current proposed management zones insufficiently provide the required certainty to obtain the conservation objectives for Frisian Front and Central Oyster Grounds which could be jeopardized by allowing abovementioned types of fisheries within these zones.

Further, although the relevant cumulative effects have been included in the BD, given the developments e.g. in offshore wind farms, the information in the BD needs an update with the most recent policy documents that exist for activities in these areas.

The following recommendations are given as input for the Draft Background Document (Anonymous, 2017).

Subject	Recommendation
Description of typical values and species	It should be made clear in the Background Document which species list is used to assess the impacts, and on what criteria the list has been composed. Supported by the overview in Table 3.1, we recommend to revise Table 3 in the Background Document and add a clear rationale for the applied indicator selection.
Available surveys	NIOZ conducted several surveys as part of their North Sea research program, and it appears not all of the survey data have been analysed or reported. It is worthwhile to investigate if more information can be drawn out of these survey-data. There may be more unpublished data from other surveys and presently the "Pulse " project financed by the Ministry of EZ is carried out which data are not yet available but highly relevant to the subject.
Status of the Frisian Front and Central Dutch Oyster Grounds	We recommend that the authorities update the Background Document with the current state of the bottom ecosystem of the two areas as well as adding the ecological potential of these areas
Description of demersal gear types and footprint	Further quantification of the footprint is only possible with more detailed information on the fishery intensity and the individual gear specifications. Such a quantification is recommended for an impact assessment.
Sensitivity of typical species to physical and biological pressures	Especially species living in the upper layer of the sediment are sensitive to bottom contacting gear, e.g. all juvenile stages of benthos but also long-lived adult bivalves, Echinoderms like <i>Leptosynapta</i> , <i>Amphiura filiformis</i> , or shallow living filter feeding polychaetes such as <i>Sabella</i> or <i>Chaetopterus</i> . In order to assess the <i>real</i> vulnerability of a species one also needs to take the life stage in account which is most vulnerable to bottom contacting fishing gears. The BD-document does not distinguish life stages of characteristic species and is thus incomplete in this respect.

1 Introduction

1.1 Background Document Frisian Front and Central Oyster Grounds

The EU Marine Strategy Framework Directive (MSFD, Directive 2008/56/EC) requires the Member States to draw up a strategy for their marine waters to achieve a good environmental status by 2020 and to take the necessary measures to actually achieve or maintain the good status. Under article 13.4 MSFD Member States are required to include spatial protection targets in their programmes of measures, contributing to coherent and representative networks of marine protected areas. In the 'Marine Strategy for the Netherlands part of the North Sea 2012-2020' (the Dutch Marine Strategy), the Frisian Front and Central Oyster Grounds are considered search areas for spatial measures aiming at the protection of benthos in addition to the sea bed protection in Natura 2000 areas on the Dutch part of the North Sea. These spatial measures are considered essential, in order to achieve the GES and the spatial conservation targets of the MSFD.

In the Background Document, (p. 17; see also the Dutch Marine Strategy) it is stated that "The conservation objective for Frisian Front and Central Oyster Grounds is the recovery of substantial parts of the sea bed ecosystem from a disrupted state towards a natural condition".

In the Joint Recommendation (p. 1) is further mentioned that "The purpose of the fisheries management measures is to reduce the pressures on the benthic habitat from towed bottom contacting fishing gear with a view of ensuring a key contribution to the achievement of conservation objectives in accordance with the Marine Strategy Framework Directive."

To this end the Netherlands have drafted a proposal for fisheries measures (latest draft version joint recommendation of 13 July 2017, attachment 2), which the Netherlands intend to submit to the European Commission as a joint recommendation under articles 11 and 18 of Regulation (EU) 1380/2013) on the Common Fisheries Policy.

According to the proposal, the realisation of the conservation objectives of the habitat should result from the following measures:

- A zoning system consisting of 3 management zones (see Annex I to the Joint recommendation for the coordinates, and Background Document, p. 5 for a map). The 3 management zones cover approx. 31,5% of the search areas of the Frisian front and Central Oyster Grounds.
- Closure of the management zones to mobile bottom-contacting gear types beam trawl, bottom otter board trawl, dredges and demersal seines (Scottish seines - also called fly-shoot - and Danish anchor seines).

The spatial protection measures in the Frisian Front and Central Oyster Grounds contribute to attain a good environmental status according to:

- descriptor 1 (MSFD, Annex I): 'Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions';

- descriptor 6: ‘Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected.’ (see also Background Document, p, 16).

For these areas, 14 specific indicator species have been selected (Dutch Marine Strategy, part 3, p. 57 and part 2, Annex I), attached to descriptors 1 and 6. See for reference also the environmental targets in the Dutch Marine Strategy (part 1).

Furthermore, the EU Commission has published a Decision in 2017 ((EU) 2017/848) providing a set of indicators or criteria for assessing the condition and change of the benthic environment. Specific criteria of this decision have been taken up by the Netherlands in the Background Document (p. 36).

1.2 Aim of the assignment

Following the procedures laid out in Article 11 of the European Common Fisheries Policy (CFP), and before submitting the Joint Recommendation to the European Commission for approval, the Netherlands aim to reach an agreement on the proposed fisheries management measures with the member states having a ‘direct management interest’: Belgium, France, Germany, Sweden, United Kingdom and Denmark.

WWF Netherlands would primarily like to have researched the impacts that demersal seines have on the habitats of the Frisian Front and the Central Oyster Grounds and their conservation objectives. However, the impacts of other bottom impacting gears (beam trawl, bottom otter board trawl and dredges) on the conservation objectives for MSFD-areas Frisian Front and Central Oyster Grounds should be included as well.

1.3 Research question

For the Frisian Front and the Central Oyster Grounds, the main question which commissioning party, WWF Netherlands, would like to have answered is:

1. Can be concluded with certainty, leaving no reasonable scientific doubt, that in case mobile bottom contacting fishing gears would be allowed in the management zones of these areas, the delivery of the conservation objective, as defined in the Dutch Marine Strategy, the Marine Strategy Framework Directive, and in compliance with the criteria of the Commission Decision (EU) 2017/848), will not be compromised?

The findings in this report also incorporate areas in the Frisian Front and the Central Oyster Grounds that are outside the management zones. Therefore an additional main question is formulated:

2. Can be concluded with certainty, leaving no scientific doubt, that allowing bottom impacting fisheries in the remaining area outside the management zones, would not jeopardize the delivery of the conservation objectives of these sites as defined in the Dutch Marine Strategy, the Marine Strategy Framework Directive, and in compliance with the criteria of the EU Commission Decision (EU) 2017/848?

2 Methodology

The effects of demersal (mobile bottom contacting) fishing gear on the conservation objectives for the Frisian Front and the Central Oyster Grounds, as defined in the Dutch Marine Strategy, are studied in this literature review. The following points of concern are addressed (Terms of Reference literature review FF and COG by Thomas Rammelt, WNF, 4 September 2017).

Methodology

1. The aforementioned question will be answered on the basis of all literature and best available data relevant to this question.
2. Is there sufficient literature available to support the conclusion that the favourable conservation objective, as defined in the Dutch Marine Strategy, the Marine Strategy Framework Directive, is ensured in case of a management regime which allows the afore mentioned bottom impacting gears in the management zones?
3. In the literature review the question will be answered if in the Frisian Front and the Central Oyster Grounds Document, (draft of 13 July 2017) selective use has been made of available literature.
 - a. Was recent literature concerning the effects of the afore mentioned bottom impacting gears on offshore circalittoral mixed sediment of Frisian Front and the offshore circalittoral sand and offshore circalittoral mixed sediment of Central Oyster Grounds, left out of the impact analysis in the Background Document.
 - b. Were conclusions of research, which have been used in the Frisian Front and the Central Oyster Grounds Background Document – also including the studies by Rijnsdorp et al. (2016), and by Eigaard et al. (2016) - correctly reproduced?

Assessment of effects

1. Is a management regime, which allows the aforementioned bottom impacting gears in the management zones, scientifically justified on the basis of pressures in the occurrences on offshore circalittoral sediment of Frisian Front and the offshore circalittoral sand and offshore circalittoral sediment of Central Oyster Grounds, and hence does it meet the conservation status of the habitat?
2. In the literature review the possibility of significant effects will be related to the question whether the delivery of the conservation objectives will be jeopardized in the light, inter alia, of the characteristics and the specific environmental conditions of the site.
3. The literature review will, inter alia, research the effects of bottom impact and bycatch of the afore mentioned bottom impacting gears on offshore circalittoral mixed sediment of Frisian Front and the offshore circalittoral sand and offshore circalittoral mixed sediment of Central Oyster Grounds. The effects on the seabed and associated species will include the effects on fish (target and non-target species), benthos, shellfish and other bottom dwelling species. The research will also focus on slow-growing and long-lived species and other effects on the food web. If possible, long term effects will be taken into account. The effects on the species as mentioned in the Background Document are part of this assessment.
4. In the assessment of the effects of the bottom impacting gears, the foot print per hour fishing of the gears should be compared.

- In the assessment the study, commissioned by the Danish government, by DTU Aqua into the impacts of demersal seines (possibly focused on the Frisian Front and Central Oyster Grounds seabed), will be taken into account as well. However, this research did not become available in time and could not be included in the study.

Cumulative effects

- Do impact assessments that support the draft proposal for the Frisian Front and the Central Oyster Grounds, include an assessment of the cumulative effects before they are related to characteristics, the specific environmental conditions and conservation objectives of the site?
- Have other plans and activities been included in an assessment of cumulative effects?
- Have 'external' activities, taking place outside the borders of the Frisian Front and the Central Oyster Grounds, sufficiently been taken into account in the assessment of the effects inside the site?

In the Background Document Frisian Front and the Central Oyster Grounds, the following bottom contacting fishing activities, to be banned from the closed zones, are listed: beam trawl, bottom otter board trawl, dredges and demersal seines (Table 2.1 below; Table 2 of the BD). Because of recent developments we added some considerations on the pulse beam trawl, too.

Table 2.1 Overview of bottom contacting gears that are part of the literature review.

Gear groups that are banned in all closed zones	Gear Code Annex XI in EU Regulation 404/2011	International Standard Classification of Fishing Gears (ISSCFG)
Beam trawl	TBB	03.1.1
Bottom Otter Board Trawl	OGB, OTT, PTB, TBN, TBS, TB, BTM	03.1.2, 03.3.0, 03.1.3, 03.1.9
Dredges	DRB, HMD	04.1.0, 04.2.0, DRM, DRX
Demersal seines	SPR, SDN, SSC, SX, SV	SPR, SDN, SSC, SX, SV

A literature survey was done to assess the current impact of mobile bottom contacting fishing gear on the status of indicator species. It was soon apparent that it is impossible to carry out a full review of "all" literature, because of the large amount of studies that have been carried out since a long period and in recent years. For this study we used the most recent and relevant sources, and in addition we accessed unpublished data of NIOZ-surveys in the Frisian Front and the Central Oyster Grounds. Because of a lack of literature on the effect of specific gear (e.g. Danish seine) on specific substrates, we also approached the matter starting from the sensitivity of indicator species to the impacts of fishery. Sources of information on species were www.marlin.ac.uk, www.genustrait handbook.org.uk, and the literature available at NIOZ and in the public domain.

The full list of cited and consulted literature is listed in Annex 1. Per reference, the author, year and title are presented and a brief description is given of the area of concern. The cited literature is available in the references.

3 Conservation status

3.1 Description of typical values and species

3.1.1 Typical values

The Frisian Front refers to a SW-NE oriented zone on the seafloor, size approximately 15x100 km, depth between 25 and 40 m. The area is enriched with fine organic rich sediments (Creutzberg and Postma, 1979) and hosts a diverse bottom fauna which shows a clear zonation across the area (Creutzberg et al., 1984). An overview of the main features is given in De Gee et al. (1991), but many other studies focussed on the area since then.

The Frisian Front forms the transition between the shallower Southern Bight and the deeper Central Oyster Grounds. The gradual deepening to the north (Oyster Grounds) leads to a decrease in tidal currents and a subsequent sedimentation of fine sediments (De Gee et al., 1991). Hence there is a gradient in sediment grain size from south to north. In the core area of the Frisian Front the silt percentage can be as high as 20%. The "benthic" front is coupled to a tidal (hydrological) front which marks the boundary between the summer stratified waters in the north and the tidally mixed waters in the south and which is accompanied by elevated primary production (Baars et al., 1991). The geographical position of the hydrographical front varies and depends on the season and on weather conditions.

The Frisian Front hydrographical gradients and benthic gradients are reflected in the spatial temporal distribution of both benthic and pelagic communities. High concentrations of fish schools (young herring, adult sprat) have been observed in acoustic surveys of the Frisian Front (Sprong, 1990). These are predated by guillemots, aggregating in this area after the breeding season (Baars et al., 1991, Baptist et al., 2010).

Less studies have focussed on the Central Oyster Grounds, but compared to for instance the Cleaver Bank area, the amount of observations available is overwhelming. The Central Oyster Grounds is the deeper area in the North Sea, south of the Dogger Bank and north of the Frisian Front. In calm summers the area gets thermally stratified which might lead to hypoxia (Greenwood et al., 2010, Weston et al., 2007). Sediment silt contents are lower in the Oyster Grounds than in the frontal area of the Frisian Front (5-8%, versus 15-20%). In the Central Oyster Grounds, a diverse and rich benthic fauna is found, among which are several rare or long-lived bivalves (a.o. *Arctica islandica*, *Mya truncata*), the parchment worm (*Chaetopterus variopedatus*). Southern fauna components get gradually replaced by more northern species (*Brisopsis lyrifera*, *Spatangus purpureus*, *Lucinoma borealis*, ea.) (Witbaard et al., 2013).

In the Marine Strategy Part 1, the main target for the structure of the Dutch marine ecosystem (encompassing the MSDF descriptors 'biodiversity', 'food webs' and 'seafloor integrity') is to reverse the trend of degradation of the marine ecosystem due to damage to seabed habitat and to biodiversity towards a development of recovery (Ministerie van IenM, 2012). This target implies an ecosystem structure in which the relative proportions of the ecosystem components (habitats and species) are in line with prevailing abiotic conditions (Ministerie van IenM, 2012). For benthos the sub-target is: "Improvement of the size, quality and distribution of populations of long-living and/or vulnerable (i.e. sensitive to physical disturbance) benthic species".

3.1.2 Typical or indicator species

Derived from the descriptors that are mentioned for the Marine Strategy Framework Directive (MSFD), Wijnhoven et al. (2013) proposed a preliminary selection of indicator species for the Frisian Front and Central Oyster Grounds (see Table 3.1 below). The initial selection was later extended with additional species by Wijnhoven & Bos (2017), to form the national benthos indicator, called BISI, which is used to describe the status of the areas of special ecological value (ASEV) in terms of the MSFD (Table 3.1).

Table 3.1. Initial (preliminary indicators; Wijnhoven et al. 2013) and extended species selection (additional BISI indicators; Wijnhoven & Bos, 2017) to form a reference list of indicator species (BISI) for the ASEV Frisian Front and Central Oyster Grounds.

Frisian Front Preliminary indicators (Wijnhoven et al., 2013)			
Class	Species	Dutch name	English name
Ophiuroidea	<i>Amphiura filiformis</i>	Draadvormige slangster	Brittlestar
Malacostraca	<i>Callinassa subterranea</i>	Moddergarnaal	Mud shrimp
Malacostraca	<i>Upogebia deltaura</i>	Harige molkreeft	Mud lobster
Bivalvia	<i>Thracia convexa</i>	Bolle papierschelp	?
Malacostraca	<i>Goneplax rhomboides</i>	Hoekige krab	Angular crab
Malacostraca	<i>Corystes cassivelaunus</i>	Helmkrab	Helmet crab
Polychaeta	<i>Nephtys incisa</i>	(borstelworm)	?
Frisian Front Additional BISI indicators (Wijnhoven & Bos, 2017)			
Class	Species	Dutch name	English name
Polychaeta	<i>Atherospio guillei</i>	Spionide worm	?
Bivalvia	<i>Dosinia lupinus</i>	Dichtgestreepte artemisschelp	Smooth artemis
Gastropoda	<i>Euspira nitida</i> (formerly <i>E. pulchella</i>)	Glanzende tepelhoren	Common necklace shell
Echinoidea	<i>Echinocardium cordatum</i>	Zeeklit	Heart-urchin
Holothuroidea	<i>Leptosynapta inhaerens</i>	Klevende zeekomkommer	?
Polychaeta	<i>Oxydromus flexuosus</i>	Neonworm	?
Ophiuroidea	<i>Ophiura albida</i>	Kleine slangster	Serpent's table brittlestar
Polychaeta	<i>Podarkeopsis helgolandicus</i>	?	?
Malacostraca	<i>Upogebia stellata</i>	Kleine molkreeft	?
Central Oyster Grounds Preliminary indicators (Wijnhoven et al., 2013)			
Class	Species	Dutch name	English name
Malacostraca	<i>Callinassa subterranea</i>	Moddergarnaal	Mud shrimp
Malacostraca	<i>Upogebia stellata</i>	Kleine molkreeft	Mud lobster
Echinoidea	<i>Brissopsis lyrifera</i>	Zwartband zeeklit	Heart urchin
Bivalvia	<i>Corbula gibba</i>	Korfschelp	Basket shell
Bivalvia	<i>Acanthocardia echinata</i>	Gedoornde hartschelp	Prickly cockle
Gastropoda	<i>Turritella communis</i>	Penhoren	Auger shell
Ophiuroidea	<i>Amphiura filiformis</i>	Draadvormige slangster	Brittlestar
Central Oyster Grounds Additional BISI indicators (Wijnhoven & Bos, 2017)			
Class	Species	Dutch name	English name
Polychaeta	<i>Aphrodita aculeata</i>	Zeemuis	Sea mouse
Bivalvia	<i>Arctica islandica</i>	Noordkromp	Ocean quahog
Polychaeta	<i>Chaetopterus variopedatus</i>	Perkamentkokerworm	Parchment worm
Bivalvia	<i>Chamelea striatula</i>	Venuschelp	Striped venus
Gastropoda	<i>Cyllichna cylindracea</i>	Valse oubliehoren	Lined chalice-bubble
Bivalvia	<i>Dosinia lupinus</i>	Dichtgestreepte artemisschelp	Smooth artemis
Echinoidea	<i>Echinocardium cordatum</i>	Zeeklit	Heart-urchin
Echinoidea	<i>Echinocardium flavescens</i>	Gele hartsegel	?
Polychaeta	<i>Nephtys incisa</i>	?	?
Bivalvia	<i>Nucula nitidosa</i>	Driehoekige parelmoerneut	?
Polychaeta	<i>Sthenelais limicola</i>	?	?

Polychaeta	<i>Terebellides stroemii</i>	?	?
Malacostraca	<i>Upogebia deltaura</i>	Harige molkreeft	Mud lobster

For the selected indicator species included in the BISI and in different ASEV, Wijnhoven & Bos (2017) present the derived reference values ('internal reference' or Ri – a composed realistic reference) that were calculated based on the monitoring data of 2015 and which also represent a T0-status. For the Central Oyster Grounds and Frisian Front, the indicator species are monitored by box-core or dredge sampling, depending on the species. The Ri-values (T0) of the indicator species are given in Appendix 1c (Central Oyster Grounds) and Appendix 1d (Frisian Front) in Wijnhoven & Bos (2017).

In this way the BISI is used to calculate the quality status of the areas Frisian Front and Central Oyster Grounds. Quality objectives have also been formulated, in terms of 'no significant decrease of the BISI' and in the future (in 12-18 years) a 'significant increase of the BISI'. Furthermore, the BISI should increase significantly in the areas closed for fishing compared to the 'open' areas (Wijnhoven & Bos, 2017). These objectives are applicable to both Frisian Front and Central Oyster Grounds.

The list of species to be used to assess the measures in the protected areas at Frisian Front and Central Oyster Grounds (Table 3 in the draft BD) should be updated, accordingly.

3.2 Available surveys

Wijnhoven & Bos (2017) give an overview of available surveys and data that they used to derive the reference values of the BISI-indicator species.

Since the 1980ies, the Netherlands Institute of Sea Research (NIOZ) collected many data in the North Sea, including in the areas of concern: the Frisian Front and Central Oyster Grounds. Countless publications were the result, although some data may have remained unpublished.

Witbaard et al. (2013) compiled the benthos datasets of the NIOZ, obtained with the Triple-D dredge in the years 2006-2012, in the search area 'Friese Front/Centrale Oestergronden'. They used benthos data of 193 sampled stations, concerning species composition (139 taxa in total), biomass and density data and length distributions where possible.

An overview of surveys that have been conducted in the Frisian Front between 2004 and 2017 by the Netherlands Institute of Sea Research (NIOZ) is given in the table below.

Table 3.2. Overview of surveys carried out on the Frisian Front and Central Oyster Grounds.

Cruise nr	ship	program	start	end	Area	subject
64PE223	Pelagia	LNV	02/04/2004	07/04/2004	L7A platform	Fishing effects
Arca2006	Arca	LNV	23/10/2006	27/10/2006	FF	Species distribution
64PE260	Pelagia	Costra	05/02/2007	08/02/2007	FF a.o. areas	Species distribution
64PE261	Pelagia	Costra	19/02/2007	02/03/2007	FF a.o. areas	Species distribution
64PE266	Pelagia	BSIK	31/03/2007	07/04/2007	FF a.o. areas	Species distribution
64PE287	Pelagia	Normomap	05/04/2008	13/04/2008	FF a.o. areas	Species distribution

64PE288	Pelagia	Costra	14/04/2008	18/04/2008	FF a.o. areas	Species distribution
64PE338	Pelagia	Normomap	10/06/2011	15/06/2011	FF a.o. areas	Species distribution
64PE340	Pelagia	NIOZmon	17/07/2011	04/07/2011	FF a.o. areas	Processes
64PE354	Pelagia	NIOZmon	01/06/2012	20/06/2012	FF a.o. areas	Processes
64PE408	Pelagia	Insite	07/05/2016	12/05/2016	L7A platform	oil rig effect
64PE422	Pelagia	Puls	01/06/2017	08/06/2017	FF	Fishing effects
64PE423	Pelagia	NIOZmon	16/06/2017	29/06/2017	FF a.o. areas	Geology

3.3 Status of the Frisian Front and Central Oyster Grounds

3.3.1 Current situation

Neumann et al. (2017) investigated the spatial distribution of epibenthic communities in the North Sea. They discern three major epibenthic communities: "Coast", "Oyster Ground" and "Tail End". Apart from these, there are five smaller communities of which the Frisian Front is one. Neumann et al. (2017) mention the very high abundance of brittle stars (*Ophiura ophiura* and *Ophiura albida*) in large areas in the south-eastern North Sea as a result of the cold winter of 1995/1996 and indicate that high abundances of brittle stars are usually more locally restricted e.g. to the Frisian Front which may function as a source area for these species.

The Frisian Front was dominated by species that feed as deposit- or filter- and suspension feeder, but also very high percentages of opportunistic trait modalities and by far the lowest functional diversity compared to other epibenthic communities in the south-eastern North Sea (Neumann et al., 2016). Examples of opportunistic trait modalities are: a short life span, early onset of sexual maturity and small size, dissemination of species via pelagic life stages. These modalities are also found in hypoxic environments, organically enriched habitats and in conjunction with cold winters, low salinity and fishing disturbance (Neumann et al., 2016). Van Kooten et al (2015) also did a trait analyses of the megafauna of the Oystergrounds and Frisian Front (Witbaard et al, 2013) in relation to the intensity of bottom fisheries. Because of spatial correlation it was impossible to separate the effects of depth and fishing intensity on benthos composition, but many of the functional characteristics of the fauna appeared to be related to fishing intensity supporting the findings of Neumann et al (2016).

The community of Frisian Front appeared to be linked to muddy sediments, and has a different species composition compared to the Oyster Grounds whose sediments have lower silt percentages. Mean fauna abundance was highest at the Frisian Front with high densities of characteristic species such as the brittle star *Ophiura albida*, the swimming crab *Liocarcinus holsatus* and *Turritella communis* (Neumann et al., 2017). Abiotic variables determining the Frisian Front community distribution (model) were a high mud content of the sediments, along with fishing effort and high annual mean temperature. However, it is difficult to disentangle the relative impacts of fishing and natural factors on the Frisian Front as both affect benthic communities in a similar way and are spatially correlated in the south-eastern North Sea (Neumann et al., 2016; Neumann et al., 2017, van Kooten et al, 2015).

The Oyster Ground community is characterised by species with a preference for muddy sediments, such as *Turritella communis* or *Nephtys norvegicus* and by high species numbers and species diversity (Neumann et al., 2017). Other characteristic species were *Astropecten irregularis*, *Pagurus bernhardus*, *Echinocardium cordatum*, and the fish

species *Buglossidium luteum*. The angular crab *Goneplax rhomboides* is a new species but now common and well-established in the Oyster Grounds after its first occurrence in the area in 2003 (Neumann et al. 2013) or 2006 (Neumann et al. 2017). Abiotic characteristics associated with the Oyster Grounds benthic community are high salinities, small seasonal temperature differences and (seasonal) stratification. The thermal stratification develops during summer with rising surface temperatures and can lead to a situation of hypoxia near the seabed (Weston et al, 2008).

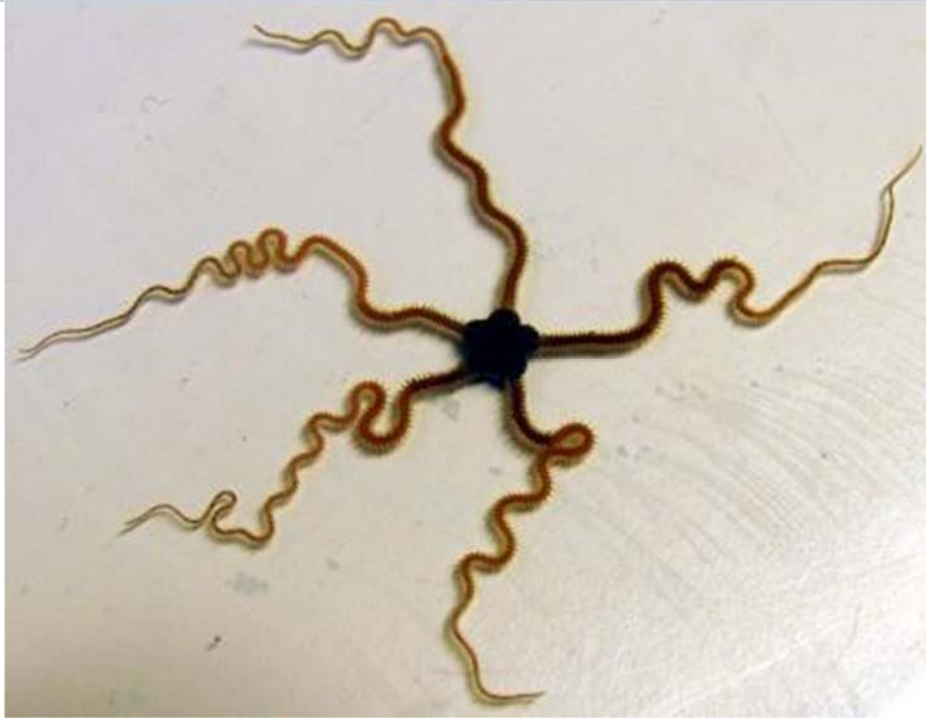
Dissolved oxygen concentration in bottom water at the Oyster Grounds was shown to be strongly influenced by short term events including storms and pulses of particulate organic matter input (Greenwood et al., 2010). The shallow topography and stratified nature of this region combined with potentially high nutrient concentrations and suitable sedimentary structure provide near ideal conditions for low oxygen levels to develop. In addition, the deep chlorophyll maximum (DCM) can be a major source of new production after the spring bloom and is therefore a potential source of biomass to the bottom waters (Weston et al., 2008).

3.3.2 Regime shifts and habitat changes

Shifts in the benthic community of the Frisian Front have been observed e.g. a decrease in densities of *A. filiformis* to an increase in densities of deep digging species e.g. *C. subterranea* (Amaro, 2005; see Box Regime shift Frisian Front). Recent observations (2017) suggest that the densities of *A. filiformis* have remained at a low level, and that the community has not returned to its "historical (1985-1995)" status (R. Witbaard, pers. com.). The status of such historical conditions can be debated as it also depends on the timeframe which is considered and its appreciation is sensitive to shifting baseline syndrome (Pauly, 1995).

Box Regime shift Frisian Front – additional information

A benthic macrofaunal regime shift in the Frisian Front during the period 1992 to 1997 was described by Amaro (2005). One of the characteristic species of Frisian Front, *Amphiura filiformis*, and the burrowing crustaceans *Callianassa subterranea* and *Upogebia deltaura*, showed remarkable changes in their densities: abundances of the brittle star *Amphiura filiformis* decreased in favour of the mud shrimp *Callianassa subterranea* (Amaro, 2005). In 1982 peak densities of approx. 1330 ind./m² and 1750 ind./m² were recorded for *Amphiura filiformis*, consisting of mainly adults and a few juveniles. In the 10 years period after this, the population decreased to a constant density of 100 ind./m². *Callianassa subterranea* showed an increasing abundance since 1982, from approx. 40 ind./m² to 319 ind./m² in 2000. Amaro (2005) observed no signs of recovery towards the situation where *Amphiura filiformis* dominated the community.



Amphiura filiformis Source: <https://www.eurekalert.org/multimedia/pub/452.php>



Callianassa subterranea (Photographer: Pisces Conservation Limited).

Source: <http://www.genustrait handbook.org.uk/genus/callianassa>

The reason for the decline of *A. filiformis* is unclear. Numerous explanations have been presented, such as climate-related changes in the ecosystem. The decline also coincided with an increase in beam trawling in the area but a causal relationship could not be demonstrated. Although not substantiated by hard evidence, the regime shift can in theory be related to fishing pressure. The brittlestar *Amphiura filiformis* lives in the top layer of the sediment (0-5 cm) and are likely to be influenced more directly by bottom contacting fishing gears than the deep living burrowing crustaceans. The burrowing crustaceans furthermore play a significant role in modifying their environment by expelling fine sediment while creating their burrows. This continuous sediment reworking might inhibit further population development of *Amphiura*. High *A. filiformis* densities increase the stability of the seabed, whereas high *C. subterranea* densities lead

to decreased stability of the seabed and with that to an increased sensitivity of the bed to re-suspension of fine particles (Amaro, 2005).

The Central Oyster Grounds has witnessed major faunal changes, too. Historical data suggest that in the Oyster Grounds and the Frisian Front, huge areas were once covered with extensive oyster reefs (Olsen, 1883). Their former existence is sometimes witnessed by nowadays samples from the area, containing "fossil" oyster shells or fragments (Witbaard pers. communication). The vast oyster beds, once covering an area of over 25.000 km², which naturally occurred here until the end of the 19th century (Olsen, 1883; Van Duren et al., 2016), since then rapidly disappeared due to overfishing (by oyster dredging and the development of bottom trawling) and diseases (although these occurred at a later date than the strong decline of oyster beds in the late 19th century) (Smaal et al. 2015). With the disappearance of these extensive oyster banks a suite of sessile epibenthic species was lost (lowering the biodiversity). It is also likely that the filtering capacity of a reef of > 25.000 km² (Van Duren et al., 2016) must have had a tremendous effect on the material, nutrient fluxes and turbidity (SPM) in this part of the North Sea.

At that time, the hydrography of the SE North Sea did most likely not differ from the present day situation, i.e. a north easterly residual current and a frontal region above the Wadden islands. On basis of this, the reefs in the Frontal zone and the Oyster Grounds likely profited from the elevated primary production. These reefs have long since gone and have been replaced by a soft sediment community. This soft sediment community also profits from the elevated levels of primary production in the frontal area, though nutrient fluxes and SPM levels and sediment behaviour (sedimentation and resuspension) must have changed considerably. The sediment has become vulnerable for resuspension because the "protective layer" of oysters with attached epifauna is gone (See figure 3.1).

In the current state, it is questionable whether oyster settlement can survive on the Oyster Grounds because of a lack of suitable substratum and the high bioturbation levels, and also because the stocking populations for larval supply have vanished.

3.3.3 Recent studies with high relevance

Several authors note a disrupted status of the benthic community in the Frisian Front and Central Oyster Grounds (Lindeboom et al., 2008). Rumohr and Kawjeski (2000) compared historical benthos collections (1902-1912) with more recent collections (1986) and showed that the frequency of occurrence of large bivalves decreased and that the frequency of occurrence of scavengers increased. They attribute these changes to direct and indirect effects of fisheries. Groenewold and Fonds (2000) demonstrated that scavengers, indeed, are attracted to the trawl tracks and consume dead and damaged fauna.

The role of beam trawling (with tickler chains) in the "disappearance" from the area of *Arctica islandica*, a large bivalve mollusc, has been demonstrated by Witbaard and Klein (1994). Field observations in the early 1990^{ies} showed that 80% of empty shells on the sea bed were damaged at the posterior (siphon) shell side and experimental work suggested that these injuries were inflicted by tickler chains. The number of repaired and dated scars in alive-caught shells showed a significant correlation with the increase in engine power of the Dutch beam trawl fleet. Not unexpectedly did the abundance of *A. islandica* in the Frisian Front decrease dramatically over the last three decades, despite the regular occurrence of spat in box core samples. Apparently, this spat does not

survive (Witbaard and Bergman, 2003). In the area, heavily damaged but repaired shells have also been found of other species, for example *Acanthocardia echinatum* and *Chlamys opercularis*. Van Kooten et al (2015) present size-frequency data for a few species from heavily fished parts and less fished parts in the Oyster Grounds and Frisian Front. Sizes of *Acanthocardia* appeared to be much smaller in the heavily fished areas, suggesting elevated mortality rates of large adults. This comparison could only be made for a few species as many of the potentially affected species were not found in the most heavily fished areas.

Duineveld et al. (2007) studied the effects of demersal fisheries on the bottom fauna by comparing a fishery exclusion zone around a gas production platform on the Frisian Front with fished areas surrounding it. The sampling methods consisted of a Triple-D dredge (Bergman en van Santbrink, 1994) in addition to a standard boxcorer. The fishery exclusion zone showed (in the Triple-D samples) higher densities of fragile bivalves including long lived species like *A. islandica*, *Thracia convexa* and shorter living species like *Abra nitida* and *Acanthocardia echinata*. Also, deep digging crustaceans (burrowing mud shrimps) unexpectedly showed higher densities in the platform subarea or a depressed abundance in the regularly trawled subareas. The no fishing area showed more species and a higher biodiversity. In contrast to the Triple-D, the box corer samples showed less explicit differences between the fishery exclusion zone and the fished areas that were compared (Duineveld et al., 2007), illustrating that the long-term effects of fishing are especially apparent in large, long lived and often low abundant species. The effect of trawling on burrowing mud shrimps was assumed to be negligible by several authors (Bergman et al. 1998, Hill 2005), because these species live deep in the bottom and are able to repair the destruction of their burrows by fishing trawls. However, based on their own findings, Duineveld et al. (2007) suggest that the impact of trawling in reducing the densities of *C. subterranea*, and presumably also of *Upogebia*, may be significant after all.

Greenwood et al. (2010) looked at the marine management implications of climate change in relation to stratification: climate change scenarios for the North Sea predict that the duration and intensity of stratification will increase (Lowe et al., 2009). These factors will have the potential to augment the decrease in the bottom mixed layer (BML) oxygen in the seasonally stratified North Sea, including the Oyster Grounds, by increasing the isolation of the BML leading to lower oxygen concentrations.

In addition, the number of summer storms may increase under worst case climate change scenarios. Such storms may disturb the seabed and result in increased levels of suspended particulate matter (SPM) which may further reduce the BML oxygen concentration and reduce water transparency over the wider North Sea. This was indicated by Cappuzzo et al. (2015) who demonstrated that water clarity (Secchi depth) in the central and southern North Sea has decreased significantly over the second half of the 20th century (see figure 3.1 for an explanation of possible causes). Water clarity can be influenced by different factors, such as an increase in phytoplankton and/or CDOM (coloured dissolved organic materials), suspended sediments (SPM; affected by resuspension and transport of bottom sediments by the action of tide, currents and waves), and water itself.

Cappuzzo et al. (2015) deduced that the observed changes in water clarity were more likely driven by an increase in the concentration of suspended sediments, rather than by phytoplankton. Contrary to McQuatters-Gollop et al. (2007), Cappuzzo did not find a trend in Chlorophyll-A concentrations which could indicate higher phytoplankton levels.

They explain the contrary findings by different methods and different spatial aggregation. Sources of SPM are bottom erosion and suspension and coastal erosion as well. Capuzzo et al. suggest that the reduction in underwater light availability was the result of a combination of causes, including decrease in sea-bed integrity, increased trawling effort, windiness, and coastal erosion (Fig. 3.1).

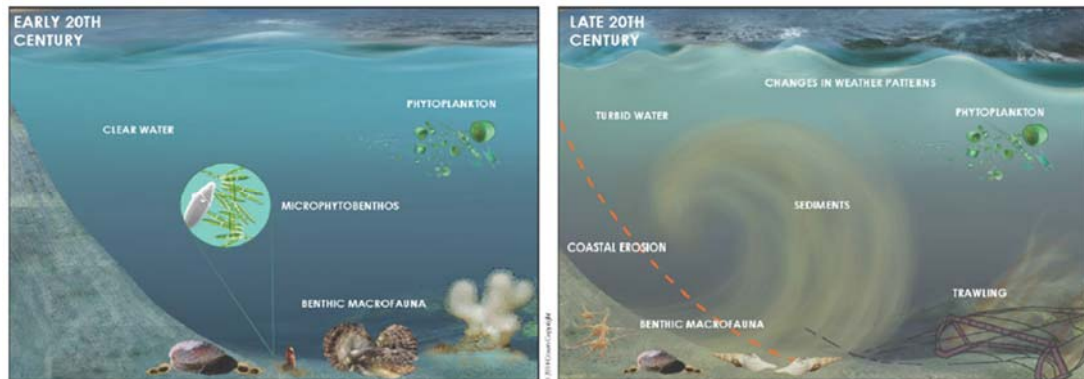


Figure 3.1 Decrease in water clarity of the southern and central North Sea during the 20th century and possible causes. The water column was clearer in the early 20th century, and the sea floor was colonized by a benthic community including oysters (*Ostrea edulis*), and potentially microphytobenthos. During the second half of the 20th century, water clarity of the southern and central North Sea decreased. For the last 25+ years, this was likely driven by a higher concentration of suspended materials in the water column. Possible causes of this increase in suspended materials could be changes in the benthic community, increased trawling effort, changes in weather pattern and coastal erosion (figure by Bayliss-Brown G: source Capuzzo et al., 2015).

3.4 Traces of fishery and fishery intensity

The Frisian Front and the Central Oyster Grounds are important fishing areas to the Dutch fishery. The most recent (available) maps based on VMS data show that the area is heavily fished, which is not unexpected given the high productivity of the area. However, it is also due to its geographical location relative to the main fishing ports of Den Helder, Texel and Urk.

A distribution map of trawl fisheries indicates that the Frisian Front is more intensively fished than the Oyster Grounds (Figure 3.2, after Fig 2f in Van Kooten) (Van Kooten et al. (2015)).

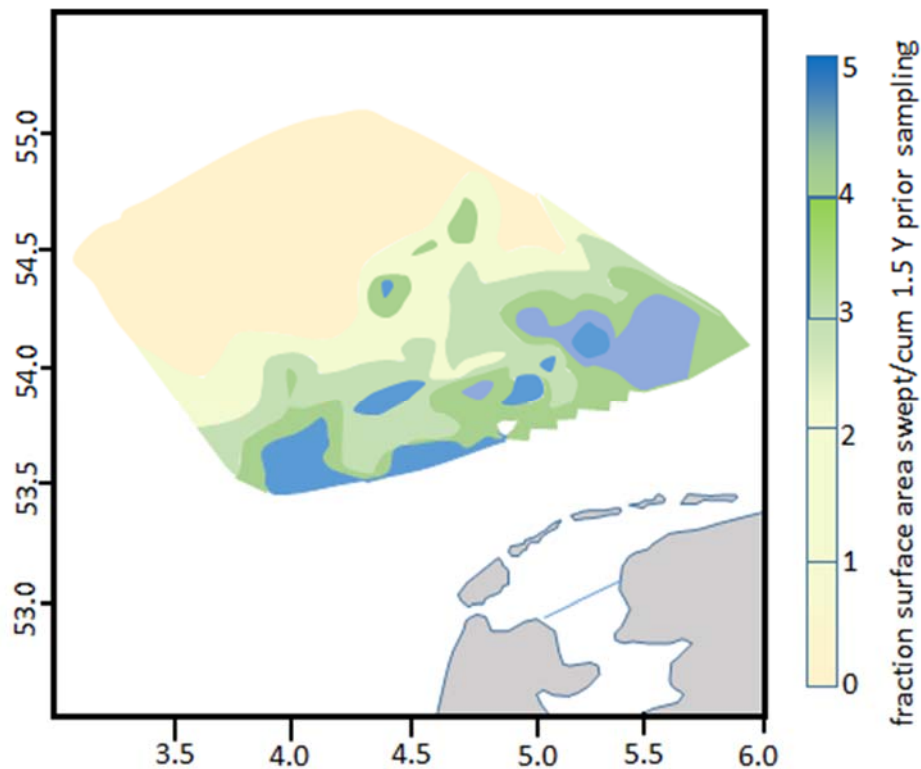


Figure 3.2 Trawl disturbance on the Frisian Front and Central Oyster Grounds (Color scale; fraction of surface area trawled within 1,5 years prior sampling). After Van Kooten et al., 2015.

For the Dutch part of the North Sea, Lindeboom et al. (2008) qualify the benthic environment as either raked (lightly trawled) or ploughed (heavily trawled) depending on the frequency of disturbance by bottom contacting gears. On the basis of that subdivision, all of the Frisian Front and parts of the Central Oyster Grounds (southeast) fall in the category of ploughed bottoms (Lindeboom et al., 2008b in: Slijkerman et al., 2013) which suggests that these bottoms are heavily disturbed.

Buisman et al. (2017) give an update on the international fishing activities on the Central Oyster Grounds and Frisian Front. Based on the combined VMS-logbook information, the majority of the fishing activities is carried out by Dutch vessels, followed by Danish, German, British and Belgian fleets. The fishing occurs mainly with beam trawls (TBB) and otter trawls (OTB, PTB). The category TBB includes also the new techniques such as pulse trawl (with 82 exemptions from the EU-ban on “electrical fishing” which are currently heavily debated) and sumwing, that have replaced the traditional beam trawl to a large extent. The Dutch fleet also operates seines (SSC, SDN) in the areas (see Figure 3.3 below), to a lesser extent.

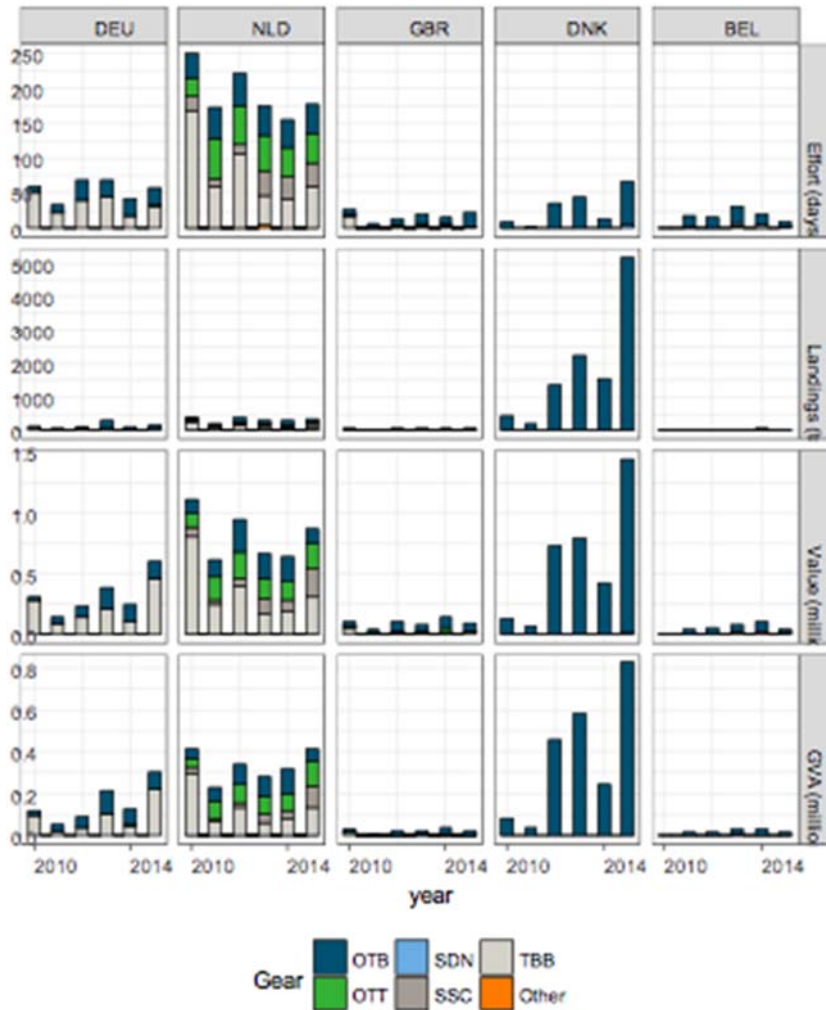


Figure 3.3 Historical trend of the fishing activities with different gears (OTB: Otterboard trawl; OTT: twinrig; SDN: Danish seine; SSC; Scottish seine; TBB: beam trawl) in the proposed closure of the Central Oyster Grounds and Frisian Front for the different countries. Effort, landings, value of landings and GVA are given by country. Source: Logbook data and VMS data and data from the Annual Economic report (STECF 2016), processed by WUR, CEFAS, TI, DTU, ILVO, SLU and IFREMER. Source: Buisman et al. 2017.

For the Belgian fleet, fishing activities effort seems to be declining while Dutch, British and German activity is more variable without a clear trend. Danish activity is increasing on the Central Oyster Grounds and Frisian Front while France and Sweden have not fished in the areas during the 2010-2015 period.

The landings remained relatively stable over the time period, despite a decreasing trend in effort (Buisman et al., 2017). Nevertheless, the landings in the last year of this time period seem relatively high which is caused mainly by the Danish fleet.

The effort of the Dutch fishery (blue bars in Figure 3.4 below) is dominant in the Frisian Front and Oyster Grounds, but the landings are dominated by the Danish fleet (see figure below, Van Oostenbrugge et al. 2017).

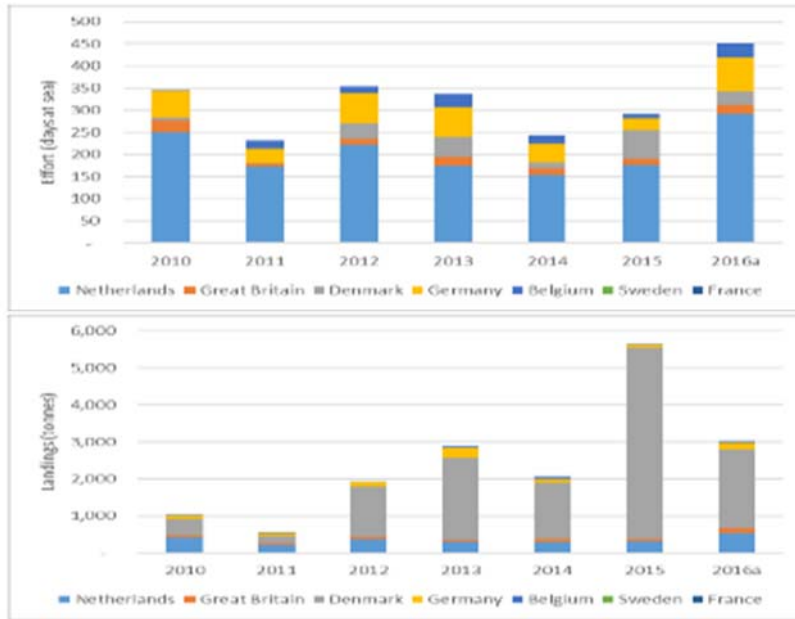


Figure 3.4. Fishing effort and landings by Central Oyster Grounds and Frisian Front bottom gears. Source: Van Oostenbrugge et al. 2017.

Please note that the data of Van Oostenbrugge et al. (2017) probably are similar to Buisman et al. (2017), but updated with the year 2016.

The main species that are targeted by the beam-trawl fleet fishing on the Central Oyster Grounds and Frisian Front are plaice and (to a minor extent) sole. The other demersal gears catch sprat, plaice and herring, with some bycatch of sole and *Nephrops* (see Figure 3.5). The Danish demersal trawlers target mixtures of small pelagic fish species and landed exceptionally high amounts of sprat in 2015 (Buisman et al. 2017). The larger part of the pelagic catch is used in the reduction industry for fish meal (ICES, 2016).

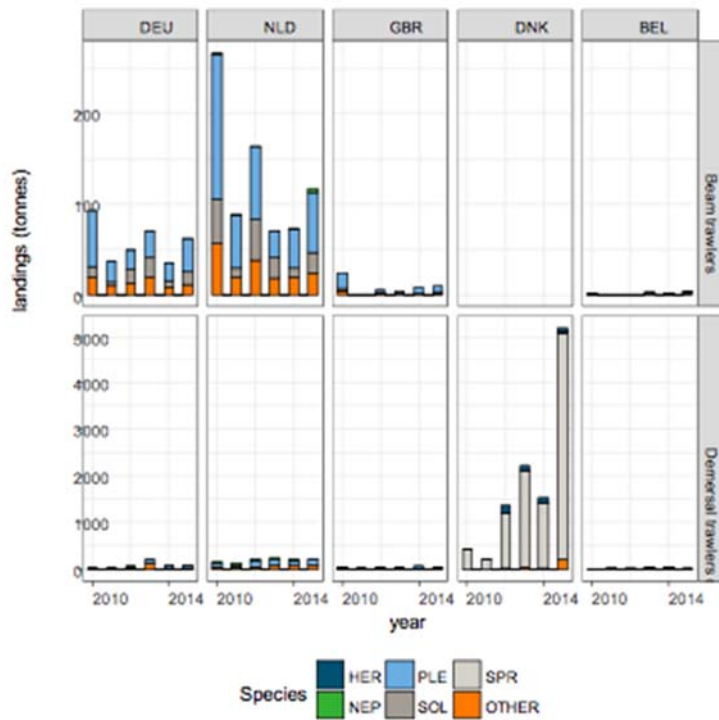


Figure 3.5 Landings in tonnes for the top 5 species per country on the proposed closed areas of the Central Oyster Grounds and Frisian Front for bottom contact gears. Source: Logbook data processed by WUR, CEFAS, TI, DTU, ILVO, SLU and IFREMER., CSH= brown shrimp, HER=herring, NEP=nephrops, PLE=plaice, SAN=sandeel, SOL=sole, SPR=sprat (Source: Buisman et al. 2017).

4 Impact of demersal fisheries

4.1 Description of demersal gear types and footprint

The different towing principles of demersal seines, otter trawls, beam trawls and dredges are illustrated by Figure 4.1 (from Eigaard et al., 2016).

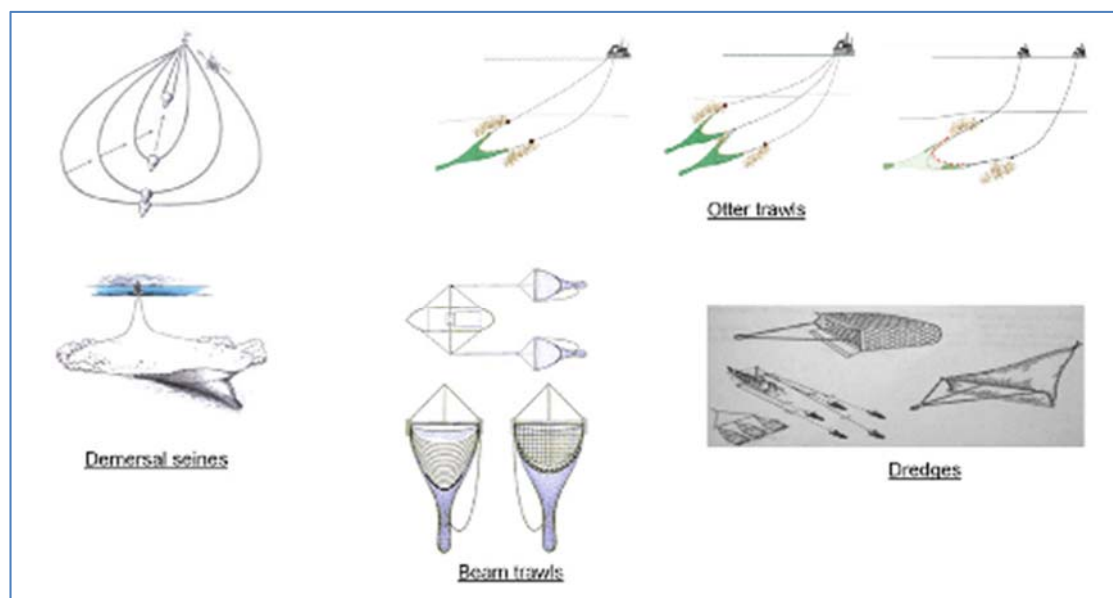


Figure 4.1. Towing principles of the four main high-impact demersal gear groups identified: DSs (left), OTs (top right), DRBs (bottom right), and TBBs (centre, bottom). Illustrations from FAO: <http://www.fao.org/fishery/geartype/search/en>. This figure is available in black and white in print and in colour at ICES Journal of Marine Science online.

Towed nets affect the sea floor in various ways (Figure 4.1, Eigaard et al., 2016), whereby the different gear components (net, ropes, boards, trawl shoes) may exert different effects. Cables and ground ropes that are dragged over the sea bed may homogenize the texture of the sea bottom, destroy hard structures and move stones or shells. Heavy gear components such as the otter boards or tickler chains penetrate into the sea bed and disturb the vertical structure of the sediment (Rosenberg et al., 2003) or compact the sediment. Sediment is brought into suspension by the turbulence generated in the wake of the gear (O'Neill and Ivanović, 2016; Pusceddu et al., 2005) and (with that) affect nutrient exchange (Couceiro et al., 2013).

The impact analyses of towed fishing gear on the Frisian Front and Central Oyster Grounds (as presented in the BD) are (a.o.) based on Deerenberg et al. (2010), Slijkerman (2013) and the BENTHIS study (e.g. Rijnsdorp, 2016, Eigaard et al., 2016), where BENTHIS provided information on the surface area impacted by the various mobile bottom contacting metiers. Previous to these studies, both national and EU funded projects aimed at unravelling the effects of beam trawling (IMPACT program, REDUCE program, BEON research) and to assess the ecosystem impacts of the first pulse gears (Pulse project, currently ongoing). Where REDUCE was the program that tried to assess the effects of the first pulse gears about 10 years ago, the presently running Pulse project aims to assess more specifically the ecosystem effects (nutrient exchange, bio irrigation, bioturbation) and to come to a better impact assessment of the electrical fishing technique, for both target and non-target species as well as processes at the

sediment water interface (<https://www.wur.nl/en/project/Impacts-of-pulse-fishing-for-flatfish-on-the-ecosystem-htm>).

Studies on the effects on sediment granulometry in the Frisian Front and Oyster Grounds in relation to fisheries have not been presented, to our best knowledge.

To compare the effects of different fishing methods on the seabed Eigaard et al. (2016) developed a generic method to compare the 'footprint' of different fishing gears, taking into account the overall size of the gear (e.g. door spread of otter trawls OT) and the relative contribution of different gear elements to the footprint. Eigaard et al. (2016) distinguish between surface abrasion (shallower than 2 cm) by all gear components that have bottom contact, and subsurface abrasion by gear components that penetrate more than about 2 cm into the sediment. Different gear elements have different properties, therefore a distinction is made in trawl shoes/doors, ground gear/tickler chains, ropes and bridles. The penetration depths of the gear components were derived from literature.

Metiers differ widely in the surface area swept per hour of trawling (Eigaard et al., 2016). Fly-shoot and otter trawls, of which in particular the twin trawls, have a large surface footprint as compared to for instance beam trawls used in the flatfish fishery. The beam trawls aiming at flatfish, however, have a relatively large subsurface footprint because all gear components penetrate into the seabed (Figure 4.2 below).

In the last decennium there has been a rapid transition from traditional tickler chain beam trawls (using mechanical stimulation) to pulse trawls and to sumwing-pulse trawls (using electrical stimulation), which is evident from the effort statistics. In 2008, beam trawl fisheries still represented 77% of the total effort in terms of horse power days. In 2014, this percentage had decreased to only 2 percent whereas the sumwing method + pulse fisheries had increased to 68% (Turenhout et al., 2016).

Although in pulse fishing (for flatfish) the tickler chains have been replaced by a system which activates, stimulates and/or paralyzes the target species so that they end up in the net, all gear varieties still have a ground rope and on basis of photographs it is suggested (Polet & Depestele, 2011) that various combinations of pulse lines/ropes and ticklers might be present.

Despite the fact that pulse fishing is strictly regulated and is officially forbidden within the EU, at present there are 82 exemptions (for NL) from this EU-ban on electrical fishing. With different specifications, these are used in coastal shrimp fisheries as well as in offshore flatfish fisheries.

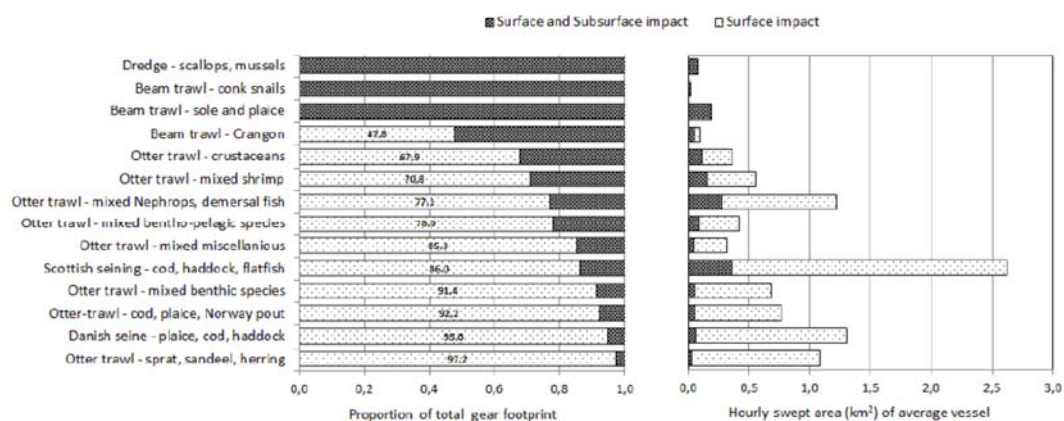


Figure 4.2. Proportion of total gear footprint (a) and the area of seabed swept in 1 h of fishing with

an average-sized vessel (b) with impact at the surface level and at both the surface and the subsurface level for the 14 BENTHIS metiers (Eigaard et al., 2016).

4.2 Sensitivity of typical species to physical and biological pressures

The genustrait handbook (www.genustraithandbook.org.uk) defines the sensitivity of species based on life trait characteristics (such as motility of adults, motility of larvae and longevity, AO), and furthermore predicts the potential that individual genera have to recolonise and the time that may be required for recolonization. The genustrait handbook, originally intended to assist in the assessment of the impacts of marine dredging on marine benthic resources, can also be used to estimate species-specific effects of fishing. Table 4.1 presents the sensitivity for mobile bottom contacting fishing gear per functional group of indicator species (for muddy sand, sandy mud etc.), based on the genustrait handbook. Of the listed species, 5 are assessed as 'vulnerable', 3 as 'intermediate', 8 as 'robust' and 8 species were not assessed (blank).

Table 4.1 Genustrait assessment of the sensitivity of selected species to bottom contacting fishery (<http://www.genustraithandbook.org.uk>). Some additions have been made on basis of related species from literature and or expert judgment (Rob Witbaard, NIOZ).

Faunaclass	Species	Biota/ sediment	Area	Faunatype		Lifespan	Assessed
				<i>juvenile</i>	<i>adult</i>		
Annelida-Polychaeta	<i>Nephtys incisa</i>	muddy sand	FF	LT planktonic	short range mobility	3-10 yrs	robust
Bivalvia	<i>Acanthocardia echinata</i>	gravelly muddy sand	COG	LT planktonic	short range mobility	>10 yrs	intermediate
Bivalvia	<i>Corbula gibba</i>	gravelly muddy sand	COG	LT planktonic	short range mobility	1-2 yrs	robust
Bivalvia	<i>Thracia convexa</i>	gravelly muddy sand	FF	LT/ST planktonic	short range mobility	>10 yrs	vulnerable
Echinodermata-Echinoidea	<i>Brissopsis lyrifera</i>	sandy mud	COG	LT planktonic	short range mobility	3-10 yrs	vulnerable
Echinodermata-Ophiurida	<i>Amphiura filiformis</i>	sandy gravel	FF + COG	LT planktonic	adult	>10 yrs	Robust
Gastropoda	<i>Turritella communis</i>	muddy sand	FF + COG	?	short range mobility	3 yrs?	? (intermediate to robust)
Malacostraca	<i>Callinassa subterranea</i>	sandy mud	FF + COG	LT planktonic, brooded or laid eggs	short range mobility	1-10 yrs	robust
Malacostraca	<i>Corystes cassivelaunus</i>	sand	FF	LT planktonic	adult	3-10 yrs	robust
Malacostraca	<i>Goneplax rhomboides</i>	?	FF	?	?	?	?
Malacostraca	<i>Upogebia deltaura</i>	muddy sand	FF	LT planktonic, brooded or laid eggs	short range mobility	3-10 yrs	robust
Malacostraca	<i>Upogebia stellata</i>	muddy sand	COG	LT planktonic, brooded or laid eggs	short range mobility	3-10 yrs	robust

Faunaclass	Species	Biota/ sediment	Area	Faunatype		Lifespan	Assessed
Polychaeta	<i>Atherospio guillei</i>	?	FF	?	?	?	?
Bivalvia	<i>Dosinia lupinus</i>	muddy sand gravel	FF + COG	LT planktonic	short range mobility	>10 yrs	intermediate
Gastropoda	<i>Euspira pulchella</i>	muddy sand	FF	?	?	?	?
Echinoidea	<i>Echinocardium cordatum</i>	sand + mud	FF + COG	LT planktonic	short range mobility	>10 yrs	intermediate
Holothuridea	<i>Leptosynapta inhaerens</i>	muddy sandy gravel	FF	Brooded or laid eggs	Short range mobility	?	vulnerable
Polychaeta	<i>Oxydromus flexuosus</i>	?	FF	?	?	?	?
Ophiuridea	<i>Ophiura albida</i>	Muddy sand	FF	LT planktonic	Short range mobility	3-10 yrs	robust
Polychaeta	<i>Podarkeopsis helgolandica</i>	?	FF	ST planktonic	Adult, Short range mobility	?	?
Polychaeta	<i>Aphrodita aculeata</i>	Muddy sand	COG	?	?	?	?
Bivalvia	<i>Arctica islandica</i>	Muddy sand	COG	LT planktonic	Short range mobility	>10 yrs	vulnerable
Polychaeta	<i>Chaetopterus variopedatus</i>	Muddy sand	COG	LT planktonic	Short range mobility	?	?
Bivalvia	<i>Chamelea striatula</i>	sand + mud	COG	LT planktonic	Short range mobility	>10 yrs	vulnerable
Gastropoda	<i>Cylichna cylindracea</i>	?	COG	?	?	?	?

Contrary to the genus-trait handbook, we would assess *Amphiura* to be quite sensitive to fishery impact, due to the long lifespan and the vulnerability of especially the small and fragile, shallow living juvenile individuals. However, the regenerative capability of this species is high.

Turritella communis is estimated to be intermediate to robust by R. Witbaard (pers. comm.) based on the relatively thick and strong shell. Its shell size is a few cm. In combination, this would make it a robust species. The estimated lifespan of 3 yrs is based on tropical species, the lifespan in moderate waters is not known.

Callianassa is supposed to be intermediate sensitive, based on the study by Duineveld et al. (2007), similar to *Goneplax* and *Upogebia spp.*

Goneplax rhomboides is a relatively new species to the area (first noticed in 2003; Neumann et al., 2013) and digs shallow holes by which some protection to fishery may be offered. The species seems to be expanding.

Dosinia lupinus is not usually found in gravel (R. Witbaard, pers. comm.), but instead rather the closely related *Dosinia exoleta*.

Chaetopterus variopedatus (parchment worm), lives in a tube; the worm itself is weak. Wijnhoven & Bos (2017) attributed an indicator score of 0.8 for the intensity of bottom fishery, and 0.3 for the frequency of fishery. R. Witbaard (pers comm.) would regard the species as vulnerable, since it extends a few cm above the sediment surface, builds a soft tube, whereas the worm itself is very soft without any firm structure.

Cylichna cylindracea is a very small gastropod with a thin shell, found in sandy mud like present on the Frisian Front and Central Oyster Grounds.

Epifauna

Because of the muddy sediments with a lack of hard substrate surfaces, *sessile* epifauna is practically absent and therefore of low relevance for the determination of sensitivity to bottom trawling in the Frisian Front and Central Oyster Grounds, at least in the present situation. It should however be noted that in historical times vast areas with biogenic reefs occurred in the area, in which sessile fauna had a prominent appearance. For the present day situation the *sessile* epifauna is therefore left outside of the considerations about the impact of sea bed disturbance.

However, the Frisian Front and Central Oyster Grounds do host *mobile* epifauna which consists of brittle stars, small fish species, shrimps, *Nephrops*, *Goneplax* and other crabs. These live on the surface of the seabed or make a shallow hide in the soft sediment top layers (and can also be categorised under benthic infauna in that case).

Infauna

The benthic infauna of the sandy-muddy sediments consists of burrowing shrimps (*Callinassa*, *Upogebia* spp.), large or long-lived bivalves (*Acanthocardia*, *Arctica*, *Dosinia*, *Thracia*), sea urchins and polychaete worms. To relate to the footprint of different fishing gear (surface or subsurface; Eigaard et al., 2015) the benthic infauna can be grouped into:

- Shallow burrowing species (<2 cm): either small species or juvenile stadia of deeper living species which comprise several taxonomic groups like Echinoderms, Polychaetes, Crustaceans and Molluscs. They comprise species such as *A. filiformis*, *Echinocardium* and bivalves like *Acanthocardia*, *Arctica*, *Dosinia*, *Thracia* and many more.
- Deep burrowing species (>2 cm): adult bivalves (*Arctica*, *Dosinia*), worms, digging Crustaceans (e.g. *C. subterranea*, *Upogebia*), Ribbonworms, Polychaetes and Echinoderms.

Many deep living species also occur at the sediment surface as they move up and down, or different life stages live at different depths. An example of this are bivalves which live at depth as adults, but as a juvenile they live in the upper sediment layers. Examples are the bivalves *Mya truncata* and *Arctica islandica*. Settlers of these bivalves start at a size of ~200 µm and it takes them several years to attain a shell height of 5 cm. In the juvenile phase shells are thin and easily damaged. With ageing they gradually move to deeper sediment strata. The sensitivity of large bivalves has been illustrated by Witbaard and Klein (1994) who estimated a size – strength relationship for *Arctica islandica* and demonstrated that both adults and juveniles are highly sensitive for all physical pressures. *Arctica islandica* can be damaged by abrasion due to mobile fishing gear, e.g. beam trawls and otter trawls. The decline in the population of *Arctica islandica* in the southeastern North Sea corresponds with the intensity of beam trawling (Witbaard & Klein, 1994; OSPAR, 2009).

4.3 Impacts of mobile demersal fishing gear

In this paragraph, the impact on the typical species and habitats is described per type of mobile bottom contacting fishing gear. For our impact assessment of the demersal fisheries on the Frisian Front and Oyster Grounds, we can focus on the beam trawl (TBB), otter trawl (OTB, PTB), Danish seine (SDN) and Scottish seine (SSC) fisheries. The habitats of concern are the soft sediments with a high mud content.

4.3.1 Beam trawl

Towed bottom contacting fishing gears have been demonstrated to alter the structure of the bottom. Linnane et al. (2000) give an overview table of penetration depths of various fishing gears on a suite of bottom types (Table 4.2). It is directly evident from the table that in softer bottoms the penetration depth is greater. According to Paschen et al. (2000) a beam trawl gear has a bottom penetration of 1 to 8 cm, in the same range as reported by Linnane et al. (2000).

In a recent study (Depestele et al., 2016) studied the penetration depth of tickler versus pulse trawl gears on a sandy bottom. They demonstrated that for a tickler chain the penetration depth depended on the diameter of the chains and that the trawl shoe on hard sand might still create 8mm deep furrows similar to the depth caused by the 18 mm tickler chain. It is conceivable that these depths are greater in soft sediments, like those found in the Oyster Grounds and Frisian Front. It is thus beyond doubt that these gears produce tracks on the seafloor. This has also been witnessed in side-scan observations (pers. comm Rob Witbaard, NIOZ).

While gears on hard sand and gravel bottoms might displace and reorient cobbles and stones, in soft bottoms the vertical sediment structure is modified (Rosenberg et al. 2003) and disturbed and depending on gear type and bottom a higher or lesser degree of compaction results. Compaction also depends on the beam trawl gear component involved (shoe, ground rope etc.). The effects of these processes (removal of top sediment layer and disturbance of bottom structure) is likely to have an impact on bottom water exchange processes, i.e. nutrient and oxygen exchange. Compaction might cause fractures in shells and Vasconcelos et al. (2011) demonstrated that this effect depends on the size of the shell, with larger shells being more sensitive for compacting forces.

Table 4.2. Summary of bottom trawling gear penetration estimates (Based on Linnane et al., 2000).

Penetration Depth	Reference	Gear type	Substratum
100-150 mm	Arntz and Weber, 1970	Otter boards	muddy fine sand
a thin layer of top substrate	Bridger, 1970	Otter trawl ticklers	sand
80-100 mm	Margetts and Bridger, 1971	Beam trawls	muddy sand
100-200 mm	Houghton <i>et al.</i> , 1971	Beam trawls	sand
0-27 mm	Bridger, 1972	Beam trawls	mud
rather limited	de Clerck and Hovart, 1972	Beam trawls	rough ground
few centimetres	Caddy, 1973	Otter boards	sandy sediment
10-30 mm	de Groot, 1984	Beam trawls	mud, sand
200 mm	Khandriche. <i>et al.</i> , 1986	Otter board	mud
a few centimetres.	Blom, 1990	Beam trawls	sand
= 60 mm	Bergman <i>et al.</i> , 1990	Beam trawls	fine to medium hard sand
5-200 mm	Krost <i>et al.</i> , 1990	Otter board	mud, sand
20-50 mm		rollers on foot rope	
200 mm	Laane <i>et al.</i> , 1990	Beam trawls	mud, sand
20-300 mm	Rauck, 1988	Beam trawls	mud, sand
5-170 mm	Rumohr (in Krost <i>et al.</i> , 1990)	Otter board	mud, sand
40-70 mm	Laban and Lindeboom, 1991	Beam trawls	fine sand
50-60 mm	BEON, 1991	Beam trawls	fine sand
few cm. - 300 mm	Jones, 1992	Otterboards	deepest in soft mud
20-40 mm	Santbrink and Bergman, 1994	Beam trawls	fine to medium sand sediment
15-70 mm	de Groot, 1995	Beam trawls	substratum dependant
~ 140 mm	Lindeboom and de Groot (edit.), 1998	Otterboards in the Irish Sea	mud

The beam trawl fishery is characterised by a high percentage of discards (40-60% STECF, Dutch fleet in 2008: 35%, Van Helmond & Van Overzee, 2010). A regular availability of discards favours scavengers that dominate heavily fished areas (e.g. Kaiser et al., 2002) and may even lead to a change in food web structure (Hintz et al 2017).

Kaiser et al. (2006) report 42% initial reduction in abundance of benthic taxa after experimental trawling. Bergman and van Santbrink (2000) estimated direct mortality for a number of species and Witbaard and Klein (1994) demonstrated the detrimental effect of beam trawls on the large bivalve *Arctica islandica*. Direct effects on other species has also been witnessed (Mensink, 2000). Especially large (catchability) and often long-lived species are affected and as such the principle of fishing down the food web also holds for benthic communities.

4.3.2 Pulse trawl ('pulskor' & 'pulswing' bottom trawls)

Since 2009, there has been a rapid transition by Dutch fishermen from traditional beam trawling to pulse trawling. Beam trawling works by dragging tickler chains across the seabed to startle the fish and make them leap into the net. In pulse trawling, the most commonly used techniques are the 'pulskor' (pulse trawl) and 'pulswing' (pulse wing). Both are based on a system in which the tickler chains have been replaced by a system which emits short electric pulses on a part of the seabed. The emitted electrical pulses make the muscles of the fish contract, whereupon the fish "jumps" from the seabed and land in the net. The pulse trawl is thought to run lighter over the seabed than the traditional beam trawl (by the absence of tickler chains), and as a consequence does not

penetrate as deeply into the seabed (Depestele et al., 2016). In addition, as the fishing speed of pulse trawlers is slower (5 instead of 6.5 knots), the trawled distance per hour is 23% less and the overall fished surface is accordingly smaller (Van Marlen et al., 2014).

An overview of the current European pulse fishing research is found in the final report of the ICES working group on electrical trawling (ICES WGELECTRA 2017). They note that no studies have been done on the effect of pulse stimulation on the functioning of the benthic ecosystem and nutrient dynamics but conclude that in ecological terms, the replacement of the tickler chain beam trawl with pulse trawl with electrodes diminish the mechanical impact of trawling on the North Sea benthic ecosystem. Although the irreversible effects of electrical stimulation seem to be restricted to the vertebral fractures in cod and whiting, further research on the effects of electrical stimulation on marine organisms and ecosystem functioning is needed to assess the effects on the scale of the North Sea. Another unintended effect might be that the lighter pulse gear enables fishery on softer bottoms than is possible with traditional (tickler chain) beam trawls. This might lead to an extension of fishing areas which were formerly unaffected.

Pulse trawls are thought to penetrate less deep in the bottom than traditional beam trawls: Depestele et al. (2016) predicted a (modelled) pulse trawl shoe penetration depth of 60 mm, while the rest of the (pulse) gear had a much shallower penetration, predicted to affect the top 3.5 to 5 mm of the seafloor (sand). The shallower penetration is substantiated by the observed lower discard rates and the distinctly reduced by-catch of undersized fish and benthos (30-50% fewer fish discards, 48-73% fewer benthic species) (Quirijns et al., 2015, Van Marlen et al., 2014). The modelled penetration depths of the different gear components (ground rope, trawl shoes) indicates that the configuration of the tested gears makes a difference which, complicates our ability to generalize the physical impacts of a certain gear type (Depestele et al., 2016). The combined impact thus depends on the used gear components. Therefore it is not possible to give absolute numbers of impact depth. Effects of gears on the bottom will continuously change in time because of technological developments and changing fishing practices (Eigaard et al., 2016).

The effects of pulse gears in the trawl track itself are still unclear. Bergman and Meesters (unpublished) are presently analysing mortality data in the trawlpath of a pulse trawl, but these results are not yet available. Studies that examined short-term effects of pulse trawling have documented changes in the abundance of some infaunal and epifaunal taxa, such as Polychaetes, Nematodes, and benthic Diatoms, which mimic effects of natural disturbance. The electrical pulses might also affect the sediment water exchange either directly, or by influencing bio-irrigating and bioturbating fauna (ICES WGELECTRA, 2017). The few available laboratory studies indicate that some benthic species respond to the pulse and others do not respond. Long-term effects on benthos of being exposed to a pulse are largely unknown. Currently, these (biogeochemical) aspects are being investigated by Wageningen Marine Research as part of the PULSEFISHING project but no reports are available yet (Effecten van de platvisvisserij met de pulskor op het ecosysteem; 2016-2019), financed by the Ministry of Economic Affairs (EZ) (<https://www.wur.nl/en/project/Impacts-of-pulse-fishing-for-flatfish-on-the-ecosystem-.htm>).

This illustrates that although the effects of the pulse gear seems to be less when compared to the traditional tickler chain trawl, the bottom contact of the gear still influences the seafloor integrity.

4.3.3 Otter board trawl

The otter boards penetrate a substrate about 1-25 cm to resuspend the sediment and chase the target fish species, whereas the ground-ropes glide or hop over the seabed and penetrate 0.5-6.5 cm depending its construction (van Marlen et al., 2010). Depending on the sediment type, the trawl doors can dig up a trench/furrow of up to 35 cm deep and transfer large amounts of sediments onto either side of their path (Lucchetti and Sala, 2012, in Eigaard et al. (2015)).

The impact of otter board trawls on mud are reviewed by Johnsson (2002), and three of the four papers summarized by Johnsson involved experimental manipulations. Those that address physical effects report that trawl doors leave tracks in the sediment that remain visible for up to 18 months. A short-term study conducted in fishing grounds reports no change in species composition, but an increase in infauna abundance in response to trawling. A long-term study in an area closed to fishing reports that prolonged fishing results in increased species richness, decreased diversity, and no change in total abundance or biomass.

On sandy sediments, based on the results of 11 studies (6 of which involved experimental trawling), physical effects of trawling on sand habitat include trawl door tracks left on the seafloor, smoothed sediments, and removal of biogenic mounds. At greater depths (>120 m) tracks were evident up to 1 year after trawling. At shallow sites (< 7 m) tracks were no longer visible after a few days. The four studies that examined effects of chronic otter trawling on sand habitat documented decreased abundance and biomass of sedentary macrofauna, and decreased diversity (Johnsson, 2002).

The otter board trawl fishery is characterised by a discard percentage of up to 28%, which is 'modest' compared to discard rates of beam trawl fisheries of 70% (flatfish beam trawl) to 83% (shrimp and Nephrops beam trawl), whereas the fishery directed at sandeel (and Norway pout) has, in contrast, a discard rate of <1% (Kelleher, 2005).

O'Neill and Ivanović (2016) reviewed research on the mechanical impact of towed bottom fishing gears with the aim to come to predictive models and refer to the numerous field studies demonstrating such effect. Swinghammer et al. (1998) reported on the observed changes of the seabed and sediment properties of trawled areas (otter) in comparison to untrawled areas. Sediment topography and roughness changed and reduced the superficial biogenic sediment structure and the presence of flocculated organic material. The study of Martín et al. (2014) showed that turbidity in a submarine canyon in the Mediterranean was dominated both in magnitude and in temporal patterns by resuspension caused by fisheries and caused intermediate nephloid layers and peak suspended particulate matter (spm) concentrations of >200 mg/l. An experimental study in the Bay of Biscay similarly demonstrated the resuspension effect of trawl doors and its effect on sediment granulometry, i.e. a gradual coarsening of the sediments in the most heavily fished area between 1967 and 2014 (Mengual et al., 2016).

4.3.4 Fly-shoot/ Danish seines

The ground ropes of the fly-shoot and Danish seine cause abrasion and resuspension of the sediments and the gear can cause collision impact with hard and/or fragile structures (Rijnsdorp, 2015). The fly-shoot and Danish seine have a large footprint in terms of the fished surface (1.5 x the circle made by the fishing line), but there are hardly any empirical studies on the benthic impact of Danish seine or Scottish seine (fly-shoot) fishery (Rijnsdorp, 2015, Bureau Waardenburg, 2017). According to Huse et al. (2003), traditionally the seine net fishery took place on very smooth and sandy bottoms. Consequently, the gear has to touch bottom with some or all of its components, which means ground rope and herding ropes (note that no trawl doors are present). The bottom touching parts of the gear will have some effect on the substrate by shifting small amounts of sediments (Huse et al., 2003). Key issue in assessing the gear impact is the nature of the contact between seine net and sea bottom, which is surmised to be light, although a moving ground rope can be expected to affect the epifauna and cause resuspension. Deerenberg et al. (2010) presume that the induced turbidity will be low due to the relatively light contact of the ground rope with the sea bottom.

The seine fishery has low discards rates of less than 5% (Kelleher, 2005). Given the high catches, this still amounts to large volumes of discarded fish and benthos. A regular availability of discards favours scavengers that dominate heavily fished areas (e.g. Kaiser et al. 2002). In the Northeast Atlantic (South of Portugal) discards in this type of fishery consist mainly of pelagic species and juveniles of the target species (Gonçalves et al., 2008).

Fly-shoot towing speed is low at the start, but increases to the end of the tow and is then comparable to other bottom trawl gears (Rijnsdorp, 2015). The physical 'sub-surface' impact inside the fished surface is not much different between fly-shoot, Danish seine on one hand and otter trawl and beam trawl on the other hand. However, the fly-shoot, of all mobile bottom contacting gears, has the largest surface footprint (1.6 km²/h for an average vessel, compared to 0.3-1.2 km²/h for a beam trawl or otter trawl) (Rijnsdorp, 2015; Eigaard et al., 2016).

For Danish seining, which is suggested to be more low-impact than fly-shooting, there is likely a difference in the gear configurations between the coastal fleet (from which most of the scientific evidence was derived) and the larger-scale offshore Danish seiners. The former use thin rope while the offshore fleet likely use heavier, thicker ropes (pers. comm. Thomas Kirk Sørensen WWF-DK to Thomas Rammelt).

Since the Frisian Front and Central Oyster Grounds are areas with relatively low natural dynamics, the benthic impact of fly-shoot fishery is assumed to be large compared to the impact by natural causes (Rijnsdorp, 2015).

4.3.5 Comparison of gear impact

Aspects of fisheries, based on the categories in Deerenberg et al. (2010) and MarLIN (see Table 4.2), are related to the pressures and impacts of beam trawl-otter trawl-Scottish seine/fly-shoot - Danish seine and pulse trawl. In this overview the fishing gears are ranked from gear with a small but deep footprint (beam trawl) to gear with large but superficial footprint (Danish seine), and all intermediate forms.

Table 4.2 Impact comparison of demersal fishing gear on the fauna and abiota (Deerenberg et al., 2010 versus MarLIN <http://www.marlin.ac.uk>) and the type of effect for different fishing gears, based on literature in combination with our own expert judgement.

Type of effect	Aspect	Description (MarLIN)	Beam Trawl	Otter trawl	Scottish seine	Danish seine	Pulse (wing)
Damage	Abrasion & physical disturbance	This factor includes mechanical interference, crushing, physical blows against, or rubbing and erosion of the organism of interest. Protrusive species may be crushed, and delicate organisms with a fragile skeleton or soft bodies may be physically damaged or broken (snapped).	high	high	medium	medium	medium
	Abrasion/disturbance of the surface of the substratum or seabed	Damage to surface features (e.g. species and physical structures within the habitat)	high	high	high	medium	medium
	Displacement	Physical removal or transportation of the species or community of interest. The community, colony or organism may be removed from its natural habitat but remain in the vicinity.	high	high	high	medium	medium
Structure of substrate	Penetration or disturbance of the substratum subsurface	Damage to sub-surface features (e.g. species and physical structures within the habitat)	high	high	high	medium	medium
	Habitat structure changes - removal of substratum (extraction)	Extraction of substratum to 30 cm (where substratum includes sediments and soft rocks but excludes hard bedrock)	high	high	medium	low	low
	Physical change (to another seabed type)	If rock was replaced with sediment, this would represent a fundamental change to the physical character of the biotope and the species would be unlikely to recover. The biotope would be lost.	low	low	low	low	low
Turbidity	Physical change (to another sediment type)	1) Change in sediment type by one Folk class (based on UK SeaMap simplified classification). 2) Change from sedimentary or soft rock substrata to hard rock or artificial substrata or vice-versa.	low	low	low	low	low
	Substratum loss	The physical removal of the substratum inhabited or required by the species or community in question.	high	high	high	medium	low
	Increase in suspended sediment	A change in one rank on the WFD (Water Framework Directive) scale e.g. from clear to intermediate for one year.	medium	medium	medium	medium	low
	Increase in turbidity	The turbidity (clarity or opacity) of water is dependent on the concentration of substances that absorb or scatter light; for example, inorganic or organic particulates (suspended matter), plankton and dissolved substances.	medium	medium	medium	medium	low
	Smothering	The physical covering of the species or community and its substratum with additional sediment (silt), spoil, detritus, litter, oil or man-made objects. Overgrowth by other species such as encrusting ascidians is also included here.	medium	high	medium	low	low
Removal/Discards	Smothering and siltation rate changes (heavy)	'Heavy' deposition of up to 30 cm of fine material added to the habitat in a single discrete event	high	high	medium	low	low
	Smothering and siltation rate changes (light)	'Light' deposition of up to 5 cm of fine material added to the habitat in a single, discrete event	high	high	medium	low	low
	Extraction of this species	If 50% of the population or biotope is removed then sensitivity is automatically assessed as intermediate. Potential for recovery after a very efficient extraction has been undertaken can also be assessed using this definition.	high	high	medium	low	low
	Removal of target species	Removal of species targeted by fishery, shellfishery or harvesting at a commercial or recreational scale.	high	high	medium	low	low
Removal of non-target species	Extraction of other species	A species that is a required host or prey for the species under consideration (and assuming that no alternative host exists) or a key species in a biotope is removed.	high	high	medium	low	low
	Removal of non-target species	Removal of features or incidental non-targeted catch (by-catch) through targeted fishery, shellfishery or harvesting at a commercial or recreational scale.	high	high	medium	low	low

As mentioned in 4.1 and based on Eigaard et al. (2016), fly-shoot and otter trawls, in particular twin trawls, have a large surface footprint (< 2 cm) as compared to for instance beam trawls used in the flatfish fishery. The flatfish beam trawls, however, have a relatively large subsurface footprint (> 2 cm) because all gear components penetrate into the seabed. When comparing different types of seine nets, the Scottish seine (or fly-shoot) is expected to have a larger impact than the Danish seine due to its weight, thicker ropes, and larger area footprint. The 'footprint' of a pulse trawl appears at first sight to be less than that of a beam trawl but a counteracting side effect can be that the fishery distribution may change because the lighter pulse gear can fish on soft bottomed fishing grounds that could not be fished before.

Thus although the bottom impact ('footprint') of Danish and Scottish seines or pulse fishery appears to be less than that of the traditional beam trawls and otter trawls they all lead to a decrease in seafloor integrity and thus potentially have impact on the conservation objectives of the Frisian Front and Central Oystergrounds management zones.. The fishery impact is described in detail in the following section.

4.4 Impact on conservation objectives

The effects of seabed disturbance by bottom contacting fishery were demonstrated in many studies and comprise increased mortality rates of non-target species (Bergman and Santbrink, 2000), increased scavenger abundance (Groenewold and Fonds, 2000), changed food web structures (Groenewold 2000, Hinz et al. 2017), changed size distributions (Van Kooten et al. 2015), and reduced abundances (Duineveld et al., 2007). In addition, the boards and ticklers expose animals to the sediment surface and make them vulnerable to predation, or make them spend extra energy on reburial (R. Witbaard, pers. comm.). Apart from the direct physical contact with parts of the fishing gear, there are also effects of compaction of the sediment (Vasconcelos et al., 2011). It appeared that small-shelled specimens were found to be less sensitive to compaction while large shells are more vulnerable to compacting forces. Several studies show that for a number of large species a significant percentage of the caught specimens are seriously damaged (Witbaard en Klein, 1994, Mensink et al., 2000). Other studies showed clear differences in mortality between species (Bergman & Santbrink, 2000).

Rijnsdorp et al. (2016) assesses the physical impact of towed nets as follows:

- Cables and ground rope: homogenise texture of sea bottom, destroy hard structures, move stones or shells
- Otter boards or tickler chains: penetrate into the seabed and disturb the vertical structure of the sediment

In summary, the impact of bottom fishery on the conservation objectives acts through its effect on seafloor integrity (with consequences for mortality rates of fauna and community succession) by: 1. gear penetration into the seabed (depending on shape and mass of the gear; higher towing speed implicates heavier gear); 2. collision of fishing gear with (hard) structures (depending on mass of the gear component and the speed at which the gear is dragged); 3. re-suspension of sediments by the towed fishing gear (determined by the grain size of the sediment and the hydrodynamic resistance - which is a function of the surface area of the gear and the square root of the speed).

According to Slijkerman et al. (2013) especially long living species are affected by bottom fishery, leading to a shift in age structure towards more juveniles or even the disappearance of species that have an irregular or absent spatfall. As a result of fishery impact, the sea floor is homogenized, having a negative impact on deep digging species such as shrimps. Those species are important for the structure, chemical conditions and mineralization of the sea floor, and they enhance the distribution other species (Slijkerman, 2013).

Van Kooten et al. (2015) analysed to what extent the Frisian Front and Central Oyster Grounds have been altered by demersal fisheries, in terms of ecosystem functions, species richness and size distributions. On the basis of trait analyses they found a number of modalities for which a true effect of fishing is likely (see table below). In particular, the modalities ‘exoskeleton’ and ‘predator’ are more abundant in fished areas, possibly representing a shift in community composition towards more mobile scavenger/predators and to species that are protected against damage. Also, an increase in the relative abundance of ‘burrow dwelling’ taxa was found i.e. mud shrimps such as *Callinassa*. These live deeply buried in the sediment, where they are largely immune to disturbance of the top sediment layer.

The most obvious trait modality that is negatively related to fishing intensity of bottom trawling, is the decline of infaunal biomass inhabiting the top 0-5 cm of the sediment. The fact that species occur in the top 5 cm of the sediment means that they are inevitably affected by physical disturbance of the trawl gear. These are often bivalves, which are generally sensitive to bottom trawling (Tillin, 2006).

Table 4.3. Selection of traits strongly associated with fishing (Van Kooten et al., 2015).

Positive	Negative
egg development – brooded	living habitat - free living
protection - exoskeleton	bioturbation - diffusive mixing
feeding mode – predator	feeding type - subsurface deposit
living habitat - burrow dwelling	sediment position - 0-5cm
bioturbation- surface deposition	egg development- benthic

In some species, body size tends to be smaller in heavily fished areas. A significant negative relationship between size and fishing intensity was demonstrated for the large bivalve *Acanthocardia echinatum* (Van Kooten et al., 2015). Lack of data, i.e. the absence of large vulnerable species in the heavily fished areas, made it impossible to explore the existence of this relationship for other species. This result supports previous field studies which showed a high impact of trawling on large bivalve species. It has been

demonstrated that especially *Arctica islandica* is vulnerable for bottom trawling (Witbaard & Klein, 1994). The almost total absence of this species from the most heavily fished areas illustrates the long-term effect of bottom disturbance on it.

Considering the cited literature, based on the best available data, we conclude that all mobile bottom contacting gears have a negative impact on the substratum or on the water column turbidity and thus on the vulnerable in- and epifauna that are included in the conservation goals of the Frisian Front and Central Oyster Grounds.

5 Cumulative effects

The North Sea is of a great economic importance. Some economic activities are directly related to the sea (e.g. oil and gas extraction, fishing), others indirectly (such as ports, industry and recreation). The North Sea is also important for transport activities (shipping, telecommunications, energy supply) and functions for which there is insufficient space on land (wind energy, sand extraction). Below, a short description is given of the relevant activities and their cumulative effects based on the integrated management plan of the North Sea (2015).

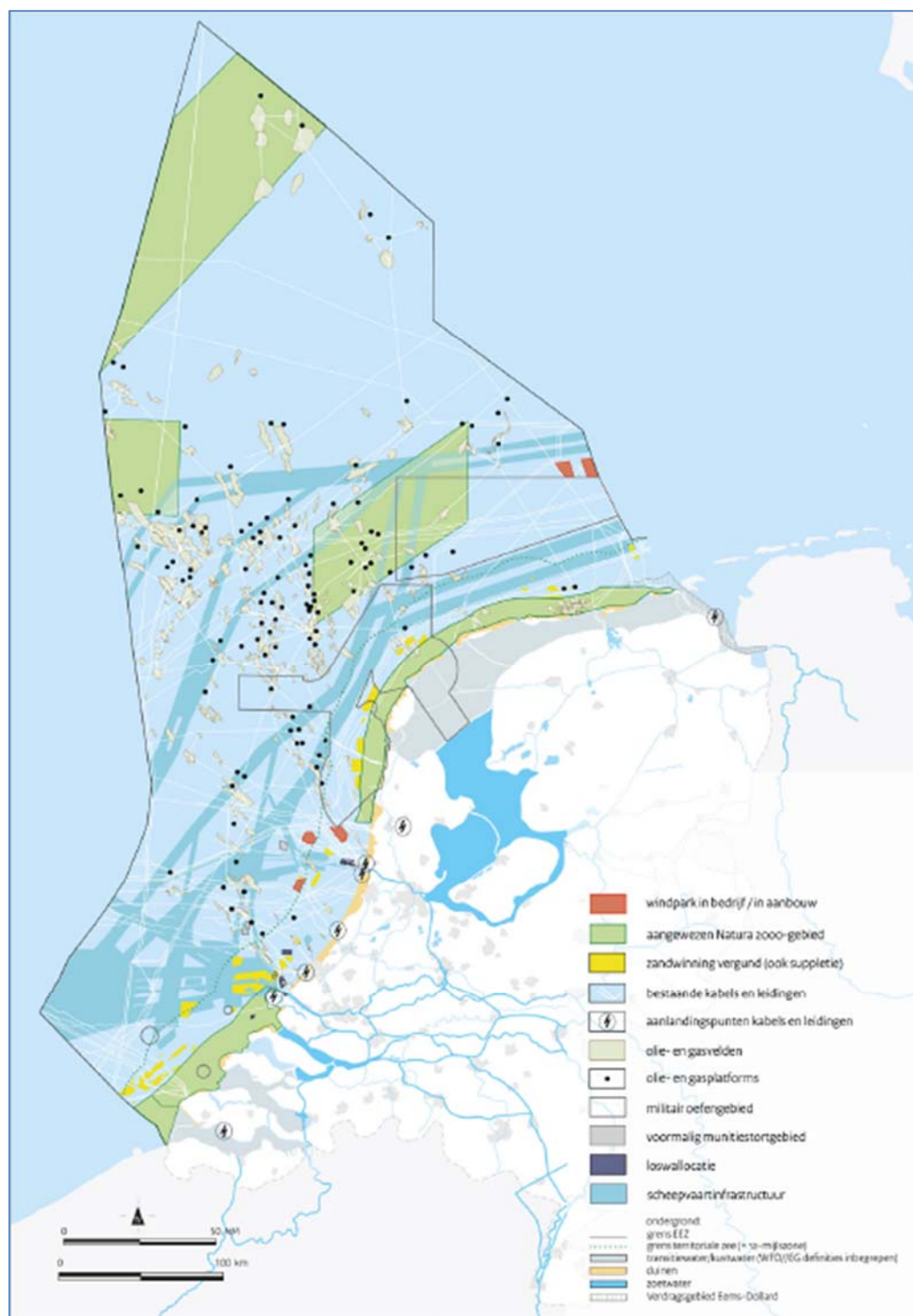


Figure 5.1. Activities in the North Sea (Beleidsnota Noordzee 2016-2021).

Shipping

The North Sea poses very busy shipping lanes. Figure 5.1 gives an impression of the shipping intensities. The Dutch seaports are junctions for international trading and a location for industry and services. Possible cumulative effects of shipping are: its contribution to underwater sound and visual disturbance, and shipping is a source of pollution. The effects of shipping on bottom integrity and benthos fauna are neglectable.

Military use

The North Sea is important to the armed forces, for training and exercising purposes. The space requirement for these activities is laid down in a separate key planning decision, named Second Structure Plan Military Grounds. In this plan the areas are designated for these activities. In the absence of exercises these areas are available to other users. There are a number of dumping areas for ammunition in the North Sea, but dumping has been banned for some time now. Cumulative effects on bottom integrity and benthos fauna are not expected.

Energy

Extraction and exploration of oil and natural gas reserves has always been an important economic activity on the North Sea. Figure 5.2 depicts the distribution of platforms of different companies on the Dutch Continental Shelf (DCS). This industry is, however, under pressure by the low oil and gas prices and the transition to an economy based on the use of sustainable energy. The cessation of production and the decommissioning of old platforms are issues that will become increasingly relevant in the near future, much depending on the development of the oil and gas prices.

Gas exploitation is happening in both areas, but especially in and close to the Frisian Front (14 platforms). In the Central Oyster grounds only 1 platform is stationed (Slijkerman et al., 2013). Beside the exploitation of the current platforms, explorative activities (e.g. seismic research) and drilling activities also take place in the areas. New developments are the system integration of different sources of offshore energy but the implications of that for the ecosystem are as yet not known. A recent prospectus of EBN, the institution that invests in the exploration for and production of oil and natural gas AO, gives some insight in the envisaged developments (EBN, 2016: Focus Dutch Oil and Gas 2016).

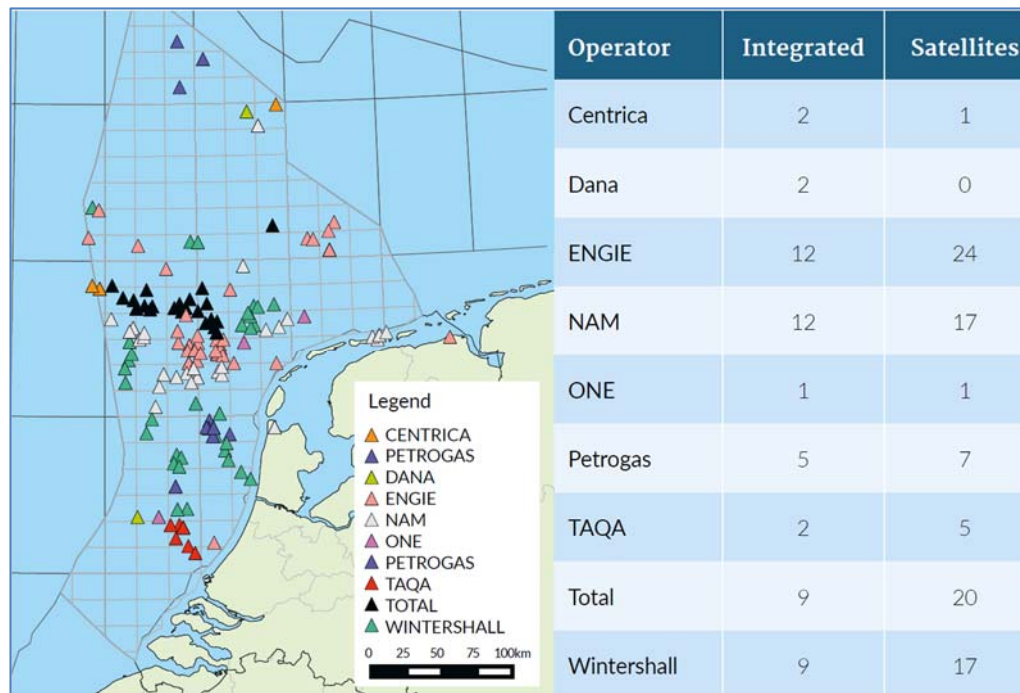


Figure 5.2 Overview of platforms in the DCS. Source: <https://www.ebn.nl/wp-content/uploads/2016/12/Focus-Dutch-Oil-and-Gas-2016.pdf>

Compared to the scale of bottom fishing, the footprint of these activities is small. Direct effects on the seabed and the benthic fauna are related to the unavailability of the substrate (habitat loss) at the site of the platform. The impact on the targets for indicator species depends on the scale of extraction (amount of facilities) in the area. With the current number of facilities in the areas, the estimated area loss is small according to Slijkerman et al. (2013). She calculated a negligible bottom surface loss in Central Oyster Grounds and Frisian Front, assuming a loss of 250 m² per facility (gas and oil) (see table below).

Table 5.1. Expected loss of surface per area (Slijkerman et al., 2013).

Natura 2000-gebied	Oppervlak gebied (ha)	Aantal platforms	Ruimtebeslag platforms (ha)	Aandeel ruimtebeslag t.o.v. gebied
Centrale Oestergronden	345.300	1	0,025	0,000007%
Friese Front	288.084	14	0,350	0,0001%

Within a zone of 500 m surrounding the platforms, other activities are excluded because of safety considerations. In this way, a closed area for fisheries exists which can function as a sanctuary for bottom fauna (see also Duineveld et al 2007) . The pile foundations of platforms locally alter the habitat from soft bottom to hard substrate, which is relative scarce in the North Sea. Effects of this change towards hard substrate on the ecosystem functioning has been studied for one platform within the INSITE project (<https://www.insitenorthsea.org/>).

Drilling of (bore)holes disturbs the bottom substrate by placement of pipes, the drilling itself and the release of cement and spacers. A surplus of cement can smother bottom fauna. The surface with a smothering layer of more than 1 mm is expected to be less than 1 ha (Tamis et al., 2011 in Slijkerman et al., 2013).

Cables and pipes

Currently 5 cable trajectories cross the Frisian Front and a couple of gas pipes that are connected to gas platforms. In the Central Oyster Grounds 3 cables and a limited amount of pipe tracings to a platform in the southwestern corner of the area are present (Slijkerman et al., 2013). (Re)placement can lead to raised turbidity and bottom fauna in the tracing is affected locally. Placing of pipelines disturbs the sediment on approximately 10 m on both sides of the pipeline. After placement a fast recovery of the bottom structure is expected. For cables the effects are similar (Slijkerman et al., 2013). Electric and/or magnetic fields occur when cables are being used, the impact is unclear.

Wind farms

Offshore wind energy has developed in the past years, with a number of three nearshore wind farms that are operational. The turbine parks Egmond at Zee (EAZ) and Prinses Amalia Windpark (PAW), outside the 12-mile zone, have a surface of 26,8 and 16,6 km², respectively (including 500 m safety zone). Windpark Luchterduinen in the Hollandse Coastal area on 12 NM) has a surface of 25 km². The Gemini Offshore Windpark (on 34 NM) in the northern area of the Wadden islands is currently under construction. The surface is approximately 68 km².

Expansion of offshore wind energy will take place to waters north of the Wadden islands and to the relatively shallow Dogger Bank in the North Sea. The government strives to install 4,450 MW of wind energy on the North Sea operational by 2023 (Nationaal Energieakkoord, 2017). None of the current or planned parks are situated in Frisian Front or Central Oyster Grounds, therefore the cumulative effects of wind farms can be left out of scope.

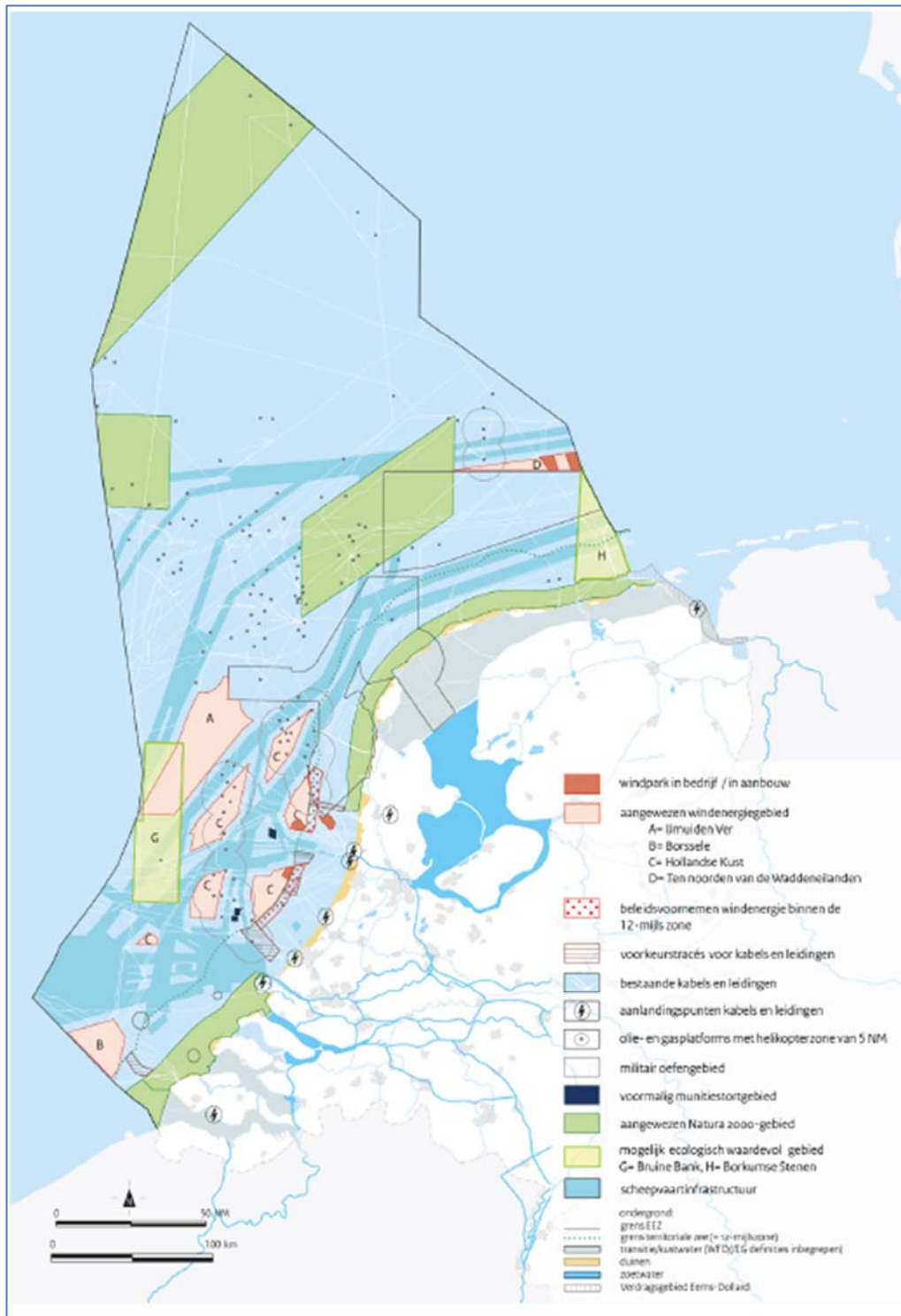


Figure 5.3 Windenergy in the EEZ (Beleidsnota Noordzee 2016-2021).

Extraction of surface minerals and sand

The silt rich deep areas of the Frisian Front and Central Oyster grounds are not suitable for aggregate extraction. Only the southern part of the Frisian Front is part of a potential extraction area. Currently, no extraction of surface minerals is taking place (Slijkerman et al., 2013).

Cumulative effects of sand extraction are not relevant for the Oyster Grounds and Frisian Front since none of these activities take place in the areas.

6 Discussion and recommendations

In this chapter an overview is presented of the conclusions of our literature review and our second opinion on the background document (BD).

In addition, recommendations are given to improve on the contents of the BD.

6.1 Scientific certainty

ToR – Main question 1

Can be concluded with certainty, leaving no reasonable scientific doubt, that in case mobile bottom contacting fishing gears would be allowed in the management zones of these areas, the delivery of the conservation objective, as defined in the Dutch Marine Strategy, the Marine Strategy Framework Directive, and in compliance with the criteria of the Decision of the EU Commission ((EU) 2017/848), will not be compromised?

If mobile bottom contacting fishing gears would be allowed in the management zones of the Frisian Front and Central Oyster Grounds, the delivery of the conservation objectives (especially the improvement of biodiversity and bottom integrity) will be negatively impacted. This is the case for gears with a sub-surface impact, but perhaps even more so for gears with a shallow surface impact but larger area footprint, since several typical features of the Frisian Front and Central Oyster Grounds protected areas are the long-lived, filter-feeding, infauna, living in the upper sediment layer of the bottom substrate.

ToR – Main question 2

Can it be concluded with certainty, leaving no scientific doubt, that allowing bottom impacting fisheries in the remaining area outside the management zones, would not jeopardize the delivery of the conservation objectives of these sites as defined in the Dutch Marine Strategy, the Marine Strategy Framework Directive, and in compliance with the criteria of the EU Commission Decision (EU) 2017/848?

Fishing with mobile bottom contacting fishing gears in the non-protected areas can also jeopardize the goals in the management zones. Bycatch of mobile species moving out of the management zone poses increased mortality of these species. Changes in the population structures of mobile predators and scavenging species might lead to changed predation pressures in the management zones and resuspension of sediments outside the management zones is likely to have effects in the "downstream" areas, causing smothering and having effects of biogeochemical water column and bottom processes inside the areas.

Depending on the timescale which one is considering, it can even be argued that in the last century the area (Oyster Grounds) has changed from a biotic oyster reef into a soft sediment habitat partly because of the selective fishing for Oysters. Thus the judgement of the effects of present day fishing also depends on the reference situation one takes in account. For the present day soft sediment community the numbers of sensitive species might already have been diminished so much that the effects of bottom disturbance by fishing gears might be hard to detect. Although there still are species like *Sabella* or *Chaetopterus* (Polychaeta) which encounter serious negative effects of physical damage and increased loads of SPM.

On basis of the effects of bottom trawling as described in literature it is unlikely that only closing the current proposed management zones will provide the required certainty that the delivery of the conservation objective for Frisian Front and Central Oyster Grounds can be met i.e. would not be jeopardized.

6.2 Is the best available knowledge applied?

Q2. Sufficiency of literature

ToR: Is there sufficient literature available to support the conclusion that the favourable conservation status of the MSFD areas is ensured in case of a management regime which allows the aforementioned bottom impacting gears in the management zones?

The Frisian Front and Central Oyster Grounds have been considered as search areas for spatial measures aiming at the protection of benthos, in addition to seabed protection in Natura 2000 areas on the Dutch part of the North Sea (GES-descriptor 1, biodiversity). The conservation objective for Frisian Front and Central Oyster Grounds is: *the recovery of substantial parts of the sea bed ecosystem from a disrupted state towards a natural condition.*

There is an acceptable amount of knowledge of the structure and functioning of these areas, which should be sufficient to understand the impact of human activities including fisheries. However, there is, and will remain, substantial scientific uncertainty on the effects of fishery because the impact of fishery and natural factors are correlated and cannot be separated, hampering any conclusions on the causality of the dominant factors. This is a particular challenge in the Frisian Front and Central Oyster Grounds areas where the depth of the area is such that natural physical impacts influence the bottom ecosystem as well as anthropogenic impacts.

Despite certain scientific uncertainties, from all available literature it becomes evident that allowing bottom impacting fishery in the management zones of the Frisian Front or the Central Oyster Grounds does not contribute to the ecological improvement of the sea bed ecosystem, which is the objective of the Marine Strategy Framework Directive. To create opportunities for a natural development of the sea bed ecosystem in these areas, an impact reduction or exclusion of the bottom fishery appears crucial. This said, it should also be acknowledged that exclusion of mobile bottom trawl activities alone may not be sufficient for a full recovery of the areas as regime shifts that have occurred in the past are not easily reversed. Furthermore, recovery is also highly dependent on climatological and hydrological conditions that are changing.

Q3. Selective use of literature

ToR: In the literature review the question will be answered if in the Background Document selective use has been made of available literature.

- a. Was recent literature concerning the effects of the afore mentioned bottom impacting gears, left out of the impact analysis in the Background Document?

- b. Were conclusions of research, which have been used in the Background Document – also including the studies by A. Rijnsdorp (2015), and by Eigaard et al. (2016) – correctly reproduced?

Ad a.

With respect to the area description, the BD does not refer to the original scientific publications of NIOZ (nl) or CEFAS (uk). The description of the ecological significance of the areas is not in-depth, therefore the statements on the uniqueness of the areas are insufficiently supported by literature references. The rationale for management measures is found in the good environmental status according to the descriptors of the MFS: biological diversity and sea-floor integrity. The descriptors used in the BD focus the attention to the benthic community, with typical elements being 'old growing' and 'big growing' species. However, as shown by Wijnhoven & Bos (2017), this can be specified to provide a better description of the typical benthic communities that are present in the selected areas of Frisian Front and Central Oyster Grounds. The recent report of Wijnhoven & Bos (2017), supporting the choice of indicator species, was not used in the BD but should be cited in this context.

The BD does not mention the regime shifts that occurred in the benthic community of the Frisian Front by the disappearance of large areas of natural oyster reefs c. 100 years ago, or the recent change in relative densities of *A. filiformis* and *C. subterranea* (see par. 3.3.2) which also might be related to fishing pressure.

The BD interpretation that the physical impact of bottom fishing results in homogenising the sea floor, having a negative impact on deep digging species such as shrimps, needs clarification. From literature there are indications that the brittle stars *Amphiura*, living in the top layer of the sediment (0-5 cm), are likely to be influenced more directly by bottom contacting fishing gears than the deep living burrowing crustaceans. The burrowing crustaceans furthermore play a significant role in modifying their environment by expelling fine sediment while creating their burrows. This continuous sediment reworking might inhibit further population development of *Amphiura*. High *A. filiformis* densities increase the stability of the seabed, whereas high *C. subterranea* densities lead to decreased stability of the seabed and with that to an increased sensitivity of the bed to re-suspension of fine particles (Amaro, 2005).

This new, and possibly steady state should be taken into account in the BD, as it could inhibit the resettlement of epifaunal bivalves like the European flat oyster and it could contribute to a slower than expected recovery of the disrupted bottom in the Frisian Front and Central Oyster Grounds.

In addition, the BD does not mention the significant decrease in water clarity that has occurred in the central and southern North Sea over the second half of the 20th century. Capuzzo et al. (2015) suggest that the reduction in underwater light availability was the result of a combination of causes, including a decrease in sea-bed integrity and changes in benthic community, increased trawling effort, windiness, and coastal erosion (see also par. 3.3.3). The water column was clearer in the early 20th century, and the sea floor was colonized by a benthic community including oysters (*Ostrea edulis*), and potentially microphytobenthos (Capuzzo et al., 2015). We note that the BD is not dealing with the impact of raised turbidity by resuspension of the substrate through fishery and the possible impact on oxygen concentrations in the BML (bottom mixed layer) in stratified waters.

The BD should take into account the above statements.

Ad b.

The conclusions of Rijnsdorp et al. (2016) and Eigaard et al. (2016) are correctly reproduced. However, it should be noted that different life stages of certain species inhabit different layers of the sediment. Therefore, these species are sensitive for both surface and subsurface bottom disturbance. An example of a conspicuous species which lives both shallow and deep (depending on its age and the feeding conditions) is the bivalve *Arctica islandica* among many other species. (see also par. 4.2).

Concerning Eigaard et al. (2016), it can be noted that the depth to which bottom disturbance is taking place (surface, sub-surface) is not determining the entire effect. The impact of similar disturbance depths can have different consequences on one type of substratum (e.g. 2 cm disturbance depth on a sandy sediment in the shallow coastal zone) or another (e.g. the same on a fine sediment or gravel offshore at 50 m depth). In other words: the difference in sensitivity of different substrates is left out of the consideration by Eigaard et al. (2016).

The Frisian Front is more intensively fished than the Oyster Grounds. The Figure 9, presented in the BD, is difficult to interpret because of the large scale and should focus on the areas of concern.

The BD correctly, but incompletely, reproduced the conclusions of research, which means that the potential impact of bottom fishery is not described in full and is not assessed in all its aspects. This poses a risk of being unable to meet the conservation objectives, in case bottom contacting fishing gears are allowed, both inside and around the management zones.

6.3 Is the impact assessment complete?

Q1. Scientific justification of chosen management regime

ToR: Is a management regime, which allows the afore mentioned bottom impacting gears in the management zones, scientifically justified and hence does it meet the (sub)targets for benthos?

As discussed in par. 6.1 Q2, we estimate that allowing bottom impacting fishery in the management zones of the Frisian Front or the Central Oyster Grounds does not contribute to the ecological improvement of the sea bed ecosystem. Exclusion of bottom trawling from these zones can offer the opportunity for a more natural development (however, without guarantee for improvement).

Since the mid 1980ies when the Frisian Front was "discovered" by Creutzberg this area has experienced an ever-increasing pressure by the rapidly developing beam trawl fleet. Despite early warnings of the detrimental effects of the heavy beam trawl gears, it was hard for science to unequivocally demonstrate the effects of bottom trawling. Partly because the used methods were insufficiently able, in relation to the natural and spatial variability and the different scales at which data was available, to prove such effects. However, a good demonstration of the long term (20 years) effects comes from the study by Duineveld et al. (2007), who sampled in the 500 m-protected zone surrounding a gas platform. They observed marked differences in densities of large species within (unfished) and outside (fished) the protected security zone.

The BD states that biological indicators aim to indicate improvement of these quality aspects. However, the basic principle of a suitable biological indicator is that it indicates the quality of the habitat type and that it can be either a 'positive indication' (indicates quality improvement) or a 'negative indication' (indicates quality deterioration). Of some indicator species in the BISI, it is not clear whether an increase of the species is indicating quality improvement or deterioration, e.g. the burrowing shrimps.

Three management zones were appointed based on the 'ecopoint' [REFS] method, focusing on the current status of the benthic ecosystem, but the method is not explained in detail. The BD states that the area on the northern part of the Central Oyster Grounds (1200 km²) of fine (silty) sand contains relatively high numbers of long lived macrobenthos species and is characterised by a high species richness, and that the area on the Frisian Front covers the central part of the gradient including the core area with the highest amount of silt, about 20%, and contains relatively high macro- and megabenthos biomass, species richness and species density. The area South-East of the Frisian Front, of coarse and medium fine sand, runs into the Frisian Front itself and contains relatively high amounts of megabenthos biomass, species richness and species density, but as such is situated outside the limits of the designated Natura 2000 area.

The BD should illustrate and demonstrate the importance of the selected management areas by showing maps of the specific distribution of biodiversity and habitats.

It is remarkable that one of the designated Frisian Front management areas (the smaller one) is merely situated outside the boundaries of the Frisian Front. Furthermore, this area of 400 km² is fully overlapping with the plaice box, an area already experiencing fishery restrictions aimed to protect juvenile plaice, that was closed to large beam trawlers (>300 hp) since 1995. This area only covers one "end-member" of (physical-hydrographical) conditions characteristic for the ecological values of the Frisian Front, instead of the entire relevant gradient known to occur in the Frisian Front. Therefore this area can never be a representative of the Frisian Front as a whole, and can never replace the other areas.

6.4 In what way have knowledge gaps and uncertainties been dealt with?

Q2. Risk of not meeting the conservation objectives

ToR: In the literature review the possibility of significant effects will be related to the question whether the delivery of the Marine Strategy targets will be jeopardized in the light inter alia of the characteristics and the specific environmental conditions of the site.

With the long history of fishing with heavy bottom contacting fishing gears and the knowledge that the Frisian Front seems to be subjected to a regime shift the recovery potential of this area for those species that heavily suffered from intense bottom trawling remains to be proven after long-term absence of anthropogenic bottom impact, which is a matter of endurance and patience. The knowledge on the (self-)sustainability of the populations in the area is lacking. Of some long-lived species the densities are nowadays so low that recruitment from within the local stock is unlikely and these stocks may thus fully depend on import of recruits from elsewhere.

For the Oyster Grounds, the disappearance of the oyster beds by overfishing (19th century) also led to a habitat modification, which may be irreversible because in the present situation it is unlikely that oyster recruitment can still take place because of a

lack of suitable substrate and the vulnerability of the sediments to resuspension. Recovery may also be hampered because the oyster populations that are stocking the larval supply have vanished or are too remote from the Central Oyster Grounds.

The BD correctly points out that there is a lack of information on the recovery potential of the protected areas. As a consequence, an assessment of the proposed measures with respect to the achievement of the conservation objectives over short term, is not possible. We conclude that this leaves a high degree of uncertainty whether the management areas have been properly selected. And the risk of prematurely jumping to conclusions in case no change is observed.

As mentioned in 6.1 Q3, the intensity of fisheries with demersal fishing gear appears to be highest in the Frisian Front. Probably this area has more favourable conditions like a higher production and a lesser water depth, but also due to its geographical location relative to the main fishing ports of Den Helder, Texel and Urk.

The Frisian Front is designated as SPA for common guillemots and underlines the importance of the area. Common guillemots benefit from the presence of sprat and herring that utilize the area because of its increased (primary + secondary) production. It should therefore be acknowledged that the Frisian Front as a Bird Habitat area is coupled to the hydrographic and benthic processes in the area. The remarkably high landings of sprat by Danish trawlers (from the area?) give rise to thoughts on possible adverse impact on the protected guillemots. The Danish fleet targeting sprat (and thus competing with the food of Guillemots)(par. 7.2) can potentially affect the status of the area as SAC adversely.

6.5 Does the BD give sufficient insight in the activity?

Q3. Literature review of fishery impact

ToR: The literature review will, inter alia, research the effects of bottom impact and bycatch of the afore mentioned bottom impacting gears on the targets of the Marine Strategy habitat for benthos. The effects on the seabed and associated species will include the effects on fish (target and non-target species), benthos, shell fish and other bottom dwelling species. The research will also focus on slow-growing and long-lived species and other effects on the food web. If possible, long term effects will be taken into account. The effects on typical species as mentioned in the Background Document are part of this assessment.

The review concluded that all mobile bottom contacting gears have a negative impact on the substratum or turbidity and thus on the vulnerable in- and epifauna and on the conservation goals. Effects of seabed disturbance by bottom contacting fishery were demonstrated in many studies and comprise increased mortality rates for non-target species (Bergman and Santbrink, 2000), increased scavenger abundance (Groenewold and Fonds, 2000), changed food web structures (Groenewold 2000, Hinz et al. 2017), changed size distributions (Van Kooten et al. 2015), and reduced abundances (Duineveld et al., 2007).

The effects on typical species as mentioned in the BD should be extended to the indicators included in the BISI for the areas Frisian Front and Central Oyster Grounds.

Q4. Footprint considerations

ToR: In the assessment of the effects of the bottom impacting gears, the foot print per hour fishing of the gears should be compared.

For a comparison of the footprint, reference is made to Eigaard (2015). Within each type of mobile bottom contacting gear, a wide range in configurations of individual fishing vessels is possible. Therefore, a more realistic comparison of footprint can only be made on the basis of realistic fishing effort data of the area.

To achieve this, it is relevant to also document the gear configurations

6.6 Is the selection of activities considered in cumulation complete?

Q1.

ToR: Do impact assessments that support the draft proposal for the Frisian Front and Oyster Grounds, include an assessment of the cumulative effects before they are related to characteristics, the specific environmental conditions and conservation objectives of the site?

Shipping, cables and pipelines, oil and gas extraction and oil pollution have been considered, beside fisheries, as human activities in the management zones. Cumulative effects of other activities were assumed to be low or absent.

In terms of impacted surface, fishery is currently the most important activity. The other listed activities have small 'footprints'. This may change in future if the area used by wind farms will expand. The foundations of hard substratum around the individual turbines are relatively small, but the total surface covered by wind farms (often with restriction zones for other use) is more substantial.

Although the relevant cumulative effects have been included, given the developments e.g. in offshore wind farms, the information in the BD needs an update with the most recent policy documents that exist for activities in these areas.

A description of current and planned activities is given in the Beleidsnota Noordzee 2016-2021.

Q2.

ToR: Have other plans and activities been included in an assessment of cumulative effects?

No other plans/activities are included in an assessment of cumulative effects. In the near future extraction of minerals and placement of windfarms may pose additional threats.

Q3.

ToR: Have 'external' activities taking place outside the borders of the management zones, sufficiently been taken into account in the assessment of the effects inside the site?

In the draft background document external activities outside the management zones have not been taken into account. External activities might lead to edge effects of the management zones, and as such diminish the effective surface area being protected.

6.7 Recommendations

Description of typical values and species

Both the Frisian Front and the Central Oyster Grounds are lacking the presence of hard substratum and the sessile epifauna that depends on this. The Frisian Front, situated at the southern edge of the Central Oyster Grounds, is the muddier (15-20% silt) of the two areas and is characterised by a high primary production. The bottom fauna consists of relatively few species, with high densities of certain species, whereas the deeper and less muddy (5-8% silt) Central Oyster Grounds have a lower density and higher species diversity of the benthic fauna. The characteristic benthic fauna includes long-lived molluscs, burrowing shrimps, tube worms and brittle stars. Especially the Frisian Front can, due to the seasonal high productivity, sustain high concentrations of pelagic fish that are the food for birds, e.g. *Uria aalge*, that are protected under the Birds' Directive in the Natura 2000 area Frisian Front.

It should be made clear in the Background Document which species list is used to assess the impacts, and on what criteria the list has been composed. Supported by the overview in Table 3.1, we recommend to revise Table 3 in the Background Document and add a clear(er) rationale for the applied indicator selection.

Available surveys

It appears that NIOZ conducted several surveys as part of their North Sea research program, and that not all of the survey data have been analysed or reported (pers. comm. Rob Witbaard). It is worthwhile to investigate if new relevant information can be drawn out of these survey-data. There is more but yet unpublished data from ongoing surveys (<https://www.wur.nl/en/project/Impacts-of-pulse-fishing-for-flatfish-on-the-ecosystem-.htm>).

Status of the Frisian Front and Central Oyster Grounds

The benthos communities in both areas show a disrupted state. In the Frisian Front a regime shift occurred. The population of the surface dwelling species *Amphiura* crashed, while the population of deep digging crustaceans (like *Callianassa*) increased impressively. To what extent the supposed regime shift as presented by Amaro (2005) is caused by bottom trawling remains unknown. It must, however, be acknowledged that community changes of this kind can also result from changing weather or climate patterns.

For the Oyster Grounds, the disappearance of the oyster beds (19th century) also led to a habitat modification, which may be irreversible because in the present situation it is unlikely that oyster recruitment can still take place.

We recommend that the BD updates the current state of the bottom ecosystem of the two areas.

Fisheries intensity in the Frisian Front and Central Oyster Grounds

Fishing intensity is high, especially in the productive Frisian Front. The fishery with beam trawl (TBB), otter board trawls (OTB) and paired bottom trawl (PTB) is carried out in the Frisian Front and Oyster Grounds areas, of which the TBB was prevalent in the period 2005-2011 and occurred especially in the Frisian Front. The category TBB includes also the new techniques such as pulse trawl and sum wing, that have replaced the traditional beam trawl with tickler chains to a large extent. The Dutch fleet also

operates seines (SSC, SDN) in the areas but to a lesser extent. The effort of the Dutch fishery is dominant in the Frisian Front and Oyster Grounds, but the landings are dominated by the Danish fleet (OTB).

Impact of bottom contacting fisheries on conservation objectives

Demersal fisheries impact conservation objectives on benthos via damage to typical species, its habitat, physical changes to the habitat, smothering/increased turbidity and removal of the species. We studied the impact for the relevant involved fishing gear types.

Demersal fishing gear on soft bottom substrates leads to removal of the top sediment layer, ploughing-raking-smoothing of the bottom surface, resuspension and sedimentation, potential consequences for nutrient exchange processes between bottom water, extra oxygen demand water column by resuspended sediments (organic matter). The damage after the first time the fishing gear interacts with the seafloor is the most impacting (Hiddink et al., 2006).

Especially species living in the upper layer of the sediment are sensitive for bottom contacting gear, e.g. long-lived bivalves, *Leptosynapta* and *Amphiura filiformis*. In order to assess the vulnerability of species we also need to take into account the life stage but when assessing the impacts of mobile bottom contacting fishing gear, the BD-document does not distinguish life stage of characteristic species.

Van Kooten et al., 2015 found that in particular, the trait modalities 'exoskeleton' and 'predator' are more abundant in fished areas, possibly representing a shift in community composition towards more mobile scavenger/predators and species which are protected against damage.

All demersal fishing gear has a surface impact (< 2 cm) on the seafloor. The impact of beam trawl is very high. Compared to beam trawl, pulse trawling can be less impacting but its effects are still surrounded by many questions and scientific uncertainties and studies are ongoing. Compared to beam trawl, seine fisheries (Danish, Scottish, fly-shoot) may at first sight appear less bottom disturbing, but the surface footprint is larger.

Cumulative effects

Cumulative effects are assumed to be minimal. All activities beside extraction of minerals have a low impact on fauna and abiota. Activities are local and restricted to a limited area (Slijkerman et al., 2013). External impact of activities outside the management areas have not been considered.

7 References

- Amaro, T.P.F., 2005. The Benthic shift of the Frisian Front (southern North Sea) ecosystem. PhD thesis, Wageningen University, Wageningen, The Netherlands.
- Anonymous, 2017. Draft background document. Joint recommendation sea bed protection Frisian Front and central Oyster Grounds draft, July 13, 2017. draft submission to the European Commission. 50pp
- Baars, M.A., G.C.A. Duineveld, F.C. van Duyl, A. de Gee, G.W. Kraay, MJF. Leopold, S. Oosterhuis, W. van Raaphorst & C. Westra, 1991. The ecology of the Frisian Front. Observations on a biologically enriched zone in the North Sea between the Southern Bight and the Oyster Ground. ICES C.M. 1991/L:25, Session Q.
- Baptist, M.J, R.S.A. van Bemmelen, M F. Leopold, H. Flores, B. Couperus, D. de Haan, S. Tribuhl, E. Dijkman. On the distribution of piscivorous seabirds and subsurface pelagic fish in the Frisian Front, the Netherlands. IMARES Report number C135/10.
- Bergman, M.J.N. and J. van Santbrink, 1994 A new benthos dredge (TRIPLE D) for quantitative sampling of infauna species of low abundance. Neth. J. Sea Res. 33, 129-133.
- Bergman M.J.N., J.W. van Santbrink, J. Buijs, J.A. Craeymeersch, G.J. Piet, A.D. Rijnsdorp, C. Laban & W. Zevenboom, 1998 The distribution of benthic macrofauna in the Dutch sector of the North Sea in relation to the micro distribution of trawling BEON report 98-2 96pp.
- Bergman, M.J.N., J.W. van Santbrink, 2000. Mortality in megafaunal benthic populations caused by trawl fisheries on the Dutch continental shelf in the North Sea in 1994. ICES J Mar Sci 57: 1321-1331.
- Budd, G.C. 2004. *Brissopsis lyrifera* Spiny mudlark. In Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Available from: <http://www.marlin.ac.uk/species/detail/1654>
- Buisman, F. C., N. T. Hintzen, K. G. Hamon, 2017. Overview of the international fishing activities on the Central Oyster Grounds and Frisian Front; Update with Dutch, British, Danish, German, Belgian, Swedish and French data for 2010-2015. Wageningen, Wageningen Economic Research, Memorandum 2017-078. 26 pp.; 4 fig.; 2 tab.; 9 ref.
- Bureau Waardenburg, 2016. Impact of demersal seine fisheries in the Natura 2000 area Dogger Bank. A review of literature and available data. Final report 15 March 2017.
- Capuzzo, E., D. Stephens, T. Silva, J. Barry, R.M. Forster, 2015. Decrease in water clarity of the southern and central North Sea during the 20th century. Global Change Biology 21: 2206-2214.
- Concalves, J.M.S., L. Bentes, R. Coelho, P. Monteiro, J. Ribeiro, C. Correia, P.G. Lino and K. Erzini, 2008 Non commercial invertebrate discards in an experimental trammel net fishery Fisheries management and ecology 15 199-210
- Couceiro, F., G.R. Fones, C. E. I. Thompson, P.J. Satham, D.B. Sivyer, R. Parker, B.A. Kelly-Gerreyen & C.I. Amos, 2013 Impact of resuspension of cohesive sediments at the Oystergrounds on nutrient exchange across the sediment water interface.pdf Biogeochemistry 113: 37-52

- Creutzberg, F. & H. Postma, 1979. An experimental approach to the distribution of mud in the Southern North Sea. *Neth. J. Sea Res.* 13: 99-116.
- Creutzberg, F., P. Wapenaar, G. Duineveld, N. Lopez Lopez, 1984. Distribution and density of the benthic fauna in the southern North Sea in relation to bottom characteristics and hydrographic conditions. *Rapp. P.-v. Réun. Cons. Int. Explor. Mer* 183: 101-110.
- De Gee, A., M.A. Baars, H.W. van der Veer, 1991. De ecologie van het Friese Front. Waarnemingen aan een biologisch-rijke zone in de Noordzee, gelegen tussen de Zuidelijke Bocht en de Oestergronden. NIOZ Rapport 1991-2.
- Deerenberg, C., L.R. Teal, D. Beare, J.T. van der Wal, 2010 Fimpas project preassessment of the impact of fisheries on the conservation objectives of Dutch marine protected areas _IMARES rapport C071 10 82pp
- Depestele, J., A. Ivanović, K. Degrendele, M. Esmaili, H. Polet, M. Roche, K. Summerbell, L.R. Teal, B. Vanelsander, F. G. O'Neill (2016). Measuring and assessing the physical impact of beam trawling. *ICES J. Mar. Sci.* 73: i15-i26.
<https://doi.org/10.1093/icesjms/fsv056>.
- Duineveld, C.A., M.J.N. Bergman, M.S.S. Lavaleye, 2007. Effects of an area closed to fisheries on the composition of the benthic fauna in the southern North Sea, *ICES Journal of Marine Science*, 64: 899-908.
- Eigaard, O. R., Marchal, P., Gislason, H., and Rijnsdorp, A. D. (2015). Technological Development and Fisheries Management. *Reviews in Fisheries Science and Aquaculture* 22: 156-174.
- Eigaard, O.R., F.Bastardie, M. Breen, G.E. Dinesen, N.T. Hintzen, P.Laffague, L.O. Mortensen, J.R. Nielsen, H.C. Nilsson, F.G.O'Neill, H. Polet, D.G. Reid, A. Sala, M. Skold, C. Smith, T.K. Sorensen, O. Tully, M. Zengin and A.D. Rijnsdorp, 2016. Estimating seabed pressure from demersal trawls and dredges based on gear design and dimensions *ICES J. Mar. Sci.* 73: 27-43
- Eigaard, O.R., F.Bastardie, M. Breen, G.E. Dinesen, N.T. Hintzen, P.Laffague, L.O. Mortensen, J.R. Nielsen, H.C. Nilsson, F.G.O'Neill, H. Polet, D.G. Reid, A. Sala, M. Skold, C. Smith, T.K. Sorensen, O. Tully, M. Zengin and A.D. Rijnsdorp, 2016b. A Correction to Estimating seabed pressure *ICES J. Mar. Sci.* 73: 5pp
- Greenwood, N., E.R. Parker, L. Fernand, D.B. Sivyver, K. Weston, S.J. Painting, S. Kröger, R.M. Forster, H.E. Lees, D.K. Mills, R.W.P.M. Laane (2010). Detection of low bottom water oxygen concentrations in the North Sea; implications for monitoring and assessment of ecosystem health. *Biogeosciences* 7: 1357-1373.
- Groenewold, S., 2000. The effects of beam trawl fishery on the food consumption of scavenging epibenthic invertebrates and demersal fish in the southern North Sea. Hamburg: Universität Hamburg.
- Groenewold, S., and Fonds, M., 2000. Effects on benthic scavengers of discards and damaged benthos produced by the beam-trawl fishery in the southern North Sea. *ICES Journal of Marine Science*, 57: 1395-1406

- Hiddink, J.G., S. Jennings, M.J. Kaiser, A.M. Quelros, D.E. Duplisea and G.J. Piet, 2006. Cumulative impacts of seabed trawl disturbance on benthic biomass, production and species richness in different habitats *Can j fish aquatic sci* 63: 721-736.
- Hill, J.M. 2005. *Callinassa subterranea* A burrowing mud shrimp. In Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Available from: <http://www.marlin.ac.uk/species/detail/1428>
- Hill, J.M. & Wilson, E. 2008. *Amphiura filiformis* A brittlestar. In Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Available from: <http://www.marlin.ac.uk/species/detail/1400>
- ICES, 2016. ICES-FishMap Sprat, 2016 (4-4-2016). <http://www.ices.dk/explore-us/projects/EU-RFP/Pages/ICES-FishMap.aspx>.
- ICES, 2017. Final Report of the Working Group on Electrical Trawling. WGELECTRA 2017 Report 17-19 January 2017. IJmuiden, the Netherlands. ICES CM 2017/SSGIEOM:11. 36 pp.
- Kaiser, M.J., J.S. Collier, S.J. Hall, S. Jennings, I.R. Poiner (2002). Modification of marine habitats by trawling activities: prognosis and solutions. *Fish and Fisheries* 3: 114-136.
- Kaiser, M.J., K.R. Clarke, H. Hinz, M.C.V. Austen, P.J. Somerfield, I. Karakassis (2006). Global analysis of response and recovery of benthic biota to fishing. *Mar. Ecol. Prog. Ser.* 311: 1-14.
- Kelleher, K. (2005). Discards in the world's marine fisheries. An update. FAO Fisheries Technical Paper. No. 470. Rome, FAO. 2005. 131p. Includes a CD-ROM.
- Lindeboom, H.J., R. Witbaard, O.G. Bos & H.W.G. Meesters, 2008. Gebiedsbescherming Noordzee. Werkdocument 114 WOT 45pp.
- Linnane A., B. Ball, B. Munday, B.V. Marlen, M. Bergman and R. Fonteyne. 2000. A review of potential techniques to reduce the environmental impact of demersal trawls. *Irish Fisheries Investigations (New Series)* 7:39.
- Lowe, J. A., Howard, T. P., Pardaens, A., Tinker, J., Holt, J., Wakelin, S., Milne, G., Leake, J., Wolf, J., Horsburgh, K., Reeder, T., Jenkins, G., Ridley, J., Dye, S., and Bradley, S. (2009). UK Climate Projections science report: Marine and coastal projections, Met Office Hadley Centre, Exeter, UK, 99, 2009.
- Lindeboom, H.J., R. Witbaard, O.G. Bos & H.W.G. Meesters, 2008. Gebiedsbescherming Noordzee. Werkdocument 114 WOT 45pp.
- Martín, J., P. Puig, A. Palanques, M. Ribó (2014). Trawling-induced daily sediment resuspension in the flank of a Mediterranean submarine canyon. *Deep Sea Research Part II: Topical Studies in Oceanography* 104: 174-183.
- McQuatters-Gollop, A., D.E. Raitsos, M. Edwards, Y. Pradham, L.D. Mee, S.J. Lavender, M.J. Attrill (2007). A long-term chlorophyll data set reveals a regime shift in North Sea phytoplankton biomass unconnected to nutrient trends. *Limnology and Oceanography*, 52, 635-648.

- Mengual, B., F. Cayocca, P. Le Hir, R. Draye, P. Laffargue, B. Vincent, T. Garlan (2016). Influence of bottom trawling on sediment resuspension in the "Grande Vasière" area (Bay of Biscay, France).
- Mensink, B.P., C.V. Fischer, G.C. Cadee, M. Fonds, C.C. Ten Hallers-Tjabbes & J.P. Boon, 2000. Shell damage and mortality in the common whelk *buccinum undatum* caused by beamtrawl fisheries .pdf Journal of Sea Research 43: 53-64.
- Ministerie van IenM, 2012; Mariene Strategie voor het Nederlandse deel van de Noordzee 2012-2020, Deel 1.
- Neumann, H., I. de Boois, I. Kröncke, H. Reiss, 2013. Climate change facilitated range expansion of the non-native angular crab *Goneplax rhomboides* into the North Sea. Mar. Ecol. Prog. Ser. 484: 143-153.
- Neumann, H., Diekmann, R., Kröncke, I., 2016. Functional composition of epifauna in the south-eastern North Sea in relation to habitat characteristics and fishing effort. Estuar. Coast. Shelf Sci. 169, 182e194.
- Neumann, H., R. Diekmann, K-C. Emeis, U. Kleeberg, A. Moll, I. Kröncke, 2017. Full-coverage spatial distribution of epibenthic communities in the south-eastern North Sea in relation to habitat characteristics and fishing effort. Marine Environmental Research 130: 1-11.
- Olsen, O.T., 1883. The piscatorial atlas of the North Sea, English and St. George's Channels, illustrating the fishing ports, boats, gear, species of fish (how, where, and when caught), and other information concerning fish and fisheries.
- O'Neill, F. G., A. Ivanović (2016). The physical impact of towed fishing gears on soft sediments. ICES Journal of Marine Science 73(Suppl. 1): i5-i14.
- OSPAR, 2009. Background document for ocean quahog *Arctica Islandica*. Biodiversity Series, OSPAR Commission, London, 1-19 pp. Available from http://qsr2010.ospar.org/media/assessments/Species/P00407_Ocean_quahog.pdf
- Paschen, M., U. Richter, W. Köpnick, 2000. Trawl Penetration in the Seabed (TRAPESE). Final Report Contract No. 96-006. University of Rostock, Rostock, Germany, 150 pp.
- Pauly, D., and M.L. Palomares, 2005. Fishing down the foodweb more pervasive than we thought.pdf Bulletin of Marine Science 76(2): 197-211.
- Polet, H. and J. Depestele, 2011. Impact assessment of the effect of a selected range of fishing gears in the North Sea ILVO Technisch Visserijonderzoek Report commissioned by Stichting Noordzee en WNF. 122 pp.
- Pusceddu, A., A. Gremare, K. Escoubeyrou, J.M. Amouroux, C. Fiordelmondo & R. Danavaro, 2005. Impact of natural storm and anthropogenic trawling sediment resuspension on particulate organic matter Continental Shelf Research 25: 2506-2520.
- Quirijns, F. W.J. Strietman, B. van Marlen, M. Rasenberg and S.R. Smith, 2015. Flatfish Pulse Fishing Research results and knowledge gaps II Imares WUR report C091/15: 39pp.
- Rijnsdorp, A.D., 2015. Flyshoot fishery in relation to sea floor protection of the Frisian front and Central Oyster ground areas.pdf

Rijnsdorp, A., D. de Haan, S. Smith & W.J. Strietman, 2016. Pulse fishing and its effects on the marine ecosystem and fisheries An update of the scientific knowledge Wageningen University & Research Report C117-16: 30pp.

Rosenberg, R., H. C. Nilsson, A. Gremare & J-M. Amouroux, 2003. Effects of demersal trawling on marine sedimentary habitats analysed by sediment profile imagery Journal of Experimental Marine Biology and Ecology: 285-286: 465-477.

Rumohr, H & T. Kujawski, 2000. Impact of trawl fishery on epifauna in the southern North Sea ICES J Mar Sci 57: 1389-1394.

Smaal, A.C., P. Kamermans, T.M. van der Have, M. Engelsma, H.J.W. Sas, 2015. Feasibility of Flat Oyster (*Ostrea edulis* L.) restoration in the Dutch part of the North Sea. IMARES Report C028/15.

Schwinghamer, P., D.C. Gordon, T.R. Rowell, J. Prena, D. McKeown, G. Sonnichsen & J.Y. Guigne, 1998. Effects of experimental otter trawling on surficial sediment properties of a sandy bottom ecosystem on the grand banks of new Foundland.pdf Conservation Biology 12(6): 1215-1225.

Slijkerman, D.M.E., O.G. Bos, J.T. van der Wal, J.E. Tamis & P. de Vries, 2013. Zeebodintegriteit en visserij op Friese Front en Centrale Oestergronden Imares Wageningen UR rapport C078/13: 100pp.

Sprong, I. B.R. Kuipers, H. Witte, 1990. Acoustic phenomena related to an enriched benthic zone in the North Sea. Journal of Plankton Research 12: 1251-1261.

STECF 2016 Scientific Technical and Economic Committee for Fisheries (STECF) (2016). The 2015 Annual Economic Report on the EU Fishing Fleet. Publications office of the EU Luxembourg:470.

Tamis, J.E. C.C. Karman, P. de Vries, R.G. Jak & C. Klok, 2011. Offshore olie en gasactiviteiten en Natura 2000 Inventarisatie van mogelijke gevolgen voor de instandhoudingsdoelen van de Noordzee Imares rapport C144/10.

Tillin, H.M., J.G. Hiddink, S. Jennings, M.J. Kaiser, 2006. Chronic bottom trawling alters the functional composition of benthic invertebrate communities on a sea-basin scale. Mar. Ecol. Prog. Ser. 318:31-45.

Turenhout, M.N.J., B.W. Zaalmink, W.J. Strietman & K.G. Hamon, 2016. Pulse fisheries in the Netherlands. WUR Report 2016-104: 36pp.

Van Duren, L.A., A. Gittenberger, A.C. Smaal, M. van Koningsveld, R. Osinga, J.A. Cado van der Leij, M.B. de Vries, 2016. Rijke riffen in de Noordzee. Verkenning naar het stimuleren van natuurlijke riffen en gebruik van kunstmatig hard substraat. Deltares Project 1221293-000, 2016.

Van Helmond, A.T.M. and H.J.M. van Overzee, 2010. Discard sampling of the Dutch beam trawl fleet in 2008. CVO report 10.001 45pp.

Van Kooten, T., D. van Denderen, S. Glorius, J.T. van der Wal, R. Witbaard, P. Ruurdij, M. Lavaleye, D. Slijkerman, 2015. An exploratory analysis of environmental conditions and trawling on species richness and benthic ecosystem structure in the Frisian Front and Central Oyster Grounds. IMARES Report C037/15.

- Van Marlen et al., 2010. Development of fishing gears with reduced effects on the environment (DEGREE). Final Publishable activity report.
- Vasconcelos, P., A. Morgado-André, C. Morgado-André, M.B. Gaspar, 2011. Shell strength and fishing damage to the smooth clam (*Callista chione*): simulating impacts caused by bivalve dredging. ICES J. Mar. Sci. 68: 32-42.
- Weston, K., Fernand, L., Nicholls, J., Marca-Bell, A., Mills, D., Sivyer, D., Trimmer, M., 2008. Sedimentary and water column processes in the Oyster Grounds: A potentially hypoxic region of the North Sea. Marine Environmental Research, doi: 10.1016/j.marenvres.2007.11.002.
- Wijnhoven, S., Duineveld, G., Lavaleye, M., Craeymeersch, J., Troost, K., van Asch, M. (2013). Kaderrichtlijn Marien indicatoren Noordzee. Naar een uitgebalanceerde selectie van indicatorsoorten ter evaluatie van habitats en gebieden en scenario's hoe die te monitoren. Monitor Taskforce Publication Series 2013-02. NIOZ, Den Hoorn & Yerseke, 105 pp.
- Wijnhoven, S., Bos, O.G., 2017. Benthische Indicator Soorten Index (BISI): Ontwikkelingsproces en beschrijving van de Nationale Benthos Indicator Noordzee inclusief protocol voor toepassing. Ecoauthor Report Series 2017 - 02, Heinkensand, The Netherlands.
- Witbaard, R., G.C.A. Duineveld, T. Amaro, M.J.N. Berman, 2005. Growth trends in three bivalve species indicate climate forcing on the benthic ecosystem in the southeastern North Sea. Clim Res 30: 29-38.
- Witbaard, R., M.S.S. Lavaleye, G.C.A. Duineveld, M.J.N. Bergman, 2013. Atlas of the Megabenthos (incl. small fish) on the Dutch Continental Shelf of the North Sea.
- Witbaard, R. & R. Klein, 1994. Long-term trends on the effects of the southern North Sea beamtrawl fishery on the bivalve mollusc *Arctica islandica* Ices J Mar Sci 51(1): 99-105.
- Witbaard, R., G. Duineveld, M. Bergman, E. van Weerlee, W. Lentingh & L. Boom, 2013. Cruise report-64PE376-NIOZ North Sea Monitoring Klaverbank NIOZ Cruise report 64PE376.: 15pp
- Witbaard, R. & M.J.N. Bergman, 2003. The distribution and Population structure of the bivalve *Arctica islandica* in the North Sea What possible factors are involved_JSR-50_11-25 JSR-50 11-25.

Annex 1. List of consulted literature on impact of mobile bottom contacting fishing gear on the status of the seafloor and benthic species.

Author	Year	Title	Journal
Abstract		Hope-for-the-European-flat-oyster-Flyer-201706	
Abstract		Jennings et al Fisheries research	
Almeida et al	2005	The effects of Area closures on Georges bank	
Amaro et al	2002	Growth variation in the bivalve <i>Mya truncata</i> a tool to trace changes in the Frisian Front macrofauna	Helg Mar Res-57-132-138
Amaro et al	2007	The consequences of changes in abundance of <i>Callianassa</i> and amphipods on sediment erosion at the Frisian Front	Hydrobiologia 589-273-285
Baars	2002	Plume and Blume Watermass patterns and nutrient dynamics in the central part of the southern bight	NIZ annual report 2002
Baars	2010	Het Friese Front de groen container van de zuidelijke Noordzee	Dijk en Duin 26 28 (3)
Baars et al	1991	The ecology of the Frisian Front	ICS CM 1991 L25
Baptist et al	2007	On the distribution of piscivorous seabirds and subsurface pelagic fish in the Frisian Front	IMARES report C135 10
Baptist et al	2010	On the distribution of piscivorous seabirds	
Barretta et al	2008	Description of the long term 1991-2005 temporal and spatial distribution of phytoplankton carbon biomass in the dutch north Sea	
Belunze et al	2011	Sediment dynamics in relation to sediment trend monitoring	ICES cooperative research report 308
Bergman and Hup	1992	Direct effects of beamtrawling on macrofauna in a sandy sediment in the southern North Sea	ICES J. Mar. Sci. 49: 5-11
Bergman and Santbrink	1994	Mortality in megafaunal benthic populations caused by trawling	
Bergman and Santbrink	2000	Mortality in megafaunal benthic populations caused by trawl fisheries on the Dutch continental shelf in the North Sea in 1994	ICES J. Mar. Sci 57: 1321-1331
Bergman et al	1990	Direct effects of beamtrawl fishing on benthic fauna in the north sea	IC CM mini: 20 pp
Bergman et al	1998	The distribution of benthic macrofauna in the Dutch sector of the North Sea in relation to the micro distribution of trawling	BEON report 98-2: 96 pp
Birchough et al	2012	Combining bioturbation and redox metrics Potential tools for assessing seabed function	Ecological indicators 12-8-16
Birchough et al	2013	SPI-ing the seafloor characterising benthic systems with traditional and in situ observations	Biogeochemistry 113 105 117
Blaber et al	2000	Effects of fishing on the structure and functioning of estuarine and nearshore ecosystems	ICES J. Mar Sci 57: 590-602
Blauw et al	2011	Temporal variability of chlorophyll-a in North Sea coastal waters	CES CM-B-17: 5pp
Bolam et al	2014	Sensitivity of macrobenthic secondary production to trawling in the English sector of the Greater North Sea A biological trait approach	JSR 85 162-177

Boon & Duineveld	1996	Phytopigments and fatty acids as molecular markers for quality of near bottom particulate organic matter in the north Saa	JSR-35-4-279-291
Boon & Duineveld	1998	Chlorophyll a as a marker for bioturbation and flux in southern and central North Sea sediments	MEPS-162-33-43
Boon & Duineveld	2012	Phytopigments and fatty acids in the gut of the deposit feeding heart urchin <i>Echinocardium</i>	JSR-67-77-84
Boon et al	1998	Relationships between benthic activity and the annual phytopigment cycle in near bottom water and sediment in the southern North Sea	ECSS 46: 1-13
Boon et al	1999	Benthic organic matter supply and metabolism at depositional and non depositional areas in the north Sea	ECSS 49-747-761
Brylinsky et al	1994	Impacts of Flounder trawls on the intertidal habitat and community of the Minas Basin Bay of Fundy	Can. J. Fish Aquat. Sci 51: 650-661
Buisman et al		Overview of the international fishing activities on the central oystergronds and Frisian Front	Wageningen EconRes memorandum 2017-78
Callaway et al	2007	A century of north sea epibenthos and trawling-comparison between 1902-1912 1982-1985 and 2000	MEPS 346"27-43
Capuzzo et al.	2015	Decrease in water clarity of the southern and central North Sea during the 20th century	Global Change Biology 21: 2206-2214
Chambers et al		Subsurface flows in the seasonally stratified central North Sea.	Poster; www.Cefas.co.uk
Chicharo et al	2002	Reburial time and indirect mortality of <i>Spisula solida</i> clams caused by dredging	Fisheries res 59:247-257
Clamer et al	1990	The distribution of heavy metals and polycyclic aromatic hydrocarbons in the sediments of the oyster grounds.	Neth. J. Sea Res 26(1): 83-87
Couceiro et al	2013	Impact of resuspension of cohesive sediments at the Oystergronds on nutrient exchange across the sediment water interface	Biogeochemistry 113:37-52
Craeymeersch et al	1997	Atlas of North Sea Benthic Fauna	ICES cooperative Research report 218
Craeymeersch et al	2000	Distribution of macrofauna in relation to the microdistribution of trawling effort	
Cunningham et al	2015	A review of the recovery potential and influencing factors of relevance to the management of habitats and species within MPAs	Scottish Natural Heritage report 771: 144pp
Dauwe et al	1998	Community structure and bioturbation potential of macrofauna at four North Sea stations with contrasting food supply	MEPS-173-67-83
Dayton et al	1995	Environmental effects of marine fishing	Aquat. Cons Mar.and FreshwEcosystems 5: 205-232
De Haan et al	2016	Pulse trawl fishing characteristics of the electrical stimulation and the effect on behavior and injuries	ICES J. Mar. Sci 73(6) 1557-1569.
De Nooijer et al	2008	The ecology of benthic forminifera across the Frisian Front southern North Sea	ECSS-78-715-726
Depestele et al	2007	Is there a way out for the beam trawler fleet with rising fuel prices	ICES CM 2007/M:06 13pp
Depestele et al	2014	Short term survival of discards	Fisheries Res 154: 82-92
Depestele et al	2011	An overview of sea trials with the alternative beam trawl	Ilvo rapport 104pp

De Vries et al	2015	Fisheries displacement effects of managed areas-a case study of De Voordelta	Imares rapport BO-11-018-02-005 27pp
Dewicke et al	2002	Evidence for an enriched hyperbenthic fauna in the Frisian Front	JSR-47-121-139
Diamond and Beukers-Stewart	2011	Fisheries discards in the north sea: Waste of resources or a necessary evil?	Reviews in Fisheries Sci 19(3) 231-245.
Diesing et al	2013	A proposed method for assessing the extent of the seabed significantly affected by demersal fishing in the greater north sea	ICES J. Mar Sci. 70(6) 1085-1096
Dinensen & Morton	2014	review of the functional morphology biology and perturbation impacts on the boreal habitat forming horse mussel <i>Modiolus modiolus</i> .	Mar. Biol. Res. 10(9): 845-870
Doornbal en Van Heteren	-	Bathymetric range map of the Dutch Continental Shelf (NCP)	emodnet-seabedhabitats-eu
Dottinga & Trouwborst	2009	The Netherlands and the designation of marine protected areas in the North Sea	Utrecht Law Review 5(10): 21-30
Dounas	2006	A new apparatus for the direct measurement of nutrient fluxes caused by fishing	J. Exp Mar Bioland Ecol. 339. 251-259
Duineveld & Boon	2001	Shortterm variations in fluxes and composition of seston in near bottom traps in the southern North Sea	Helgol Mar Res-56-140-148
Duineveld et al	2007	Effects of an area closed to fisheries on the composition of the benthic fauna in the southern North Sea.	ICES J. Mar. Sci. 64:899-908
Eisma et al	1979	Sea-floor morphology and recent sediment movement in the North Sea	The Quaternary History of the North Sea 217-231.
Eleveld et al	2008	seasonal variations remotely sensed turbidity North Sea	ECSS 80: 103-113
Ens et al	2007	International comparison of fisheries management with respect to nature conservation 118pp	WOT rapport 42 122pp
Fanelli et al	2010	Trophodynamic effects of trawling on the feeding ecology of pandorra, <i>Pagellus erythrinus</i> , off the northern Sicily coast.	Mar, Fresh. Res. 61: 408-417.
Foden et al	2011	Human pressures on UK seabed habitats a cumulative impact assessment	MEPS 428: 33-47.
Frid et al	2000	Long-term changes in the benthic communities on North Sea fishing grounds.	ICES J. Mar. Sci 57: 1303-1309
Friedrich et al	1990	Sedimentologische auswirkngen der grundfisherei in der Kieler bucht	Meyniana 42: 123-151
Friedrich et al	2016	Long term impact of bottom trawling on pelagic-benthic coupling in the southern North Sea (German Bight)	Abstract EGU2016-15791
Garth et al	1996	Amount of discards by commercial fisheries and their significance as food for seabirds in the North Sea	MEPS 136: 1-11
Geelhoed et al	2014	Marine mammals surveys dutch waters in 2013	BO 11-011-02004
Gehlen et al	1995	Spatial and temporal variability of benthic silica fluxes in the south eastern North Sea	Cont Shelf Res 15-1301675-1696
Gilbert et al	2015	Visions for the North Sea-The societal dilemma behind specifying good environmental status	Ambio 44: 142-153.
Gilkinson et al	1998	Impacts of trawl door scouring on infaunal bivalves-results of physical drawl door model dens sand interaction	J. Exp Mar Biol Ecol 224: 291-312
Goni	1998	Ecosystem effects of marine fisheries an overview	Ocean and Coastal Management 40: 37-64

Gordon et al	2006	A review of Maritimes regions research on the effects of mobile fishing gear on benthic habitat and communities	Canadian Science Advisory Secretariat Research Document 2006/056: 45pp
Grabowski and Peterson	-	Restoring oyster reefs to recover ecosystem services	in: Ecosystem engineers
Greenwood et al	2010	Detection of low bottom water oxygen concentrations in the North Sea-implications for monitoring and assessment	Biogeosciences 7: 1357-1373.
Groenewold and Fonds	2000	Effects on benthic scavengers of discards and damaged benthos produced by the beam trawl fishery in the southern North Sea	ICES J. Mar. Sci 57: 1395-1406
Gronholz et al	2017	Investigating the effects of a summer storm on the North Sea Stratification using a regional coupled ocean atmosphere model	Ocean dynamics 67: 211-235
Groot	1984	The impact of bottom trawling on benthic fauna of the North Sea	Ocean Management 9; 177-190
Guillon et al	2017	A seasonal study of particulate organic matter composition and quality along an offshore transect in the southern north sea	ECSS 188-1-11
Haas et al	1997	Recent sedimentation and organic carbon burial in a shelf sea-the North Sea	Marine Geology 144: 131-146
Hamon et al	2013	Fishing activities at the Frisian Front and the Cleaverbank. Historic developments and effects of management.	Lei memorandum 13050: 69pp
Herfort et al	2007	Variations in spatial and temporal distribution of archaea in the North sea in relation to environmental variables	FEMS Microbiol Ecol 62: 242-257
Hiddink et al	2006	Indicators of ecological impact of bottom-trawl disturbance on seabed communities	Ecosystems 9: 1190-1199
Hiddink et al	2007	predicting the relative ecological impacts of disturbance on habitats with different sensitivities	J. Applied Ecol. 44: 405-413
Hintz et al	2017	Stable isotopes reveal the effect of trawl fisheries on the diet of commercially exploited species	Nature Scientific reports 7: 6334. DOI:10.1038/S4158-017-06379-6
Hinz et al	2009	Trawl disturbance on benthic communities chronic effects and experimental predictions of chronic ottertrawl fishing	Ecological applications 19(3): 761-773
Hondeveld et al	1994	Temporal and spatial variations in heterotrophic nanoflagellate abundance in North Sea sediments	MEPS 109:235-243
Jackson	2001	What was natural in the coastal oceans	PNAS-98-10-5411-5418
Jennings	2001	Patterns and prediction of population recovery in marine reserves	Reviews in Fish Biology and Fisheries 10: 209-231
Jennings et al	2002	Effects of chronic trawling disturbance on the production of infaunal communities	MEPS 243: 251-260
Johnson	2002	A review of national and international literature on the effects of fishing on benthic habitats	NOAA Technical memorandum NMFS-F/SPO-57: 77pp
Jones	1992	Environmental impact of trawling on the seabed A review	New Zealand J. Mar Fresh Res 26(10): 59-67
Kaiser et al	1999	Fishing effects in northeast Atlantic shelf seas: patterns in fishing effort, diversity and community structure VII. The effects of trawling disturbance on the fauna associated with the tubeheads of serpulid worms.	Fisheries Research 40: 195-205
Kaiser et al	2000	Chronic fishing disturbance has changed shelf sea benthic community structure.	J. Anim. Ecol. 69: 494-503
Kenchington et al	2007	Multi-decadal changes in the megabenthos of the Bay of Fundy: The effects of fishing.	J. Sea Res58: 220-240.

Klamer et al	2005	A chemical and toxicological profile of Dutch North Sea surface sediments	Chemosphere 58: 1579-1587
Kumar and Deepthi	2006	Trawling and by-catch implication on marine ecosystem	Current science 90 7 922-931
Kunitzer et al	1992	Benthic infauna of the North Sea	ICES J mar. Sci 49: 127-143.
Kurten et al	2013	Trophodynamics and functional feeding groups of North Sea faun:a-a combined stable isotope and fatty acid approach.	Biogeochemistry: 113: 189-212.
Leeuwen et al	2015	Stratified and non stratified areas in the North Sea: Long term variability and biological and policy implicacations.	J. Geophysical Res. : Oceans DOI: 10,1002.2014HCO10485
Lindeboom	2006	Impacts of bottom trawling on habitats in European Seas. In: Krause et al, Marine Nature conservation in Europe.	Marine Nature Conservation in Europe 2006. Stralsund, Germany. Conf. proceedings 279pp
Lindeboom & De Groot	1998	Impact-II the effects of different types of fisheries on the North Sea and Irish Sea Benthic Ecosystems	NIOZ Rport 1998-1/RiVo-DLO report C003/98: 412 pp.
Lindeboom et al	2005	Areas with special ecological values on the Dutch continental Shelf	RIKZ-ALTERRA report 2005.008. Alterra report nr 1203.
Lindeboom et al	2008	Gebiedsbescherming Noordzee.	Werkdocument 114 WOT natuur en milieu 45 pp
Linnane et al	2000	Overview of the physical and biological effects of bottom trawling I: A review of potential techniques to reduce the environmental impact of demersal trawls.	Irish Fish Invest No.7: 43pp
Lock et al	2011	Did global warming and alien invasions affect surfzone hyper benthic communities on sandy beaches in Belgium beaches	Hydrobiologica 664: 173-181
Lohse et al	1996	Oxygen pore water profiles in continental shelf sediments of the North Sea turbulent versus molecular diffusion	MEPS-145: 63-75.
Lohse et al	1996	Denitrification rates as measured by the isotope pairing method shelf sediments of the North Sea	MEPS 132: 169-179.
Lotze et al	2007	Rise and fall of fishing and marine resource use in the wadden sea southern North Sea	Fisheries-Research 87: 208-218
MacDonald et al	1996	Disturbance of benthic species by fishing activities a sensitivity index.	Aquat. Cons. Mar. Fresh Ecosystems 6: 257-268.
MacKenzie et al	1997	The history present condition and the future of molluscan fisheries of North Central America And Europe	NOAA Technical Report NMFS 129. 248 pp
Marlen et al	2014	Catch comparson of flatfish pulse trawls and tickler chain beamtrawl	Fisheries Res. 151: 57-69.
Martin et al	2014	commercial bottom trawling as driver of sediment dynamics.	Deep Sea Res. II 104: 174-183.
McQuatters-Gollop et al	2007	A long-term chlorophyll data set reveals regime shift in North Sea phytoplankton biomass unconnecteed to nutrient trends	Limnol. Oceanogr. 52(2): 635-648
McShane et al	1999	Trophic consequences of prawn trawling.	Australian Society for Fish Biology 106-112.
Megens et al	2001	Temporal variations in 13C en 14C concentrations in particulate organic matter from the southern North Sea	Geochimica et Cosmochimica Acta 65(17) 2899-2911.
Meire et al	2013	Impact of global change on coastal oxygen dynamics and risk of hypoxia	Biogeosciences 10: 2633-2653.
Messieh et al	1990	The effects of trawling dredging and ocean dumping on the eastern canadian continental shelf sea bed	Continental Shelf Res. 11(8) 1237-1263.

Moodly & Van Weering	1993	Foraminiferal record of the holocene development of the marine environment in the southern North Sea	JSR 31 1 -43-52
Neuman et al	2013	Benthos and demersal fish habitats in the German Exclusive economic zon of the North Sea	Helgoland mar. Res 67: 445-459.
Neuman et al	2016	Functional composition of epifauna in the south-eastern North Sea in relation to fishing	ECSS 169-194
Neuman et al	2017	Full coverage spatial distribution of epibenthic communities in the south eastern North Sea in relation to habitat characteristics and fishing effort	Mar Env Res-13
Neumann et al	2013	Climate change facilitated range expansion of the non-native angular crab <i>Goneplax</i>	MEPS 484: 143-153.
Norkko et al	2013	Size matters implications of the loss of large individuals for ecosystem function	Scientific reports 3 2646. DOI: 10.1038/srep02646.
Norse and Watling	1999	Impacts of mobile fishing gear. The biodiversity perspective.	Am. Fish Soc Symp 22: 31-40.
Olgard et al	2008	Effects of bottom trawling on ecosystem functioning	JEMBE 366: 123-133
ONeill and Summerbell	2011	The mobilisation of sediment by demersal otter trawls	Mar Poll Bull-62-1088-1097
ONeill et al	2013	The mobilisation of sediment and benthic infauna by scallop dredges.	Mar Env Res 90 104-112
Oostenbrugge et al	2013	Fishing activities on the central Oyster Grounds 2006-2011.	LEI memorandum 13-049: 45pp.
Oostenbrugge et al	2015	Effects of seabed protection on the Frisian Front and Central Oyster Grounds A cost benefit analyses.	LEI report 2015-145: 170pp
Oostenbrugge et al	2016	Costs of the final proposal for seabed protection on the Frisian Front and Central Oyster Grounds for the Dutch fishing sector	Addendum to LEI rapport 2015-145. Memorandum 2016-117: 32pp.
Osinga et al	1997	Benthic mineralization rates at two location in the southern North Sea	Oceanographic lieterature review 44(8)
Ottosson	2008	By-catches of non commercial invertebrate taxa in Skagerak and Katttegat by ottertrawling	Krisinebergs Marina Forskingsstation: publication-428: 67pp.
Painting and Forster	2013	Marine ecosystem connections-essential indicators of healthy, productive and biologically diverse seas	Biogeochemistry 113-1-7
Kurten et al	2013	Tracking seasonal changes in North sea zooplankton trophic dynamics using stable isotopes.	Biogeochemistry 113: 167-187
Painting et al	2010	Marine ecosystems connections essential indicators of healthy productive and biologically diverse seas	CEFAS Final Fieldwork Report 2010 6 12 Su
Painting et al	2013	Development of indicators of ecosystem functioning in a temperate shelf sea- a combined field work and modelling approach	Biogeochemistry 113: 237-257.
Piet et al	2000	A quantitative evaluation of the impact of beam trawling on benthic fauna in the southern North Sea	ICES Mar Sci 57 1332-1339
Piet et al	2005	A method to quantify the trawl fisheries induced mortality of benthos and fish	RIVO reprot c087/05: 58pp.
Pietrzak et al	2011	Mechanisms controlling the intra annual mesoscale variability of SST and SPM in the southern North Sea.	Cont. Shelf. Res. 31: 594-610.

Polet & Depestele	2011	Impact assessment of the effect of a selected range of fishing gears in the North Sea.	Report commissioned by Stichting Noordzee en WNF. ILVO technisch visserij onderzoek: 122pp..
Pommer et al	2016	Impact and distribution of bottom trawl fishing on mud-bottoms communities in the Kattegat	MEPS 548: 47-60.
Postma & Rommets	1984	Variations of particulate organic carbon in the central north sea	Neth. J. Sea Res. 18 (1/2) 31-50
Pranovi et al	2001	Discard analysis and damage to non target species in the "rapido" trawl fishery	Mar. Biol. 139 863-875.
Provoost et al	2013	Modelling benthic oxygen consumption and benthic pelagic coupling at a shallow station in the southern North Sea.	ECSS-120:1-11
Puls et al	1997	Suspended particulate matter in the southern North Sea: Application of a numerical model to external NERC North Sea project Data interpretation.	Deutsches Hydrographisch Zeitschrift-49:(2/3): 307-327
Quan et al	2013	Habitat values for artificial oyster reefs compared with natural shallow water habitats in Changjiang river estuary	Chin.J.Ocean.Limn 31-5-957-969.
Queste et al	2013	Spatial extent and historical context of North Sea oxygen depletion in August 2010	Biogeochemistry 113: 53-68.
Raaphorst et al	1998	Tidal resuspension and deposition of particulate matter in the Oyster Grounds, North Sea	J. Mar. Res. 56: 257-291.
Ragnarson & Lindgarth	2009	Testing hypotheses about temporary and persistent effects of otter trawling on infauna: changes in diversity rather than abundance..	MEPS 385: 51-64.
Ramsay et al	2000	Damage autotomy and arm regeneration in starfish caught by towed demersal fishing gears.	Mar. Biol. 138: 527-536.
Rees & Eleftheriou	1989	North Sea Benthos-A review of field investigations into the biological effects of mans activities	J. Cons. int. Explor. Mer. 45: 284-305.
Reiss et al	2009	Effects of fishing disturbance on benthic communities and secondary production within an intensively fished area	MEPS 394: 201-213.
Reiss et al	2010	Spatial patterns of infauna epifauna and demersal fish communities in the North Sea	ICES J. Mar. Sci. 67 : 278-293.
Rijnsdorp	2015	Flyshoot fishery in relation to sea floor protection of the Frisian front and Central Oyster ground areas	Imares report C065/15. 23pp.
Rijnsdorp et al	2008	The arms race between fishers	J. Sea Res. 60: 126-138.
Rijnsdorp et al	2016	Pulse fishing and its effects on the marine ecosystem and fisheries. An update of the scientific knowledge.	Wageningen University & Research Report C117/16: 30pp.
Robinson and Frid	2008	Historical marine ecology examining the role of fisheries in changes in North Sea benthos	Ambio:37:(5) 362-372.
Rumohr & Krost	1991	Experimental evidence of damage to benthos by bottom trawling with special reference to <i>Arctica islandica</i>	Meeresforsch 33: 340-345.
Sas et al	2016	Shellfish reef restoration pilots Voordelta The Netherlands	Annual report 2016 " The Voordelta Shelfish reef restoration project. 45pp.
Schipper et al	2008	Cultivation of the heart urchin and validation of its use in marine toxicity testing	J. Exp.Mar.Biol.Ecol 364: 11-18
Schroot et al	2005	Surface and subsurface expressions of gas seepage to the seabed-examples for the southern North sea	Mar Petr Geol 22-499-515

Schuckel et al	2017	Are species rich gravel, coarse sand and shell layers within the natura 2000 site Sylt outer reef sensitive to seine fishing	Bioconsult report 11pp.
Schuttenhelm	1980	The superficial Geology of the dutch sector of the North Sea	Marine geology 34-27-37
Simpson and Watling	2006	An investigation of the cumulative impacts of shrimp trawling on mud bottom fishing grounds in the gulf of Maine: effects on habitat and macrofauna community structure	ICES J. Mar. Sci. 63-1616-1630.
Slomp et al	1996	Iron and Manganese cycling in different sedimentary environments on the North Sea continental margin	CSR-17-9-1083-1117
Soetaert et al	2016	Reducing bycatch in beam trawls and electrotrawls with (electrified) benthos release panels.	ICES J. Mar. Sci. doi:10.1093/icesjms/fsw096.
Sprong et al	1990	Acoustic phenomena related to an enriched benthic zone in the North Sea	J. Plankton Res. 12(6) 1251-1261.
Stamhuis et al	1997	Burrow architecture and turbative activity of the thalassinid shrimp <i>Callinassa subterranea</i> from the central North Sea	MEPS-151: 155-163
Stanev et al	2009	Bed shear stress in the southern North Sea as an important driver for suspended sediment dynamics	Ocean Dynamics-59-183-194
Stoeck et al	2002	Phospholipid fatty acid profiles at depositional and non depositional sites in the North Sea	MEPS-241-57-70
Tempelman et al	2013	De molkreeften <i>Upogebia deltaura</i> en <i>U. stellata</i> en geassocieerde soorten in de Noordzee	Nederlandse Faunistische mededelingen: 41: 15-29.
Thiel et al	2011	Spatio temporal distribution of floating objects southern north sea	JSR-65-368-379
Thompson et al	2011	In situ flume measurements of resuspension in the North Sea	ECSS 94: 77-88.
Tijssen & Wetsteyn	1984	Hydrographic observations near a subsurface drifter in the oyster ground North Sea	Neth. J. Sea Res. 18(1/2): 1-12.
Tijssen and Wetsteyn	1984	Diurnal pattern seasonal change and variability of oxygen in the water column of the oysterground in Spring summer 1981	Neth. J. Sea Res. 18(1/2): 13-30.
Tolley et al	2005	The role of Oysters in habitat use of Oyster reefs resident fishes and decapod crustaceans	
Trimmer et al	2005	Impact of long term benthic trawl disturbance on sediment sorting and biogeochemistry in the southern North Sea	MEPS 298: 79-94.
Turner et al	1999	Fishing impacts and the degradation or loss of habitat structure.	Fisheries Management and Ecology 6: 401-420.
Tyler-Walters et al	2009	A method to assess the sensitivity of sedimentary communiti to fishing activities.	Aquat. Cons.Mar.Fresh Ecosystems 19: 285-300.
Van den Brink	2010	Biodiversity on artificial oysterreefs	
Van Denderen et al	2014	Habitat specific effects of fishing disturbance on benthic species richness in marine soft sediments	Ecosystems 17: 1216-1226
Van der Zee & Raaphorst	2004	Manganese reactivity in North Sea sediments	JSR-52-73-85
Van der Zee et al	2003	Manganese diageneses in temporal and permanent depositional areas of the North Sea	CSR-23-625-646
Van Kooten et al	2015	An explanatory analyses and trawling on species richness and benthic ecosystem structure at the Frisian Front and central Oystergrounds	Imares report c03715

Van Nes et al	1997	Possible mechanisms for a marine benthic regime shift in the North Sea	MEPS-330-39-47
Van Alphen	1990	A mud balance for Belgian dutch coastal waters between 1969-1986	Neth. J. Sea Res. 25(1/2) 19-30.
Van Denderen et al	2015	Similar effects of bottom trawling and natural disturbance on composition and function of benthic communities across habitats	MEPS: 31-43
Van der Molen	2002	The influence of tides wind and waves on the net sand transport in the North Sea	Cont. Shelf. Res. 2739-2762.
Van der Molen et al	2013	Modelling marine ecosystem response to climate change and trawling in the North Sea	Biogeochemistry 113: 213-236.
Van der Molen et al	2017	A 3D spm model for biogeochemical modelling with application to the northwest european continental shelf	JSR 127-63-81
Van Duyl et al	1992	Mesocosm experiments mimicking seasonal developments of microbial variables in North Sea sediments	Hydrobiologica 235-236-267-281
Van Duyl et al	1997	Short term variability in pelagic benthic exchange of phytopigments and their relations to benthic bacterial variables.	Aquatic Microbial Ecology 13: 47-61.
Van Haren et al	1997	The integrated North Sea Programme	Operational Oceanography in: The challenge for european co-operation. eds. by Stel et al.: 529-538
Van Marlen et al	2006	Performance of pulse trawling compared to conventional beam trawling	RIVO report C014/06: 60pp.
Van Marlen et al	2008	Study of the effect of a by catch reduction panel in a twin trawl on reducing plaice discards.	Imares report C106-08.
Vorberg	2000	Effects of shrimp fisheries on reefs of Sabellaria spinulosa (Polychaeta)	ICES J. Mar. Sci. 57: 1416-1420.
Weaver	2008	Environmental Impacts of bottom trawling suspended solids generation.A review of the impacts of bottom trawling re-suspension of sediments on the environment.	A report for the united anglers of southern California. 51pp.
Weston et al	2008	Sedimentary and water column processes in the Oyster Grounds: A potentially hypoxic region of the North Sea.	Mar Envir Res.65: 235-249.
Widicombe et al	2004	Importance of bioturbators for biodiversity maintenance: indirect effects of fishing disturbance	MEPS: 275:1-10.
Wiesner et al	1990	Organic facies of surface sediments in the North Sea	Org. Geochem. 15(4): 419-432.
Wijnhoven & Bos	2017	Benthos-Indicator-Noordzee (BIS). Ontwikkelingsproces en beschrijving van de Nationale Benthos Indicator Noordzee inclusief protocol voor toepassing.	ECOauthor report 2017-02 67pp.
Witbaard et al	1989	Some aspects of the biology and ecology of the burrowing shrimp Callianassa from the southern North Sea	Sarsia 74 209-219
Witbaard et al	2005	Growth trends in three species of bivalves point to climate forcing of Frisian Front	Climate Research 30: 29-38.
Zevenboom et al	1991	Exceptional algal blooms in Dutch North Sea waters	Wat.Sci.Tech 24(10):-251-260

NIOZ Royal Netherlands Institute for Sea Research is an institute of The Netherlands Organization for Scientific Research (NWO-I), since 2016 in cooperation with Utrecht University (UU).

NIOZ Texel
Landsdiep 4
1797 SZ 't Horntje, Texel

Postbox 59
1790 AB Den Burg, Texel
Nederland
Telephone: +31(0)222 - 369300
Fax: +31(0)222 - 319674

NIOZ Yerseke
Korringaweg 7
4401 NT Yerseke

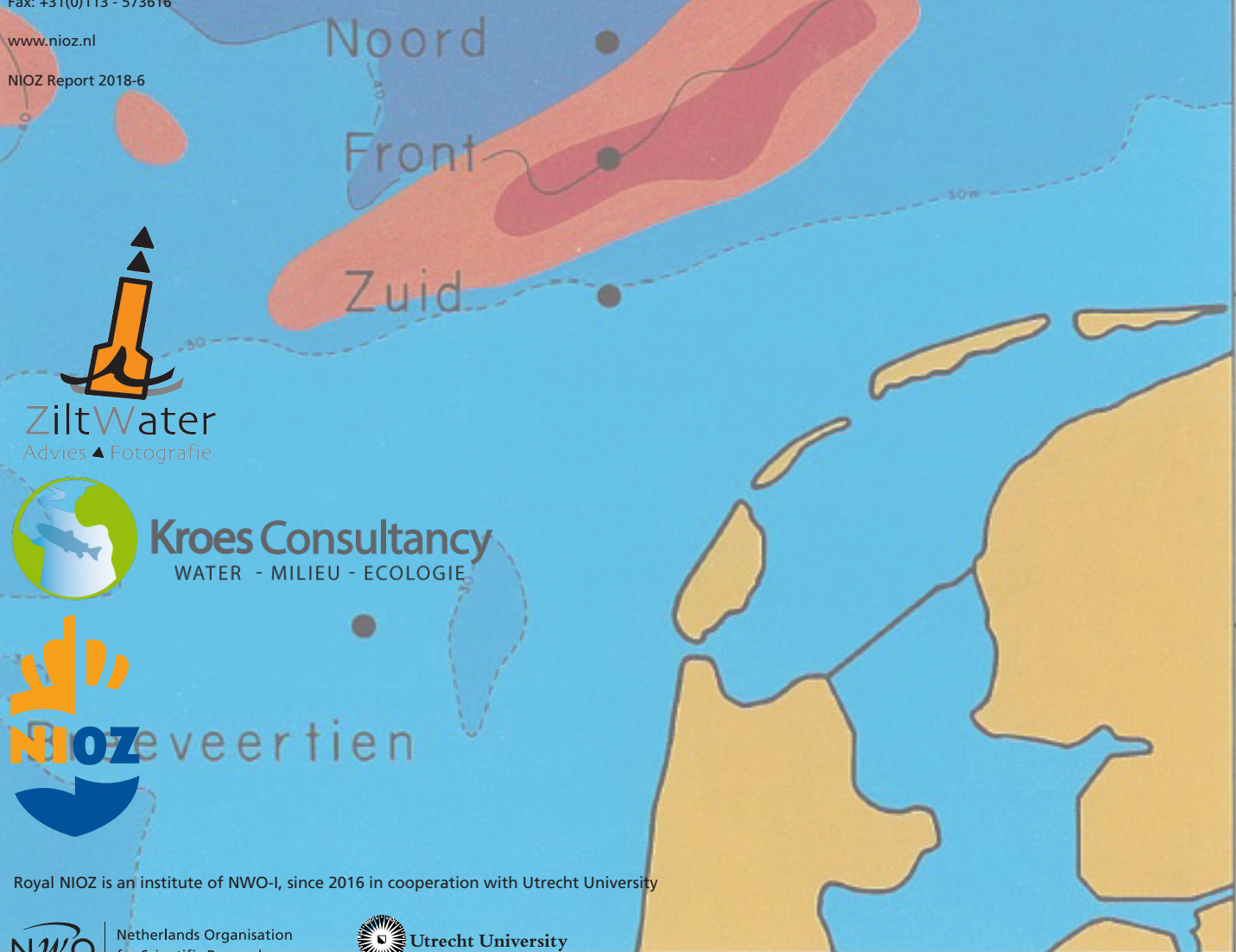
Postbox 140
4400 AC Yerseke
Nederland
Telephone: +31(0)113 - 577417
Fax: +31(0)113 - 573616

www.nioz.nl

NIOZ Report 2018-6

Oostergroonden

Protecting and using our blue planet responsibly starts with understanding our changing seas. NIOZ conducts excellent marine research for society, from the deltas to the deepest oceans. Our science and national marine facilities help scientific communities, businesses, ngo's and policy makers to address some of the biggest challenges ahead.



ZiltWater
Advies ▲ Fotografie



Kroes Consultancy
WATER - MILIEU - ECOLOGIE



NIOZ
veertien

Royal NIOZ is an institute of NWO-I, since 2016 in cooperation with Utrecht University

