Impacts of beam trawl fisheries in the North Sea

A summary of fifty-five publications

W. Lengkeek
S. Bouma

Bureau Waardenburg bv
Adviseurs voor ecologie & milieu

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W. Lengkeek
S. Bouma

Bureau Waardenburg bv
Consultants for environment & ecology
P.O. Box 365, 4100 AJ Culemborg The Netherlands
Tel. +31 345 51 27 10, Fax +31 345 51 98 49
E-mail wbb@buwa.nl Website: www.buwa.nl

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Bureau Waardenburg bv
Consultants for environment & ecology

P.O. Box 365, 4100 AJ Culemborg The Netherlands
Tel. +31 345 51 27 10, Fax +31 345 51 98 49

E-mail wbb@buwa.nl Website: www.buwa.nl

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1 Introduction

Possible impacts of beam trawling in the North Sea are a regular subject of debate among scientists, policy makers and those that exploit the sea's natural resources. Knowledge about impacts is, for example, necessary to assess potential conflicts with the implementation of European legislation, such as the Birds Directive and Habitats Directive (establishing an ecological network known as Natura 2000) and the Marine Strategy Directive. Such debates may benefit from insight in scientific findings about the ecological impacts of beam trawl fisheries on the North Sea ecosystem. This report is a summary of such findings, based on a short and concise search effort into scientific literature.

The main objective of this study was to address the following question:

- What are scientifically demonstrated ecological impacts of beam trawl fisheries in the North Sea and neighbouring coastal seas?

A secondary objective was to address the more specific question:

- What are scientifically demonstrated impacts of beam trawl fisheries on habitat types 1170, 1110_B and 1110_C and species protected under the Natura 2000 network?

Additionally, we recorded ecological impacts of otter trawling (as a potential alternative for beam trawling) when mentioned in these publications.

We did not aim to provide a complete scientific literature review incorporating all available resources. Instead, we aimed to summarise the result of our short search effort in scientific literature. This includes information presented in a range of scientific publications including literature reviews, analyses of long-term data sets, field experiments and modelling studies.

2 Methods

The scientific publications used for this study were partly provided by our commissioners based on previous literature studies: 18 beam trawl publications and two on proposed Natura 2000 management goals (see chapter 5). Most documents (37), however, were found in a short and limited web-based search (chapter 5). We carried out this search effort in a transparent manner that is replicable for anyone. Therefore, our search was limited to a few search terms and to two freely available Google based search engines (table 1). We focussed mainly on papers in international peer-reviewed journals, which should indicate a certain level of scientific quality. However, some highly relevant books, research reports and conference publications were also incorporated, but only if they originated from an internationally recognised scientific institution. When a document was not directly available on the Internet attempts were undertaken to obtain the particular document from other sources (e.g. university libraries).

For each of the selected studies on scientifically demonstrated ecological impacts of beam trawling, the essence of the study, key methods, location(s) and information on the habitats were summarised (chapter 3). Citations within the selected publications were not followed in order to maintain full transparency.

Any ecological impacts of otter trawling that were encountered within these publications were also recorded (see figure 1 for difference between otter- and beam trawling). In addition we considered two publications on otter trawling that were found while searching for beam trawl impacts. Beyond that, no specific effort was put into collecting additional information on this fishing method (chapter 3.3). In chapter 3.2 we summarise studies on the impacts of beam trawl fisheries on habitats and species protected under the Natura 2000 network. To date only few studies specifically focus on beam trawl impacts on Natura 2000 goals. Therefore we added more widely presented impacts that are relevant for the ecology of Dutch Natura 2000 areas.

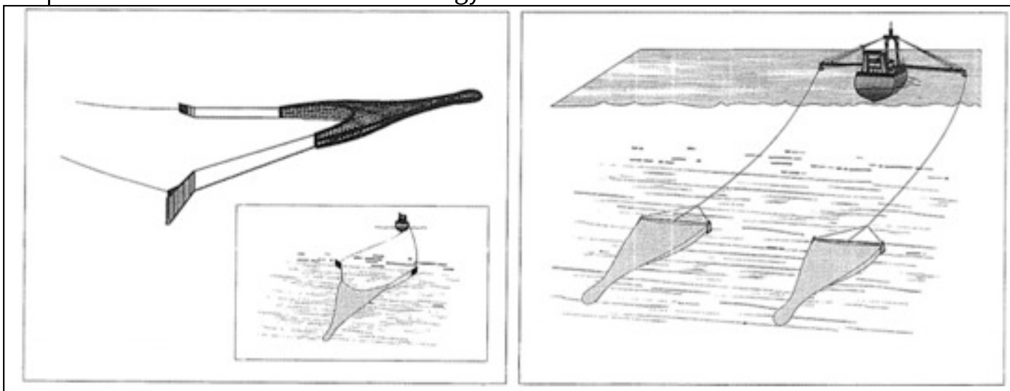

Figure 1. Left: Otter trawling. Right: Beam trawling. Beam trawl rigs include heavy steal beams and chains that are dragged over the seabed. Otter trawl rigs do not include such heavy structures, but include 2 otter boards that keep the net wide open. Source: Lindeboom & de Groot (1998).

Table 1. Summary of search effort.

Date	Search engine	Search term	Number of hits considered, starting from top of list	Selection criteria
03-02-2010	Google scholar	effects trawling	20	Only effects on North Sea life
10-02-2010	Google	effects bottom trawling	20	Only effects on North Sea life, only papers
10-02-2010	Google	impacts bottom trawling	20	Only effects on North Sea life
10-02-2010	Google scholar	bottom trawling north sea	40	Only effects on North Sea life and Irish Sea, only papers
11-02-2010	Google scholar	North Sea epibenthos trawling	20	Only effects on North Sea life and Irish Sea, only papers
11-02-2010	Google scholar	effect trawling birds	40	Only effects on North Sea life , only studies directly downloadable
11-02-2010	Google scholar	effect trawling natura 2000	20	Only effects on North Sea life , only studies directly downloadable
11-02-2010	Google scholar	effecten boomkorvisserij habitattypen	9 (all)	Only effects on North Sea life
11-02-2010	Google scholar	effecten boomkorvisserij	20	Only effects on North Sea life
11-02-2010	Google scholar	effects bottom trawling fish	40	Only effects on North Sea life , only studies directly downloadable
12-02-2010	Google scholar	review trawl fisheries	20	Only effects on North Sea life and general reviews, only studies directly downloadable
12-02-2010	Google scholar	fishing gear	20	Only effects on North Sea life and general reviews, only studies directly downloadable
12-02-2010	Google scholar	effects fisheries	20	Only effects on North Sea life and general reviews, only studies directly downloadable
12-02-2010	Google scholar	North Sea benthic ecosystem	40	Only effects on North Sea life and general reviews, only studies directly downloadable
12-02-2010	Google scholar	beam trawl	50	Only effects on North Sea life and general reviews
12-02-2010	Google scholar	beam trawl biodiversity	20	Only effects on North Sea life and general reviews
12-02-2010	Google scholar	impacts trawl disturbance	10	Only effects on North Sea life and general reviews
15-02-2010	Google	impact boomkorvisserij Noordzee	10	Only effects on North Sea life and general reviews

3 Results

3.1 Impacts of beam trawl fisheries in the North Sea

3.1.1 Benthos

Empirical field studies and analyses of databases

1) Bergman & van Santbrink (2000), ICES Journal of Marine Science:

- Essence of study: Direct damage to megafaunal benthic populations after one single trawl track with both 12m and 4m beam trawl. Direct measurable mortality of 20-65% in bivalves and 5-40% in other taxa. Direct mortality per surface unit is similar for both the 4m and 12m beam trawl. Estimated annual mortality is higher for 12m beam trawls, but only because of higher fishing intensity.
  Essence of methods: Empirical data through field experiment.
  Location: Coastal and offshore in North Sea (Dutch and German EEZ).
  Habitat: Sand and silty bottoms.

2) Bergman *et al.* (2005), NIOZ research report:

- Essence of study: To determine the effects of areas closed for beam trawling on the composition and diversity of macrofauna, the fauna community in the 500m exclusion zone around an offshore platform was compared with fauna in regularly fished subareas in the vicinity. Multivariate analysis showed a distinct difference between Triple-D dredge samples (collected in April 2004) from the 500 m exclusion zone around the platform and those from the regularly trawled reference areas. Conspicuous differences were higher abundances of mud shrimps (*Callianassa subterranea*, *Upogebia deltaura*) and sensitive bivalves (*Arctica islandica*, *Thracia convexa, Dosinia lupinus, Abra nitida*, *Cultellus pellucidus*) in the non-fished area near the platform. Species richness and evenness were higher as well. The boxcore samples did not clearly reveal the distinctness of the non-fished platform area. This is attributed to the large proportion of small, short-living species and the relatively low numbers of vulnerable larger species common to all boxcore samples. Nevertheless, boxcore samples confirmed the higher abundance of mud shrimps (*Callianassa subterranea*, *Upogebia deltaura*) in the non-fished platform sub-area and demonstrated higher densities of the brittlestar *Amphiura filiformis*. The authors conclude that the effect of beam trawling on the presence of long-lived large bivalves is in line with previous studies, namely that these are more vulnerable to beam trawling than other smaller species. Furthermore, the observation that deep-living mud shrimps are affected by trawling may point to larger consequences for the functioning of the benthic ecosystem than solely loss of biodiversity.

Essence of methods: Empirical field data.
Location: North Sea.
Habitat: Sandy.

3) Callaway *et al*. (2007), Marine Ecology Progress Series:

- Essence of study: Effects of a century of trawling on North Sea epibenthos. A comparison of epibenthos between 1902-1912, 1982-1985 and 2000. Analysis of biodiversity and biogeographical species distributions. The south and central North Sea is more heavily fished than the northern North Sea. From the 1960s onwards, fishing effort intensified heavily. Analyses of the available data since this increase from the period 1982 to 1985 showed that the biodiversity of epibenthos significantly decreased from 1980 to 2000. Biogeographical changes occurred from the beginning of the previous century, in 27 of 48 taxa. For 14 taxa the spatial presence was reduced by 50% (i.e. the bivalves *Arctica islandica* and *Aequipecten opercularis* and the echinoderms *Brissopsis lyrifera, Ophiothrix fragilis* and *Henricia sanguinolenta*). 12 taxa doubled their spatial presence (e.g. *Aphrodita aculeata, Psammechinus miliaris, Echinocardium cordatum, Ophiura ophiura* and *Corystes cassivelaunus*).
  Essence of methods: Comparison of preserved museum material and present day sampling data.
  Location: North Sea.
  Habitat: Various.

4) Collie *et al.* (2000), Journal of Animal Ecology:

- Essence of study: Meta-analysis of fishing impact on sea shelf benthos, using data from 39 published studies. Specifically on beam trawling in the North Sea: Fauna in stable habitats such as gravel, mud or biogenic habitats are most negatively affected. Recovery rates are most rapid in physically less stable habitats, where generally more opportunistic species are present. Areas that are fished up to three times a year or more (some parts of the North Sea) do not recover and stay in a permanently altered state.
  Essence of methods: Meta-analysis of existing data.
  Location: Global, and specifically North Sea.
  Habitat: Various.

5) Evans *et al*. (1996), Journal of Experimental Marine Biology and Ecology:

- Essence of study: Behaviour and energetics of whelks (*Buccinum undatum*) feeding on animals killed by beam trawling. Whelks are able to efficiently utilise animals killed by beam trawling. The results of this study indicate that they prefer the most energetically rich species. The authors conclude that in areas of intense beam trawling, such as the southern North Sea, dead or moribund animals, which result from fishing activities, could constitute a considerable proportion of whelk diets.

Essence of methods: Empirical data through laboratory experiments.
Location: Southern North Sea.
Habitat: Laboratory conditions.

6) Frid *et al.* (2000), ICES Journal of Marine Science:

- Essence of study: Long-term changes in benthic communities on North Sea fishing grounds. Analysis of data from the early 1920s to the late 1980s. No significant differences in benthic community composition were found for the Dogger Bank and Inner Shoal. Significant changes in benthic community composition were found for Dowsing Shoal, Great Silver Pit, and Fisher Bank. These changes in community composition were more due to changes in abundance of many taxa than to large-scale losses of sensitive organisms. The authors conclude that these are indeed fishery-induced changes in benthic communities. Furthermore, they hypothesise that Dogger Bank and Inner Shoal had already seen fishery-induced changes prior to the 1920s.
Essence of methods: Analysis of long-term data set.
Location: North Sea, specifically Dogger Bank, Inner Shoal, Dowsing Shoal, Great Silver Pit and Fisher Bank.
Habitat: Various.

7) Jennings *et al*. (2001), Journal of Animal Ecology:

- Essence of study: Effects of trawling disturbance, specifically on benthic production processes. In the Silver Pit area, a large variation in trawling intensity enabled good analysis. Total infaunal biomass and production decreased significantly with trawling intensity. By contrast, relative production (per unit biomass) increased with trawling intensity, an effect attributable to the presence of a greater number of smaller individuals. This increase, however, did not fully compensate for the loss in total production. Effects on epifauna were not significant. In the Hills region, a smaller range of trawling intensity existed and similar relationships could not be established. The authors conclude that increases in biomass and production of small infaunal invertebrates reported in other studies, are attributable more to climate change than to fishing activities.
Essence of methods: Empirical data through field sampling.
Location: Silver Pit and Hills in the central North Sea.
Habitat: Silver Pit depth 60-80m; muddy-sand. Hills depth 40-60m; sandy.

8) Jennings *et al*. (2001), Marine Ecology Progress Series:

- Essence of study: Effects of bottom trawling on the trophic structure of infaunal and epifaunal benthic communities. The frequency of trawling was estimated at 0.2 to 6.5 times a year in the Silver Pitt area and 0.2 to 2.3 times a year in the Hills. Chronic trawling disturbance led to dramatic reductions in the biomass of infauna and epifauna, but these reductions were not reflected in changes to the mean trophic level of the community, or the relationships between the trophic levels of different sizes of epifauna. Within the infauna there were highly

significant decreases in the biomass of bivalves and spatangoids (burrowing sea-urchins), but no significant changes in polychaetes.
Essence of methods: Empirical data through field sampling.
Location: Silver Pitt and Hills in the central North Sea.
Habitat: Silver Pit depth 60-80 m; muddy sand. Hills depth 40-60 m; sandy.

9) Jennings *et al*. (2002), Marine Ecology Progress Series:

- Essence of study: The effects of beam trawling disturbance on the production of small benthic infauna at nine sites that were subject to a 17.5-fold range in annual trawling disturbance. The results showed that chronic beam trawling has minimal effects on the production and size structure of small benthic infauna. Since small infaunal polychaetes are a key source of food for flatfishes, it was concluded that beam trawling disturbance does not have a positive or negative effect on their food supply. The authors conclude that these results are contrasting to studies focusing on larger infauna showing significant decreases in the production, and order of magnitude reductions in the biomass of bivalves and spatangoids (burrowing sea-urchins) across trawling frequencies of 0.2 to 6.5 times a year.
Essence of methods: Empirical data through field sampling combined with modelling.
Location: Silver Pit in the central North Sea.
Habitat: depth 50-75 m; homogeneous area of sand and mud.

10) Kaiser & Spencer (1996), Journal of Applied Ecology:

- Essence of study: Effects of beam trawl disturbance on infaunal communities in different habitats. In the north-western sector of the study area, trawling led to 58% decrease in the mean abundance of some taxa and a 50% reduction in the mean number of species per sample. Multivariate analysis revealed that differences between control and fished sites were largely due to the reduction or removal of less common species. These effects were less apparent in the mobile sediments of the south-eastern sector of the study area, which had a naturally impoverished fauna and high level of heterogeneity. Variables, such as abundance and total number of species per sample, indicated that the variation between replicate samples increased as a result of trawling disturbance. However, examination of the community data using an index of multivariate dispersion revealed no difference between fished and unfished areas, indicating that the effects of fishing disturbance are consistent between replicate samples. The authors conclude that fishing with demersal gears modifies communities in relatively stable sediments. Frequent and repeated physical disturbance by fishing gears may lead to long-term changes in the benthic community structure of these habitats.
Essence of methods: Empirical field data.
Location: Irish Sea.
Habitat: Various.

11) Kaiser *et al.* (1998), ICES Journal of Marine Science:

- Essence of study: The immediate impact of beam trawling on the megafaunal component of two distinct benthic communities in two different habitats (mobile megaripple structures and stable uniform sediment) and the extent of recovery after six months. The benthic community in the stable sediments with a rich fauna was significantly altered immediately after fishing. A reduction in the abundance of the polychaetes, *Aphrodita aculeata* and *Nephtys spp*. contributed most to the dissimilarity between trawled and control areas. However the change in abundance was not always consistent as species such as *Pagarus bernhardus* increased within the trawled areas. Effects of trawl fishing were statistically not detectable in the mobile sediments. Six months later seasonal changes had occurred and effects of trawling disturbance were no longer evident in both communities. Sessile fauna such as hydroids and dead men's fingers *Alcyonium digitatum* were a prominent feature of both benthic communities and occurred in the by-catch of the trawl beam. However the authors were unable to detect any change in biomasses of these species as a result of fishing.
  Essence of methods: Empirical data through field sampling.
  Location: North Sea, Liverpool Bay.
  Habitat: 26 – 34 m depth; mobile megaripple structures and stabile uniform sediments.

12) Kaiser *et al*. (2000), Journal of Animal Ecology:

- Essence of study: Comparison of benthic fauna in areas that have been exposed to either high or low levels of bottom-fishing disturbance. The results indicated that chronic fishing caused a shift from communities dominated by relatively sessile, emergent, high biomass species to communities dominated by infaunal, smaller-bodied fauna. The authors conclude that the removal of emergent fauna degraded the topographic complexity of seabed habitats in areas of high fishing effort. The biomass of the emergent soft coral *Alcyonium digitatum*, the large sea urchin *Echinus esculensis*, the bivalve *G. glycymeris* and the gastropod *Buccinum undatum* was lowest in the areas of high fishing effort. By contrast the biomass of brittlestars such as *Ophiura albida* and *Ophiocomina nigra* was highest in these areas.
  Essence of methods: Empirical data through field sampling.
  Location: Irish Sea.
  Habitat: Mainly coarse sand.

13) Kaiser *et al*. (2006), Marine Ecology Progress Series:

- Essence of study: A global analysis of response and recovery of benthic biota to fishing. Specifically for beam trawling: Great impacts on deposit and suspension feeders and dependent on habitat type. The biota of soft-sediment habitats, in particular muddy sands, were surprisingly vulnerable, with predicted recovery times measured in years. Slow-growing large-biomass biota such as sponges

and soft corals took much longer to recover (up to 8 yr) than biota with shorter life-spans such as polychaetes (<1 yr).
Essence of methods: Meta-analysis of large data collection.
Location: Global.
Habitat: Various.

14) Mensink *et al*. (2000), Journal of Sea Research:

- Essence of study: The amount of shell damage and mortality of whelks (*Buccinum undatum*) caused by beam trawl fishery. In whelks collected by beam trawling, minor shell damage was observed in 17-75% and severe damage in 10-83%. In the laboratory only 40% of whelks caught with a 12 m beam trawl survived. Whelks that did survive repaired their shell damage after six weeks.
  Essence of methods: Empirical data through field and laboratory measurements.
  Location: Southern North Sea.
  Habitat: Information not provided.

15) Piet *et al*. (2000), ICES Journal of Marine Science:

- Essence of study: The effects of using environmental data and higher-resolution fishing effort data on the annual mortality of 21 infauna and epifauna species caused by the passing of a beam trawl. Variation in species abundance was markedly smaller based on sediment-depth strata than based on the ICES rectangles and the resulting population mortality estimates differed significantly among species (ratio 0.3 to 1.6) depending on the overlap of the spatial distribution of a species and of beam trawl effort. Changing the resolution of fishing effort data resulted in a systematic reduction of population mortality by a factor 0.7 due to the patchy effort distribution. The authors conclude that the annual fishing mortality should preferably be based on relevant environmental strata and that the accuracy of the estimates markedly increases when the resolution of spatial fishing effort data sufficiently reflects the patchiness of the beam trawling activities.
  Essence of methods: Analysis of existing data.
  Location: Southern North Sea.
  Habitat: Depth ranging from 5 to 50 m, sand.

16) Queirós *et al*. (2006), Journal of Experimental Marine Biology and Ecology:

- Essence of study: The effects of chronic bottom trawling disturbance on benthic biomass, production and size spectra in two different habitat types (sandy area Dogger Bank and muddy area Irish Sea). Chronic trawling had a negative impact on the biomass and production of benthic communities in the muddy habitat, but no impact was identified on benthic communities in the sandy habitat. In the Irish Sea biomass and production were dominated by brittlestars in less intensively trawled stations, while in the most intensively disturbed areas there was no consistent dominance of community composition. The biomass and production of *Amphiura filiformis* decreased significantly with increasing

trawling intensity. The trawling intensity (fraction of the area covered by trawls per year) on the Dogger Bank varied between 0 and 1.55 per year and in the Irish Sea between 0.10 en 3.53 annually.
Essence of methods: Empirical data through field sampling.
Location: Irish Sea and Dogger Bank.
Habitat: Sandy (Dogger Bank) and muddy (Irish Sea).

17) Rabaut *et al.* (2008), Fisheries Research:

Essence of study: This small-scale study quantified the impact of beam-trawling passage on intertidal *L. conchilega* reefs and its associated fauna. The hypothesis was that the impact on *L. conchilega* would be minimal, but that the fauna benefiting from the biogenically structured habitat would be impacted by beam trawling. Species richness was significantly related to *L. conchilega* density. Community analyses showed a clear impact of beam trawling, followed by a relatively quick recovery of the fauna community that is associated with *L. conchilega* reefs. These effects were largely explained by two species: *Eumida sanguinea* (worm) and *Urothoe poseidonis* (amphipod).
Species analysis confirmed the beam-trawl passage significantly impacted *E. sanguinea*, but for the whole period of the experiment. The same result appeared for total macrofauna density (mainly *E. sanguinea, Capitella capitata, U. poseidonis, Nephtys cirrosa and S. filicornis*), but not for species richness. The authors conclude that the experiment confirmed that closely associated species of *L. conchilega* reefs are impacted by beam-trawl fisheries.
Essence of methods: Empirical data through field experiment. One-off experimental trawling and impact investigated for a period of 9 days post-trawling.
Location: Intertidal zone of the seashore of Boulogne-sur-mer, France.
Habitat: Sand.

18) Ramsay *et al*. (1996), Marine Ecology Progress Series:

- Essence of study: The behaviour of two species of hermit crabs (*Pagarus bernhardus* and *Pagarus prideaux*) in response to beam trawl disturbance. Catch numbers and stomach contents of *P. bernhardus* were significantly higher on the beam trawl track in comparison to the control tracks 2 and 3 days after fishing. On the fourth day they were no longer significantly different. Catch numbers and stomach contents of *P. prideaux* did not vary significantly between tracks. It was concluded that *P. bernhardus* migrates into recently trawled areas feeding on the damaged or disturbed fauna and that *P. prideaux* does not respond to trawling activities.
Essence of methods: Empirical data through field experiment.
Location: Irish Sea in an area rarely visited by commercial fishing vessels.
Habitat: depth circa 40 m; details on sediment characteristics not provided.

19) Rumohr & Kujawski (2000), ICES Journal of Marine Science:

- Essence of study: Qualitative historical benthos data (1902–1912) were compared with data from 1986 to find long-term trends in epifauna species composition in the southern North Sea that may be attributed to fishery-induced changes. In general, the frequency of occurrence of bivalve species declined, whereas scavenger and predator species (crustaceans, gastropods, and sea stars) were observed more frequently in 1986. The authors hypothesise that these shifts can be attributed not only to the physical fishery impact, but also to the additional potential food for scavenging and predator species provided by the large amounts of discards and moribund benthos.
  Essence of methods: Comparison of historical (museum) data with data from 1986.
  Location: Offshore southern North Sea.
  Habitat: Various.

20) Van Rijnsdorp *et al*. (1998), ICES Journal of marine science:

- Essence of study: Analysis of beam trawl effort distribution on a micro-scale. The implications for benthic communities are discussed by the authors. A strong spatial overlap of fishing effort distribution over years exists. As a consequence of this overlap some patches are fished more frequently than other patches. Even within heavily fished areas, patches of seabed exist that are fished infrequently: 5% of the surface area is fished less than once every 5 years, 29% is fished less than once a year. This could imply that even in heavily fished areas, sensitive organisms can survive on the patches that are fished more infrequently.
  Essence of methods: Analysis of fishing vessel positions.
  Location: North Sea.
  Habitat: Various.

21) Schratsberger & Jennings (2002), Marine Biology:

- Essence of study: Impacts of chronic trawling disturbance on meiofaunal (nematode) communities. Study areas are trawled 1, 4 and 6 times per year. Trawling disturbance had a significant effect on the composition of nematode assemblages. The number of species, diversity and species richness were significantly lower in the high disturbance area compared to the areas with medium and low disturbance. Overall abundance of nematodes was not significantly affected.
  Essence of methods: Empirical data through field sampling.
  Location: Central North Sea, Silver Pit.
  Habitat: Muddy-sandy bottom, 60-80m deep.

22) Tillin *et al.* (2006), Marine Ecology Progress Series:

Essence of study: The effects of chronic bottom trawling disturbance on the functional composition of faunal benthic invertebrate communities were investigated in four areas with different habitat types (in terms of sediment,

depth and tidal currents): Dogger Bank: depth 25-30m; sediment sand; bottom shear stress 0,10-0,15 N per m^2); Fladen Ground: depth 142-153m; sediment mud; bottom shear stress 0,08-0,11 N per m^2); Long Fourties: depth 74-83m; sediment gravelly sand; bottom shear stress 0,30-0,36 N per m^2); Northwest Rough: depth 49-63m; sediment sand; bottom shear stress 0,11-0,17 N per m^2). Samples were taken using a beam trawl and information on the life history and ecological function traits of the taxa sampled were used to analyse the relationship between life history and functional roles within the ecosystem. Changes in the functional structure of the community due to the effects of long-term trawling were identified in three of the four areas (not in the Dogger Bank area). Filter-feeding, attached and larger animals were relatively more abundant in lightly trawled areas, while areas with higher levels of trawling were characterised by a higher relative biomass of mobile animals and infaunal and scavenging invertebrates. It was concluded that chronic bottom trawling can lead to large scale shifts in the functional composition of benthic communities.
<u>Essence of methods</u>: Empirical data through field experiment.
<u>Location</u>: Four areas in the North Sea namely Dogger Bank, Fladen Ground, Long Fourties and Northwest Rough.
<u>Habitat</u>: Respectively for the four areas sand, mud, gravely mud and sand.

23) Tuck *et al*. (1998), Marine Ecology Progress Series:

- <u>Essence of study:</u> Experimental trawling in a sea loch which had been closed for fishing for 25 years. The benthic community structure changed after trawling, and these changes where detectable for 18 months after the last trawl. The abundance of rare species decreased, while the abundance of more common species increased. The species that decreased in abundance where mainly molluscs, species that increased mainly polychaetes. Although overall numbers of individuals and species did not decrease, a calculated biodiversity index became lower, indicating a community more dominated by a few abundant species.
  <u>Essence of methods</u>: Empirical data through field experiment.
  <u>Location</u>: Scottish sea loch.
  <u>Habitat</u>: Fine muddy substrate.

24) Witbaard *et al*. (2007), Poster presentation on the Noordzee dagen conference:

- <u>Essence of study:</u> Long-term effects of bottom trawling in the North Sea. Frequent beam trawling negatively affects large bivalves (e.g. *Arctica islandica*). Densities of *A. islandica* significantly increase with decreasing fishing intensity. In an area around an offshore installation, where fishing has been prohibited for 20 years, numbers of large bivalves were significantly higher than in fished areas. For the development of a Natura 2000 network, areas of the North Sea have been destined to receive a protected area status. The authors conclude, that if present day fishing methods and intensity are allowed in those protected areas, recovery and optimisation of nature values in those areas will not be possible.

Essence of methods: Empirical data through field sampling.
Location: North Sea.
Habitat: Various.

25) Zülke *et al*. (1998), Seckenbergiana Maritima:

- Essence of study: In 1999 the epibenthic fauna of the North Sea was investigated sampling 241 stations covering 143 ICES triangles. The objectives were to analyse epibenthic diversity patterns in the North Sea, to identify the spatial distribution of faunal communities and to relate environmental factors as well as fishing effort to species diversity. A clear division was shown between the southern North Sea and the central northern North Sea, roughly along the 50 m depth line. This separation was based on an overall higher number of species in the central and northern North Sea and a change in the species composition from north to south. Depth was positively correlated with the diversity of free-living fauna, whereas the type of sediment showed no significant relationship with variations in numbers of species. Beam trawling was negatively correlated with the diversity of sessile fauna.
Essence of methods: Field sampling versus existing data on beam trawl effort.
Location: Entire North Sea.
Habitat: Various.

Reviews

26) Jennings & Kaiser (1998), book chapter in Advances in Marine Biology:

- Essence of study: The effects of fishing on benthic fauna and habitat, community structure and trophic interactions worldwide. The authors conclude that direct effects of fishing vary according to the gears used and the habitats fished, but they usually include the scraping, scouring and re-suspension of substratum and occur against a background of natural disturbance. The relative impact of fishing on habitat and benthic community structure is determined by the magnitude of natural disturbance. The direct effects of a given fishing method on infaunal and epifaunal communities will tend to increase with depth and the stability of the substrate. In sheltered areas where complex habitats develop at minimal depth, such as coral reefs, the direct effects of fishing may be marked and have profound effects on the ability of the habitat to sustain fish production. This document summarises aspects and impacts of beam trawling activities using results from many studies already included in this report.
Essence of methods: Literature review.
Location: Global.
Habitat: Various.

27) Lindeboom *et al*. (2005), Alterra / RIKZ research report:

- Essence of study: Areas of special ecological value on the Dutch Continental Shelf. Specifically for beam trawling: In comparison with other anthropogenic activities, beam trawling has by far the highest impact on benthic fauna. Benthic

fauna mortality leads to shifts in species composition and age structure of populations. Beam trawling also influences habitat characteristics. Especially slow-growing and slow-reproducing species are vulnerable. Mortality of shellfish in a single beam trawl track ranges from 12-84%, while that of polychaetes is considerably lower (1-14%). 55% of the Dutch Continental Shelf is trawled more than once a year, only 14% is trawled less then once every four years.
Essence of methods: Literature review for policy making.
Location: Dutch Continental Shelf.
Habitat: Various.

28) Watling & Norse (1998), Conservation Biology:

- Essence of study: The disturbance of the seabed by mobile fishing gear is compared to forest clear cutting. It was concluded that the global area of trawled seabed, however, is 150 times larger than that of clear cutter forest. The authors summarise the impacts of mobile fishing gear as follows: 'Use of mobile fishing gear crushes, buries and exposes marine animals and structures on and in the substratum, sharply reducing structural diversity. It also alters geochemical cycles, perhaps even globally. Recovery after disturbance is often slow because recruitment is patchy and growth to maturity takes years, decades, or more for some structure-forming species. Trawling and dredging are especially problematic where the return interval (the time from one trawling event to the next) is shorter than the time it takes for the ecosystem to recover. The effects of mobile fishing gear on biodiversity are most severe where natural disturbance is least prevalent, particularly on the outer continental shelf and slope, where storm-wave damage is negligible and biological processes, including growth, tend to be slow.
Essence of methods: Literature review.
Location: Global.
Habitat: Various.

Modelling studies

29) Dinmore *et al.* (2003). ICES Journal of Marine Science:

- Essence of study: Impact of a large-scale seasonal area closure on patterns of fishing disturbance and the consequences for benthic communities. Based on the observed response of the North Sea beam trawl fleet to the closure of the ''cod box'' and an existing size-based model of the impacts of beam trawling. The analysis shows that repeated seasonal area closures would lead to a slightly more homogeneous distribution of annual trawling activity, although the distribution would remain patchy rather than random. The increased homogeneity, coupled with the displacement of trawling activity to previously unfished areas, is predicted to have slightly greater cumulative impacts on total benthic invertebrate production and lead to localized reductions in benthic biomass for several years.

Essence of methods: Modelling.
Location: North Sea.
Habitat: Mainly sand bottoms.

30) Hiddink *et al*. (2006), Ecosystems:

- Essence of study: Modelling of ecological impact of bottom trawl disturbance on seabed communities. Indicators for a good state of benthic biomass and production are developed: 90% of pristine biomass and 90% of pristine production. In 2003, 56% of the southern North Sea was trawled too frequently to reach 90% of pristine benthic biomass, and 27% was trawled too frequently to reach 90% of pristine production. Modelled recovery times to 90% of the pristine situation are 2.5 to >6 years.
  Essence of methods: Modelling study.
  Location: North Sea.
  Habitat: Various.

31) Hiddink *et al.* (2006), Canadian Journal of Fisheries and Aquatic Sciences:

- Essence of study: Cumulative impacts of seabed trawl disturbance on benthic biomass, production and species richness in different habitats. Both the model and the field data demonstrated that trawling reduced biomass, production, and species richness. The impacts of trawling were greatest in areas with low levels of natural disturbance, while the impact of trawling was small in areas with high rates of natural disturbance. For the North Sea, the model showed that the bottom trawl fleet reduced benthic biomass and production by 56% and 21%, respectively, compared with an unfished situation. Because of the many simplifications and assumptions required to synthesize these data, additional work is required to refine the model and evaluate applicability in other geographic areas.
  Essence of methods: Modelling, validated with field data.
  Location: North Sea.
  Habitat: Various.

32) Hiddink *et al*. (2007), Journal of Applied Ecology:

- Essence of study: A method was developed that meets the criteria for assessing the sensitivity of seabed habitats to physical disturbance. This study mapped habitat sensitivity to trawling in 9 km^2 boxes across an area of 125,000 km^2 in the North Sea. Habitat sensitivities varied widely, and a trawling frequency of 5 times annually in the least sensitive habitat had the same ecological effect as a trawling frequency of once every 3 years in the most-sensitive habitat (based on production). When trawling effort was held constant but redirected to the least-sensitive habitats, the existing impacts on production and biomass were reduced by 36% and 25%, respectively.
  Essence of methods: Modelling, validated with field data.
  Location: North Sea.
  Habitat: Various.

33) Jones (1992), New Zealand Journal of Marine and Freshwater Research:

- Essence of study: An overview of the environmental impact of trawling on the seabed reviewing many studies carried out worldwide. Direct effects include scraping and ploughing of the substrate, sediment re-suspension, destruction of benthos, and dumping and processing of waste. Indirect effects include post-fishing mortality and long-term trawl-induced changes to the benthos. There are few conclusive studies linking trawling to observed environmental changes since it is difficult to isolate the cause. Research has established that the degree of environmental perturbation from bottom trawl activities is related to the weight of the gear on the seabed, the towing speed, the nature of bottom sediments, and the strength of the tides and currents. The greater the frequency of disturbance, the greater the likelihood of permanent change. In deeper water where the fauna is less adapted to changes in the sediment regimes and disturbance from storm events, the effects of gear take longer to disappear. Studies indicate that in deep water (>1000 m), the recovery time is probably measured in decades.
  Essence of methods: Literature review.
  Location: Global.
  Habitat: Diverse.

34) Schoeder & Gutow (2008), Presentation on ICES conference in Copenhagen:

- Essence of study: A conference presentation with title 'Impact assessment of bottom trawling on benthic species in marine protected areas in the German EEZ of the North Sea: a modelling approach'. The model uses detailed information on trawling activities using data from a satellite-based vessel monitoring system together with biological data to assess impacts of beam trawling on benthic species in marine protected areas. The model predicted considerable impact in parts of the investigated areas especially on long-lived species, including changes in size structure and production. A 'safe' level was not determinable and first disturbances were most severe. Some questions remained open, including a definition of an 'undisturbed' population, a potential temporal mismatch of existing fauna- and reliable satellite-based vessel monitoring data, and the interannual variation in the spatial scale of fishing distribution.
  Essence of methods: Modelling.
  Location: North Sea, German EEZ.
  Habitat: Various.

3.1.2 Fish

Empirical field studies and analyses of databases

35) Daan *et al*. (2005), Journal of marine Science:

- Essence of study: Possible evidence for changes in North Sea Fish communities through indirect effects of fishing. The abundance of small fishes has increased over the past 30 years. This increase levelled off slightly in most recent years. Fishing effort reached its maximum in the 1980s and slightly declined since. If fish community changes result from fishing, there must be a considerable delay in response, indicating indirect effects (e.g. removal of predators) more than direct effects (e.g. removing large individuals). Indeed significant correlations exist between fishing effort and community size metrics, if time lags of six years or more are introduced. This can be evidence for an indirect and delayed effect of fishing on population structures of fish.
  Essence of methods: Analysis of long-term data sets.
  Location: North Sea.
  Habitat: Various.

36) Jennings *et al*. (1999), Journal of Animal Ecology:

- Essence of study: Long-term trends in the abundance of species in the North Sea demersal fish community. Between 1925 and 1996 changes in species composition led to an increase in mean growth rate, while maximum size, age at maturity and size at maturity decreased. Linking trends to life histories demonstrated that trawl fishing has greater effects on slower growing, larger species with later maturity and lower rates of potential population increase. Of the 23 species included in the analyses 15 species decreased in abundance between 1925 and 1996.
  Essence of methods: Analysis of existing data.
  Location: East of the Shetlands Islands in the northern North Sea.
  Habitat: No details provided.

37) Jennings *et al*. (2002), Marine Biology:

- Essence of study: Effects of beam trawling on the long-term trends in the trophic structure of the North Sea fish community. Analyses of a 1982-2000 time-series of trawl survey data for the whole North Sea showed that there was a slow but progressively decline in the trophic level of the demersal fish community, while there was no trend in the trophic level of the combined pelagic and demersal community. Analyses of a longer time-series from 1925-1996 for the central and northern North Sea did not show a trend in the trophic level of the demersal fish community. The authors conclude that effects of fishing on the trophic structure of fish communities can be very complex. Changes in size structure are a more universal indicator of fishing effects than changes in mean trophic level.
  Essence of methods: Analysis of long-term data.

Location: North Sea.
Habitat: Diverse.

38) Kaiser & Spencer (1994), Marine Ecology Progress series:

- Essence of study: Fish scavenger behaviour into recent beam trawl tracks. Beam trawling damaged heart urchins, scallops, amphipod tubes, *Ensis spp*. and *Laevocardion spp*. Gurnards and whiting increased their food intake on recent trawl tracks, in particular the intake of amphipods. Dogfish did not increase their food intake. Side scan sonar showed that fish densities increase near recent beam trawl tracks. Fish move rapidly into recent trawl tracks to eat damaged organisms. The authors conclude that this can lead into a long-term alteration in fish community structure.
  Essence of methods: Empirical data through field experiment.
  Location: Irish Sea.
  Habitat: Coarse sand, gravel and broken shell.

39) Pastoors *et al.* (2000), ICES Journal of Marine Science:

- Essence of study: The effects of a partially closed area in the North Sea (the so-called "plaice box" established in 1989) on the stock development of plaice. The trawl efforts in this area decreased in two phases. Between 1989 and 1993 the plaice box was only closed during the second and third quarter with a reduction of 40% of the original effort of the Dutch beam trawl effort. When the box closed in the fourth (1994) and fifth quarter (1995) the effort decreased to 6% of the original efforts. In contrast to the expected positive effects, yield and spawning stock biomass decreased. Analysing the relevant factors and processes (natural and anthropogenic) affecting recruitment made the authors to conclude that a reduced growth rate and possibly a higher natural mortality may have counteracted the expected positive effects of the reduction in fishing effort.
  Essence of methods: Analysis of existing data.
  Location: North Sea.
  Habitat: Diverse.

40) Van Rijnsdorp & van Leeuwen (1996), ICES Journal of Marine Science:

- Essence of study: Changes in growth rates of North Sea plaice in relation to density, eutrophication, seabed disturbance by beam trawling and temperature. Plaice <25cm: Growth rates increased from mid-1950s and decreased again from 1980s. Significant positive correlations existed between growth rate and eutrophication and growth rate versus disturbance by beam trawling. A negative correlation was found between plaice density and growth rate. No correlation was found with temperature. Plaice intermediate size: No pattern emerged. Plaice > 35cm: Growth rates increased from 1970s. The authors conclude that eutrophication mainly affected growth rates of plaice in coastal areas, whereas increased food availability through disturbance of the seabed by beam trawling mainly affected growth rates in offshore areas.

Essence of methods: Growth rate back calculation from otoliths.
Location: Southern North Sea.
Habitat: various.

41) Rogers & Ellis (2000), Journal of Marine Science

- Essence of study: Changes in the demersal fish assemblages were calculated using data from 1901 to 1907 and then compared with data from the same areas from 1989 to 1997. In Start Bay (NW English Channel) and the Irish Sea, species diversity was the same in both periods, although the most abundant species in each period were not the same. In English coastal regions of the southern North Sea, fish populations became more diverse, as plaice *Pleuronectes platessa* and whiting *Merlangius merlangus* became less abundant, and the relative abundance of several non-target species such as dragonet *Callionymus spp.*, bib *Trisopterus luscus*, and bull-rout *Myoxocephalus scorpius* increased. The proportion in the catch of small fish species (maximum body length <30 cm), which would be least vulnerable to capture by commercial trawls, increased between the two survey periods in Start Bay and the southern North Sea. None of these small species was commercially exploited. The proportions of larger teleosts (maximum body length >30 cm) in catches decreased in all regions during the time period, except in the Irish Sea where plaice replaced grey gurnard *Eutrigla gurnardus* as a dominant species. There was a decline in abundance of large sharks, skates and rays, including the common skate, *Raja batis*, white skate *R. alba* and the angel shark *Squatina squatina*. During historic surveys, 60% of the elasmobranch fauna consisted of thornback ray *Raja clavata*, whereas in contemporary surveys the lesser-spotted dogfish *Scyliorhinus canicula* was the most abundant elasmobranch. Changes in length-frequency distribution of fish in both target and non-target categories, and other observed changes, were thought to be a response to commercial exploitation, and corresponded to similar observations recorded elsewhere.
  Essence of methods: Analysis of long-term data sets.
  Location: North Sea, Irish Sea and Channel.
  Habitat: Various.

3.1.3 Birds

Reviews

42) Furness (2003), Scientia Marina:

- Essence of study: Impacts of fisheries on seabird communities. Specifically for the North Sea: Sandeels are an important food source for fish eating seabirds. Although commercial fisheries target sandeels, the loss of sandeels has been more than compensated by the removal of predatory fish by other fisheries. Sandeel fisheries and seabirds seem to coexist successfully. Discards produced by fisheries in the North Sea can stimulate scavenging seabird numbers. Desirable reduction of discards may have unfortunate side effects on seabird communities.
  Essence of methods: Literature review.
  Location: Global and North Sea specific.
  Habitat: Diverse.

43) Tasker *et al*. (2000), ICES Journal of Marine Science:

- Essence of study: Seabirds experience different effects of fishing. Direct effects include killing (mainly longline and gillnetting) and disturbance. Indirect effects mainly include changes in the food chain and are more relevant with respect to beam trawling. Discards may lead to increased food availability for fulmars, gannets, great skua and gull species. Increased small fish numbers by removing large predatory fish may increase food availability of fish eaters. Alternatively prey fish abundance may decrease when the prey fish is a commercial target (e.g. sandeel). Since shellfish stocks have mainly decreased as a consequence of bottom fishing, birds relaying on shellfish stocks such as scoters and eiders may have experienced decreasing prey stocks as a consequence of fishing.
  Essence of methods: Literature review.
  Location: Global.
  Habitat: Diverse.

3.1.4 Integral studies

44) Allen & Clark (2007), Marine Ecology Progress Series:

- Essence of study: Effects of beam trawling on ecosystem functioning in the North Sea were investigated by coupling of a physical-ecological model (the European Regional Seas Ecosystem Model (ERSEM)) with the General Ocean Turbulence Model (GOTM). Perturbation experiments were used to simulate trawling events using estimates of mortality of benthic fauna caused by different fishing gears in different habitats, derived from a meta-analysis of over 100 trawling disturbance experiments reported in literature. The models shows, that the biogeochemical impact of demersal trawling is most significant in regions where gear type, trawl frequency and bed type cause high levels of filter feeder mortality. This results in substantially increased oxygen content of the benthic system and significant changes in its biochemistry (increased phosphorus absorption, increased nitrification of ammonia, reduced silicate cycling). The impacts of these changes on the overlying pelagic ecosystem are, however, buffered by the physical environment and the ability of the phytoplankton to vary their internal nutrient contents. The model indicated that a system on complete cessation of demersal trawling return to its original state within 5 years, except in extreme cases where the deposit or filter feeding function is effectively removed.
  Essence of methods: Modelling.
  Location: North Sea.
  Habitat: Various.

45) Deerenberg *et al*. (2009), IMARES research report:

- Essence of study: Possibilities for sustainability of beam trawling in the Voordelta. Specifically on the impact of beam trawling on Natura 2000 goals: Beam trawling causes changes in habitat structure and fish- and benthos populations. Beam trawling can decrease benthic diversity and abundance. Fishing vessel activity may disturb animals (e.g. birds or seals). Protected fish may be caught and prey fish for protected animals may be removed.
  Essence of methods: Literature review for policy making.
  Location: Voordelta.
  Habitat: Sandy and silty.

46) Enever *et al.* (2007), Fisheries Research:

- Essence of study: Catch and discard data have been collected between 2002 and 2005 conducting sampling operations on English and Welsh registered fishing vessels in the English Channel, Western approaches, Celtic Sea and Irish Sea. Data included in the analyses were data from 3.643 hauls from 306 trips aboard 142 different boats. An estimated 186 million fish and cephalopods were caught every year of which 117 million were discarded. Beam trawlers (58%) and otter trawlers (35%) were together responsible more than 90% of these discards. Discards of beam trawlers consisted of 139 species (on average 10

species per haul), discards of otter trawlers of 159 species (on average 11 species per haul). The 10 most discarded species (by number) and selected commercially important species by beam trawlers were gurnards, common cuttlefish, European plaice, dab, lesser-spotted-dogfish, poor cod, dragonets, whiting-pout, whiting and melgrim. The 10 most discarded species (by number) and selected commercially important species by otter trawlers were dab, gurnards, European plaice, lesser-spotted-dogfish, whiting, boar fish, silver melt, poor cod, horse-mackerel and dragonets.
Essence of methods: Analyses of data collected during sampling operations between 2002 and 2005.
Location: English Channel, Western approaches, Celtic Sea and Irish Sea.
Habitat: Various.

47) Groenewold & Fonds (2000), ICES Journal of Marine Science:

- Essence of study: Effects on benthic scavengers of discards and damage produced by beam trawling. The main scavengers were: swimming crabs, hermit crabs, sea stars, ophiurids, amphipods and gadoid fish species. Scavengers actively migrate into recently trawled areas. Discards are consumed within days after trawling. The direct importance of the additional food resource for scavengers is considered relatively small. By modelling the authors estimate that after a trawl, 6-13% of the annual secondary production becomes suddenly available to scavengers. The others conclude that beam trawling leads to short cuts in trophic relationships.
  Essence of methods: Empirical data through field experiment combined with modelling.
  Location: Southern North Sea.
  Habitat: Various.

48) Kaiser *et al.* (2002), Fish and Fisheries:

- Essence of study: Review of known and potential effects of fishing gears on the structure of marine habitats. Some conclusions that can be relevant for beam trawling activities in the North Sea include:
  - Structural complex habitats (e.g. seagrass meadows, biogenic reefs) and those that are relatively undisturbed by natural perturbations (e.g. deep-water mud substrata) are more adversely affected by fishing than unconsolidated sediment habitats that occur in shallow coastal waters. These habitats also have the longest recovery times in terms of the recolonisation of the habitat by the associated fauna.
  - Chronic fishing disturbance leads to the removal of high-biomass species mostly composed of emergent seabed organisms. Generally these organisms increase the topographic complexity of the seabed, which has shown to provide shelter for juvenile fishes.
  - The benthic productivity is lowered as fishing intensity increases.
  - Scavengers and small-bodied organisms, such as polychaete worms, dominate heavily fished areas.

- Major changes in habitat can lead to changes in the composition of the resident fish fauna.
- Fishing has indirect effects on habitat through the removal of predators.

Essence of methods: Literature review.
Location: Global.
Habitat: Various.

49) Kaiser & Spencer (1995), Marine Ecology Progress Series:

- Essence of study: The survival of fauna caught by a 4 m beam trawl in order to identify those species most susceptible to capture.
  Specifically for benthos:
  Survival of discards: Between 7 and 8% of sea mice (*Aphrodite aculeata*), 6% of common hermit crabs (*Pagarus bernhardus*), 24% of the spider crab (*Macropodia rostrata*), 50-57% of the swimming crab (*Liocarcinus depurator*), 10% of queen scallops (*Aequipecten opercularis*), 0-1% of starfish (*Asterias rubens* and *Astropecten irregularis*), 19% of brittlestars (*Ophiura ophiura*) and 62% of the sea urchin *Psammechinus miliaris* died during the experiments. Whelks (*Buccinum undatum* and *Neptunia antiqua*) and scallops (*Pecten maximus*) were well protected by their thick shells, hence 100% survived. *Survival passing through the cod-end*: 100% of the hermit crab *Pagarus bernhardus* and 90% of the hermit crab *Pagarus prideaux* that passed through the meshes of the cod-end survived.
  Specifically for fish:
  Survival of discards: Despite their robust appearance and no initial mortality dragonets (*Callionymus lyra*) continued to die and had a final mortality between 68 and 97%. Initially none of the cuckoo rays (*Raja naevus*) were dead, but after 5 days 41% had died. Plaice (*Pleuronectes platessa*) and dab (*Limanda limanda*) had the highest initial mortality rate of fish examined and had a final mortality of respectively 61 and 76%. Lesser-spotted dogfish (*Scyliorhinus canicula*) were extremely resilient as 90% survived after 6 days.
  Survival passing through the cod-end: 86% of dragonets and 84% of dab that passed through the meshes of the cod-end survived.
  Essence of methods: Empirical data through field experiment.
  Location: Irish Sea and North Sea.
  Habitat: 34 m depth; details on sediment characteristics not provided.

50) Lindeboom & de Groot (1998), NIOZ / RIVO research report:

- Essence of study: Extensive international EU research project on effects of different types of fisheries on the North Sea and Irish Sea benthic ecosystems.
  On impacts of beam trawling specifically:
  Physical impact - 4 m beam trawls exert pressure of 1.7-3.2 N/cm^2 on the seabed at speeds of 4-6kt. At 7 kt. larger beam trawls exert similar pressure, as their large weight is compensated by increased lift.

By-catch – By-catch of flatfish was at least as high as the marketable fish, by-catch of invertebrates was several times the amount of marketable fish, by-catch of round fish was relatively low (5% of total catch).
Direct mortality in discards– Mortality was variable among invertebrates, ranging from <19% in starfish to 50-70% in crustaceans to 90% in the bivalve *A. islandica*. Discarded fish showed mortality rates of 50-100%, with 100% for gadoids.
Direct mortality in trawl tracks – 10-40% for gastropods, starfish, crustaceans, worms and seamouse, 10-50% for *Echinocardium cordatum* and *Corystes cassavelaunus* and 30-80% for bivalves. Most species showing high direct mortality rates are fragile (e.g. *Echinocardium)* or live in the upper layer of the sediment (e.g. *Spisula*). Robust and deeply burrowing animals show lower mortality rates.
Effects on scavengers – Seabirds eat approximately 20% of discards. Annual food production by trawl mortality in northern North Sea is estimated at 1.8 g afdw/m^2. In southern North Sea, food addition supplied by fisheries to the benthic ecosystem may amount to 9% of total food demand per year. This is probably insufficient to promote a significant increase in population numbers.
Disturbance of the seabed – Trawling has a long-term effect on infaunal communities that were previously undisturbed, with some recovery times so long that they fail to recover before they are trawled again.
Long-term changes – In heavily trawled areas, greater numbers of opportunistic species were found whilst vulnerable, large and long-lived species are found more in protected areas. It is concluded that the observed long-term changes in benthic invertebrate communities are to a great extent caused by effects of fishing, and are not solely caused by eutrophication and pollution.
<u>Essence of methods</u>: Emperical data through field experiments and measurements, analysis of large and historical data sets, inquiries and literature review.
<u>Location</u>: North Sea and Irish Sea.
<u>Habitat</u>: Various.

51) Pederson *et al*. (2009), ICES Journal of Marine Science:

- <u>Essence of study</u>: The process used by the ICES project Environmentally Sound Fishery Management in Protected Areas (EMPAS) in developing fishery-management plans for each Natura 2000 site in German offshore waters. In the German exclusive economic zone, the habitat types protected by Natura 2000 include sandbanks and reefs; protected species include marine mammals, sea birds, and specific migratory fish species.
  Potential conflicts between fishing activities and nature conservation objectives in the Natura 2000 sites have been identified by the EMPAS project and in further analyses conducted by ICES, but they need to be documented further and evaluated scientifically. Nonetheless the following general passage is given in this paper: "A consequence of fishing with bottom-contacting gears on sandbank and reef habitats is the physical disturbance of the substratum caused

by trawling. Effects include the restructuring of the sediments, removal of large features, and reduction of habitat complexity and changes in benthic communities. The most damaging effect of trawling are the homogenization of the heterogeneous habitats, the structures of which are maintained by the benthic organisms themselves. For reefs there is evidence that the physical structures of stone and boulder reefs have been adversely affected in the past by towed gears. Bottom trawling increases the mortality of target and non-target species but also of benthic species that are damaged by the passing fishing gear. The impact of demersal trawling on the benthic communities increases with body size and fragility, as well as with decreasing mobility of the organisms. The selective mortality of benthic invertebrates has reduced the abundance of large, slow-growing species and shifted the benthic communities to a dominance of smaller, fast-growing species with high rates of reproduction in several areas of the North Sea.
Essence of methods: Analysis of large data sets and literature review.
Location: Natura 2000 sites in the German excusive economic zone (North Sea and Baltic Sea).
Habitat: Sandbanks and reefs.

52) Philippart (1998), ICES Journal of Marine Science:

- Essence of study: The long-term impact of otter- and beam trawl fisheries on several by-catch species of demersal fish and benthic invertebrates in the south-eastern North Sea. Within the last decades the main bottom fishery in this area has changed from otter- to beam trawling with beam trawling effort increasing from 1960 onwards. Otter trawls caught relatively more fish than invertebrates, while beam trawlers caught proportionally more invertebrates (e.g. velvet swimming crab, slender spindle shell). Furthermore the trends provided by the model show that bottom fisheries had a considerable impact on several demersal fish and benthic invertebrates. Otter trawling appeared to have resulted in an about 95% decline in the exploitable populations of roker and greater weever in the sampling area between 1947 and 1960. Smooth hound, common skate and angler fish populations decreased by more than 75%, whilst lesser-spotted dogfish, stingray, European lobster and edible crab decreased by more than 50% during this 14-year period. The slender spindle shell, velvet swimming crab and dahlia anemone appeared hardly affected by the otter trawling, but rapidly declined to less than 20% of the original population size (in 1947) when he beam trawling increased from 1960 onwards. The increase in beam trawling also coincided with a further reduction of smooth hound, roker, stingray, anglerfish, red whelk and lesser octopus to less than 5% of their original abundance in 1947.
Essence of methods: Analysis of existing data combined with modelling.
Location: North Sea, northwest of Netherlands.
Habitat: Various.

53) Thrush & Dayton (2002), Annual Review of Ecology and Systematics:

- Essence of study: The environmental effects of fishing are placed into the context of direct and indirect effects on marine biodiversity, considering biodiversity having both structural and functional components. Structural components include the distribution and abundance patterns of landscapes, habitats, communities, populations, and genotypes. Functional components involve mechanisms that drive interactions between species themselves and between them and other components of the environment, as well as other processes generating fluxes of energy and matter. The authors conclude that the extent and intensity of human disturbance to oceanic ecosystems is a significant threat to both structural and functional biodiversity and in many cases this has virtually eliminated natural systems that might serve as baselines to evaluate these impacts.

  Essence of methods: Literature review.

  Location: Global.

  Habitat: Diverse.

3.2 Potential impacts on Natura 2000 areas

To date, only a few studies have focussed on the impacts of beam trawling activities on habitats and species protected under the Natura 2000 network:

- Witbaard *et al.* (2007) concluded that recovery of natural values in future protected areas in the North Sea is impossible combined with beam trawling. This conclusion was drawn mainly with respect to large bivalves such as *Arctica islandica*.
- Deerenberg *et al*. (2009) concluded that beam trawling causes changes in habitat structure and populations of fish and benthos. Beam trawling has been found to decrease benthic diversity and abundance and fishing vessel activity may disturb protected animals such as birds or seals. Protected fish may be caught and prey fish for protected animals may be removed.
- Pederson *et al*. (2009):"A consequence of fishing with bottom-contacting gears on sandbank and reef habitats is the physical disturbance of the substratum caused by trawling. Effects include the restructuring of the sediments, removal of large features, and reduction of habitat complexity and changes in benthic communities. The most damaging effects of trawling are the homogenization of the heterogeneous habitats, the structures of which are maintained by the benthic organisms themselves. For reefs there is evidence that the physical structures of stone and boulder reefs have been adversely affected in the past by towed gears. Bottom trawling increases the mortality of target and non-target species but also of benthic species that are damaged by the passing gear."

To analyse potential conflicts between impacts of beam trawl fisheries and specific Natura 2000 goals, up to date analyses of fishing intensity and biodiversity aspects in such specific areas are needed. Such analyses are beyond the scope of this study. In the following paragraphs the habitat characteristics and the proposed management goals for the Dutch Natura 2000 habitats and species in the North Sea are summarised with the most relevant beam trawl impacts in relation to those goals.

3.2.1 1170 Reefs on open sea (Cleaver Bank)

Brief description of this habitat type extracted from Jak et al. (2009):
Characteristic for the Cleaver Bank is its high benthic biodiversity supported by large variation in habitat types (i.e. sand, mud, coarse gravel and rocks). Therefore it is one of the most unique areas in the Dutch North Sea. Over 44% of all species that occur in the Dutch Exclusive Economic Zone occur exclusively on the Cleaver Bank.

The proposed Natura 2000 goal for this area is:
Conservation of surface area and improvement of the quality of reefs. 'Good quality' is defined as 'presence of long-lived sessile hard substrate fauna'.

Scientifically demonstrated impacts (§ 3.1):
In addition to the three studies mentioned above, we found many studies demonstrating strong negative effects of beam trawling on long-lived, sessile, slow-growing epifauna and loss of benthic biodiversity. One study, Collie *et al*. (2000), concludes that gravel (present on the Cleaver Bank) and biogenic habitats are amongst the most vulnerable to the effects of beam trawl fisheries. High biodiversity is characteristic for the Cleaver Bank and the presence of long-lived sessile hard substrate fauna is a proposed Natura 2000 management goal.

3.2.2 1110_B Permanently flooded shallow sand banks (Noordzee-kustzone en Vlakte van de Raan)

Brief description of this habitat type extracted from Dutch Ministry of Agriculture, Nature and Food Quality (2008) and Jak et al. (2009):
Characteristic for these areas are dynamic conditions with regard to current velocity, wave action, clarity of the water and salinity. Typical species include the sensitive *Echinocardium cordatum*, the structure building *Lanice conchilega,* and the bivalves *Spisula subtruncata and Ensis spp..* The coastal zone is also a designated area for species protected under the Habitats Directive such as sea lamprey, river lamprey, twaite shad and several bird species protected under the Birds Directive (benthic bottom feeders, fish eaters and scavengers).

The proposed Natura 2000 goal for this area is:
Conservation of surface area and improvement of the quality of sand banks. To define the quality of sandbanks, characteristics of a good structure and function, and a list of characteristic species is given. Amongst others, local high densities of *Lanice conchilega, Spisula subtruncata* and *Ensis spp*. represent good structure and function.

Scientifically demonstrated impacts (§ 3.1):
In addition to the three studies that specifically focus on impacts on Natura 2000 areas, the general consensus is that sensitive species such as *Echinocardium cordatum* and shallow burrowing bivalves such as *Spisula spp.* experience high mortality rates from beam trawling. *Echinocardium chordatum* and *Spisula spp*. are characteristic species for the management goal 'improvement of the quality of sand banks'.

3.2.3 1110_C Permanently flooded shallow sand banks (Dogger Bank)

Brief description of this habitat type extracted from Jak et al. (2009):
Characteristic for the Dogger Bank is its large variability in depth and soft sediment types. In addition it is situated on the geographical border of many northerly- and southerly-distributed species. These two aspects result in a relatively high biodiversity of benthic fauna. Generally, individuals are numerous, but biomasses are relatively low on the Dogger Bank. Sandeels occur on the Dogger Bank in great numbers and are an important food source for seabirds. The Dogger Bank is one of the few areas in the North Sea with stingrays. Historically high numbers of rays (different species) were

caught in this area. Nowadays, numbers of opportunistic species have increased, whereas long-lived species such as rays and some bivalves have decreased.

The proposed Natura 2000 goal for this area is:
Conservation of surface area and improvement of the quality of sand banks. 'Good quality' is defined as 'presence of long-lived benthic species'.

Scientifically demonstrated impacts (§ 3.1):
In addition to the three studies mentioned above, we found many studies demonstrating strong negative effects of beam trawling activities on long-lived, sessile, slow-growing epifauna and loss of benthic biodiversity. High biodiversity is characteristic for the Dogger Bank and the presence of long-lived benthic species is a proposed Natura 2000 management goal.

3.2.4 Protected species (Birds Directive and Habitats Directive)

- Marine mammals: No empirical evidence for the impact on marine mammals by beam trawl fisheries in the North Sea was found. Deerenberg *et al*. (2009) made the general remark: "Fishing vessel activity may disturb animals (e.g. birds or seals). "
- Habitats Directive species sea lamprey, river lamprey and twaite shad: No empirical evidence for impacts on these specific species by beam trawl fisheries in the North Sea was found. However, Deerenberg *et al*. (2009) made the general remark: Protected fish may be caught and prey fish for protected animals may be removed.
- Birds Directive species linked to habitat 1110_b are (from Jak *et al*. 2009):
    - red-throated loon (fish eater)
    - black-throated loon (fish eater)
    - common eider (benthic feeder)
    - common scoter (benthic feeder)
    - little gull (feeds on small marine prey)
    - little tern (fish eater)

  Additional species listed for the proposed protection area of the Frisian Front:
    - great skua (scavenger and kleptoparasite)
    - great black-backed gull (scavenger and surface feeder)
    - common guillemot (fish eater)
    - lesser black-backed gull (scavenger and surface feeder)

  In Furness (2003), Lindeboom & de Groot (1998) and Tasker *et al*. (2000) it is suggested that fish eating birds are, in general, not negatively affected by beam trawl fisheries. The abundance of prey fish for such birds can be increased by changing fish population structures and removing large predatory fish. Scavenging species may benefit from discards thrown overboard by beam trawlers. Benthic feeders, especially those with bivalves as a main food source, may be adversely affected. Furness (2003) remarks: "desirable reduction of discards may have unfortunate side effects on seabird communities."

3.3 Impacts of otter trawling

This study focussed on impacts of beam trawling, but additionally we recorded impacts of otter trawling (as a potential alternative for beam trawling) when mentioned in the publications included in this study. The information provided in this paragraph is therefore very limited and should not be regarded as a literature review of impacts of otter trawling.

(1) Bergman & van Santbrink (2000), ICES Journal of Marine Science:

- Otter trawl versus beam trawl: Comparison of direct mortality of benthic megafaunal populations based on empirical data from field experiments. Otter trawling caused similar mortality to beam trawling on sandy substrate, but less mortality on silty bottoms.

(54) Hinz *et al*. (2000), Ecological Applications:

- Chronic otter trawling had a significant negative effect on the abundance, biomass and species richness of infaunal species. For epifauna, such an effect only existed for species richness. The community composition was affected by otter trawling, both for infauna and epifauna. The authors conclude that otter trawl impacts are cumulative and lead to profound changes in the benthic community.

(50) Lindeboom & de Groot (1998), NIOZ / RIVO research report:

- Otter trawlers have a lower catch-efficiency than beam trawlers, on both marketable fish as well as by-catch. In beam trawling, marketable fish accounted for 5-29% of the total catch (the rest is by-catch). In otter trawl hauls marketable fish accounted for 14-33% of the total catch. These differences result in a marketable fish / by-catch ratio for otter trawling that is more efficient than that of beam trawling. Thus, otter trawlers catch less by-catch per weight of marketable fish. Otter trawling has similar mortality rates of discards as beam trawling. In silty seabeds otter trawling causes lower mortality rates of burrowing species in trawl tracks than beam trawling. This is probably due to lower penetration depths of the sediment.

(55) Moran & Stephenson (2000), ICES Journal of Marine Science:

- Fishing with a semi-pelagic trawl had no measurable effect on benthos. The demersal otter trawl reduced the density of benthos species larger than 20 cm (only organisms larger than 20 cm were included in this study because of the limitations of the technique used: underwater video) by 15.5% on each tow through the site. Only 4% of the benthos detached was actually retained in the net. Comparison with other studies indicates that macrobenthos mortality can vary greatly, depending on how an otter trawl is rigged.

(52) Philippart (1998), ICES Journal of Marine Science:

- Results from models based on historical North Sea data show that otter trawls catch relatively more fish than invertebrates, while beam trawlers catch proportionally more invertebrates (e.g. velvet swimming crab, slender spindle shell) that were rarely delivered by otter trawlers. Furthermore, trends indicated by the model-output, show that bottom fisheries have considerable impact on several demersal fish and benthic invertebrates. Otter trawling appeared to have resulted in decline of about 95% in the exploitable populations of roker and greater weaver in the sampling area between 1947 and 1960. Smooth hound, common skate and angler fish populations decreased by more than 75%, whilst lesser-spotted dogfish, stingray, European lobster and edible crab decreased by more than 50% during this 14-year period. The slender spindle shell, velvet swimming crab and dahlia anemone appeared to be hardly affected by the otter trawling, but rapidly declined to less than 20% of the original population size (in 1947) when beam trawling increased from 1960 onwards. The increase in beam trawling also coincided with a further reduction of smooth hound, roker, stingray, anglerfish, red whelk and lesser octopus to less than 5% of their 1947 levels.

4 Discussion and conclusions

Interpreting impacts of beam trawling is complex as it depends on many different factors including the organisms present in the areas with trawling activities, the natural fluctuations in the abundance of these organisms, the recovery time, the nature of the substrate, the fishing gear characteristics, hydrodynamic conditions etc. For scientific evidence of impacts of beam trawling in either specific areas (e.g. Natura 2000 areas) or on particular species (e.g. benthos, fish, birds, marine mammals) detailed information about these factors is needed.

Most of the studies included in this report focus on direct impacts of beam trawling on benthic communities (34 studies) and/ or fish (14 studies). Direct impacts on these species may also have indirect effects on other species in the food chain. These effects can be 'bottom-up' (e.g. effects on benthic communities leading to changes in fish communities and/ or birds) or 'top-down' (e.g. removal of predatory fish species, causing shifts in prey species). Scientific research on these so called 'trophic cascade effects' is very limited and mainly depends on expert judgement. In this study no specific effort was carried out to collect such information (see search terms chapter 2). We focussed on direct effects on the species and community-level.

No papers were found in this study that scientifically demonstrate impacts of beam trawling activities on marine mammals in the North Sea and only few studies provided information about impacts on birds. This may be due to the fact that it is very difficult to scientifically demonstrate effects on these highly mobile species. Potential effects of beam trawling activities on marine mammals include capture of marine mammals and avoidance of or attraction to areas with beam trawling activities.

4.1 Ecological impacts of beam trawling

Despite the complexity of the causalities and the need for detailed information on both the trawling activities and organisms present in the areas with trawling activities, our short and limited literature review allows the following conclusions:

Benthic communities

Most papers included in this study specifically investigate impacts of beam trawling activities on benthic communities (34 of which 27 in the North Sea) (§ 3.1.1). In addition, information about impacts on benthic communities from eleven integral studies (§ 3.1.4) was used. The focus of these studies varied both in scale (from specific areas tot the entire North Sea) and time (short field experiments to long-term datasets), and different methods were applied to demonstrate impacts (field- and laboratory experiments, analyses of long-term datasets, modelling, literature review). Based on these documents the following conclusions can be drawn about impacts of beam trawling on benthic communities in the North Sea (in brackets reference numbers of studies demonstrating a specific impact/ aspect):

- Long-lived, slow-growing species (such cold-water sponges and -corals and large bivalves) are most negatively affected by beam trawling activities (12 studies: 2, 8, 12, 13, 19, 22, 23, 24, 27, 34, 50, 51);
- Shifts occur in the benthic species composition as a result of beam trawling activities (2, 3, 6, 7, 10, 11, 12, 19, 22, 23, 27, 33, 51);
- Ecosystems changes occur as a result of beam trawling activities through alteration of production levels, food chains or population structures (7, 8, 10, 16, 21, 22, 26, 27, 29, 30, 31, 32, 34, 45, 47, 43, 44, 48, 53);
- Beam trawling activities lead to loss of benthic biodiversity (2, 3, 21, 25, 31, 45, 53);
- Beam trawling activities temporarily increase the food availability for scavengers (5, 11, 12, 18, 19, 47, 48, 50);
- In many areas recovery times take longer than between-trawling intervals (4, 11,13, 30, 50);
- Beam trawling activities cause direct mortality of certain species (1, 14, 27, 33, 48, 49, 50); One study states that direct mortality on infauna and epifauna caused by trawling in the North Sea is overestimated in several studies (15);
- Impacts of beam trawling on benthic communities differ between habitats. In sandy areas Impacts are lower than in muddy areas or areas with coarse gravel (4, 10, 11, 13, 16, 26, 32, 33, 48).

Fish

In this study, seven scientific publications were included that specifically investigate impacts of beam trawling activities on fish (six in the North Sea; § 3.1.1). In addition, information about impacts on fish from eleven integral studies (§ 3.1.4) was included. Most of the specific studies on impacts of fish were based on analyses of long-term existing datasets (five studies) for (large areas of) the entire North Sea. The integral studies were based on the collection of empirical data through field experiments, sometimes combined with modelling (three studies), analyses of long-term datasets (three studies), and literature reviews (four studies). Based on these documents the following conclusions can be drawn about impacts of beam trawling on fish in the North Sea (in brackets reference numbers of studies demonstrating a specific impact/ aspect):

- Beam trawling activities can cause an increase in the abundance of smaller sized fish (35, 36, 41);
- Beam trawling activities can increase the growth rate of some fish species (e.g. plaice) as a result of higher food abundance, removed competition and/ or less predation by large fish (36, 39, 40);
- Beam trawling increases the food availability for scavenging fish species (38, 41);
- Large slow-growing fish species (e.g. elasmobranchs) tend to be most adversely affected by beam trawling activities (36, 41);
- Trawling activities cause direct mortality of unwanted catches (discards) (46, 49, 50).

Birds
The number of scientific publications found in this study, which specifically demonstrate impacts of beam trawling on birds, is low (two specific studies and one integral study). The articles included in this report (42, 43, 50) suggest that fish-eating birds are not negatively affected, that scavenging species may profit from discards, and that birds feeding on bivalves can be affected negatively.

4.2 Impacts in relation to Natura 2000

Very few studies on the impacts of beam trawling were carried out in the specific Natura 2000 areas in the North Sea. Comparing former conclusions on species or communities with specific Natura 2000 goals though, gives insight in expected impacts on these goals. Based on our brief and limited literature research the following conclusion can be drawn about impacts of beam trawling on Natura 2000 areas identified in the Dutch part of the North Sea:

- For habitats 1170 (Cleaver Bank) and 1110_C (Dogger Bank) a proposed conservation goal is improvement of the natural qualities of these areas with “quality” defined as the ‘presence of long-lived benthic species’. Both areas are characterised by a high benthic diversity. This relates to two of the scientifically most demonstrated impacts of beam trawling on benthic communities: 1) a negative impact on long-lived, slow-growing species and 2) loss of benthic biodiversity.
- The proposed Natura 2000 goals for habitat 1110_B (Vlakte van de Raan and Kustzone) is conservation of the surface area and improvement of the quality of sand banks. Characteristic species for ‘good quality of sand banks’ are, amongst others, *Echinocardium cordatum* and *Spisula subtruncata*. This relates to one scientifically demonstrated impact of beam trawling: a high direct mortality rate in both of these species.

With respect to the impact of beam trawling activities on species protected under the Birds and Habitat Directives:

- No empirical evidence was found that scientifically demonstrates impacts of beam trawling activities on marine mammals or sea lamprey, river lamprey and twaite shad (species protected by the Habitats Directive) in the North Sea.
- No empirical evidence was found that demonstrates impacts on the following species linked to Natura 2000 areas in the Dutch part of the North Sea: red-throated loon (fish eater), black-throated loon (fish eater), common eider (benthic feeder), common scoter (benthic feeder), little gull (feeding on small marine preys), little tern (fish eater), great skua (scavenger and kleptoparasite), great black-backed gull (scavenger and surface feeder), common guillemot (fish eater) and lesserblack-backed gull (scavenger and surface feeder).

  However results of studies focussing on seabirds included in this report suggest that fish-eating birds are not negatively affected, that scavenging species may profit from discards, and that birds feeding on bivalves can be affected negatively.

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