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POSSIBLE EFFECTS ON BENTHIC ECOSYSTEMS OF FISHERY EXCLUSION, A REVIEW IN THE FRAME OF WINDMILL FARMS. PARTIM SAND HABITATS

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Auteurs

Gert Van Hoey

Jochen Depestele

Kris Hostens

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Gert Van Hoey, Jochen Depestele, Kris Hostens

Instituut voor Landbouw- en Visserijonderzoek

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1 Introduction

In order to ensure safety, wind farms are prohibited area for most other human activities, including bottom trawling. Bottom trawls are used to catch demersal fish and invertebrates but also plough the seabed, with a negative impact on fragile, long-lived bottom dwelling organisms. It is generally accepted that bottom trawling has a strong impact on the structure of benthic communities: trawl gear ploughs the seabed to a depth of 3 to 6 cm, causes sediment resuspension, and removes both the fisheries target and non-target species (Bergman & Hup 1992, Dayton et al. 1985, Jones 1992, Rabaut et al. 2008; Rijnsdorp et al. 2017). As a result of this disturbance, the macro-endofauna communities have evolved into communities dominated by opportunistic, short-lived, fast-growing and quickly reproducing, so-called r-strategist species (Collie et al. 2000, Frid et al. 2000, Jennings et al. 2001, Kaiser et al. 2002, Kaiser & Spencer 1996). Removing regular physical disturbance can possibly lead to a return and survival of long-lived, vulnerable species (K-strategists). Therefore, the exclusion of bottom-disturbing activities in wind farms could provide sheltering areas for demersal fish species and offer local opportunities for the recovery of key species in terms of endo- and epifauna (including K-strategists and habitat structuring species). Regarding fishery exclusion at current operational wind farms in the BPNS, we observed subtly changes in fishing activity (De Backer et al., 2019). There is a remarkable decrease in fishing activity in the Offshore Wind Farm (OWF) area, but fishermen are not avoiding the areas around the OWF, and even seem to be attracted to the edges. This is a common phenomenon observed around fishery exclusion areas. Therefore, the potential of wind farms as sheltering area, thereby contributing to the health status of commercial fish stocks, still needs to be proved on the longer term.
At present, scientific research is fragmentary and limited to grey literature in monitoring reports and a limited number of scientific publications, which cautiously suggest a recovery of endofauna in wind farms (e.g. Bergman et al. 2015, Coates et al. 2016). However, sound conclusions require a more thorough literature review, in which the fragmented results are analysed in a more consistent manner and accompanied by an estimate of the uncertainty surrounding the conclusions, in relation to the quality of the data, duration of the studies, used methodology, etc.).

The aim of this partim study is to get more insight into the effect of excluding bottom disturbing activities, in casu bottom trawling, on the characteristics (diversity, density, biomass and size spectra of long-lived and habitat structuring species) of the endo- and epifauna communities of sandy sediments in wind farms. Additionally, a number of key species that can contribute to nature restoration in relation to Natura 2000 and/or the Marine Strategy Framework Directive (MSFD), are defined. An analysis of the impact of the exclusion of fisheries on gravel bed habitat is not comprised in this study, but will be subject of a follow-up study.

2 Material and Methods

To get a sound insight into the potential effects of fishery exclusion on the benthic ecosystem in wind farms, a literature review was carried out on the following aspects:

1) Aspect 1: Literature on the bottom fauna in current offshore wind farms, where no fishing activity is allowed;
2) Aspect 2: Studies that summarize the effect of bottom trawling on the endo- and epifauna in shallow sandy bottoms;
3) Aspect 3: Literature on the evolution of bottom fauna in fishery exclusion zones in shallow sandy bottoms in temperate climate regions (<50 m, excluding tropical and deep sea studies).

The literature examined for these different aspects were selected as follows. For aspect 1, the A1 publications on changes in benthos in wind farms (Coates et al., 2015, 2016; Bergman et al., 2015; Roach et al., 2018) were supplemented with information from a non-exhaustive number of monitoring reports of wind farms in the North Sea (Belgium, the Netherlands, Germany, Denmark, UK), as summarized in Jak & Glorius (2016) plus other reports that recently became available (Degraer et al., 2019). This literature was analyzed according to the analytical protocol as defined below. For aspects 2 and 3, we used the literature overview published in Hiddink et al. (2019 & 2020 [in revision], see Annex 1), representing a meta-analysis of fishery bottom impact studies by means of an experimental or comparative set-up. For aspect 2, those meta-analyses are shortly summarized, as there is enough documentation of benthic impact over a gradient of fishing intensities. For aspect 3, a number of publications on real fishery exclusion studies in relevant ecosystems were selected from the literature list in Hiddink et al. (2019, 2020), and summarized according to the analytical protocol (see below). For Northwest-Europe, there are only a few examples around offshore oil and gas installations and one large MPA area (Lyme Bay - UK, protecting cobbles and boulders). Beside it, we included a few studies from the Mediterranean area and from North America (Georges bank in the Gulf of Maine). Most studies looked at epifauna, whereas infauna sampling was not always included in the monitoring.

<u>Analytical protocol for literature review</u>

A set of relevant publications were evaluated for the observed effects in terms of impact on and recovery of sea bottom fauna (endo- and epifauna). Extra attention was paid to the confidence level of the observed results in the various studies. A qualitative assessment was carried out with three classes for both effect and confidence (+: positive effect or low uncertainty; 0: no effect or average uncertainty; -: negative effect or high uncertainty).

To assess the uncertainty, we looked at the sampling design (i.e. number of observations, distribution of samples), the time period covered by the measurements, the covered surface area, historical disturbance (based on the background knowledge on the area), and the presented confidence levels.

To assess the effect of bottom trawling, we concentrated on generic community characteristics (i.e. endo- and epifauna density, diversity, biomass and size-spectra) and basic characteristics of habitat structuring and long-lived, K-strategist species (Table 1).

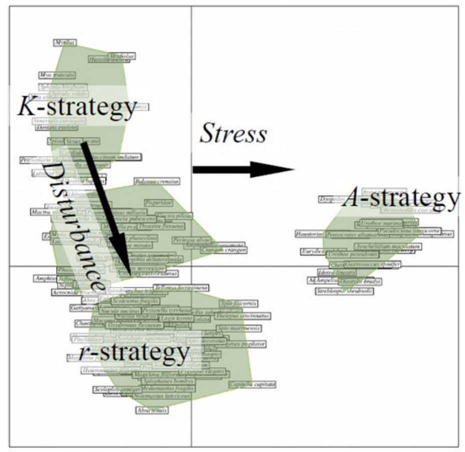
Table 1. Fictitious example of literature summary.

	Study A	**Study B**
Metadata		
Timing	1 year	10 years
Surface area	Not specified	10 km²
Sampling frequency	3 x per year	1 x per year

Historical disturbance	2 years after construction			
	Effect	**Confidence**		**Effect**
Community	+	-	Community	+
Key species A	0	-	Key species A	0
Key species B	-	-	Key species B	-

Based on the information in the table, we formulated recommendations, focusing on what is needed (preconditions) to facilitate the recovery of certain key species in terms of endo- and epifauna of soft-sediment ecosystems, potentially within wind farms. This aspect is tackled by explaining which type of species can profit from reduced physical disturbance (by fishery cessation) in the Belgian Part of the North Sea (BPNS).

BOX: Life history strategy (K, r and A-type) of benthic species (Beauchard et al., 2017; ICES, 2017).



Life history typologies may provide a useful approach to derive meaningful marine ecological indicators expressing the effects of environmental pressures and their variability (Beauchard et al., 2017). Based on life history, species can be grouped in three strategic groups (r, K and A strategists), in relation to natural stress and anthropogenic disturbance gradients.
A-strategist species are those that are adapted to naturally highly stressed environments, have a short life span, early maturity, continuously reproduction and release progenies with a high degree of survival.
R-strategists are more adapted to anthropogenically disturbed environments and mainly consist of pioneer and opportunistic organisms with fast growth and local dispersal.
When the anthropogenic and natural disturbance is lower, the ecosystem will be more dominated by K-strategists. The K-strategists exhibit quite vulnerable functions, such as slow growth, late sexual maturity and absence of parental care.
K-strategists are most vulnerable as their sensitivity to disturbance is high and their recoverability low. In contrast, r-strategist species are resilient as their sensitivity can be high or low, but their recoverability is high. A-strategists are classified as resistant species, which are able to tolerate the physical stress and may provide strong reproductive allocation (e.g. continuous reproduction to sustain reproductive success).

Functional ability	Species type		
	Resistant	Resilient	Vulnerable
Sensitivity	None	Low or High	High
Recoverability	Not applicable	High	Low

3 Results

3.1 Aspect 1: Bottom fauna changes in the current wind farms.

There are yet hardly any peer-reviewed publications on the effects of wind farms on sea-bottom fauna. Two mechanisms are hypothesized to cause a potential effect, namely the exclusion of bottom trawling (Bergman et al., 2015, Coates et al., 2016) and the introduction of hard substrates (the enrichment effect) (Coates et al., 2015, 2016). The major conclusion from these publications is that if any effects are found, those are subtle, scattered and often temporary (Table 2). Similar effects were listed in the summarizing reports, regarding the monitoring in different wind farm concessions in Belgium, The Netherlands, UK, Germany and Denmark (Table 3).

Most benthic community variables (density, biomass, diversity, species composition) showed no changes over time, except for a slight diversity increase in the study of Bergman et al. (2015). No significant shift in species composition, compared to the T0 or a control area (similar habitat) is observed in any of those studies. In relation to ecological relevant species for our waters, a possible increase of *Spisula solida* can be expected as observed in the Netherlands. Also, the size of certain bivalve species (e.g. *Tellina fabula*) can increase (Bergman et al., 2015), although this finding was not confirmed in other Dutch wind farm monitoring reports (Jarvis et al., 2004, Vanagt et al., 2013, Lock et al., 2014). The sea-urchins *Echinocardium cordatum* and *Echinocyamus pusillus* are positively affected in the Belgian wind farms, whereas this is not observed in the German and Dutch studies. Some other epibenthic species (European lobster, edible crab) seem to profit from the scour protection around the foundations (Roach et al., 2018, Gutow et al., 2014). In general, the diversity and density of epifauna does not change on the scale of the wind farm concession area, except for a temporary increase after the construction works, as observed in the Belgian wind farms (De Backer et al., 2017).

Table 2. Overview of bottom fauna changes in wind farms as distilled from published A1 papers

	Bergman et al., 2015		**Coates et al., 2015**		**Coates et al., 2016**		**Roach et al., 2018**	
Time frame	2007-2011		2005-2010-2011		2008-2012		Effect during closure for construction	
Area	Dutch coastal zone		Thornton bank (Belgium)		Thornton bank (Belgium)		Westermost Rough OWF (35km²), North East England	
Sampling	Boxcorer + Triple D dredge		Van Veen grab		Van Veen grab		creels	
Historic disturbance	yes, fishery		yes, fishery		yes, fishery		Fishery area and boulder removal prior to construction	
Habitat type	Sandy		Medium sands		Medium sands		Rock - cobble substrate, with sandy patches	
Community characteristics	**Effect**	**confidence**	**Effect**	**confidence**	**Effect**	**confidence**	**Effect**	**confidence**
Density	0	+	0	+	0	+		
Biomass	0	+	0	+	0	+		
Diversity	+	+	0	+	0	+		
Species composition	0	+	0	+	0	+		
Spisula solida	+	+						
Gastrosaccus spinifer			+	+	+	+		
Echinocyamus pusilus			+	+	+	+		
Terebeliidae spp			+	+	+	+		
Size (*Tellina fabula, Ensis directus*)	+	+						
European lobster (density, size)							+	+
Comments	Subtle changes		Temporary effect of construction; only increase in species number and density very close to turbine		Subtle changes			

Table 3. Overview of bottom fauna changes as distilled from recent wind farm monitoring reports. Effect: + significant density increase, 0 no change, - significant decrease. Confidence: low (-), medium (0), high (+).

	WinMon.BE (Belgium); Lefaible et al., 2019		**WinMon.BE (Belgium); Lefaible et al., 2019**		**WinMon.BE (Belgium); De Backer et al., 2017**		**Leonhard & Pedersen, 2006**	
Time frame	2018-2019: Close to the turbine (37.5m)		2018-2019: Close to the turbine (37.5m)		2005-2016 (construction 2008&2011)		1991&2001 (pre) - 2003-2005 (post)	
Area	Thornton bank (Jacket foundation)		Bligh bank (monopiles)		Thorntonbank		Denmark, Horns REV I	
Sampling	Van Veen grab		Van Veen grab		Beam trawl (8m)		cores by diving	
Habitat type	Medium sands		Medium sands		Medium sands		Medium fine sand to coarse sand; shallow (5-13m)	
Community characteristic	**Effect**	**confidence**	**Effect**	**confidence**	**Effect**	**confidence**	**Effect**	**confidence**
Density	+	+	0	+	0	+	0	+
Biomass	+	+	+	+	0	+	0	+
Diversity	+ (S) and -(J')	+	0	+	0	+	0	+
Species composition	+	+	0	+	0	+	0	+
Spisula solida							0	+
Echinocyamus pusilus			+	+				
Comments	Turbine related impacts only very local (not always obvious): changes in species composition, is mainly a density issue of different typical species (e.g. *Spiophanes bombyx*)		Also positive changes, but not significant as for Thornton bank. *Spiophanes bombyx* is also increased		Epifauna and demersal fish. A post-construction "overshoot" in epibenthic density and biomass observed, but temporary (only 2 years after construction)		The results show rather a large natural fluctuation than a wind farm effect. No difference with distance from piles.	

	Vattenfall, 2009		**Gutow et al. (2014)**		**Jarvis et al., 2004, Lock et al., 2014, van Hal et al., 2013**		**Jarvis et al., 2004, Daan et al., 2009, Bergman et al., 2012**	
Time frame	2002 (pre) - 2005-2007 (post)		2008 (pre) - 2009-2011		2003 (pre) - 2012-2013 post)		2003 (pre) - 2012-2013 post)	
Area	Kentish Flats wind farm (UK)		Alpha Ventus (Germany)		Prinses Amelia (Nederland)		Egmond-aan-zee (Nederland)	
Sampling			Van Veen grab & 2m beam trawl		Boxcorer, shell dredge, 6m shrimp beam trawl		Boxcorer, different dredges	
Habitat type	From sand (moderate to poorly sorted) to gravely sand and gravely muddy sand; shallow area (3-5m)		Homogenuous fine sand, 30m depth		sandy, 22m depth		sandy, 19m depth	
Community characteristic	**Effect**	**confidence**	**Effect**	**confidence**	**Effect**	**confidence**	**Effect**	**confidence**
Density	0	+	0	+	0	+	0	+
Biomass	0	+	0	+	0	+	0	+
Diversity	0	+	0	+	0	+	+	+
Species composition	0	+	0	+			0	+
Spisula solida							+	+
Terebeliidae spp	0							
Echinocardium cordatum			0	+	0	+		
Size (*Tellina fabula, Ensis directus*)					0	+	+	+
Editable crab			+	+				
Abundance/Biomass epifauna			-	0	0	0		
Comments	Changes due to natural variation, also for certain species as *Lanice conchilega, Spiophanes bombyx, Abra alba, Scoloplos armiger* .		No significant wind farm effect. Changes due to natural variation; dominant species *Spiophanes bombyx, Echinocardium cordatum*		No significant wind farm effect observed		Positive values only in some years, no real wind farm effect, only some nonsignificant indications of potential wind farm effects were found.	

In the vicinity of the windmills, an increase in density of certain species is mentioned in several studies (Coates et al., 2015; Lefaible et al., 2019). This was not confirmed in the Horns Rev I wind farm, where no difference with distance from piles was noted (sampling by divers, taking cores from near the pile to further away) (Leonhard & Pedersen, 2006). If there are changes over time, the bristleworm *Spiophanes bombyx* is mentioned most frequently. *Spiophanes bombyx* is regarded as a typical r-strategist species with a short lifespan, high dispersal potential and high reproductive rate, quickly colonizing unstable habitats (Ager, 2005). Furthermore, Terebellidae spp. (*Lanice conchilega*) are sometimes observed in higher abundances nearby the windmills. As for *S. bombyx*, also *L. conchilega* prefers sandy mud to sandy sediments in more sheltered environments (Ager, 2005, 2008). Such environmental conditions are typically found in the vicinity of the windmills. Therefore, those species may be found more frequently and in higher abundances than what is normally expected in offshore sandy environments.

All these observations mainly prove a so-called ‘enrichment effect’, i.e. certain benthic species from different taxonomic groups profit from the shelter and higher food supply in the wind farms. Although effects concerning the recovery potential of benthic communities are expected when fishery is excluded within an area (see further), up till now, not that much can actually be attributed to the fact that fishery is indeed excluded in the wind farms.

The effect of changes in physical disturbance on benthic species strongly depends on local environmental conditions, which has been noted in different wind farm monitoring programs (Jak & Glorius, 2017). Most offshore wind farms are installed in relatively shallow areas, characterized by medium to coarse sandy sediments. In such benthic habitats, the natural physical disturbance due to tides and wave action is already high, and the endo- and epifauna is already adapted to physical stress (also see 3.4). This may largely explain why general effects of the exclusion of bottom trawling, mainly concerning typical A and r-strategist species, will probably remain subtle, especially on a wider scale.

On the other hand, recovery of long-lived K-strategist species is slow, and as the time period after construction for most wind farms is still too short, the potential effects of fishery exclusion in wind farms may not yet be detectable (e.g. Bergman et al., 2015).

Additionally, the whole wind farm concession area is probably not yet large enough to demonstrate (positive) effects of fisheries exclusion beyond the immediate vicinity of the windmills. The example of the European lobster (Roach et al., 2018), and in some studies the occurrence of larger bivalve species (*Spisula, Tellina*), may indicate a size effect, potentially related to fishery exclusion. However, this size effect cannot be confirmed yet, as in most monitoring studies length-frequency measurements for bivalves are not taken into account.

3.2 Aspect 2: impact of bottom trawling on endo- and epifauna (diversity, density, biomass) in shallow soft-sediments

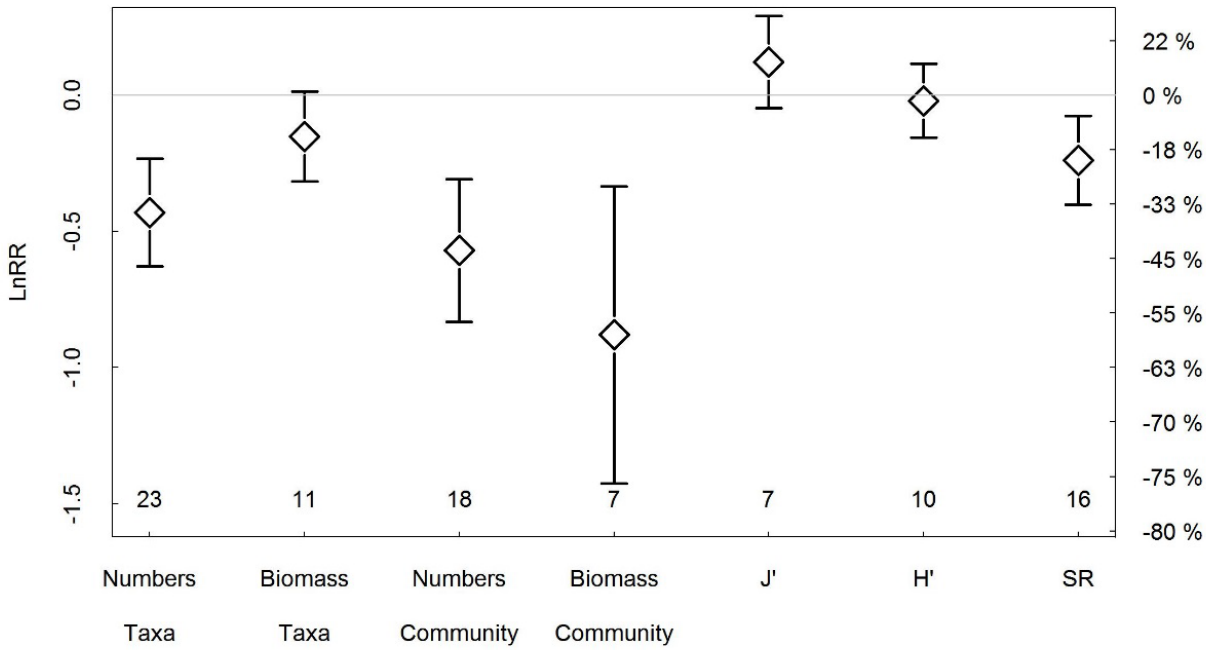


Figure 1. ***Outputs of the meta-analysis of control-impact studies with 95% confidence intervals. If the 95% confidence interval overlaps 0 the effect was not significant. Left-axis = logarithmic response ratio (LnRR); Right axis gives % changes for ease of interpretation. J': Evenness, H': Shannon-Wiener diversity index, SR: species richness. Numbers at the bottom of the graph represent the number of studies. Figure and legend taken from Hiddink et al. (in revision).***

Seabed disturbing fishing techniques have a strong influence on the structure of benthic communities, as summarized in the meta-analysis in Hiddink et al. (in revision). Trawling has a negative effect on community biomass, and to a lesser extent on community density, number of taxa and benthic species diversity (Figure 1). The evenness and Shannon-Wiener diversity indicators do not show changes after bottom trawling.

The abundance and biomass of all taxonomic groups are lower due to bottom trawling, but significant effects were only shown for some groups (30-40 % reduction for Anthozoa, Polychaeta, Malacostraca and Bivalvia) (Figure 2). The responses in density and biomass for Ascidiacea, Gastropoda, Asteroidea and Ophiuroidea were weaker and not significant. Due to the size of the confidence intervals for each benthic group, we can assume that there are no significant differences in response to bottom fishing pressure between the taxonomic groups . This indicates that in soft substrate ecosystems there is no specific benthic group more suitable than others as an indicator for fishery impact assessments.

Hiddink et al. (2019) also looked at differences in response in abundance of taxa of different longevity classes (Figure 3). There was no significant difference for organisms with a life span of <1 year, while there is a more or less significant decrease (on average -10 ± 10 %) for organisms with a life span >1 year in the experimental setup, and a significant decrease (on average -37% ± 20 % CI) for organisms with a life span >3 years, when looking at chronic trawling effects.

Studies on the effect of fishery disturbance on the functioning of the sediments are scarce. Sciberras et al. (2016) conclude that the effects of trawling on the biogeochemistry are larger in mud compared to mobile sands, and that these effects are not mediated by changes in the infauna. The study of Tiano et al. (2019) implies that bottom trawling disturbance can lead to immediate declines in benthic community metabolism.

In conclusion, impact studies clearly show a negative effect of fishery on the benthic community, which seems not dependent on the higher ‘benthic Class’ division, albeit a bit more pronounced for some taxa. A clear negative effect on biomass and abundance is noted, at least for the long-lived taxa (>1 year longevity). Important to note is that the meta-analysis of Hiddink et al. (in revision) did not take into account the shifting baseline phenomenon, which implies that species which are highly vulnerable to trawling most probably already disappeared before any trawling impact study could detect these changes.

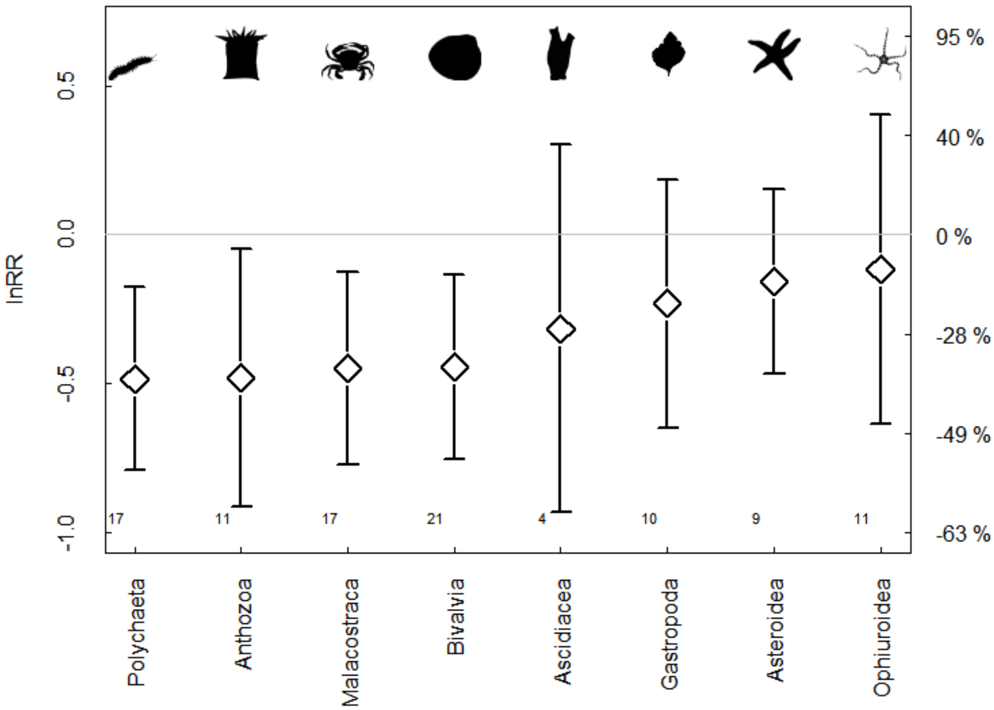


Figure 2. Effect of trawling on the number and biomass of different taxonomic Classes of benthic invertebrates, represented by as mean logarithmic response ratio (lnRR) and 95% confidence intervals (Left axis) and % change (Right axis). N (= number of studies reporting on each taxon) is given under each bar. Effect sizes represent the mean of the responses of the individual taxa that constitute a Class.” Figure taken from Hiddink et al. (in revision)

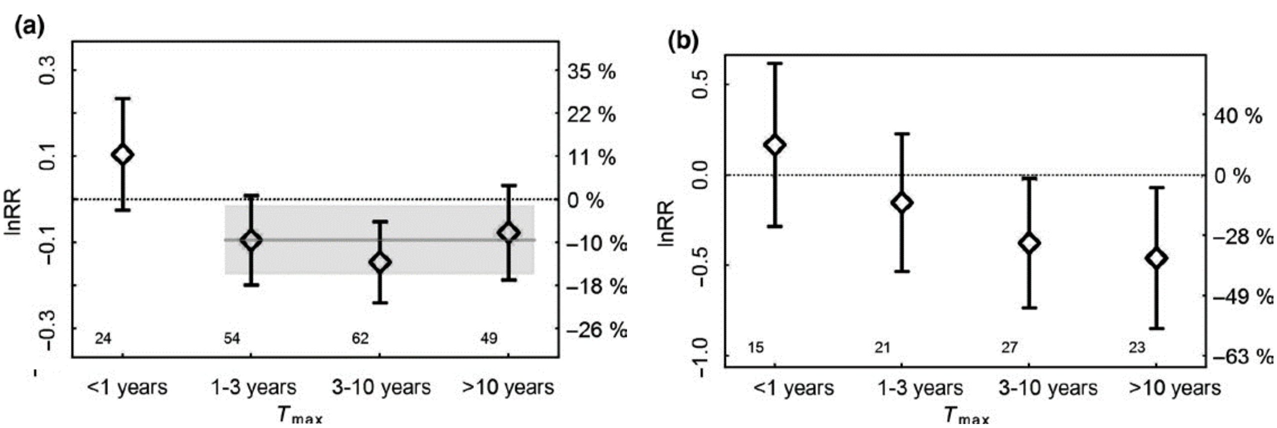


Figure 3. The effect of bottom trawling on the abundance of benthic taxa (as log response ratio, lnRR) for different longevities (mean and 95% confidence interval). (a) Effect of a single trawl pass in experimental studies. The grey line and shaded bar indicate the mean effect (d = 0.09) and confidence interval for biota with $T_{max} > 1$ year. (b) Difference between control and impact locations in comparative TU studies concerning chronic trawling. If the 95% confidence interval of lnRR overlaps 0, the effect was not significant. The right-hand axis indicates the responses in % changes. The number of studies included in each estimate is given below each bar. Figure taken from Hiddink et al. (in revision).

3.3 Aspect 3: Evolution in sea-bottom fauna following bottom trawling cessation in shallow areas in temperate regions (<50m).

In Hiddink et al. (2006a), two trawling cessation strategies were put forward to provide benefit for the benthic communities on a large scale: (1) closures in areas where existing fishing effort is low will lead to less effort displacement and are more likely to benefit benthic communities than closures in areas where fishing effort is high; (2) effort reductions resulting from days at sea restrictions and decommissioning schemes are likely to reduce the spatial footprint of fishing activity.

Accordingly, estimates of recovery time for North Sea benthos were based on experimental trawling or on the comparison of "lightly" and "heavily" trawled areas (Collie et al., 2000; Kaiser et al., 2006). Models derived from these estimates predict recovery rates of 100 days in terms of abundance (Collie et al., 2000) and 1 to 3 years in terms of biomass and production (Hiddink et al., 2006b) after cessation of bottom trawling in sandy bottom communities. The recovery rates of biota depend on their life-history, including larval longevity and dispersal potential (Kaiser et al., 2018). Recovery for species that had low dispersal potential and specific habitat requirements was slow and could take >20 years in Lyme Bay (UK). This suggests that activities such as bottom-trawling or dredging should be avoided where such species occur, at least if their conservation is an objective. In contrast, species with high dispersal potential and less habitat specific requirements had shorter recovery timescales of ~2-3 years and would be more amenable if trawling frequencies in fishing areas are managed adequately (Kaiser et al., 2018).

It remains to be seen whether trawling cessation will cause a benthic regime shift (sensu Amaro, 2005; Allen and Clarke, 2007; Van Nes et al., 2007) towards a high biomass–low turnover system (K-strategists), presumably leading to a higher biodiversity (see Worm et al., 2006). Regarding fishery management, both closure and effort reductions will have an effect. However, closure should focus mainly on areas with sensitive benthic habitats, and still containing slowly recovering species. Effort reduction is expected to have a much lower effect for slow recovering species. Nevertheless, the recovery time after the implementation of a fishery management strategy is crucial, as outlined above.

The above theory was explored in more detail by comparing studies where real fishery cessation takes places (Table 4). Collie et al. (2005) reported an increase in benthic abundance, biomass and production after 2.5 years fishery cessation on gravely bottoms (Georges Bank, Gulf of Maine), which continued until 5 years after closure (end of observational period). This was confirmed by Asch & Collie (2008), where the colonial epifauna is clearly more abundant in the fishery exclusion zone. For the western closure area in Gulf of Maine 3-6 years after cessation, this area was more dominated by disturbance intolerant, sessile families, compared to the fished area. Only two studies dealt with infaunal recovery. De Juan et al. (2007) found fewer scavengers and more surface infauna and epifauna (in particular suspension feeders and predatory fish) 1 year after closure of a muddy habitat situated in the north-western Mediterranean Sea. This was confirmed in another study from this area, where more places, with longer fishery exclusion periods, were compared (De Juan et al., 2011). The infauna species richness, density and biomass were higher in the fishery exclusion areas, whereas the epifauna was not really different between the places. Duineveld et al. (2007) reported an increase in species richness, evenness, and abundance of mud shrimps and fragile large bivalves in epifaunal beam-trawl samples in a sandy habitat at the Frisian front (southern North Sea). The results from infauna box-core samples were inconsistent, even after 20 years of closure. In the study of Dannheim et al. (2014) at an offshore installation, a subtle, positive effect on the trophic structure of the benthic fauna was observed.

In conclusion, it is more or less clear from most studies that an increase in the benthic community characteristics can be expected when fishery is excluded within an area. The duration of the recovery depends on the local conditions and the historical fishing effort in the area. The reported examples show changes following a long fishery exclusion history (up to 20-30 years).

Table 4. Overview of publications on studies dealing with trawl cessation and impact on epi- and endofauna..

	Hiddink et al., 2006		**Danheim et al., 2014**		**De Juan et al., 2007**		**Duineveld et al., 2007**		**Asch & Collie, 2008**		**De Biasi, A.M. & Pacciardi, L. (2008**	
Time frame	Modelling study		14 months closure		unfished area (20j) versus fished		around gas production platform		fishery exclusion zone		around Gas platform	
Area	North Sea		research platform FINO 1		NW Meditarenean sea (Ebro delta)		Frisian Front		George bank (N America)		Middle Adriatic Sea	
Size area	North Sea area		0.43 km2		2.7km²		very small					
Sampling	model		Van Veen grab		epifaunal dredge		epifauna € triple D-dredge/ box cores (infauna[i]		photography			
Historic disturbance	NVT		yes		20 years undisturbed		20 years closure				10 year	
Habitat type	Soft -sediment		fine sand (mud ±4%, D50: +177µm)		mud		sandy habitat		sand & gravel			
Community characteristics	**Effect**	**confidence**	**Effect**	**confidence**	**Effect**	**confidence**	**Effect**	**confidence**	**Effect**	**confidence**	**Effect**	**confidence**
Density					+	+			+	+		
Biomass	-	+										
Diversity	-	+					+ €; 0 (i)	+				
Species composition												
Trophic changes			-	+								
Epifaunal suspension feeders					+	+						
epifaunal scavangers					-	+						
Callianassa, Upogebia							+	+			+	0
fragile Bivalves							+	+				
colonial epifauna									+	+		
Comments	Only positive effect on total North Sea are, when effort reduction, not closure		Subtle changes in trophic structure									

	De Juan, S., et al 2011		**Link et al., 2005**		**Sciberras et al., 2013**		**Sheehan et al., 2013**		**Collie et al., 2005**	
Time frame	gradient study, oil		Western Gulf of Maine Closure		Cardigan Bay SAC (UK)		MPA			
Area	NW Mediterranean		Gulf of Maine (N America)		Cardigan Bay SAC (UK)		Lyme Bay (UK)		George bank (N America)	
Size area			relative large				206km²			
Sampling	epifaunal dredge (e) / Van Veen grab (i)		video transect / grab samples		video for epifauna		video for epifauna			
Historic disturbance	10 to 30 years closure		3-6 years after fishery		23 months after		3 years monitoring after closure		yes	
Habitat type	mud		coarse sand		coarse sand to gravel		sand, but mainly cobles and boulders		gravel	
Community characteristics	**Effect**	**confidence**	**Effect**	**confidence**	**Effect**	**confidence**	**Effect**	**confidence**	**Effect**	**confidence**
Density	0 (e) / + (i)	+	+	+			+	+	+	+
Biomass	+ (e)	+							+	+
Diversity	0 (e&i); + (Srich i)	+	+	+	0	0	+	+		
Species composition	0	+	+	+						
Trophic changes										
scallops					0	0				
Alcynonium digitatum							+	+		
Comments	more biogenically habitat-structured communities at undisturbed sites		WGOMC were dominated by more disturbance intolerant, sessile families				the New Closure community characteristcs becoming more similar to the Closed Controls and less similar to the Open Controls (fished); slow recovery			

3.4 Key species that may profit from reduced physical disturbance

In this section, we give some suggestions on benthic key species in the Belgian Part of the North Sea (BPNS) that can profit from a reduced physical disturbance (in relation to fishery exclusion). The benthic communities and their structural and functional characteristics in the BPNS are well known (Breine et al., 2018). For this report, we modelled the probability of occurrence of different life-history strategic groups in the BPNS (Figure 4). This indicates that A-strategists dominate the sandbanks in the offshore area where the current and new wind farm concessions are located. This type of species will profit less from lowered physical disturbance by fishery exclusion, except maybe a small density increase. Such higher density is observed in the Thornton bank area in the vicinity of the turbines for the amphipod *Urothoe brevicornis* (Lefaible et al., 2019) and the mysid *Gastrosaccus spinifer* (Coates et al., 2015, 2016), both A-strategists and common species in sandy sediments. Nevertheless, also K-strategists are present in this offshore area (probability 10-20 %), and their occurrence can increase when wind farms are built and subsequently bottom trawling fisheries are excluded.

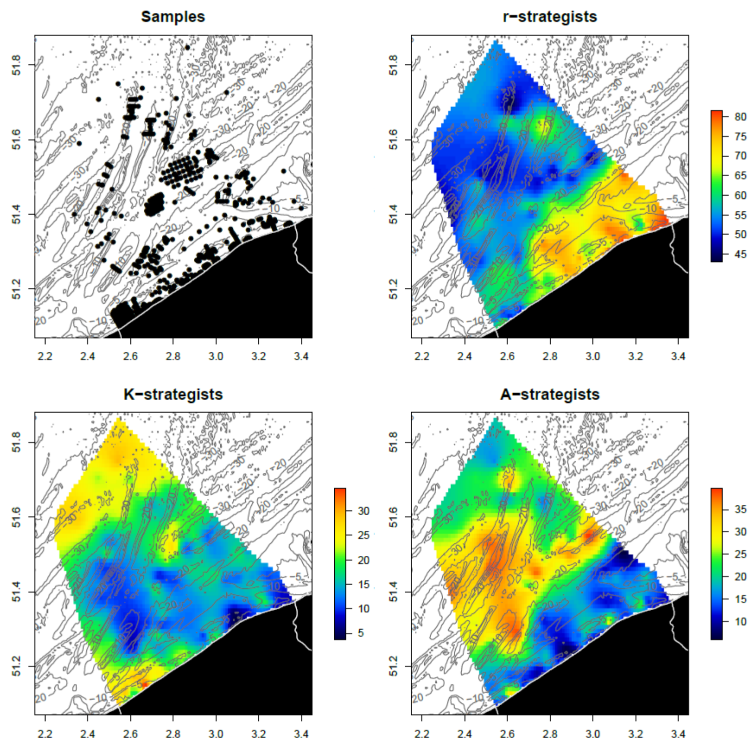


Figure 4. Spatially modelled distributions of r-, K- and A-strategists macrobenthic species in the Belgian part of the North Sea (credits to Olivier Beauchard), based on benthic data from Breine et al. (2018).

Those K-strategist species are also defined within the MSFD guidelines, in order to improve their status related to a sound nature conservation program (Table 5). Species like *Aphrodita aculeata* (much more abundant before 2000 in the BPNS) and *Dosinia exoleta* are catalogued as very rare for the BPNS, whereas *Glycemeris glycemeris* and *Buccinum undatum* are rare (Belgische staat, 2018). Some of the species (*Lutraria lutraria* and *Upogebia deltaura [r-strategist]*) are not optimally sampled for estimating their occurrence. Nevertheless, they have seldomly been recorded over the last 20 years in the BPNS. The edible crab, *Cancer pagurus*, is not frequently recorded in regular soft sediment monitoring in the BPNS, but is known to occur in higher densities in stony areas and around the windmills (Gutow et al., 2014). *Echinocardium cordatum* is recorded frequently (30 to 40 % of the samples) in medium to coarse sands, with densities between 5 to 10 ind/m². *Pestarella* spp. (r-strategist) are recorded sometimes (<10 % of the

samples) and in low densities. The occurrence of those species will potentially increase when their habitat is less disturbed.
Active restoration measures for those K- and r-strategist species are not known yet. The conditions to facilitate recovery of those species are mainly: reduction of disturbance and enough time. The explored studies (Table 4) revealed that the timing of observing an effect is very variable and dependent on local conditions. The time needed for recovery of K-(and r)- strategist species in the BPNS area, cannot easily be predicted, as this depends on many factors (e.g. recruitment success, presence of nearby populations, currents, the species itself, habitat type, local conditions, etc.). Moreover, there is not yet any area with a fishery closure to learn from. Nevertheless, recovery in the BPNS, and more specifically the wind farm concessions, seems to be feasible, as most of the mentioned species are still present in the Southern Bight of the North Sea.

Table 5. Examples of long-lived, slowly reproducing, and habitat structuring species in mud to muddy sand and medium to coarse sands (Belgische staat 2018).

	Long-living and/or slow reproducing species; K-strategists	Important habitat structuring species; r-strategists
Mud to muddy sand	Bigger Bivalves as *Venerupis corrugata, Mya truncata* and *Lutraria lutraria**	Big tube worms as *Lanice conchilega, Owenia fusiformis* and *Lagis koreni*
	Other big species as *Buccinum undatum* and *Aphrodita aculeata*	Bigger deep sediment digging species as *Pestarella* spp.
Medium to coarse sand - gravel	Bigger bivalves as *Laevicardium crassum, Glycymeris glycymeris* and *Dosinia exoleta*	Bigger deep sediment digging species as *Upogebia deltaura* and *Corystes cassivelanus*
	Other big species *Cancer pagurus, Echinocardium cordatum* and *Branchiostoma lanceolatum*	

4 General conclusions and recommendations

Surprisingly, the current literature review study did not find much evidence of effects on benthic ecosystems in wind farms in relation to fishery exclusion, which does not mean that there is no effect. There were no or only subtle changes noted in some general benthic community parameters (diversity, density, biomass) and for a limited number of species. It remains difficult to proof that fishery exclusion really has an effect on the benthic communities in those areas.
The major compromising issue here is the short time frames of the different monitoring studies and the slow recovery time of certain types of species (e.g. K-strategists). Most monitoring studies, and for sure the limited number of A1-publications up till now, only cover a relatively short study period (one to three years). Benthic recovery (at least for K-strategists) is a slow process, so to obtain a more complete insight into the combined effects of operational wind farms and fishery exclusion, the time period monitored should cover at least one – and preferably more - decennia. Ideally, it should be a combination of a yearly monitoring program at some locations, and more intensely at certain periodic intervals with a broader spatial coverage. Moreover, the monitoring strategy should be based on a combination of different observation techniques (e.g. grab, video, beam trawl, dredge) to be able to observe the entire benthic ecosystem spectrum.

Another compromising issue is the fact that the windfarms are currently built in highly hydrodynamic areas, populated by A and r-strategists. Those resistant and resilient species are less sensitive to physical disturbance, which reduces the ability of finding effects of fishery exclusion in those areas.
The main effects currently seen in most wind farms can be attributed to a so-called enrichment effect (provision of shelter and food) close to the foundations for a limited number of soft bottom benthic species from different taxonomic Classes, i.e. bivalves (e.g. *Spisula solida*), polychaetes (e.g. *Spiophanes bombyx*), echinoderms (e.g. *Echinocyamus pusillus*) and crustaceans (e.g. *Homarus gammarus*). These effects are not uniform across different wind farms in the North Sea. Potentially, the presence of larger specimen of different species may be related to fishery exclusion in wind farms and in MPAs, however, currently there is no sound information to prove this size-effect. We suggest that monitoring for size-dependency should be taken into account in future research and benthos monitoring in wind farms.
Fishery exclusion in relation to MPAs and nearby oil- and gas platforms, shows a clear benefit for the benthic community after cessation of bottom disturbing activities. Fishery impact studies have shown that bottom trawling has a clear negative effect on benthic community biomass and diversity (number of taxa). Density and biomass (sometimes significantly) decrease for different (endo)benthic taxonomic groups in relation to fisheries. Those negative effects were not reflected in short-lived species (r-strategists), but well pronounced for long-lived (K-strategist) species with a lifespan of >3 years.
All fishery exclusion studies (both short experimental and long-term research), , showed a clear increase in benthic community characteristics after cessation of bottom disturbing activities (aka fisheries) in the studied areas, in European as well as in Mediterranean and US waters. Still, the recovery clearly depends on the local conditions and the historical fishing effort in the area.
For the Belgian (and other) parts of the North Sea, the effects of fishery exclusion (which as shown is most obvious for K-strategists) will probably not be visible in the short term. In these chronic disturbed and dynamic environments, it will be hard to observe changes in diversity, abundance or biomass of the benthic communities after fishery exclusion. Several bigger, ecologically important species, e.g. *Echinocardium cordatum*, *Aphrodita aculeata* and some bivalve species (*Spisula*, *Dosinia*), might benefit from wind farm concession areas where fishery remains excluded. Reduced physical disturbance and long time periods (decennia) will create optimal conditions for recovery of such K-strategists. Active restoration measures for those type of species are not yet known, and deserve more attention.

5 References

Ager, O.E.D. 2005. Spiophanes bombyx A bristleworm. 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. [cited 11-12-2019]. Available from: https://www.marlin.ac.uk/species/detail/1705

Ager, O.E.D. 2008. Lanice conchilega Sand mason. 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. [cited 11-12-2019]. Available from: https://www.marlin.ac.uk/species/detail/1642

Belgische Staat, 2018. Actualisatie van de initiële beoordeling voor de Belgische mariene wateren. Kaderrichtlijn Mariene Strategie – Art 8 lid 1a & 1b. BMM, Federale Overheidsdienst Volksgezondheid, Veiligheid van de Voedselketen en Leefmilieu, Brussel, België, 243 pp.

Bergman, M.J.N., Hup, M., 1992. Direct effects of beam trawling on macrofauna in a sandy sediment in the Southern North Sea. ICES Journal Marine Science 49, 5–11.

Bergman M., G. Duineveld, R. Daan, M. Mulder & S. Ubels 2012. "Impact of OWEZ wind farm on the local macrobenthos community". OWEZ_R_261_T2_20121010.

Bergman, M. J. N., Ubels, S. M., Duineveld, G. C. A., and Meesters, E. W. G. 2015. "Effects of a 5-year trawling ban on the local benthic community in a wind farm in the Dutch coastal zone". ICES Journal of Marine Science, 72: 962-972.

Beauchard, O., Verissimo, H., Queiros, A.M., Herman, P.M.J., 2017. The use of multiple biological traits in marine community ecology and its potential in ecological indicator development. Ecological indicators 76, 81-96.

Collie, J.S., Hall, S.J., Kaiser, M.J., Poiner, I.R., 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. Journal of Animal Ecology 69, 785–798

Collie, J.S., Hermsen, J.M., Valentine, P.C., Almeida, F.P., 2005. Effects of fishing on gravel habitats: assessment and recovery of benthic megafauna on Georges Bank. American Fisheries Society Symposium, 41, pp. 325–343.

Daan, R., M. Mulder, M.J.N. Bergman 2009. "Impact of wind farm OWEZ on the local macrobenthos community". NIOZ report OWEZ_R_261_T120091216, pp 77.

Dayton, P.K., Thrush, S.F., Agardy, M.T., Hofman, R.J., 1995. Environmental effects of marine fishing. Aquatic Conservation for Marine and Freshwater Ecosystems 5, 205–232.

De Backer, A., Hostens, K., 2017. Effects of Belgian offshore wind farms on soft sediment epibenthos and fish: an updated time series. In Degraer, S., Brabant, R., Rumes, B. & Vigin, L. (eds). 2017. Environmental impacts of offshore wind farms in the Belgian part of the North Sea: A continued move towards integration and quantification. Brussels: Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management Section.

De Backer, A., Polet, H., Klaas, S., Vanelslander, B., Hostens,K. , 2019. Fishing activities in and around Belgian offshore wind farms: trends in effort and landings over the period 2006-2017. In Degraer, S., Brabant, R., Rumes, B. & Vigin, L. (eds). 2019. Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Marking a Decade of Monitoring, Research and Innovation. Brussels: Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management, 134 p.

Denderen PD, Bolam SG, Hiddink JG, Jennings S, Kenny A, Rijnsdorp AD, van Kooten T (2015) Similar effects of bottom trawling and natural disturbance on composition and function of benthic communities across habitats. Marine Ecology Progress Serie 541:31-43. https://doi.org/10.3354/meps11550

Duineveld, G.C.A., Bergman, M.J.N., Lavaleye, M.S.S., 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.

Frid, C.L.J., Harwood, K.G., Hall, S.J., Hall, J.A., 2000. Long-term changes in the benthic communities on North Sea fishing grounds. ICES Journal of Marine Science 57,1303–1309.

Gutow, L., K. Teschke, A. Schmidt, J. Dannheim, R. Krone, and M. Gusky. 2014. Rapid Increase of Benthic Structural and Functional Diversity at the Alpha Ventus Offshore Test Site. Pp. 67-81 in Ecological Research at the Offshore Wind farm Alpha Ventus. Springer Fachmedien, Wiesbaden, Germany.

Hiddink, J. G., Hutton, T., Jennings, S. & Kaiser, M. J., 1 Jun 2006, Predicting the effects of area closures and fishing effort restrictions on the production, biomass, and species richness of benthic invertebrate communities. In : ICES Journal of Marine Science. 63, 5, p. 822-830

Hiddink, J. G., Jennings, S., Kaiser, M. J., Queiros, A. M., Duplisea, D. E. & Piet, G. J., Apr 2006, Cumulative impacts of seabed trawl disturbance on benthic biomass, production, and species richness in different habitats. In : Canadian Journal of Fisheries and Aquatic Sciences. 63, 4, p. 721-736

Hiddink, J., Jennings, S., Sciberras, M., Szostek, C., Hughes, K., Ellis, N., ... Kaiser, M. (2017). Global analysis of depletion and recovery of seabed biota following bottom trawling disturbance. Proceedings of the National Academy of Sciences of the United States of America, 114(31), 8301-8306. https://doi.org/10.1073/pnas.1618858114

Hiddink, J.G., Kaiser, M.J., Sciberras, M., McConnaughey, R.A., Mazor, T., Hilborn, R., Collie, J.S., Pitcher, R., Parma, A.M., Suuronen, P., Rijnsdorp, A.D., Jennings, S., in revision. Selection of indicators for assessing and managing the impacts of bottom trawling on seabed habitats. Journal of Applied Ecology.

Hughes, K. M., Kaiser, M. J., Jennings, S., McConnaughey, R. A., Pitcher, R., Hilborn, R., ... Rijnsdorp, A. D. (2014). Investigating the effects of mobile bottom fishing on benthic biota: a systematic review protocol. Environmental Evidence, 3(23). https://doi.org/10.1186/2047-2382-3- 23

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

Jarvis, S., J. Allen, N. Proctor, A. Crossfield, O. Dawes, A. Leighton, L. McNeill, W. Musk 2004. "Dutch Wind farms: NSW Lot 1 Benthic Fauna". Final Report. ZBB607.2-F-2004, pp.89.

Jennings, S., Dinmore, T.A., Duplisea, D.E., Warr, K.J., Lancaster, J.E., 2001. Trawling disturbance can modify benthic production processes. Journal of Animal Ecology 70,459–475.

Jones, J.B., 1992. Environmental impact of trawling on the seabed: a review. New Zealand Journal of Marine and Freshwater Research. 26, 59–67.

Jak, R. & S.T. Glorius, 2017. Marcobenthos in offshore wind farms; A review of research, results, and relevance for future developments. Wageningen Marine Research (University & Research centre), Wageningen Marine Research report C043/17. 477 pp

Lefaible, N., Colson, L., Braeckman, U., Moens, T., 2019. Evaluation of turbine-related impacts on macrobenthic communities within two offshore wind farms during the operational phase. In Degraer, S., Brabant, R., Rumes, B. & Vigin, L. (eds). 2019. Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Marking a Decade of Monitoring, Research and Innovation. Brussels: Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management, 134 p.

Leonhard, S.B. & J. Pedersen, 2006. "Benthic Communities at Horns Rev Before, During and After Construction of Horns Rev Offshore Wind farm." Final Report - Annual Report 2005. Bio/consult as. 134 pp.

Lambert GI, Jennings S, Kaiser MJ, Hinz H, Hiddink JG (2011) Quantification and prediction of the impact of fishing on epifaunal communities. Marine Ecology Progress Serie 430:71-86. https://doi.org/10.3354/meps09112

Lock, K., M. Faasse, T. Vanagt, 2014. "An Assessment of the soft sediment fauna six years after construction of the Princess Amalia Wind farm". eCOAST report 2013002, pp. 151.

Kaiser, M.J., Spencer, B.E., 1996. The effects of beam-trawl disturbance on infaunal communities in different habitats. Journal of Animal Ecology 65, 348–358.

Kaiser, M.J., Collie, J.S., Hall, S.J., Jennings, S., Poiner, I.R., 2002. Modification of marine habitats by trawling activities: prognosis and solutions. Fish and Fisheries 3,114–136.

Kaiser, M. J., Hilborn, R., Jennings, S., Amaroso, R., Andersen, M., Balliet, K., ... Sutherland, W. J. (2016). Prioritization of knowledge-needs to achieve best practices for bottom trawling in relation to seabed habitats. Fish and Fisheries, 17(3), 637-663. https://doi.org/10.1111/faf.12134

Kaiser, M., Hormbrey, S., Booth, J. R., Hinz, H. & Hiddink, J., May 2018, Recovery linked to life history of sessile epifauna following exclusion of towed-mobile fishing gear. In : Journal of Applied Ecology. 55, 3, p. 1060-1070

Queiros, A. M., Hiddink, J. G., Kaiser, M. J. & Hinz, H., 25 Jul 2006, Effects of chronic bottom trawling disturbance on benthic biomass, production and size spectra in different habitats. Journal of Experimental Marine Biology and Ecology. 335, 1, p. 91-103

Rabaut, M., Braeckman, U., Hendrickx, F., Vincx, M., Degraer, S., 2008. Experimental beam-trawling in Lanice conchilega reefs: impact on the associated fauna. Fishery Research 90, 209–216.

Rijnsdorp, A.D., Eigaard, O.R., Kenny, A., Hiddink, J.G., Hamon, K., Piet, G., et al. 2017. Benhtis Final report, 27 p.

Sciberras, M., Parker, R., Powell, C., Robertson, C., Kroger, S., Bolam, S., & Hiddink, J. (2016). Impacts of Bottom Fishing on Sediment Biogeochemical and Biological Parameters in Cohesive and Non-cohesive Sediments. Limnology and Oceanography, 61(6), 2076-2089. https://doi.org/10.1002/lno.10354

Skold, M., Göransson, P., Jonsson, P., Bastardie, F., Blomqvist, M., Agrenius, S., ... Bartolino, V. (2018). Effects of chronic bottom trawling on soft seafloor macrofauna in the Kattegat. Marine Ecology Progress Series, 586, 41-55. https://doi.org/10.3354/meps12434

Tiano, J.C., Witbaard, R., Bergman, M.J.N., van Rijswijk, P., Tramper, A., van Oevelen, D., Soetaert, K., 2019. Acute impacts of bottom trawl gears on benthic metabolislm and nutrient cycling. ICES Journal of Marine Science, 76(6), 1917-1930.

Tillin, H. M., Hiddink, J. G., Jennings, S. & Kaiser, M. J., 3 Aug 2006, Chronic bottom trawling alters the functional composition of benthic invertebrate communities on a sea basin scale. Marine Ecology Progress Series. 318, p. 31-45

Vattenfall, 2009. "Kentish Flats Offshore Wind farm FEPA Monitoring Summary Report, March 2009". pp 74.

6 Annex 1. References from the meta-analysis paper by Hiddink et al. (in revision) that were selected or rejected for the literature review on real fishery exclusion studies.

Archambault, P. & Goudreau, P. (2006) Effect of the commercial fishery on the Ile Rouge Iceland scallop (Chlamys islandica) bed in the St. Lawrence estuary: assessment of the impacts on scallops and the benthic community. Fisheries and Oceans Canada, Institut Maurice-Lamontagne, Ottawa, ON (Canada).

➔ Not relevant, no fishery exclusion

Asch, R.G. & Collie, J.S. (2008) Changes in a benthic megafaunal community due to disturbance from bottom fishing and the establishment of a fishery closure. Fishery Bulletin, 106, 438-456.

➔ Included

Blyth, R.E., Kaiser, M.J., Edwards-Jones, G. & Hart, P.J.B. (2004) Implications of a zoned fishery management system for marine benthic communities. Journal of Applied Ecology, 41, 951-961.

➔ No fishery exclusion, four fishery regimes, no significant changes

Bordehore, C., Ramos-Espla, A.A. & Riosmena-Rodriguez, R. (2003) Comparative study of two maerl beds with different otter trawling history, southeast Iberian Peninsula. Aquatic Conservation-Marine and Freshwater Ecosystems, 13, S43-S54.

➔ Not relevant, mearl beds

Brown, E., Finney, B., Hills, S. & Dommisse, M. (2005) Effects of commercial otter trawling on benthic communities in the southeastern Bering Sea. American Fisheries Society Symposium, 41, 439-491.

➔ Not relevant, no fishery exclusion

Carbines, G. & Cole, R.G. (2009) Using a remote drift underwater video (DUV) to examine dredge impacts on demersal fishes and benthic habitat complexity in Foveaux Strait, Southern New Zealand. Fisheries Research, 96, 230-237.

➔ Not relevant, no fishery exclusion

Chícharo, L., Regala, J., Gaspar, M., Alves, F. & Chícharo, A. (2002) Macrofauna spatial differences within clam dredge-tracks and their implications for short-term fishing effect studies. Fisheries Research, 54, 349-354.

➔ Not relevant, no fishery exclusion

Clarke, S. & Tully, O. (2014) BACI monitoring of effects of hydraulic dredging for cockles on intertidal benthic habitats of Dundalk Bay, Ireland. Journal of the Marine Biological Association of the United Kingdom, 94, 1451-1464.

➔ Not relevant, intertidal habitat

Collie, J.S., Escanero, G.A. & Valentine, P.C. (1997) Effects of bottom fishing on the benthic megafauna of Georges bank. Marine Ecology-Progress Series, 155, 159-172.

➔ Not relevant, no fishery exclusion, already studies of that area examined

Collie, J.S., Escanero, G.A. & Valentine, P.C. (2000) Photographic evaluation of the impacts of bottom fishing on benthic epifauna. ICES Journal of Marine Science, 57, 987-1001.

➔ Not relevant, no fishery exclusion, already studies of that area examined.

De Biasi, A.M. & Pacciardi, L. (2008) Macrobenthic communities in a fishery exclusion zone and in a trawled area of the middle Adriatic Sea (Italy). Ciencias Marinas, 34, 433-444.

➔ Included

de Juan, S., Thrush, S.F. & Demestre, M. (2007) Functional changes as indicators of trawling disturbance on a benthic community located in a fishing ground (NW Mediterranean Sea). Marine Ecology Progress Series, 334, 117–129.

➔ Included

De Juan, S., Demestre, M. & Sanchez, P. (2011) Exploring the degree of trawling disturbance by the analysis of benthic communities ranging from a heavily exploited fishing ground to an undisturbed area in the NW Mediterranean. Scientia Marina, 75, 507-516.

➔ Included

Engel, J. & Kvitek, R. (1998) Effects of otter trawling on a benthic community in Monterey Bay National Marine Sanctuary. Conservation Biology, 12, 1204-1214.

➔ Not relevant, Site at deep water (180m)

Frid, C.L.J., Clark, R.A. & Hall, J.A. (1999) Long-term changes in the benthos on a heavily fished ground off the NE coast of England. Marine Ecology Progress Series, 188, 13-20.

➔ Not relevant, no fishery exclusion

Handley, S.J., Willis, T.J., Cole, R.G., Bradley, A., Cairney, D.J., Brown, S.N. & Carter, M.E. (2014) The importance of benchmarking habitat structure and composition for understanding the extent of fishing impacts in soft sediment ecosystems. Journal of Sea Research, 86, 58-68.

➔ Not relevant, no fishery exclusion & other climate region (Tasman sea)

Hannah, R.W., Jones, S.A., Miller, W. & Knight, J.S. (2010) Effects of trawling for ocean shrimp (Pandalus jordani) on macroinvertebrate abundance and diversity at four sites near Nehalem Bank, Oregon. Fishery Bulletin, 108, 30-38.

➔ Not relevant, no fishery exclusion

Hiddink, J.G. (2003) Effects of suction-dredging for cockles on non-target fauna in the Wadden Sea. Journal of Sea Research, 50, 315-323.

➔ Not relevant, intertidal environment

Hinz, H., Tarrant, D., Ridgeway, A., Kaiser, M.J. & Hiddink, J.G. (2011) Effects of scallop dredging on temperate reef fauna. Marine Ecology-Progress Series, 432, 91-102.

➔ Not relevant, rock bottom

Kaiser, M.J., Ramsay, K., Richardson, C.A., Spence, F.E. & Brand, A.R. (2000) Chronic fishing disturbance has changed shelf sea benthic community structure. Journal of Animal Ecology, 69, 494-503.

➔ Not relevant, no fishery exclusion

Langton, R.W. & Robinson, W.E. (1990) Faunal associations on scallop grounds in the western Gulf of Maine. Journal of Experimental Marine Biology and Ecology, 144, 157-171.

➔ Not relevant, no fishery exclusion

Ligas, A., De Biasi, A.M., Demestre, M., Pacciardi, L., Sartor, P. & Cartes, J.E. (2009) Effects of chronic trawling disturbance on the secondary production of suprabenthic and infaunal crustacean communities in the Adriatic Sea (NW Mediterranean). Ciencias Marinas, 35, 95-207.

➔ Not relevant, no fishery exclusion

Link, J., Almeida, F., Valentine, P., Auster, P., Reid, R. & Vitaliano, J. (2005) The effects of area closures on Georges Bank. Benthic habitats and the effects of fishing. American Fisheries Society Symposium 41 (ed. by P. Barnes and J. Thomas), pp. 345-369. American Fisheries Society, Bethesda, M.D.

➔ Included

McConnaughey, R.A., Mier, K.L. & Dew, C.B. (2000) An examination of chronic trawling effects on soft-bottom benthos of the eastern Bering Sea. ICES Journal of Marine Science, 57, 1377-1388.

➔ Not relevant, no fishery exclusion, other climate region

Percival, P. (2004) Impacts of trawl fisheries on marine benthic biogeochemistry. (BL: DXN071512). Ph.D., University of Newcastle Upon Tyne (United Kingdom), Ann Arbor.

➔ Not relevant, no fishery exclusion

Piersma, T., Koolhaas, A., Dekinga, A., Beukema, J.J., Dekker, R. & Essink, K. (2001) Long-term indirect effects of mechanical cockle-dredging on intertidal bivalve stocks in the Wadden Sea. Journal of Applied Ecology, 38, 976-990.

➔ Not relevant, intertidal environment

Sciberras, M., Hinz, H., Bennell, J.D., Jenkins, S.R., Hawkins, S.J. & Kaiser, M.J. (2013) Benthic community response to a scallop dredging closure within a dynamic seabed habitat. Marine Ecology Progress Series, 480, 83-+.

➔ Included

Sheehan, E.V., Stevens, T.F., Gall, S.C., Cousens, S.L. & Attrill, M.J. (2013) Recovery of a temperate reef assemblage in a marine protected area following the exclusion of towed demersal fishing: E83883. PLoS ONE, 8

➔ Included

Sheridan, P. & Doerr, J. (2005) Short-term effects of the cessation of shrimp trawling on Texas benthic habitats. Benthic Habitats and the Effects of Fishing (ed. by B.W. Barnes and J.P. Thomas), pp. 571-578.

➔ Not relevant, other climate region

Simpson, A.W. & Watling, L. (2006) An investigation of the cumulative impacts of shrimp trawling on mud-bottom fishing grounds in the Gulf of Maine: effects on habitat and macrofaunal community structure. ICES Journal of Marine Science, 63, 1616-1630.

➔ Not relevant, no fishery closure

Smith, B.E., Collie, J.S. & Lengyel, N.L. (2013) Effects of chronic bottom fishing on the benthic epifauna and diets of demersal fishes on northern Georges Bank. Mar. Ecol. Prog. Ser, 472, 199-217.

➔ Not relevant, no fishery closure

Smith, C., Papadopoulou, K. & Diliberto, S. (2000) Impact of otter trawling on an eastern Mediterranean commercial trawl fishing ground. ICES Journal of Marine Science, 57, 1340.

➔ Not relevant, no fishery closure

Stokesbury, K.D.E. & Harris, B.P. (2006) Impact of limited short-term sea scallop fishery on epibenthic community of Georges Bank closed areas. Marine Ecology Progress Series, 307, 85-100.

➔ Not relevant, already similar work of that area included

Van Dolah, R.F., Wendt, P.H. & Levisen, M.V. (1991) A study of the effects of shrimp trawling on benthic communities in two South Carolina sounds. Fisheries Research, 12, 139-156.

➔ Not relevant, no fishery closure

7 Annex 2: Abstracts of the A1 publications that were used for the detailed analyses in this report.

Wind farm studies:

Bergman, M. J., Ubels, S. M., Duineveld, G. C., & Meesters, E. W. (2015). Effects of a 5-year trawling ban on the local benthic community in a wind farm in the Dutch coastal zone. *ICES Journal of Marine Science: Journal du Conseil*, *72*(3), 962-972.

As part of a large impact study in a wind farm (OWEZ) in the Dutch coastal zone, the effects of exclusion of bottom trawling on the benthic community were studied by comparison with nearby reference areas which were regularly fished. In addition to a standard boxcorer for common macrofauna, a Triple-D dredge was used to collect longer-lived, more sparsely distributed infauna and epifauna. Multivariate analysis did not reveal any difference between the assemblages in and outside OWEZ with respect to abundance, biomass, and production after a 5year closure. T he ShannonWiener diversity index pointed to a significantly higher diversity in OWEZ compared with some of the r eference areas. A minority of the bivalve species assumed to be sensitive to trawling showed higher abundances (Spisula solida) or larger sizes (Tellina fabula, Ensis directus) in OWEZ than in some of the reference areas. In genera l, samples collected with the TripleD showed more differences between areas than boxcore samples. No evidence was also found that the species composition in OWEZ relative to the reference areas had changed in the period bet ween 1 (2007) and 5 (2011) years after closure. The change observed in all areas between 2007 and 2011 was main ly due to relatively small variations in species abundances. In conclusion, 5 years after the closure of OWEZ to fishe ries, only subtle changes were measured in the local benthic community, i.e. a higher species diversity and an incre ased abundance and lengths of some bivalves. Depleted adult stocks, faunal patchiness, and a limited time forreco very (5 years) might explain that a significant recovery could not be found. The current study shows that designation of large-scale marine protected areas as planned for the North Sea will not automatically imply that restoration of benthic assemblages can be expected within a relatively short period of years.

Coates D, Van Hoey, G., Colson, L., Vincx, M., Vanaverbeke, J., 2015. Rapid macrobenthic recovery after dredging activities in an offshore wind farm in the Belgian part of the North Sea. Hydrobiologia 756(1). P3-18

The development of offshore wind farms (OWFs) in the North Sea has increased considerably to create alternatives for fossil fuel energy. Activities related to the construction of OWFs, in particular gravity based foundations (GBFs), are mainly associated to dredging, causing direct effects to the macrofauna in the seabed. The sediment characteristics and macrofauna were studied before and after construction (2005 – 2010) of six GBFs in an OWF in the Belgian part of the North Sea. We distinguished natural from anthropogenic related fluctuations in macrofaunal communities by analysing a long term dataset (1980 - 2012). The analysed sandbanks are characterised by sandy substrates and a community with low species abundance (180 – 812 ind m-222) and diversity (6 – 15 species per 0.1 m223). Strong temporal variations were observed possibly related to variable weather conditions in the area. Significant differences in community composition were observed due to the installation of six GBFs in the construction year of the OWF followed by a rapid recovery a year later and confirmed by the benthic ecosystem quality index BEQI. Even though the construction of GBFs creates a physical disturbance to the seabed, the macrobenthic community of these sediments have illustrated a fast recovery potential.

Coates, D.A., Kapasakali D.-A, Vincx, M., Vanaverbeke, J. 2016. Short-term effects of fishery exclusion in offshore wind farms on macrofaunal communities in the Belgian Part of the North Sea. Fisheries Research 179: 131-138

With the wide scale construction of offshore wind farms (OWFs) throughout the entire North Sea, large areas are permanently being closed to beam trawl fisheries. Beam trawling has affected macrobenthic assemblages for cent uries, especially the fragile and longlived species. Due to the prohibition of bean trawling in many OWFs, opportun ities are being provided to investigate the potential recovery of vulnerable species and the creation of defacto Ma rine Protected Areas (MPAs). The softsubstrate macrobenthic community was investigated from 2008 to 2012, bef ore and after the construction of an OWF in the Belgian part of the North Sea, situated on the Bligh Bank. The fish ery enclosed area (±21 km2) within the OWF (No Fishery area) was compared with a surrounding control area (±30 km) where regular fishing activities were registered through vessel monitoring system (VMS) data throughout the period 2010&2011. Three years after the exclusion of beam trawl fisheries, subtle changes within the macrobenthi c community were observed in the No Fishery area. The benthic mysid shrimp Gastrosaccusspinifer (30 ± 15 ind m−2), tubebuilding polychaetes Terebellidae sp. (196 ± 151 ind m−2) and the echinoderm Echinocyamus pusillus (73 ± 71 ind m−2), sensitive to trawling activities, showed increased abundances within the No Fishery area. With an ex pansion of the wind farm concession area to 238 km2 in the future, the likely increase of dense Terebellidae patch es (e.g., Lanice conchilega reefs) within the No Fishery area could create an ecological important largescale refugiu m for higher trophic levels. This study creates a baseline for the evaluation of long-term changes due to the fishing impacts and effects related to the presence of OWFs and highlights the importance of executing long-term monitoring programs in combination with targeted research.

Roach, M, Cohen, M, Forster, R., Revill, AS., Johnson, M., 2018. The effects of temporary exclusion of activity due to wind farm construction on a lobster (Homarus gammarus) fishery suggests a potential management approach. ICES Journal of Marine Science 75(4), 1416-1426.

Offshore wind farms (OWF) form an important part of many countries strategy for responding to the threat of climate change, their development can conflict with other offshore activities. Static gear fisheries targeting sedentary benthic species are particularly affected by spatial management that involves exclusion of fishers. Here we investigate the ecological effect of a short-term closure of a European lobster (Homarus gammarus(L.)) fishing ground, facilitated by the development of the Westermost Rough OWF located on the north-east coast of the United Kingdom. We also investigate the effects on the population when the site is reopened on completion of the construction. We find that temporary closure offers some respite for adult animals and leads to increases in abundance and size of the target species in that area. Reopening of the site to fishing exploitation saw a decrease in catch rates and size structure, this did not reach levels below that of the surrounding area. Opening the site to exploitation allows the fishery to recuperate some of the economic loss during the closure. We suggest that our results may indicate that temporary closures of selected areas may be beneficial and offer a management option for lobster fisheries.

Fishery studies (in alphabetic order):

Asch, R.G. & Collie, J.S. (2008) Changes in a benthic megafaunal community due to disturbance from bottom fishing and the establishment of a fishery closure. *Fishery Bulletin*, **106**, 438-456.

Trawling and dredging on Georges Bank (northwest Atlantic Ocean) have altered the cover of colonial epifauna, as surveyed through in situ photography. A total of 454 photographs were analyzed from areas with gravel substrate between 1994 and 2000 at depths of 40–50 m and 80–90 m. The cover of hydroids, bushy bryozoans, sponges, and tubeworms was generally higher at sites undisturbed by fishing than at sites classified as disturbed. The magnitude and significance of this effect depended on depth and year. Encrusting bryozoans were the only type of colonial epifauna positively affected by bottom fishing. Species richness of noncolonial epifauna declined with increased bottom fishing, but Simpson's index of diversity typically peaked at intermediate levels of habitat disturbance. Species that were more abundant at undisturbed sites possessed characteristics that made them vulnerable to bottom fishing. These characteristics include emergent growth forms, soft body parts, low motility, use of complex microhabitats, long life spans, slow growth, and larval dispersal over short distances. After the prohibition of bottom fishing at one site, both colonial and noncolonial species increased in abundance. Populations of most taxa took two years or more to increase after the fishing closure. This finding indicates that bottom fishing needs to be reduced to infrequent intervals to sustain the benthic species composition of Georges Bank at a high level of biodiversity and abundance.

Dannheim, J., Brey, T., Schro¨der, A., Mintenbeck, K., Knust, R., and Arntz, W. E. 2014. Trophic look at soft-bottom communities—short-term effects of trawling cessation on benthos. Journal of Sea Research, 85: 18–28

The trophic structure of the German Bight soft-bottom benthic community was evaluated for potential changes after cessation of bottom trawling. Species were collected with van-Veen grabs and beam trawls. Trophic position (i.e. nitrogen stable isotope ratios, δ15N) and energy flow (i.e. species metabolism approximated by body mass scaled abundance) of dominant species were compared in trawled areas and an area protected from fisheries for 14 months in order to detect trawling cessation effects by trophic characteristics. At the community level, energy flow was lower in the protected area, but we were unable to detect significant changes in trophic position. At the species level energy flow in the protected area was lower for predating/scavenging species but higher for interface feeders. Species trophic positions of small predators/scavengers were lower and of deposit feeders higher in the protected area. Major reasons for trophic changes after trawling cessation may be the absence of artificial and additional food sources from trawling likely to attract predators and scavengers, and the absence of physical sediment disturbance impacting settlement/survival of less mobile species and causing a gradual shift in food availability and quality. Our results provide evidence that species or community energy flow is a good indicator to detect trawling induced energy-flow alterations in the benthic system, and that in particular species trophic properties are suitable to capture subtle and short-term changes in the benthos following trawling cessation.

De Biasi, A.M. & Pacciardi, L. (2008) Macrobenthic communities in a fishery exclusion zone and in a trawled area of the middle Adriatic Sea (Italy). Ciencias Marinas, 34, 433-444.

Macrobenthic communities in a commercial fishing ground (middle Adriatic Sea) exploited by otter trawling were compared with communities living in an area closed to fishing for over 10 years located near a gas platform. Our data highlighted significant differences in macrofaunal community structure between the two areas. In addition, the macrofaunal communities in the fished area displayed evidence of a higher level of stress compared with the other one. Several taxa reported in the literature as being sensitive to trawling (e.g., Ebalia tuberosa, Callianassa subterránea) were markedly more abundant in the area not affected by fishing. Macrofaunal community analysis using the index of multivariate dispersion and k-dominance curves provided evidence of stress in the fished area; however, it is not possible to predict whether the patterns observed will remain consistent over time based on only two temporal replicates. It is likely that the magnitude of the macrofaunal community response to fishing changes during the year according to season and fishing effort.

De Juan, S., Thrush, S.F., Demestre, M., 2007. Functional changes as indicators of trawling disturbance on a benthic community located in a fishing ground (NWMediterranean Sea). Mar. Ecol. Prog. Ser. 334, 117–129.

Trawling disturbs benthic communities, eliminating the most vulnerable organisms and modifying habitat structure. While the cumulative effects of disturbance resulting from commercial trawling activities are poorly understood, several studies suggest that chronically disturbed communities are dominated by opportunistic organisms. This study focuses on changes in functional compo-nents of the benthic community occurring in muddy sediments in a NW Mediterranean trawling ground, including an area that has not been fished for 20 yr. In both disturbed and undisturbed areas, the overall benthic community from the fishing ground was dominated by burrowing epifaunal deposit feeders and predators, and deep burrowing infaunal deposit feeders. The fished area had a higher abundance of burrowing epifaunal scavengers and motile burrowing infauna, while the undisturbed area was characterised by higher abundance of surface infauna, epifaunal suspension feeders and predatory fish. This study clearly demonstrates that changes in the functional compo-nents of a benthic community can result from fishing in areas dominated by organisms not considered especially vulnerable to trawling activities. Thus, fisheries managers aiming to reduce ecosystem dis- turbance must consider the implications of trawling on the structure and functioning of all types of benthic communities.

De Juan, S., Demestre, M. & Sanchez, P. (2011) Exploring the degree of trawling disturbance by the analysis of benthic communities ranging from a heavily exploited fishing ground to an undisturbed area in the NW Mediterranean. Scientia Marina, 75, 507-516.

This study focuses on 4 sites in the northwestern Mediterranean to investigate the response of benthic fauna across a gradient of trawling impact. One site was located in a heavily exploited fishing ground. The second site was enclosed in the fishing ground but had not been trawled in twenty years. The third site was located adjacent to a marine protected area and was subjected to occasional trawling. The fourth site was located inside the marine protected area, where trawling was banned thirty years ago. Side-scan sonar records of trawl marks on the seabed confirmed the gradient of trawling intensity. We investigated the response of benthic fauna to trawling disturbance at the mesoscale of a fishing ground. We compared the observed patterns of abundance, biomass, diversity and community structure for epifauna and infauna with responses predicted from previous studies. Results showed that those communities less impacted by trawling sustained more biogenically habitat-structured communities (e.g. more abundance of sessile suspension feeders at the less disturbed sites against higher dominance of small invertebrates at the disturbed site). Moreover, these results confirm the benefits of restricting trawling activities for benthic communities, with marine reserves as the paradigm for the conservation of Mediterranean fishing grounds.

Duineveld, G.C.A., Bergman, M.J.N., Lavaleye, M.S.S., 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.

The effects of fishery exclusion on the composition of the macrofauna were determined by comparing the fishery-exclusion zone around a gas production platform in the southern North Sea (Frisian Front) with nearby regularly fished areas. A Triple-D dredge was used, in addition to a standard box corer, to collect the relatively rare and larger species. Multivariate analysis showed greater species richness, evenness, and abundance of mud shrimps (*Callianassa subterranea*, *Upogebia deltaura*) and fragile bivalves (*Arctica islandica*, *Thracia convexa*, *Dosinia lupinus*, *Abra nitida*, *Cultellus pellucidus*) in the Triple-D samples from the exclusion area. Although box cores did confirm the higher abundance of both mud shrimps in the exclusion zone and demonstrated greater densities of the brittlestar *Amphiura filiformis*, they did not clearly reveal the distinctness of the exclusion zone. This is attributed to the large proportion of small, short-living species in the samples and the relative scarcity of vulnerable larger species common to all the box core samples. There was no evidence of greater recruitment in the relative small exclusion zone, despite its positive effect on adult survival. The observation that the fishery affects deep-living mud shrimps may point to consequences for the functioning of the benthic ecosystem other than simple loss of biodiversity.

Hiddink, J. G., Hutton, T., Jennings, S., and Kaiser, M. J. 2006. Predicting the effects of area closures and fishing effort restrictions on the production, biomass, and species richness of benthic invertebrate communities. e ICES Journal of Marine Science, 63: 822-830.

To effectively implement an Ecosystem Approach to Fisheries (EAF), managers need to consider the effects of management actions on the fishery and the ecosystem. Methods for assessing the effects on target stocks are generally well developed, but methods for assessing the effects on other components and attributes of the ecosystem are not. Area closures and effort controls are widely used fishery management tools that affect the distribution of fishing effort and may therefore have consequences for a range of species and habitats. An approach is developed to predict the effects of area closures and effort control on the biomass, production, and species richness of benthic communities in the North Sea. The redistribution of beam trawling effort as a result of management action was modelled with a random utility model, assuming that fishers selected fishing grounds on the basis of their knowledge of past catch rates. The effects of trawling on benthic invertebrates were predicted using a size-based model that accounted for differences in habitat among fishing grounds. Our simulations demonstrated that closures of different sizes and in different locations could have positive or negative effects on benthic communities. These predicted effects resulted from the trade-off between recovery in the closed areas and additional trawling effects in the open areas that arose from displaced fishing activity. In the absence of effort controls, closure of lightly fished areas had the strongest positive effect on benthic communities. Effort reduction also had a positive effect. Therefore, area closures in lightly fished areas, coupled with effort reduction, are expected to minimize the effects of fishing on benthic communities. As it was not possible to access full international data for the North Sea beam trawl fleet, the results of the analyses are illustrative rather than complete. Nevertheless, what is demonstrated is an effective approach for assessing the environmental consequences of fishery management action that can be used to inform management decision-making as part of an EAF.

Link, J., Almeida, F., Valentine, P., Auster, P., Reid, R. & Vitaliano, J. (2005) The effects of area closures on Georges Bank. Benthic habitats and the effects of fishing. American Fisheries Society Symposium 41 (ed. by P. Barnes and J. Thomas), pp. 345-369. American Fisheries Society, Bethesda, M.D

Otter trawling, a common method to catch commercially valuable groundfish, has been shown to reduce benthic habitat complexity by the direct reduction of abundance levels of epifaunal and infaunal species. Such reductions in benthic biodiversity may have long-term consequences for ecosystem resilience and function of benthic habitats. In the Gulf of Maine, in order to address concerns of declining groundfish stocks while simultaneously conserving benthic habitats, marine protected areas (MPA) have been designated that restrict groundfish trawling. One such MPA, the Western Gulf of Maine Closure (WGOMC), encompasses regions that, as of 2004, had been closed to trawling for 6 and 4 years, respectively. Such a time frame allows the question, how have benthic communities responded to the cessation of chronic groundfish trawling? To address this question, an observational study was conducted where the community composition of coarse sediments in the WGOMC at different times were compared to coarse sediment community composition of an actively trawled fishing ground (the Kettle) at a similar depth. Video transects of epifaunal communities were taken in the WGOMC in August 2002 (2-year closed sites). Video transects of the epifaunal community and grab samples of the infaunal community were taken in the Kettle in August of 2003 (Open 2003), and resampled in August 2004 (Open 2004). Finally, video transects and grab samples were taken again in the WGOMC in August 2004 in what were the 2-year closed sites (now the 4-year closed sites), and in the 6-year closed region of the WGOMC (6-year closed sites). Multivariate analysis showed significant differences in benthic community composition between the Kettle and the WGOMC which could be attributed to the cessation of chronic trawling disturbance. In general, benthic communities in the Kettle were dominated by more disturbance tolerant, opportunistic families, while communities in the WGOMC were dominated by more disturbance intolerant, sessile families.

Sciberras, M., Hinz, H., Bennell, J.D., Jenkins, S.R., Hawkins, S.J. & Kaiser, M.J. (2013) Benthic community response to a scallop dredging closure within a dynamic seabed habitat. Marine Ecology Progress Series, 480, 83-+.

Fishing with bottom towed gear is widely considered an invasive form of fishing in terms of its impacts upon seabed habitats and fauna. Fishery closures or marine protected areas provide baseline conditions against which to assess the response to the removal of fishing disturbance and thus shed light on their use as fisheries management tools. We conducted repeat underwater camera surveys inside a recently established area that is permanently closed to scallop fishing and a seasonally fished area in Cardigan Bay, UK, to test for differences in scallop abundanceand epibenthic community structure and to examine recovery processes over a 23 mo study period. Changes in scallop density and epifaunal diversity and community composition were primarily driven by seasonal fluctuations; no differences were found between the permanently closed area and the seasonally fished area. Temporal changes in epibenthic community inside the permanently closed area were not related to recovery processes associated with the cessation of scallop dredging. Sediment composition and bedforms shifted between surveys, suggesting that this community is exposed to a dynamic environment. It is likely that scallop dredging at the present levels of fishing may be insufficient to induce changes large enough to be detected in the presence of strong natural disturbance. We highlight the importance of considering the physical nature and dynamics of the environment and the nature of the species concerned throughout the process of designating closed areas, to avoid negative impacts on fisheries and limited conservation benefits.

Sheehan, E.V., Stevens, T.F., Gall, S.C., Cousens, S.L. & Attrill, M.J. (2013) Recovery of a temperate reef assemblage in a marine protected area following the exclusion of towed demersal fishing: E83883. PLoS ONE, 8

Marine Protected Areas MPA have been widely used over the last 2 decades to address human impacts on marine habitats within an ecosystem management context. Few studies have quantified recovery of temperate rocky reef communities following the cessation of scallop dredging or demersal trawling. This is critical information for the future management of these habitats to contribute towards conservation and fisheries targets. The Lyme Bay MPA, in south west UK, has excluded towed demersal fishing gear from 206 km2 of sensitive reef habitat using a Statutory Instrument since July 2008. To assess benthic recovery in this MPA we used a flying video array to survey macro epi-benthos annually from 2008 to 2011. 4 treatments (the New Closure, previously voluntarily Closed Controls and Near or Far Open to fishing Controls) were sampled to test a recovery hypothesis that was defined as ‘the New Closure becoming more similar to the Closed Controls and less similar to the Open Controls’. Following the cessation of towed demersal fishing, within three years positive responses were observed for species richness, total abundance, assemblage composition and seven of 13 indicator taxa. Definitive evidence of recovery was noted for species richness and three of the indicator taxa (Pentapora fascialis, Phallusia mammillata and Pecten maximus). While it is hoped that MPAs, which exclude anthropogenic disturbance, will allow functional restoration of goods and services provided by benthic communities, it is an unknown for temperate reef systems. Establishing the likely timescales for restoration is key to future marine management. We demonstrate the early stages of successful recruitment and link these to the potential wider ecosystem benefits including those to commercial fisheries.

Contact

Gert Van Hoey, Wetenschappelijk onderzoeker
Instituut voor Landbouw-, Visserij- en Voedingsonderzoek
Dier
Ankerstraat 1
8400 Oostende
T +32 59 56 98 47
gert.vanhoey@ilvo.vlaanderen.be

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Instituut voor Landbouw-, Visserij- en Voedingsonderzoek
Burg. Van Gansberghelaan 92
9820 Merelbeke - België

T +32 9 272 25 00
ilvo@ilvo.vlaanderen.be
www.ilvo.vlaanderen.be