

Master Research Project

The impact of bottom trawling on epifauna in the North Sea

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Abstract

Introduction

The North Sea is one of the most intensively fished seas in the world. Fishing here often happens by the means of bottom trawling, making it one of the most widespread forms of anthropogenic seabed disturbance. Because of various life-history traits, benthic epifauna is particularly vulnerable for this form of fishing. Various studies have shown that chronic trawl disturbance leads to changes in species composition, decreased biodiversity and decreased abundance of various epifaunal species. In this research, I have examined bottom trawling impact on epifauna in the North Sea. I have first looked at the impact of bottom trawling on the community level by looking at biotic indicators such as biodiversity and species composition. For the species level, I looked at various life-history traits of individual species like size, body type and mobility. I hypothesized that bottom trawling will, in general, have a negative impact on epifauna in terms of i.e. biodiversity, while it also alters the species composition. As hydrodynamic forces (i.e. natural disturbance) have a similar impact on benthic epifauna, I expect to find the same changes here.

Methods

The study area is located in the southern part of the North Sea. A total of 10 variables have been used to explain species abundance, species composition and biodiversity. As a proxy for natural hydrodynamics I have taken the tidal-induced bed shear stress and the (maximum) wind driven bed shear stress (wave-induced bed shear stress). For fishing intensity, an average value was calculated for the years 2008 to 2015. Other variables are temperature, salinity, sediment type and depth. Species were taxonomically and functionally classified. For each species, physical characters such as size and morphology have been identified. Data analysis was conducted by the means of constructing generalized linear models (GLMs)

Results

The results show that fishing intensity significantly correlates with altered benthic communities in terms of species composition and biodiversity. The relative proportion of arthropods increases with higher fishing intensity, while the relative proportion of echinoderms decreases. Also, species with exoskeletons are more prevalent in benthic communities that are intensively fished. At last, there's also an increased proportion of small animals in communities with high fishing intensities.

Implications

With the recent ban on pulse fishing, a method of bottom trawling that is thought to be better for benthic communities, in the European Union, it is expected that many fishermen will go back to traditional fishing methods such as beam trawling. This is something to think about, as traditional beam trawling has a significant negative impact on benthic communities. Countries surrounding the North Sea have pledged to protect benthic communities and other sea life in the North Sea. It is therefore necessary to keep looking for sustainable alternatives that won't impact benthic communities.

Introduction

Epifauna species are an important part of marine life. Epifauna includes all species that live on the surface of the seabed, or species that are attached to other aquatic organisms or submerged rocks. In the North Sea, epifauna species show a heterogeneous distribution pattern (Reiss *et al.*, 2010). The highest values of epifauna abundance are found near the Norwegian coast, Cleaver Bank and in the German Bight (fig. 1). Species number of epifauna showed a gradient (fig. 1). The number of epifauna species increases at higher latitudes, with the highest number of species found along the English coast and around the Shetland islands (Reiss *et al.*, 2010). Due to various life-history traits, epifaunal species are particularly vulnerable for the effects of bottom trawling (Collie *et al.*, 2017).

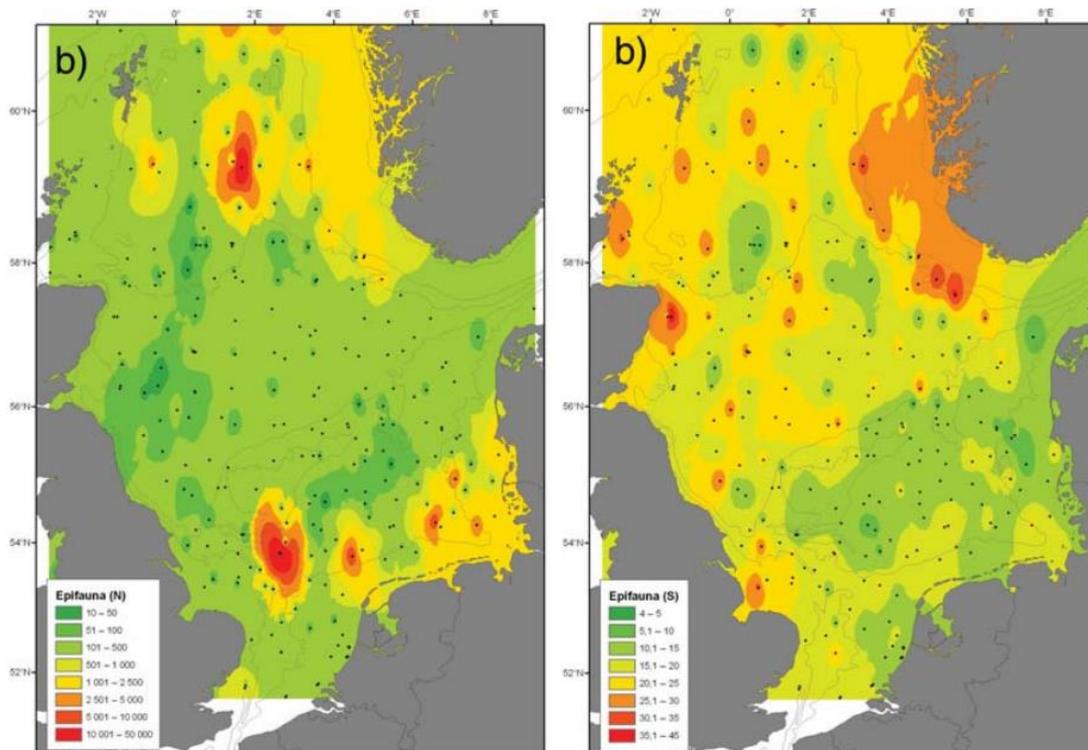


Figure 1. Abundance of epifauna (ind. 500 m⁻²) (left) and species number of epifauna (S haul⁻¹) (right) (Reiss *et al.*, 2010).

Bottom trawling is one of the most widespread forms of fishing in the world, with an annual caught weight of 30 million tonnes of fish, making it the most successful fishing method in the world (Watson & Tidd, 2018). Bottom trawling is particularly widespread in the North Sea, one of the most intensively fished seas in the world (Eigaard *et al.*, 2017) (fig. 2 & 3). Beam trawls, a form of bottom trawls, are mostly deployed in the southern part of the North Sea. (Eigaard *et al.*, 2017). Bottom trawling is a fishing method in which trawl nets are pulled over the seabed by a fishing ship. With beam trawling, the mouth of the net is held open by a solid metal beam, attached to two "shoes", which are solid metal plates, welded to the ends of the beam. These beams slide over and disturb the seabed, making it the most common form of anthropogenic seabed disturbance (Halpern *et al.*, 2008). Forms of physical disturbance include, among others, modification of seabed habitat, disruption of food web processes and extinction of vulnerable species (Hall 1999; Hiddink *et al.*, 2006a).

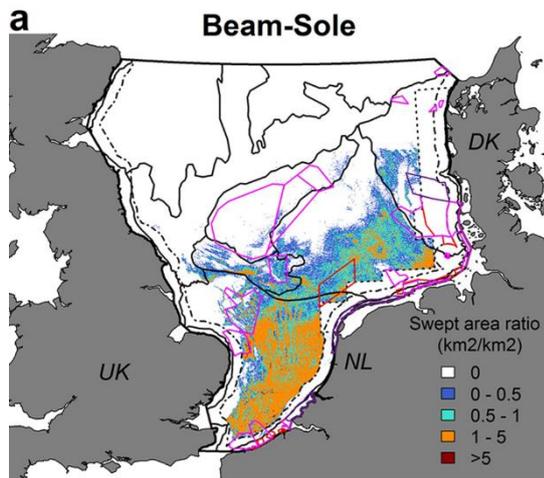


Figure 2. Fishing intensity by beam trawling aiming at sole between 2008-2015. Fishing intensity is measured as the average fished area in km² per year (Van der Reijden *et al.*, 2018).

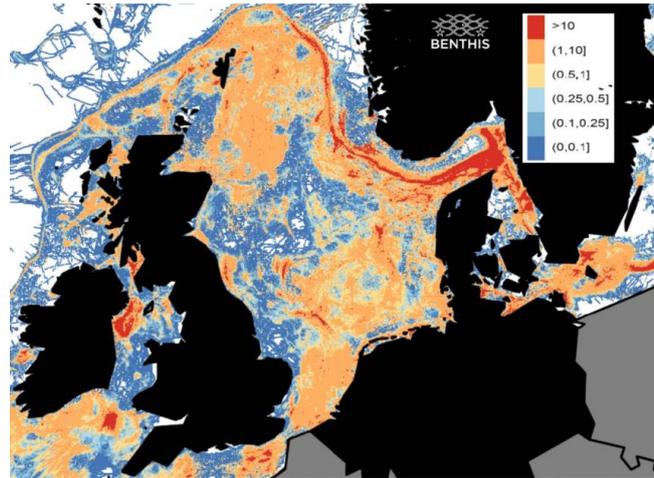


Figure 3. Fishing intensity by bottom trawls in the North Sea and Celtic seas between 2010-2012. Fishing intensity is measured by the average number of times per year a place is fished. Countries in black provided VMS data. Source: BENTHIS.

Bottom trawling impact can vary on the community level and on the species level. On the community level bottom trawling reduces biomass, production and species richness (Hiddink *et al.*, 2006a). Bottom trawling normally kills between 20 to 50% of benthic invertebrates in its path (Collie *et al.*, 2017). Chronic trawl disturbance also leads to changes in community composition of both benthic infauna and epifauna (Hinz *et al.*, 2009). Benthic epifauna also show a significant, negative response to trawling in terms of abundance and species richness (Hinz *et al.*, 2009; Asch & Collie, 2008; Thrush *et al.*, 1998), with epifaunal species richness peaking in relatively undisturbed areas (Asch & Collie, 2008). The effect of bottom trawling is the greatest in areas with low levels of natural disturbance. Conversely, bottom trawling has relatively less impact in areas that are already exposed to high levels of natural disturbance (Hiddink *et al.*, 2006a).

Some functional groups of species are more vulnerable to disturbance by bottom trawling than others (Lindeboom & De Groot, 1998). Various epifaunal species stabilize sediment and provide a habitat for benthic invertebrates and demersal fish (Collie *et al.*, 2017). An example of this are large filter feeding bivalves. Filter feeders are important for clarifying water. Furthermore, Henkel & Pawlik (2005) show that some invertebrates and demersal fish benefit from aggregated food sources in the microhabitats created by epifaunal species. One could therefore argue that a relative low abundance of these epifauna species as a result of bottom trawling has a negative impact on the ecosystem functioning. When particular sessile epifaunal species, such as sponges and corals, are removed, the ecosystem loses an important source of shelter. Juvenile fish can no longer find refuge to protect itself from predator species or tidal currents (Auster & Langton, 1999; Lindholm *et al.*, 2015).

Sessile epifaunal species are more seriously affected by bottom trawling than motile epifaunal species (Freese *et al.* 1999; Bradshaw *et al.* 2002; Asch & Collie 2008). However, sessile epifaunal species possess various morphological forms and life history characteristics, resulting in different responses to bottom trawling (Asch & Collie, 2008). Some epifaunal species, like hydroids, seem to be less affected by

bottom trawling (Asch & Collie, 2008). An existing theory is that frequent bottom trawling leads to an increase in the abundance of smaller benthic species (Jennings *et al.*, 2001b). These species are known for having faster life histories and they can better withstand bottom trawling-imposed mortality. Also, smaller epifaunal species may benefit from decreased rates of competition or predation by larger epifaunal species (Jennings *et al.*, 2001b). Because smaller species are more productive, bottom trawling may even have beneficial effects for consumer species (Jennings *et al.*, 2001b). Not all epifaunal species show a negative response to trawling disturbance. Rumohr & Kujawski (2000) show that while the occurrence of bivalve species declines, scavenger and predator species – e.g. crustaceans, gastropods and sea stars – occur more frequently in areas with increased fishing pressure. It is suggested that these species may benefit from bottom trawling because it increases food availability because of discards and moribund benthic species.

In this study, I examined the effects of bottom trawling on epifauna in the North Sea. In order to be able to answer this, I took two different approaches to this question: the effects on the community-level and the species-level. I determined the relation of fishing pressure with species richness, biodiversity and community composition. I hypothesize that biodiversity and species richness will be significantly lower in areas with a high fishing intensity and that species composition will be significantly different. Various studies have shown that benthic epifauna showed a significant, negative response to trawling in terms of abundance and species richness (Hinz *et al.*, 2009; Asch & Collie, 2008; Thrush *et al.*, 1998). The effects of natural disturbances were included in this study, as I expect that this is also a driving factor for community composition. Van Denderen *et al.* 2015 found evidence for the hypothesis that high levels of natural disturbance affect benthic communities in a very similar way as disturbance induced by bottom trawling. Therefore, I expect to see similar effects of natural disturbance on epifaunal communities.

At second, I examined the effects of bottom trawling on the species-level. As physical characteristics heavily influences a species' ability to cope with environmental changes, i.e. resilience, I studied a possible variation in responses to bottom trawling by epifauna species that have different physical characteristics such as body type and size. I hypothesize that small epifauna species will appear in relative high numbers in areas with a high fishing intensity. Small species may be more resilient to bottom trawling (Van Denderen *et al.*, 2015). I expect to see soft-bodied epifaunal species and species with an endoskeleton in relative low numbers in areas with a high fishing intensity. Soft-bodied species may be more vulnerable to bottom trawling because of the high mortality rates it imposes on benthic communities. Studies have shown that soft-bodied corals, for example, are particularly vulnerable to bottom trawling (Sciberras *et al.*, 2018).

Methods

Study area

The study area encompasses the southern part of the North Sea, along the Dutch coast. This study area is chosen because fishing data of the Dutch fishing fleet is available for this part of the North Sea.

Environmental data

A total of ten abiotic factors were used in this study. As a proxy for natural hydrodynamics I have taken the tidal-induced bed shear stress and the (maximum) wind driven bed shear stress (wave-induced bed shear stress) (fig. 5). These show the physical power of the (moving) water at the bottom (in Newton per m²), caused by tidal currents (tidal) and waves (wind-driven).

Subsequently, the proportion of sand, gravel and mud were used to determine sediment type. A simplified Folk classification triangle was used. All hauls with a sand to mud ratio (sand:mud) greater than 9 and with a proportion of gravel lower than 5% were classified as 'sand (S)'. When the proportion of gravel was above 5% with the same sand-to-mud ratio, the sediment was classified as 'gravelly sand (gS)'. Finally, when the proportion of gravel was below 5% and the sand-to-mud ratio was lower than 9, the sediment type was classified as 'muddy sand (mS)'. Moreover, three other abiotic variables were included: depth (m), average temperature (°C) and salinity (‰) (fig. 4). At last, sediment type, depth, average temperature and salinity are used as covariables that might partly explain differences in species abundance, species composition, biodiversity and species richness.

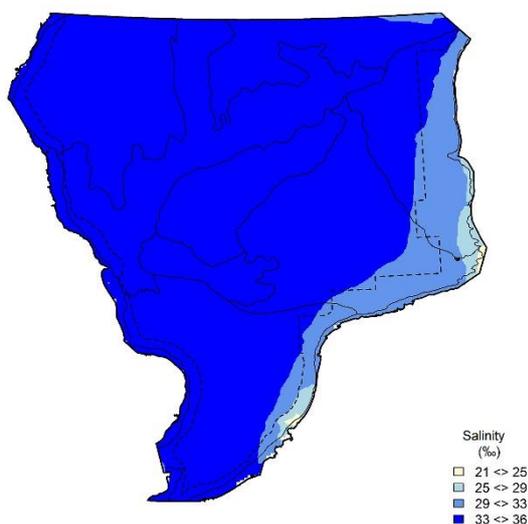


Figure 4. Salinity in the southern North Sea in permille (‰) (Van der Reijden *et al.*, 2018).

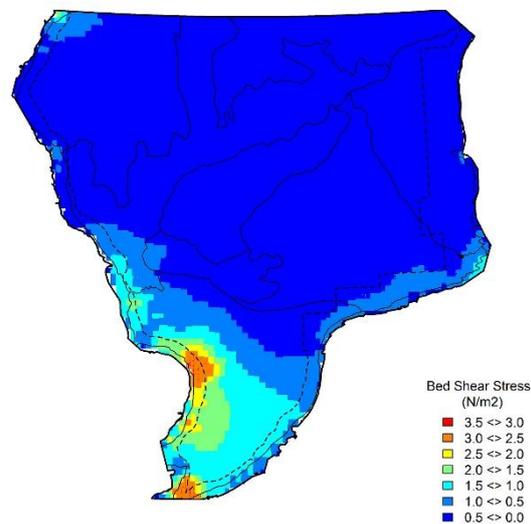


Figure 5. Bed shear stress in the southern North Sea in N/m² (Van der Reijden *et al.*, 2018).

For all variables, the values are extracted from the specific coordinates of the hauls. So, for each haul it is known what the temperature is, how much is being fished on average and what the salinity is at that specific spot. All abiotic variables, along with fishing intensity, were subdivided in 'classes'.

Table 1: Values of different classes of various variables.

Abiotic factors		
Variable	Class	Values
Fishing intensity	High	>0.5 trawls per year
	Medium	>0.2 to ≤0.5 trawls per year
	Low	≤0.2 trawls per year
Tidal bed shear stress	High	>1 (N/m ²)
	Medium	>0.5, ≤1 (N/m ²)
	Low	≤0.5 (N/m ²)
Wave bed shear stress	High	>1 (N/m ²)
	Medium	>0.5, ≤1 (N/m ²)
	Low	≤0.5 (N/m ²)
Sediment type	Sand (S)	SAND:MUD>9, %Gravel<0,01%
	Muddy sand (mS)	SAND:MUD<9, %Gravel<0,01%
	Gravelly sand (gS)	SAND:MUD>9, %Gravel>5% & %Gravel<30%

Fishing data

Fishing intensity is estimated based on data resulting from a vessel monitoring system (VMS) (fig. 2). For this study, VMS data of the Dutch fishing fleet between 2008 and 2015 is available. It is therefore necessary to look at marine habitats close to the Dutch coastline, because that is where Dutch fishing vessels predominantly fish. An average fishing intensity was calculated for this period as the average annual swept area ratio (km² year⁻¹).

Population data

For this study I used the Beam Trawl Survey (BTS). The BTS is part of ICES' larger Database of Trawl Surveys (DATRAS). The main goal of the BTS is to supply fisheries with stock indices and estimates of the age-structure of North Sea plaice and sole. The BTS is carried out annually by various countries, but only hauls conducted by Dutch ships are included in this study. In the Netherlands, the BTS is conducted in July to September by the Wageningen Marine Research institute. In each ICES rectangle, a geographic subdivision of the North Sea of approximately 3584 km², one to four hauls are carried out with an 8-meter beam trawl. Besides the monitoring of sole and plaice, benthic species are also caught and monitored. All species caught in a given haul are listed in a large database. For all species, a record is made for the total number of caught individuals. Moreover, various species characteristics such as weight, length are also noted for economically important species such as plaice and sole.

In this study, the total number of caught individuals is corrected for the total fished area (distance travelled multiplied by the width of the net). The abundance of species is therefore measured as the total number of individuals per square kilometer.

Species classification and characteristics

The species, encrypted in the BTS with a specific code, were identified with the use of the DATRAS Species query tool. Only codes of the World Register of Marine Species (WoRMS) were used in the dataset. Taxonomic classification of each species was done with the help of Wikipedia. Physical characteristics of each species have been obtained through the Biological Traits Information Catalogue (BIOTIC) (MarLIN 2006). Species were divided in five different 'size' classes: very small (< 2cm), small (2 to 10 cm), medium (10 to 20 cm), large (> 20cm) and unknown ('NA'). Looking at morphology, species were classified as 'soft-bodied', 'endoskeleton' or 'exoskeleton'.

Statistical analysis

For statistical analysis, I used generalized linear models (GLMs) to examine the impact of each variable on the response variable. I initially started with all eight variables (fishing intensity, sediment type, depth, maximum wave-induced bed shear stress, wave-induced bed shear stress, tidal-induced bed shear stress, average temperature and salinity). Because of multicollinearity, the following variables were left out: maximum wave-induced bed shear stress, average temperature, depth and salinity. The variables that were used in the final statistical analysis were: fishing intensity, wave-induced bed shear stress, tidal-induced bed shear stress and sediment type. These four variables were initially put in the model, and non-significant variables were gradually removed from the model, until only significant variables were left (i.e. minimal adequate model (MAM)).

For data storage I used Microsoft Excel (Office 365). Data provided by ICES' are in this format. For statistical analysis I used the programming language R (version 3.5.2) and RStudio (version 1.1.463).

Results

In the study area, depth ranged from 10 to 70 metres. The further away from the coast, the deeper it gets. A noteworthy exception to this is the Dogger Bank, which is considerably shallower. The sediment was overwhelmingly sandy. Only the Frisian front is more muddy. The temperature in the study area ranged from 9.5°C to 12.5°C. As with depth, it can be said that the further away from the coast, the colder it gets. Also, water temperature in the German bight is slightly colder than on the Dutch coast. The tidal-induced bed shear stress is the highest in and close to the Outer Thames Estuary and around the German island of Heligoland. Wave-induced bed shear stress is the highest right on the coast. On average, the salinity in this part of the North Sea is around 33‰. In the Rhine and Elbe estuaries, salinity is significantly lower due to the influx of freshwater from rivers.

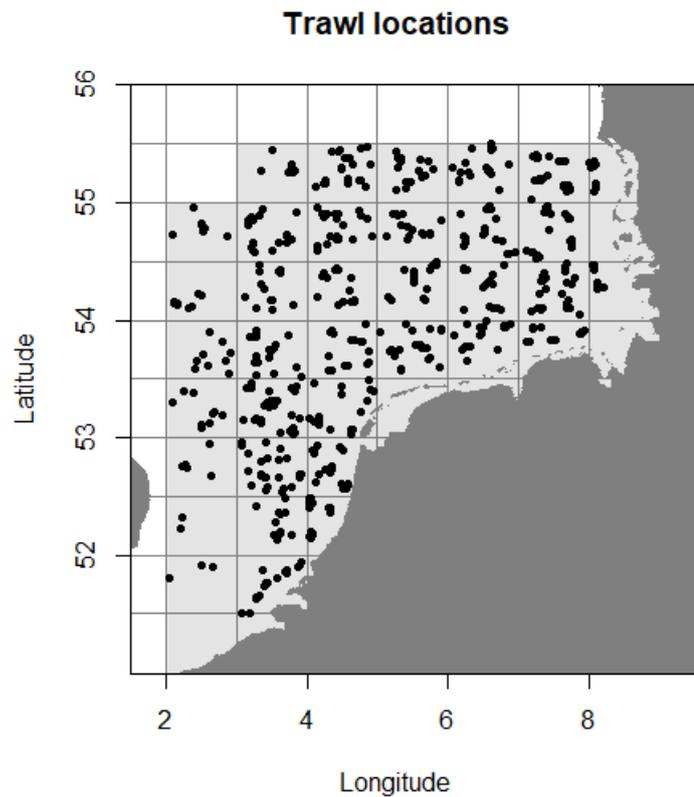


Figure 6. Trawl locations on the Dutch North Sea coast. The study area is displayed in light grey. ICES rectangles are present in the background. The mainland is displayed in dark grey.

A total of 643 valid hauls have been conducted in the study area by Dutch ships between 2008 and 2015 (fig. 6). In these hauls, a total of 122 species and genera have been caught and identified. Four species accounted for more than 80% of the caught individuals: the sand sea star (*Astropecten irregularis*), the common sea star (*Asterias rubens*), the flying crab (*Liocarcinus holsatus*) and the serpent star (*Ophiura ophiura*). Species that have a lower abundance, but nevertheless are present in a lot of hauls include: the common hermit crab (*Pagurus bernhardus*), the helmet crab (*Corystes cassivelaunus*), the brown crab (*Cancer pagurus*), the sea potato (*Echinocardium cordatum*), the sandy swimming crab (*Liocarcinus depurator*), the common shrimp (*Crangon crangon*) and the serpent's table brittle star (*Ophiura albida*). The most abundant phylum are echinoderms, followed by arthropods. Together, they account for almost all caught individuals. Far less abundant, but nonetheless present are the phyla of molluscs, porifera, cnidarians, chordata and bryozoans.

Community approach

For the community-approach, I have looked at species richness, Shannon index and Simpson index as indicators of biodiversity.

Biodiversity

Species richness showed a significant ($p = 0.0035$) negative correlation with fishing intensity. Wave-induced bed shear stress too was negatively correlated with species richness ($p = 1.84e-05$). Tidal-induced bed shear stress did not show a significant correlation with species richness ($p = 0.0794$) (fig. 7).

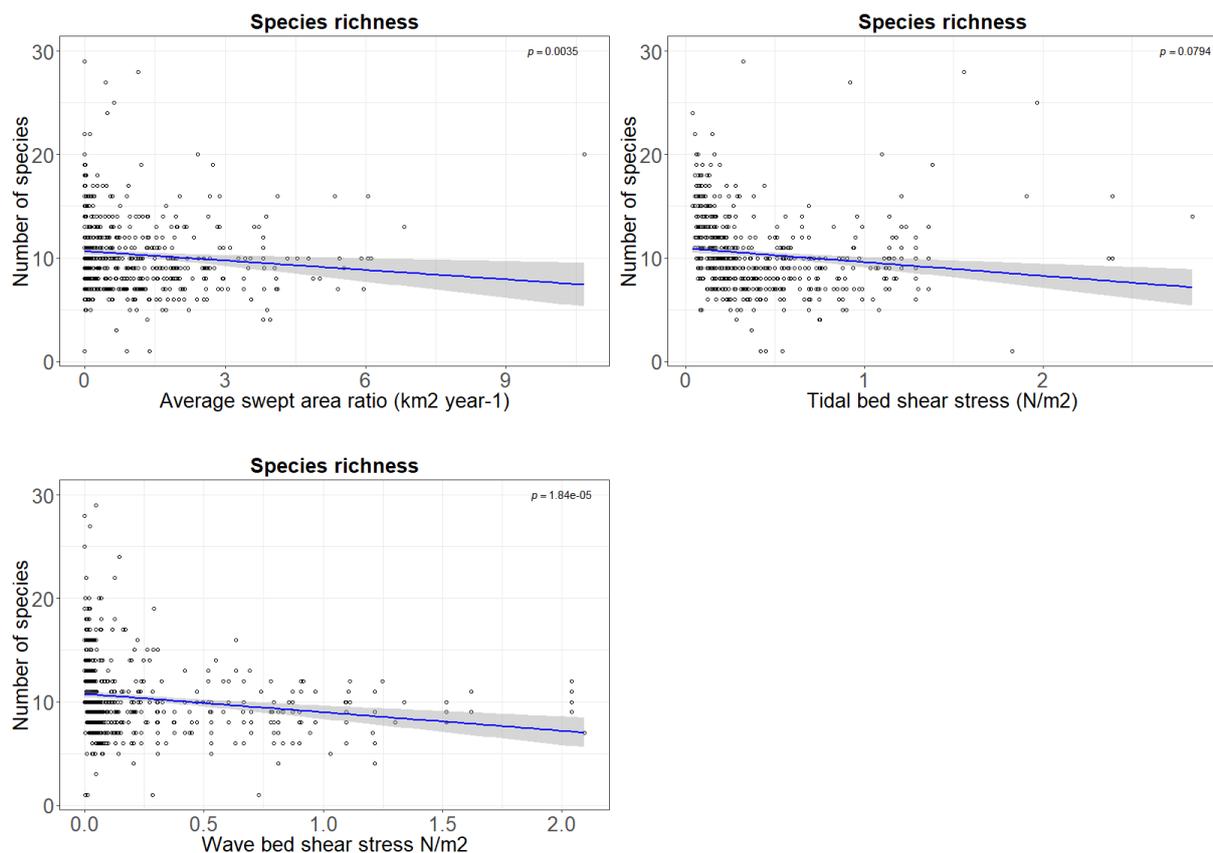


Figure 7: Species richness and wave-induced bed shear stress, tidal-induced bed shear stress and fishing intensity. Blue line is modelled relation, grey area is the 95% confidence interval.

Table 2: Estimated regression parameters, standard errors, z-values and P-values for the Poisson GLM with fishing intensity (FIAverage), sediment type (FolkClassName) and wave-induced bed shear stress (WaveBSS) to predict species richness.

	Estimate	Std. Error	z value	P - value
(Intercept	0.02709	1.00004	0.027	0.9784
FIAverage	-0.02968	0.01017	-2.92	0.0035 **
FolkClassNameMuddy_sand	2.45328	1.00055	2.452	0.0142 *
FolkClassNameSand	2.36361	1.00012	2.363	0.0181 *
WaveBSS	-0.16364	0.0382	-4.284	1.84e-05 ***

Fishing intensity and the Shannon index did not have a significant correlation ($p = 0.928986$). Both tidal-induced bed shear stress ($p = 2.3e-10$) and wave-induced bed shear stress ($p = 0.011713$) had a significant positive correlation with the Shannon index (fig. 8).

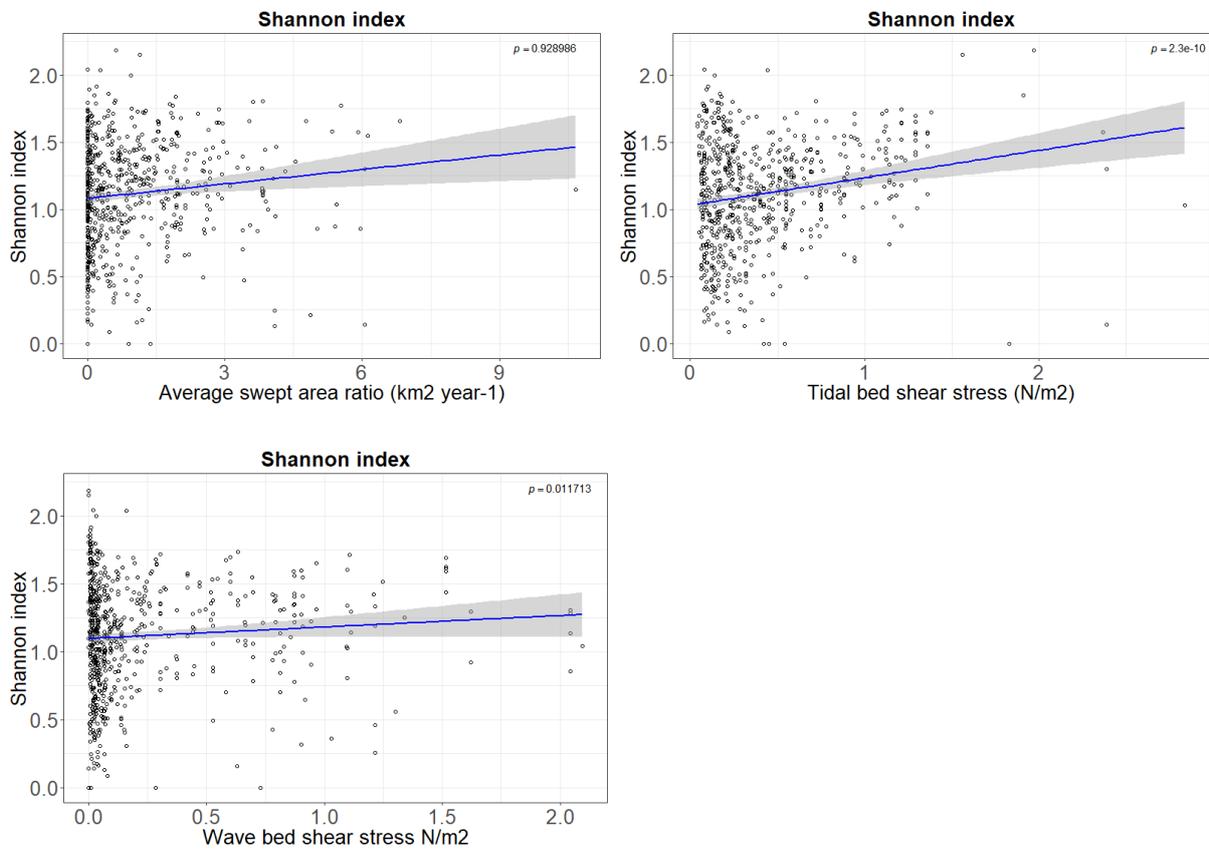


Figure 8: The Shannon index and wave-induced bed shear stress, tidal-induced bed shear stress and fishing intensity. Blue line is modelled relation, grey area is the 95% confidence interval.

Table 3: Estimated regression parameters, standard errors, t-values and P-values for the Gaussian GLM with sediment type (FolkClassName), tidal-induced bed shear stress (TidalBSS) and wave-induced bed shear stress (WaveBSS) to predict the Shannon index.

	Estimate	Std. Error	t value	P - value
(Intercept)	-0.48297	0.38645	-1.25	0.211846
FolkClassNameMuddy_sand	1.65262	0.38749	4.265	2.3e-05 ***
FolkClassNameSand	1.44212	0.38384	3.757	0.000188 ***
WaveBSS	0.10861	0.04296	2.528	0.011713 *
TidalBSS	0.26384	0.04094	6.444	2.3e-10 ***

Both wave-induced bed shear stress ($p = 8.03e-05$) and tidal-induced bed shear stress ($p = 3.95e-14$) showed a significant positive correlation with the Simpson index, while fishing intensity ($p = 0.969$) did not show a correlation with the Simpson index (fig. 9).

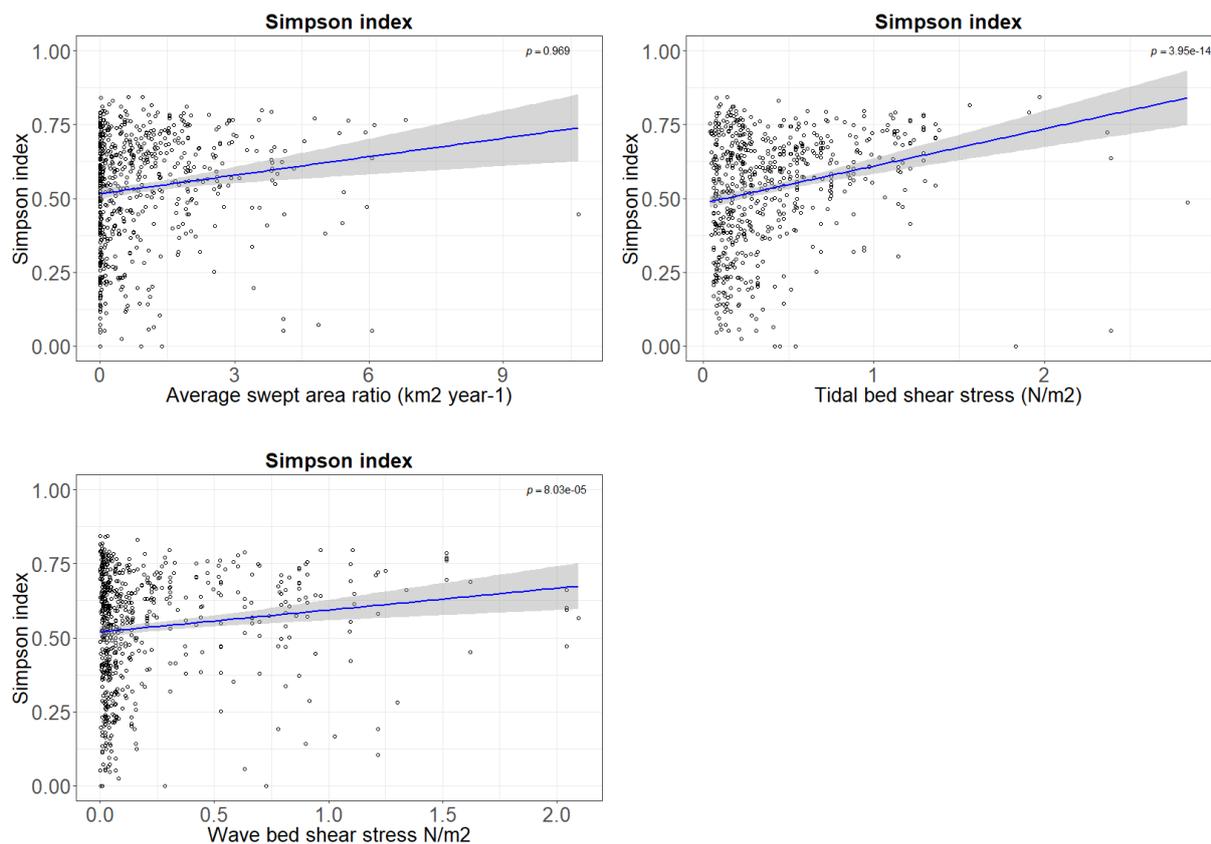


Figure 9: The Simpson index and wave-induced bed shear stress, tidal-induced bed shear stress and fishing intensity. Blue line is modelled relation, grey area is the 95% confidence interval.

Table 4: Estimated regression parameters, standard errors, t-values and P-values for the Gaussian GLM with sediment type (FolkClassName), tidal-induced bed shear stress (TidalBSS) and wave-induced bed shear stress (WaveBSS) to predict the Simpson index.

	Estimate	Std. Error	t value	P - value
(Intercept)	-0.27448	0.18287	-1.501	0.134
FolkClassNameMuddy_sand	0.80486	0.18336	4.389	1.33e-05 ***
FolkClassNameSand	0.72164	0.18163	3.973	7.91e-05 ***
WaveBSS	0.08069	0.02033	3.969	8.03e-05 ***
TidalBSS	0.14993	0.01937	7.738	3.95e-14 ***

Species composition

The relative proportion of arthropods in the total catch shows a significant positive correlation with fishing intensity ($p = 1.04e-07$). That is, the higher the fishing intensity, the higher the proportion of arthropods. The same significant positive correlation was found with wave-induced bed shear stress ($p = 4.02e-16$) and tidal-induced bed shear stress ($p < 2e-16$). With other words, the higher wave- or tidal-induced bed shear stress, the higher the relative proportion of arthropods (fig. 10).

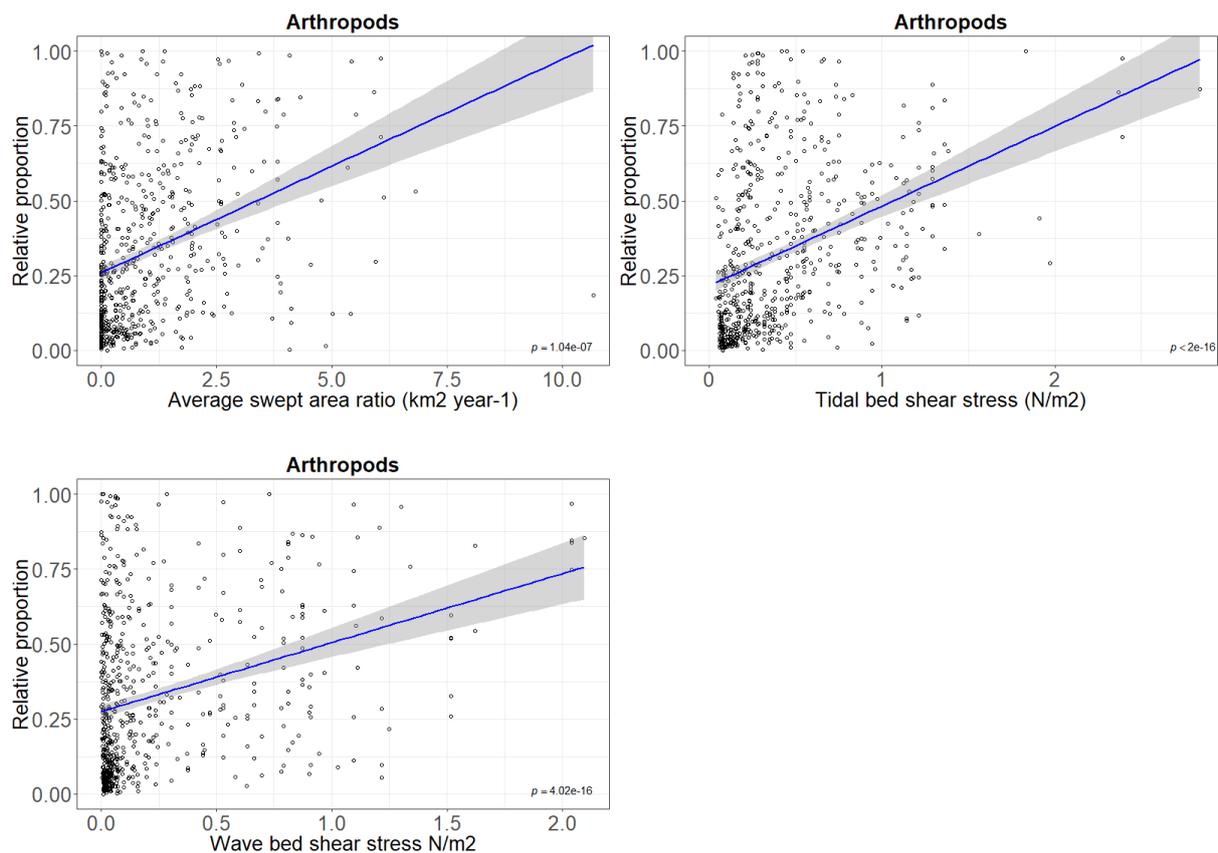


Figure 10: The relative proportion of arthropods. Blue line is modelled relation, grey area is the 95% confidence interval.

Table 5: Estimated regression parameters, standard errors, t-values and P-values for the Gaussian GLM with fishing intensity (FIAverage), tidal-induced bed shear stress (TidalBSS) and wave-induced bed shear stress (WaveBSS) to predict the relative proportion of arthropods in the population.

	Estimate	Std. Error	t value	P - value
(Intercept)	0.350941	0.013424	26.142	< 2e-16 ***
FIAverage	0.038738	0.007198	5.382	1.04e-07 ***
WaveBSS	0.19589	0.02344	8.357	4.02e-16 ***
TidalBSS	0.203631	0.023909	8.517	< 2e-16 ***

In contrary to arthropods, echinoderms showed a significant negative correlation with fishing intensity ($p = 1.93e-06$), wave-induced bed shear stress ($p = 3.47e-14$) and tidal-induced bed shear stress ($p = 6.77e-12$). The higher the fishing intensity, the lower the relative proportion of echinoderms. Also, the higher the natural disturbance by means of wave- or tidal-induced bed shear stress, the lower the relative proportion of echinoderms (fig. 11).

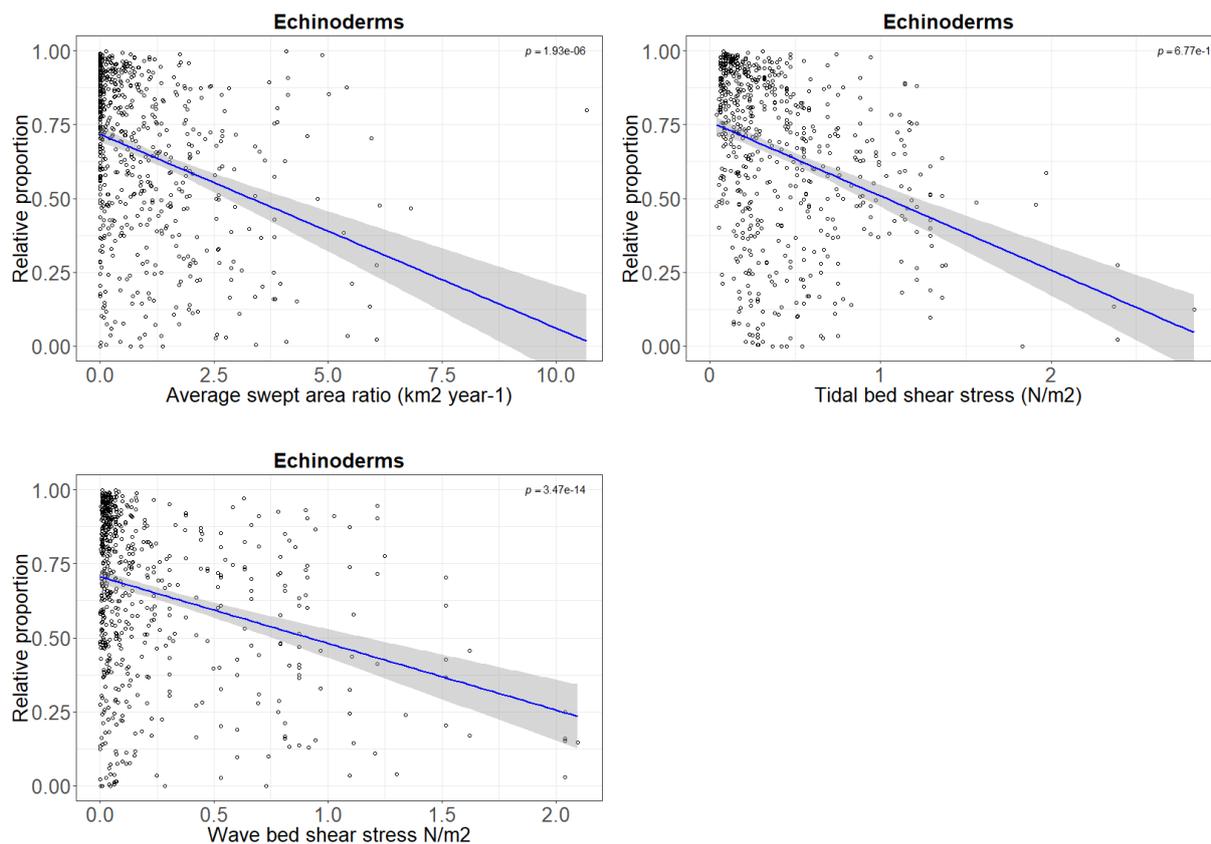


Figure 11: The relative proportion of echinoderms. Blue line is modelled relation, grey area is the 95% confidence interval.

Table 6: Estimated regression parameters, standard errors, t-values and P-values for the Gaussian GLM with fishing intensity (FIAverage), tidal-induced bed shear stress (TidalBSS) and wave-induced bed shear stress (WaveBSS) to predict the relative proportion of echinoderms in the population.

	Estimate	Std. Error	t value	P - value
(Intercept)	0.816787	0.015277	53.466	< 2e-16 ***
FIAverage	-0.039355	0.008191	-4.805	1.93e-06 ***
WaveBSS	-0.206897	0.026675	-7.756	3.47e-14 ***
TidalBSS	-0.190288	0.027209	-6.994	6.77e-12 ***

Echinoderms and arthropods are the most abundant phyla in the North Sea epifauna communities. Together they encompass almost all caught individuals (fig. 12).

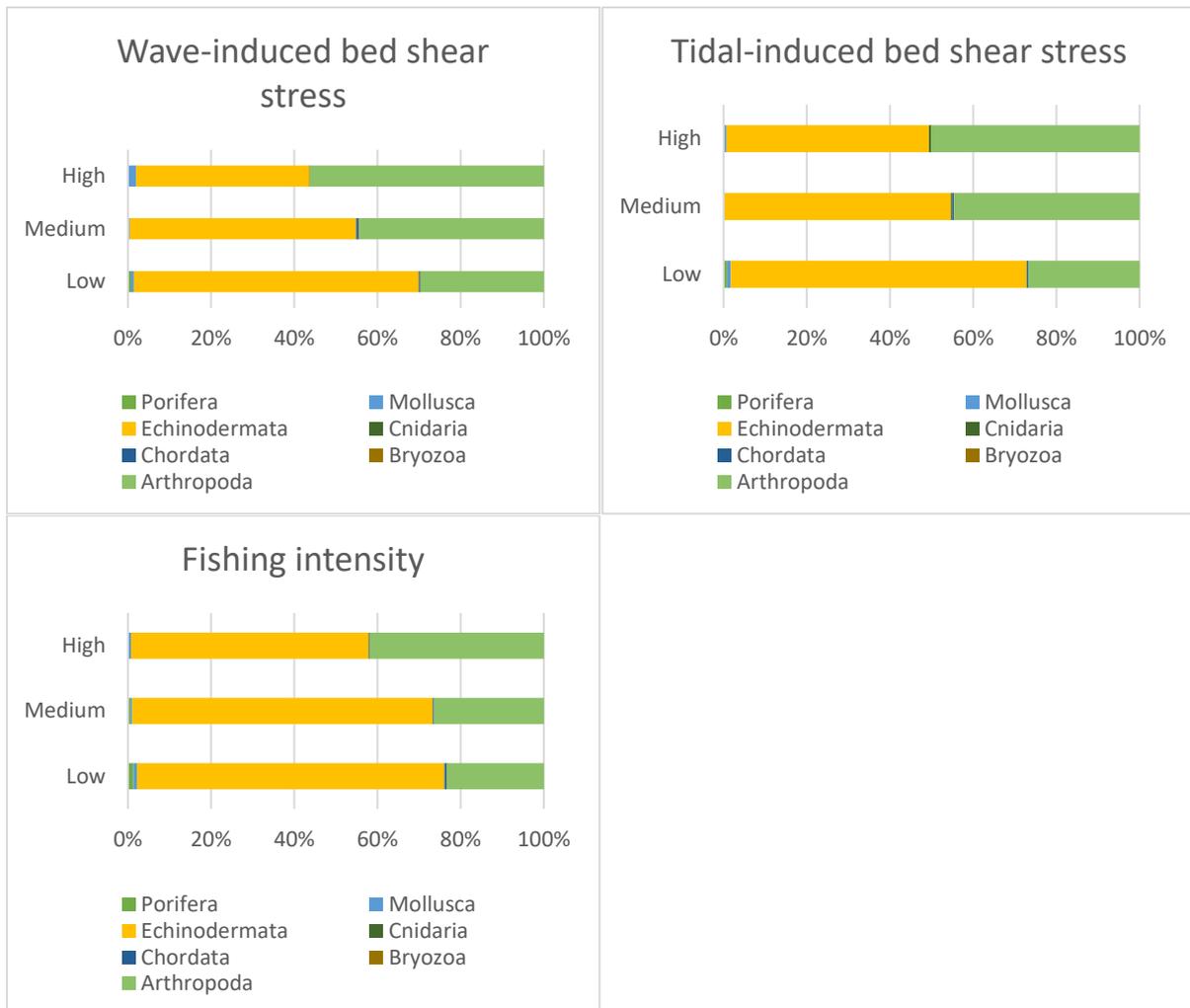


Figure 12: Relative phylum abundance. Composition of abundant phyla for each of the three predicting variables: wave-induced bed shear stress, tidal-induced bed shear stress and fishing intensity. The three variables are subdivided into three classes: low, medium and high.

Species approach

Three most abundant species

Liocarcinus holsatus, also known as the flying crab, is one of the most abundant species in the study area. The species does not show a significant positive or negative correlation with fishing intensity ($p = 0.06143$). There is however a significant positive correlation with both wave-induced bed shear stress ($p < 2e-16$) and tidal-induced bed shear stress ($p = 1.27e-10$). The higher the natural disturbance, the more abundant this species is (fig. 13).

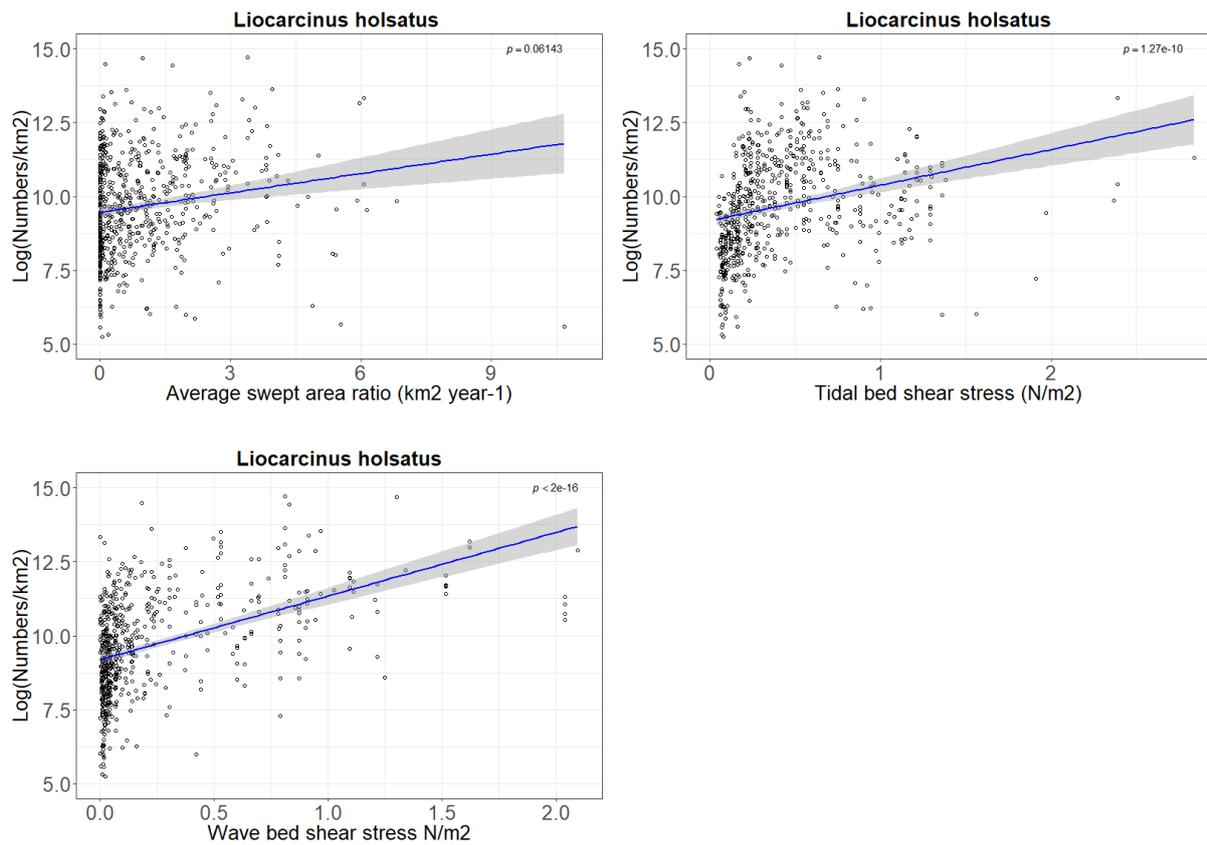


Figure 13: Abundance of *Liocarcinus holsatus*. Blue line is modelled relation, grey area is the 95% confidence interval.

Table 7: Estimated regression parameters, standard errors, t-values and P-values for the Gaussian GLM sediment type (FolkClassName), tidal-induced bed shear stress (TidalBSS) and wave-induced bed shear stress (WaveBSS) to predict the abundance of *Liocarcinus holsatus*.

	Estimate	Std. Error	t value	P - value
(Intercept)	8.3881	0.1686	49.761	< 2e-16 ***
FolkClassNameSand	0.4682	0.1863	2.513	0.0122 *
WaveBSS	2.0069	0.164	12.235	< 2e-16 ***
TidalBSS	1.0246	0.1566	6.542	1.27e-10 ***

Asterias rubens, also known as the common starfish, shows a significant negative correlation with fishing intensity ($p = 1.02e-05$). The higher the fishing intensity, the lower the abundance of *Asterias rubens*. Both wave-induced bed shear stress ($p < 2e-16$) and tidal-induced bed shear stress ($p = 0.03939$) showed a significant positive correlation with *Asterias rubens*. The higher natural disturbance, the more abundant *Asterias rubens* is (fig. 14).

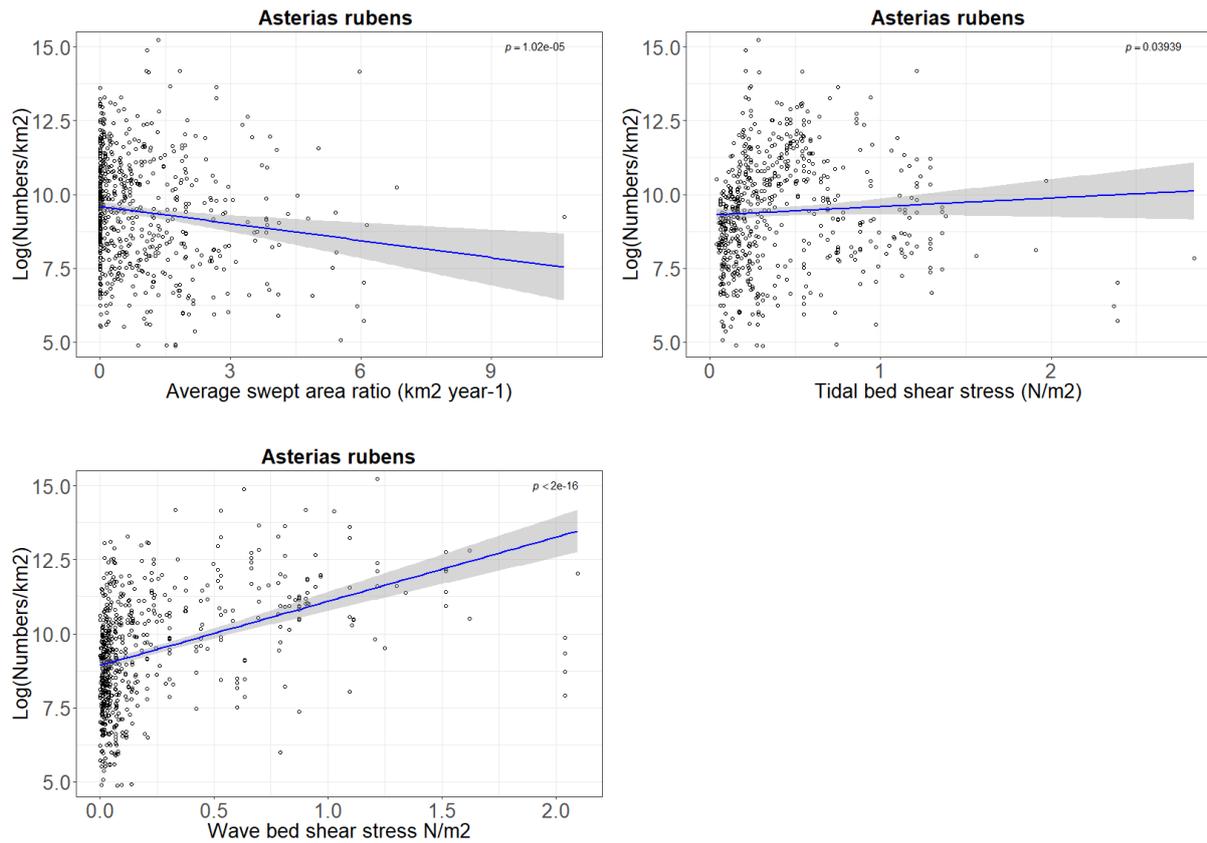


Figure 14: Abundance of *Asterias rubens*. Blue line is modelled relation, grey area is the 95% confidence interval.

Table 8: Estimated regression parameters, standard errors, t-values and P-values for the Gaussian GLM sediment type (FolkClassName), tidal-induced bed shear stress (TidalBSS) and wave-induced bed shear stress (WaveBSS) to predict the abundance of *Asterias rubens*.

	Estimate	Std. Error	t value	P - value
(Intercept)	8.428	0.2041	41.298	< 2e-16 ***
FIAverage	-0.2608	0.0586	-4.451	1.02e-05 ***
FolkClassNameSand	0.6809	0.221	3.081	0.00216 **
WaveBSS	2.0617	0.1913	10.78	< 2e-16 ***
TidalBSS	0.417	0.202	2.065	0.03939 *

Astropecten irregularis, commonly known as the Sand sea star, also shows a significant negative correlation with fishing intensity ($p < 2e-16$). However, unlike *Asterias rubens*, abundance of this species is also negatively correlated with both wave-induced bed shear stress ($p = 4.72e-06$) and tidal-induced bed shear stress ($p = 3.07e-06$) (fig. 15).

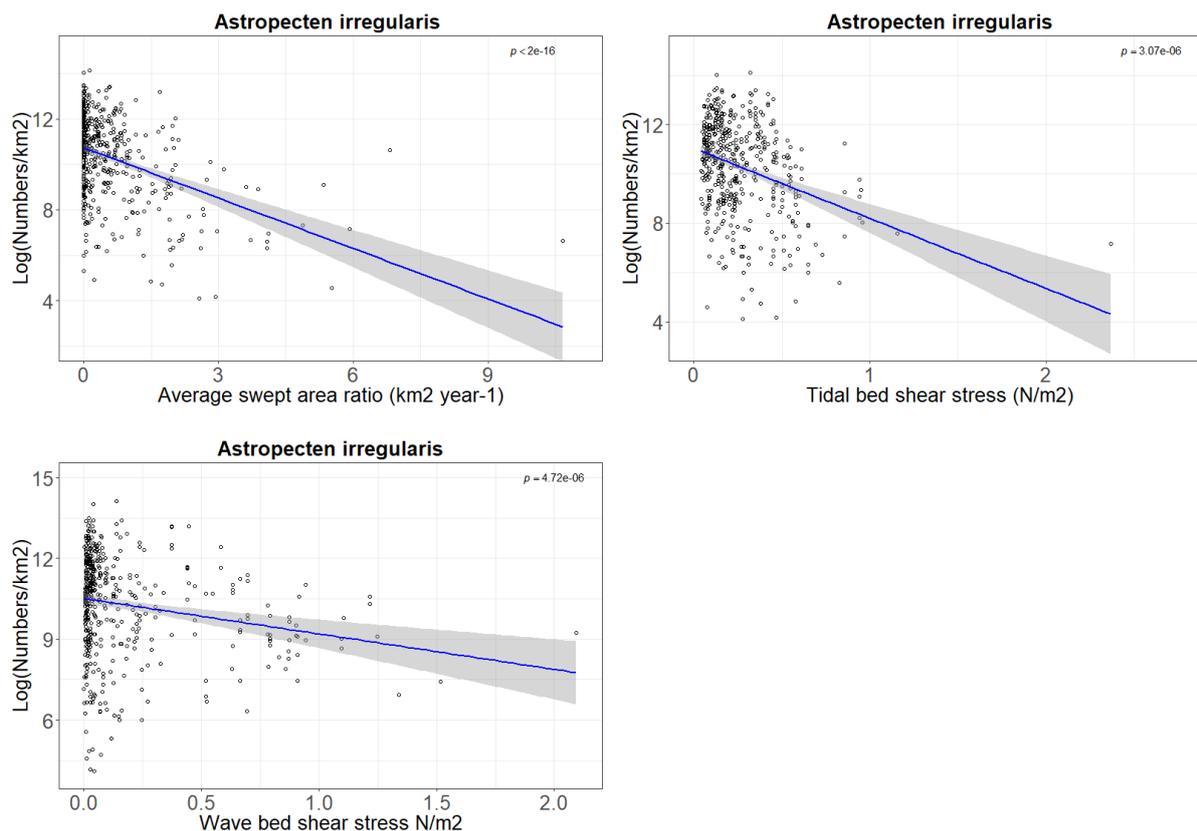


Figure 15: Abundance of *Astropecten irregularis*. Blue line is modelled relation, grey area is the 95% confidence interval.

Table 9: Estimated regression parameters, standard errors, t-values and P-values for the Gaussian GLM sediment type (FolkClassName), tidal-induced bed shear stress (TidalBSS) and wave-induced bed shear stress (WaveBSS) to predict the abundance of *Astropecten irregularis*.

	Estimate	Std. Error	t value	P - value
(Intercept)	11.3797	0.12463	91.307	< 2e-16 ***
FIAverage	-0.6942	0.07435	-9.337	< 2e-16 ***
WaveBSS	-1.2859	0.27759	-4.632	4.72e-06 ***
TidalBSS	-1.7629	0.37315	-4.724	3.07e-06 ***

Species characteristics

Morphology

Species were classified in three different classes: species with an exoskeleton, endoskeleton and soft-bodied species. Soft-bodied species only represented a tiny minority of all caught species. In most circumstances, species with an endoskeleton made up the majority of all caught individuals. Species with an endoskeleton showed a significant negative response to fishing intensity ($p = 5.96e-07$). The higher the fishing intensity, the lower the proportion of animals with an endoskeleton. The same significant negative pattern was found for wave-induced bed shear stress ($p = 2.48e-15$) and tidal-induced bed shear stress ($p = 3.58e-13$) (fig. 16).

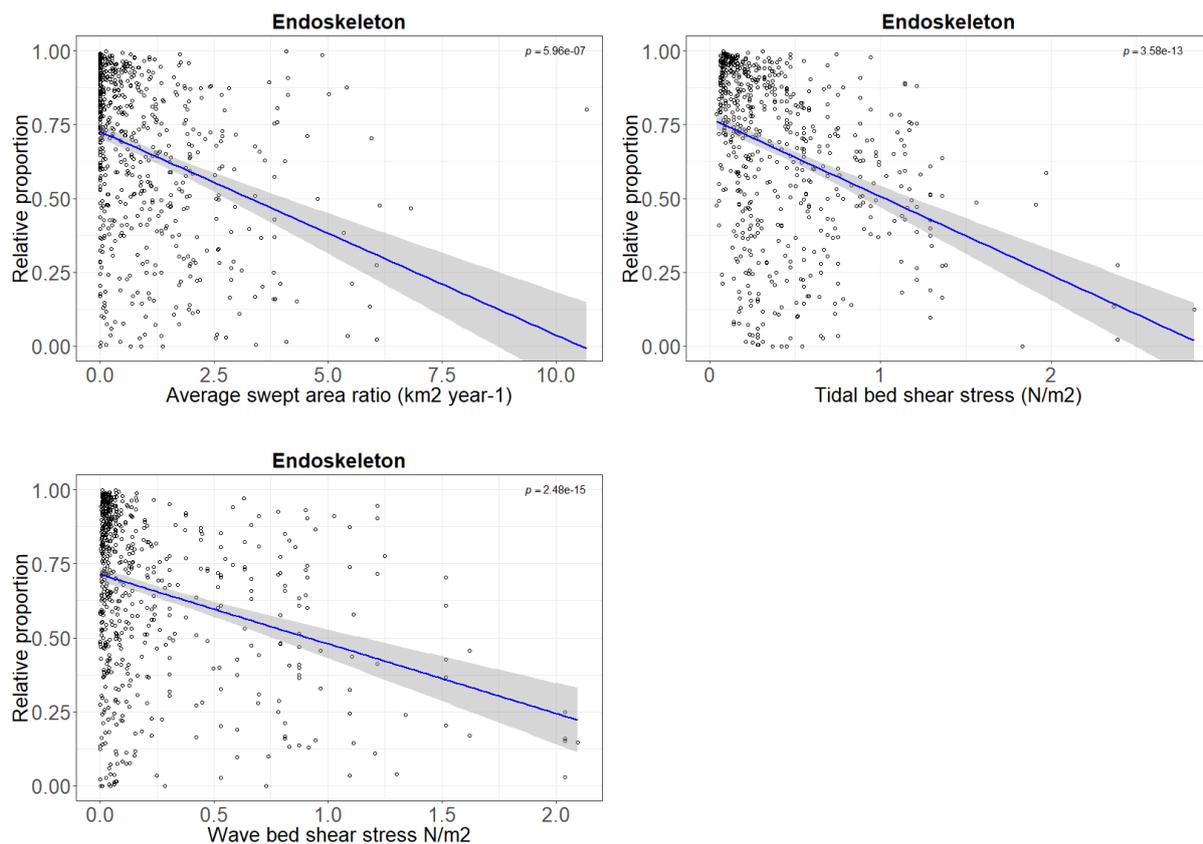


Figure 16: The relative proportion of animals with an endoskeleton. Blue line is modelled relation, grey area is the 95% confidence interval.

Table 10: Estimated regression parameters, standard errors, t-values and P-values for the Gaussian GLM fishing intensity (FIAverage), tidal-induced bed shear stress (TidalBSS) and wave-induced bed shear stress (WaveBSS) to predict the proportion of caught animals with an endoskeleton.

	Estimate	Std. Error	t value	P - value
(Intercept)	0.83092	0.01522	54.601	< 2e-16 ***
FIAverage	-0.04115	0.00816	-5.043	5.96e-07 ***
WaveBSS	-0.21566	0.02657	-8.116	2.48e-15 ***
TidalBSS	-0.20129	0.02711	-7.427	3.58e-13 ***

The opposite was true for species with an exoskeleton. A significant positive correlation was found between the relative proportion of animals with an exoskeleton and fishing intensity ($p = 1.37e-07$). Natural disturbance by the means of wave-induced bed shear stress ($p = 9.25e-16$) and tidal-induced bed shear stress ($p = 7.18e-13$) also showed a significant positive correlation with the relative proportion of animals with an exoskeleton (fig. 17).

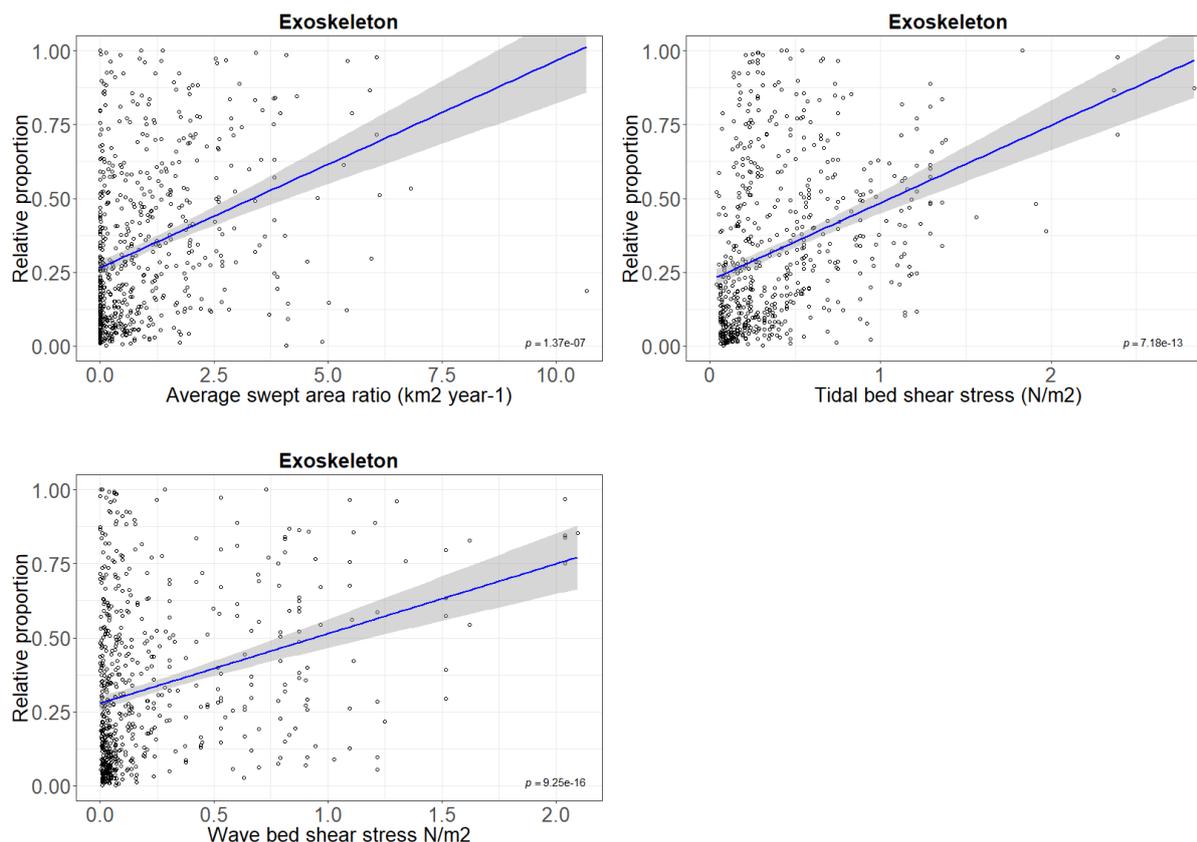


Figure 17: The relative proportion of animals with an exoskeleton. Blue line is modelled relation, grey area is the 95% confidence interval.

Table 11: Estimated regression parameters, standard errors, t-values and P-values for the Gaussian GLM fishing intensity (FIAverage), tidal-induced bed shear stress (TidalBSS) and wave-induced bed shear stress (WaveBSS) to predict the proportion of caught animals with an exoskeleton.

	Estimate	Std. Error	t value	P - value
(Intercept)	0.16216	0.01503	10.788	< 2e-16 ***
FIAverage	0.04296	0.00806	5.33	1.37e-07 ***
WaveBSS	0.21647	0.02625	8.247	9.25e-16 ***
TidalBSS	0.19614	0.02677	7.326	7.18e-13 ***

The relative proportion of soft-bodied species seem to decrease at places with higher rates of fishing intensity. However, this has not been statistically tested and it remains to be seen whether this is a significant trend or not.

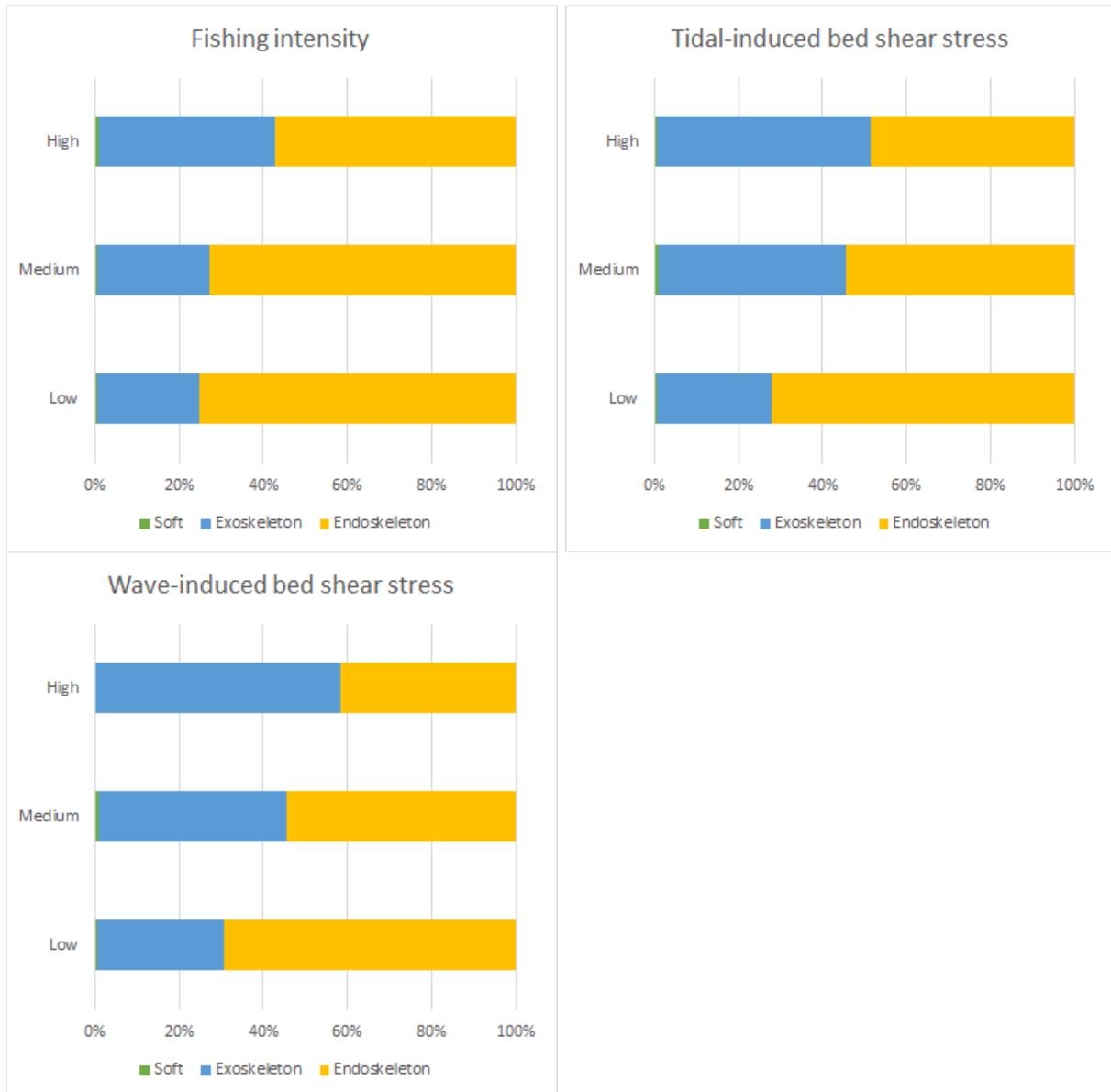


Figure 18: Relative abundance and morphology.

Size

Species were classified as very small (< 2cm), small (2 to 10 cm), medium (10 to 20 cm) and large (> 20cm). The vast majority of caught individuals were small to medium-sized. Species classified as small showed a significant positive correlation with fishing intensity ($p = 6.00e-14$). The higher the fishing intensity, the higher the relative proportion of small animals. The same pattern was found for natural disturbance. The relative proportion of small animals showed a significant positive correlation with both wave-induced bed shear stress ($p = 7.59e-09$) and tidal-induced bed shear stress ($p < 2e-16$) (fig. 19).

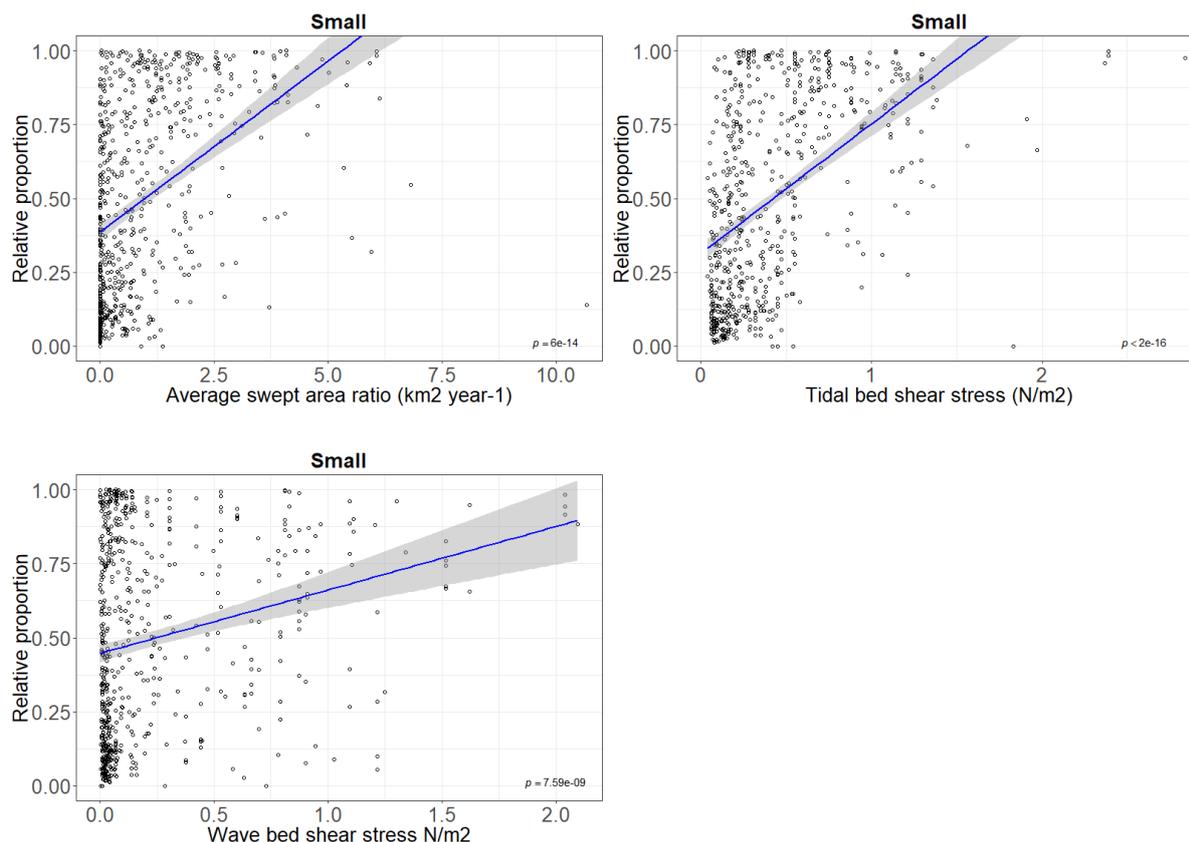


Figure 19: The relative proportion of small animals. Blue line is modelled relation, grey area is the 95% confidence interval.

Table 12: Estimated regression parameters, standard errors, t-values and P-values for the Gaussian GLM with sediment type (FolkClassName), fishing intensity (FIAverage), tidal-induced bed shear stress (TidalBSS) and wave-induced bed shear stress (WaveBSS) to predict the proportion of small animals (between 2 and 10 cm).

	Estimate	Std. Error	t value	P - value
(Intercept)	-0.704233	0.271465	-2.594	0.009699 **
FIAverage	0.070988	0.009243	7.68	6.00e-14 ***
FolkClassNameMuddy_sand	0.943209	0.272816	3.457	0.000582 ***
FolkClassNameSand	0.952247	0.269745	3.53	0.000445 ***
WaveBSS	0.177017	0.030227	5.856	7.59e-09 ***
TidalBSS	0.349583	0.031795	10.995	< 2e-16 ***

There is a very weak but nonetheless significant negative correlation between the proportion of large animals and fishing intensity ($p = 0.00367$). On the other hand, natural disturbance has a significant positive correlation with the relative proportion of large animals. With increasing wave-induced bed shear stress ($p = 4.66e-10$) and tidal induced bed shear stress ($p = 0.01672$), the relative proportion of large animals also increases (fig. 20).

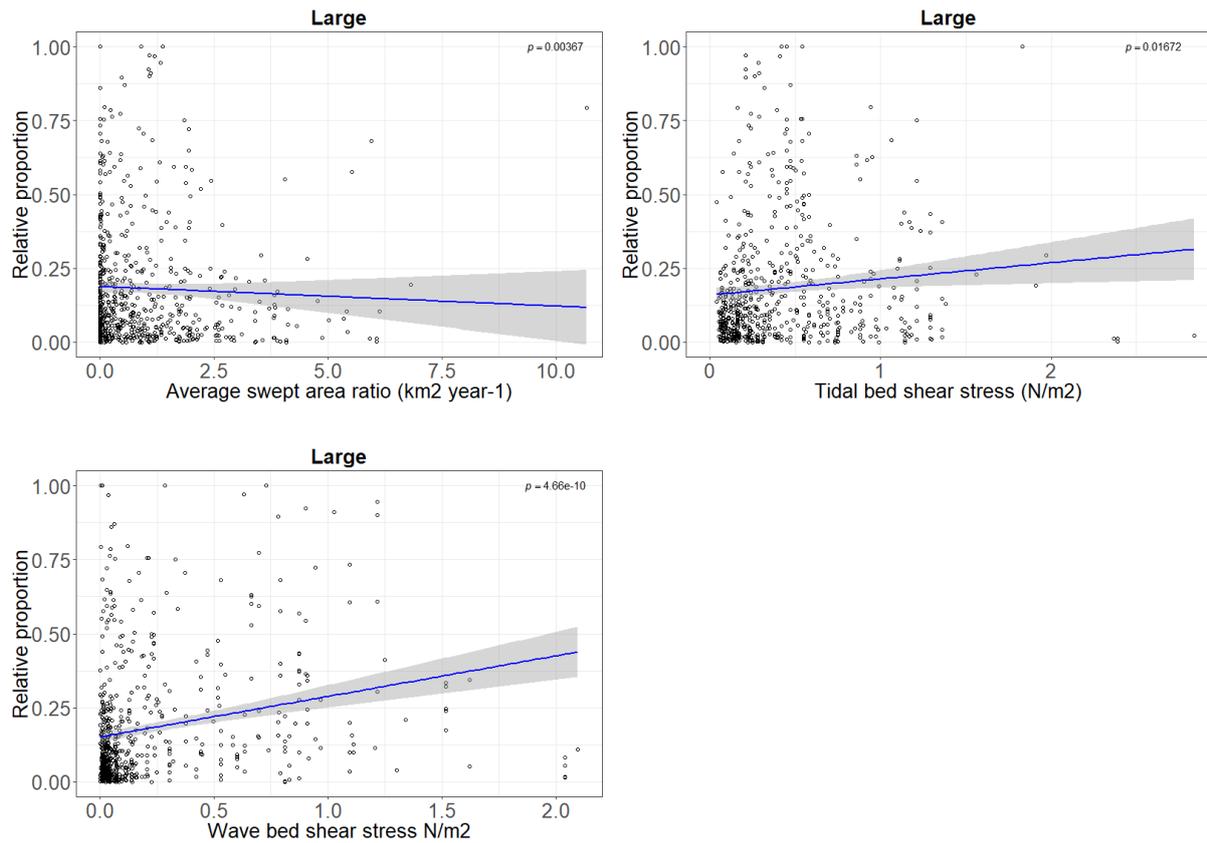


Figure 20: The relative proportion of large animals. Blue line is modelled relation, grey area is the 95% confidence interval.

Table 13: Estimated regression parameters, standard errors, t-values and P-values for the Gaussian GLM with sediment type (FolkClassName), fishing intensity (FIAverage), tidal-induced bed shear stress (TidalBSS) and wave-induced bed shear stress (WaveBSS) to predict the proportion of large animals (> 20 cm).

	Estimate	Std. Error	t value	P - value
(Intercept)	0.90719	0.21823	4.157	3.67e-05 ***
FIAverage	-0.02167	0.00743	-2.916	0.00367 **
FolkClassNameMuddy_sand	-0.60085	0.21932	-2.74	0.00632 **
FolkClassNameSand	-0.58105	0.21685	-2.679	0.00756 **
WaveBSS	0.15379	0.0243	6.329	4.66e-10 ***
TidalBSS	0.06132	0.02556	2.399	0.01672 *



Figure 21: Relative abundance and size.

Discussion and conclusion

Species richness showed a very weak, but nonetheless significant negative correlation with fishing intensity. The higher the fishing intensity, the lower the amount of species present. This has also been found in various other studies (Hinz et al., 2009; Asch & Collie, 2008; Thrush et al., 1998). I hypothesized that species richness would indeed show a significant negative response to increased fishing intensity. Bottom trawling may cause some species to go extinct. Biodiversity, however, did not show a significant positive or negative correlation with fishing intensity. This is contrary to expectations. A possible explanation is that while less species are present in a heavily fished benthic community, species evenness increases because highly abundant species are more negatively influenced by fishing. Future research may show whether this is true or not.

The species composition was also significantly correlated with fishing intensity. High fishing intensity showed a significant positive correlation with the relative proportion of arthropods. The higher the fishing intensity, the higher the relative proportion of arthropods in a benthic community. This could be because of the exoskeletons these species have. There was a significant positive correlation with fishing intensity and the relative proportion of species with an exoskeleton. It is possible that species with a hard and strong external structure are more resistant to anthropogenic disturbance by the means of bottom trawling. This is in line with my hypothesis. Soft-bodied species may be more vulnerable to bottom trawling because of the high mortality rates it imposes on benthic communities. Studies have shown that soft-bodied corals, for example, are particularly vulnerable to bottom trawling (Sciberras et al., 2018).

While the relative proportion of arthropods increased, the relative proportion of echinoderms decreased significantly when fishing intensity was higher. With other words, the more a benthic community was fished, the lower the relative proportion of echinoderms. This also may be explained with the help of morphology. Echinoderms have an endoskeleton which gives them internal robustness, but maybe endoskeletons are not able to withstand external threats such as bottom trawling. Mortality may therefore very well be higher for echinoderms than for arthropods.

Another interesting result was that the relative proportion of small animals (between 2 and 10 cm) is significantly positively correlated with fishing intensity. The higher the fishing intensity, the higher the relative proportion of small animals. This has also been found by Van Denderen *et al.* (2015) and Jennings *et al.* (2001b). Small species often have faster life histories and they can better withstand bottom trawling-imposed mortality. Also, smaller epifaunal species may benefit from decreased rates of competition or predation by larger epifaunal species (Jennings et al., 2001b). The results show that there is a weak but nonetheless significant negative correlation with a large body size (bigger than 20cm) and fishing intensity. With other words, the higher the fishing intensity, the lower the relative proportion of large animals.

There are some limitations that have to be made. There were sometimes conflicting sources when classifying species as 'epifauna'. This was particularly the case with molluscs. Various sources stated that some molluscs species are infauna, while others classified it as epifauna. The same problem occurred while determining physical characteristics. It proved to be difficult to classify some species as 'large' or 'medium' regarding their size.

Another limitation is that various variables were highly correlated. For example, depth and wave-induced bed shear stress are highly correlated. Depth was also correlated with salinity, while tidal-induced bed shear stress and temperature were also highly correlated. It has therefore been decided to include the most interesting variables in the model. These were sediment type, fishing intensity, wave-induced bed shear stress and tidal-induced bed shear stress. However, because wave-induced bed shear stress is correlated with many other variables, it cannot be said with certainty that wave-induced bed shear stress is solely responsible for a certain pattern. This is a major limitation to this research.

Another limitation is the lack of evidence for a causal relationship. Due to the nature of the study, it is not possible to prove causal relationships based on the results. The large spatial and temporal scales have the effect that only significant correlations can be demonstrated.

Pristine benthic communities in the North Sea are virtually non-existent, since the North Sea is one of the most intensively fished seas in the world (Reiss et al., 2010). Due to the lack of data that goes far back in time, for both fishing intensity and population data, nothing can be said with absolute certainty about benthic communities in the North Sea. It is therefore impossible to draw conclusions about the temporal changes. Because changes in benthic communities have probably been going on for a long time, it is possible that we see effect of shifting baselines. What seems to be relatively undisturbed or pristine, may very well be significantly altered already by bottom trawling. It is therefore important to see the results of this research in perspective. We can only say something about the relative impact of bottom trawling on benthic communities by comparing highly fished areas with relatively undisturbed areas. But we have to keep in mind that 'relatively undisturbed' doesn't been pristine. It is very hard to quantify the absolute impact of bottom trawling on benthic communities because of these shifting baselines.

The results show that it is likely that bottom trawling has significant impact on benthic communities in the North Sea. While some species may benefit from decreased competition from other species, in general it can be said that high fishing intensity correlates with negative trends for benthic communities. The results suggest that high fishing rates alter benthic communities and that it functions as a driver for smaller and hard-bodied epifauna species. It is therefore advantageous to develop alternatives for bottom trawling. In recent years, the Dutch fishing fleet has been modernized with the introduction of electric pulse fishing (Poos *et al.*, 2013). Although rising fuel costs were the main reason for this switch, it has been thought that this fishing method caused far less seabed disturbance than traditional bottom trawling (Poos *et al.*, 2013). In theory this may be very beneficial for benthic communities in the North Sea. However, the European Parliament voted in early 2018 for a ban on electrical fishing in the North Sea. It is therefore likely that many fishermen will start fishing in the traditional way again. This is something to think about, as traditional beam trawling has a significant negative impact on benthic communities. Countries surrounding the North Sea have pledged to protect benthic communities and other sea life in the North Sea. It is therefore necessary to keep looking for sustainable alternatives that won't impact benthic communities.

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