Shrimp fishery and natural disturbance affect longevity of the benthic invertebrate community in the Noordzee-kustzone Natura 2000 area

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Wageningen University & Research report C123/19

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Contents

Summary

The Noordzeekustzone is an important fishing ground for fishing vessels targeting brown shrimp (Crangon crangon). Shrimp trawling is by far the dominant fishing activity in this area. However, the effect of shrimp fishery on the benthic invertebrate community has never been clearly established. It is important to establish this effect (or lack of effect) because the Noordzeekustzone is a designated Natura 2000 area, with a policy target to improve the quality of the seafloor habitat (so-called H1110b, permanently submerged sand banks).

In this paper, the longevity composition of the benthic community is studied in relation to environmental variables. First the longevity composition is estimated for seafloor habitats and the effect of depth, grainsize, tidal shear stress and trawling intensity on the longevity composition is estimated and used to derive quantitative relationships that can be used to determine the changes in the benthic community and the effect of natural and human pressures. The analysis is carried out using dredge sampling data, which effectively samples only the larger individuals (>0.5cm) in the upper 7cm of the sediment. The methodology developed in the FP7-project BENTHIS (Rijnsdorp et al, 2015) was used to assess the changes in the benthic community in the Noordzeekustzone and the importance of all those candidate factors with special attention to fishing effort.

In this study we find clear evidence that intensive shrimp trawling is associated with a reduction in the longevity of the benthic invertebrate community. However, the direction and intensity of that impact is determined by the wind regime in the area, which we take as a proxy for the degree and/or frequency of natural disturbance of the seafloor. The entire Noordzeekustzone area is subject to strong natural disturbance, and it has often been suggested that trawling has no effects in such areas. Our analysis shows otherwise. Even within this highly dynamic area there is a clear gradient along the magnitude of natural disturbance, in the effect of shrimp fishing. At the lower end, we find that shrimp trawling truncates community longevity, while at the higher end shrimp trawling actually enhances longevity. The mechanism for this reversal remains to be studied. To our knowledge, this is the first study where a clear effect of shrimp trawling on the benthic ecosystem has been found in empirical data.

This study shows a statistically significant effect of an admitted economic activity on the seafloor in a Natura2000 area where protection of seafloor habitat is one of the key reasons for the protection. The admission of shrimp trawling in this area has been granted based on an appropriate assessment which concluded that there are no known significant effects of the activity on the seafloor habitat. The *statistically significant* results of this study indicate that there *are* effects and hence warrant further study to determine significance in the sense of the natura2000 framework.

1 Introduction

The seafloor is affected by a multitude of anthropogenic activities. And among them, bottom trawl fisheries are considered pervasive due to the strong physical interaction with the sea floor and large spatial coverage (Jennings and Kaiser, 1998). The EU Marine Strategy Framework Directive (MSFD) developed a policy for maintaining or achieving good environmental status. In order to assess the status of the seafloor indicators of sea floor integrity are required. Seafloor integrity includes the morphological characteristics of the seafloor, as well as the structure and function of the benthic ecosystem.

Bottom trawling disturbs the seafloor, damages biogenic structures and kills benthic invertebrates. The impact of trawling differs between fishing gears and is related to the surface and sub-surface footprint of the gear and the weight and speed with which the heavy parts of the gear are towed over the seafloor and the extent and intensity spectrum of bottom trawling (Eigaard et al., 2016). The impact is further modulated by the sensitivity of the seafloor habitat, and the degree of natural disturbance (Hall, 1994). Biogenic habitats are particularly sensitive for bottom trawling (Jennings and Kaiser, 1998).

The Noordzeekustzone is an important fishing ground for fishing vessels targeting brown shrimp (Crangon crangon). Shrimp trawling is by far the dominant fishing activity in this area. However, the effect of shrimp fishery on the benthic invertebrate community has never been clearly established. It is important to establish this effect (or lack of effect) because the Noordzeekustzone is a designated Natura 2000 area, with a policy target to improve the quality of the seafloor habitat (so-called H1110b, permanently submerged sand banks).

This study aims to quantify the effect of shrimp trawling on the invertebrate benthic community. We do this using an analysis framework developed recently within the EU-funded project, which has been successfully applied to show effects of bottom trawling on the benthic community in the wider North Sea. We do our analysis on the existing data collected annually by Wageningen Marine Research as part of the WOT Schelpdiersurvey. This is the first time the method is applied to data collected using a bottom dredge rather than a core- or grab-type sampling device.

A quantitative understanding of the impact of shrimp fishing on the benthic community would facilitate an evidence-based and effective approach to the regulation of shrimp fishing in the Noordzeekustzone.

In order to assess the impact of bottom trawling, information is also needed on the seafloor habitats and their sensitivity to bottom trawling. In this paper, the longevity composition of the benthic community is studied in relation to environmental variables. First the longevity composition is estimated for seafloor habitats and the effect of depth, grainsize, tidal shear stress and trawling intensity on the longevity composition is estimated and used to derive quantitative relationships that can be used to determine the changes in the benthic community and the effect of natural and human pressures. The analysis is carried out using dredge sampling data, which effectively samples only the larger individuals (>0.5cm) in the upper 7cm of the sediment.

2 Materials and Methods

The methodology developed in the FP7-project BENTHIS (Rijnsdorp et al, (2015) was used to assess the changes in the benthic community in the Noordzeekustzone and the importance of all those candidate factors with special attention to fishing effort.

2.1 Data

2.1.1 Data sources

The state of the benthic community was assessed using data from the shellfish survey conducted annually in the Dutch coastal zone. This survey falls within the DLO Program 406. This sampling program carries out Legal Research Tasks, which deal with fisheries management. The program covers both seafront, inland waterway and aquaculture fisheries and includes a number of different research topics, carried out within the framework of the Ministry of Economic Affairs, Programs under BAS code WOT-05-406-080-IMARES-2, under the Legal Research Tasks (WOT) program.

The primary purpose of shellfish inventories in Dutch coastal waters is to determine the current size of the stock of commercially important species and map their distribution for the implementation of fisheries policy. However the data from these surveys are also of importance as reference values for environmental impact of sand nourishment. The WOT shellfish survey in the coastal zone provides an important basis for status monitoring for Natura 2000 and MSFD (Troost et al., 2013).

These surveys have been conducted since 1994 during the spring-early summer. The research vessel ISIS of Rijkswaterstaat was used to sample in the deeper parts of the coastal zone, while the vessel Anna Elizabeth was used to sample in the shallow depths of the Voordelta. The sampling points are distributed across the research area according to a grid, in which for an efficient distribution of research effort the area is divided into a number of strata. Three different fishing gear were used. The bottom dredge is the most widely used gear during this survey, and in this study has been the only gear considered. Each year a trawl of 150 meters has been conducted on each sampling location, with the centre point of that transect always located in the same latitude and longitude, but with the transect having variable directions between years. More information about the survey can be obtained from Troost et al (2015).

In this survey a wide range of organisms from different taxonomic groups are regularly sampled (Table 1). On each sampled station, all the species collected are identified and the number of individuals are counted and weighted. Species of genus Ensis, Pagurus and Diogenes were not included in this study due to the difficulty to estimate the weight of separate individuals all years.

The survey stations located within the Noordzeekustzone Natura2000 area within which the shrimp fishery takes place were selected for this study (Figure 1). Despite the survey started in 1994, due to the lack of fishing effort estimates before 2004, the benthic data used in this study ranged from years 2004-2015. On average 152 stations were sampled within the study area, although it ranged from 133 in 2005 to 165 in 2013.

The longevity composition of the benthic assemblage was estimated by assigning longevity (<1, 2-3, 3-10, >10 years) by taxon as compiled by Bolam et al (2014) and estimating the cumulative biomass by longevity class for each sampling station. Separate analyses were carried out for different subsets of the taxa sampled.

In this study, a wide range of data sources have been used in order to account for the most important environmental factors that, together with fishing effort, are considered potential drivers inducing changes in the benthic community composition, and specifically, the age distribution of the benthic community. These factors are:

- Sea floor structure
- Water movement
- Depth
- Fishing effort (shrimp fishery)

Table 1: Species_dredge_BenthicFauna_data_no_outliers

phyllum	class	order	species
Arthropoda	Malacostraca	Decapoda	Callianassa
			Cancer pagurus
			Carcinus maenas
			Corystes cassivelaunus
			Diogenes pugilator
			Liocarcinus depurator
			Liocarcinus holsatus
			Liocarcinus navigator
			Macropodia
			Pagurus bernhardus
			Pinnotheres pisum
			Portumnus latipes
			Thia scutellata
Cnidaria	Anthozoa	Actiniaria	Actiniaria
Echinodermata	Asteroidea	Forcipulatida	Asterias rubens
		Paxillosida	Astropecten irregularis
	Ophiuroidea	Ophiurida	Ophiura
			Ophiura albida
			Ophiura ophiura
Mollusca	Bivalvia	[unassigned] Euheterodonta	Ensis
		Myoida	Barnea candida
		Mytiloida	Mytilus edulis
		Veneroida	Abra alba
			Abra prismatica
			Cerastoderma edule
			Chamelea striatula
			Donax vittatus
			Lutraria lutraria
			Macoma balthica
			Mactra stultorum
			Mactroidea
			Petricolaria pholadiformis
			Spisula elliptica
			Spisula solida
			Spisula subtruncata
			Tellina fabula
			Tellina tenuis
			Venerupis corrugata
	Gastropoda	Littorinimorpha	Euspira catena
			Euspira nitida
			Naticidae
		Neogastropoda	Nassarius nitidus
			Nassarius reticulatus

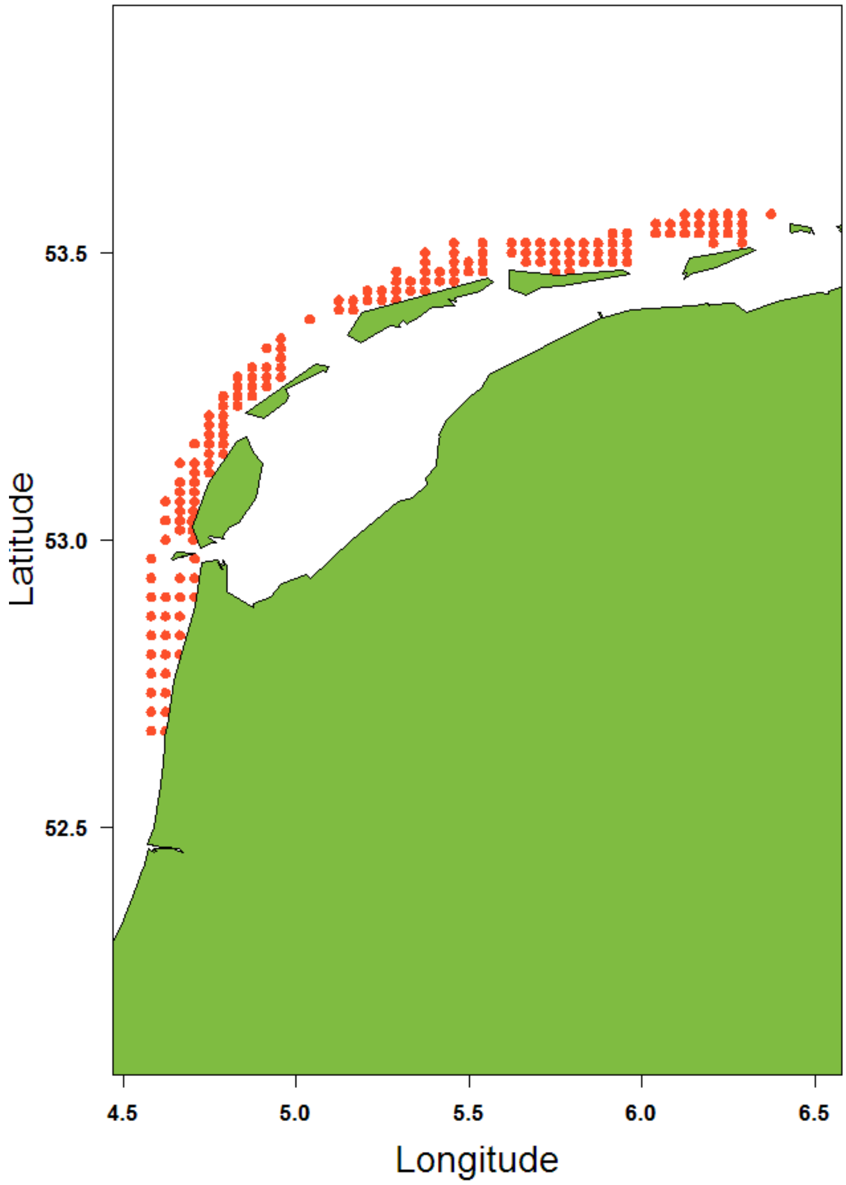

Figure 1: Sampling stations from the Benthic survey used in this study to assess the influence of environmental and human drivers in the benthic community composition or the Noordzeekustzone.

The sea floor structure was represented by 1) the average granulometry (average grain size in µm) of the portion of the sediment with particles larger than 63 µm; and 2) the percentage of sediment consisting of particles below 63 µm (hereafter called silt content). The information to estimate these two indicators of the sea floor structure was collected as part of monitoring programme financed by the Ministry of Infrastructure and Environment I&M in 2006.

The water movement was represented in this study through two of the main factors: the tidal regime and wind. The effect of tides in the movement of water at each station (hereafter shear stress) was obtained from estimates made with the model GETM/GOTM (Tiessen et al, 2012). These estimates were obtained for year 2010, and were considered constant over the whole time period analysed. The mean and maximum annual wind speed were obtained from the website of the Meteorological Institute of the Dutch Government (https://www.knmi.nl/home). The values for the Vlieland area were used as proxies of the wind conditions in the study area.

The depth at each benthic station was obtained directly from the Benthic survey. Due to different problems, in some of the stations sampled during the Benthic survey, the bottom depth was not registered. In those cases, as a compromise solution the average depth of the closest stations was estimated and used instead.

The fishing effort of the shrimp fleet was estimated for each survey station as the number of hours of fishing trawl within an area of 200 m diameter around the latitude-longitude defining the midpoint of the transect for each sampling station. Information of trawling intensity of all vessels targeting shrimp in the Noordzeekustzone was obtained from the Vessel Monitoring System VMS database from 2004 to 2015. In order to assess the cumulative impact of fishing effort on the benthic community, the fishing effort was estimated at a half year, one year, two and three years prior to the each annual benthic survey from 2004 to 2015.

Due to data restrictions, the information about the two sea floor structure indicators (silt content and granulometry), as well as the shear stress index allowed the consideration of spatial variation in this study, but not for temporal changes. Hence a constant value per sampling station over time was used for these parameters. On the opposite side, the spatial resolution of the wind speed data was coarser than that of the survey sampling design, and hence a unique value was used for all sampling stations, changing over time. Finally, the information about fishing effort and depth allowed for spatial and temporal variability, and hence independent measures per station and year were considered in this study. However, the depth of the sampling station did not changed over the study period and could be also considered as constant over time.

2.1.2 Data overview

2.1.2.1 Biomass longevity data

Due to limitations in the sampling designs, the weight of species of bivalves like Ensis, or hermit crabs like Pagurus and Diogenes could not being sampled all years. For this reason, these species were removed from the analysis. In addition, an outliers analysis was conducted and any extremely high/low values were removed from the database.

As indicated in the data section, the longevity composition of the benthic assemblage was estimated by assigning one of four longevity classes: <1, 2-3, 3-10 and >10 years to each taxon, as compiled by Bolam et al (2014). Next the cumulative biomass was estimated for each sampling station and year as a function of longevity. Finally, the proportion of biomass accumulated by the different longevity classes was estimated. In Figures 2 and 3 the proportion of the biomass for groups of age 1-3 and 3-10 in relation to the total biomass is presented for each sampling station. In Figure 4 a boxplot with the proportions of the four longevity classes over the study period are shown for all stations. For categories 1 (<age 1) and 4 (all ages) this figure is trivial, since values are 0 and 1 respectively all years for all stations. For category 2 (cumulative biomass up to age 3) proportions are below 0.1 most years for nearly all the stations, although some years values were as high as 0.5. For category 3 (cumulative biomass up to age 10), despite some stations presented very low values some years (as low as zero in a few cases), the most common annual values were between 0.3 and 0.9, with the median around 0.7.

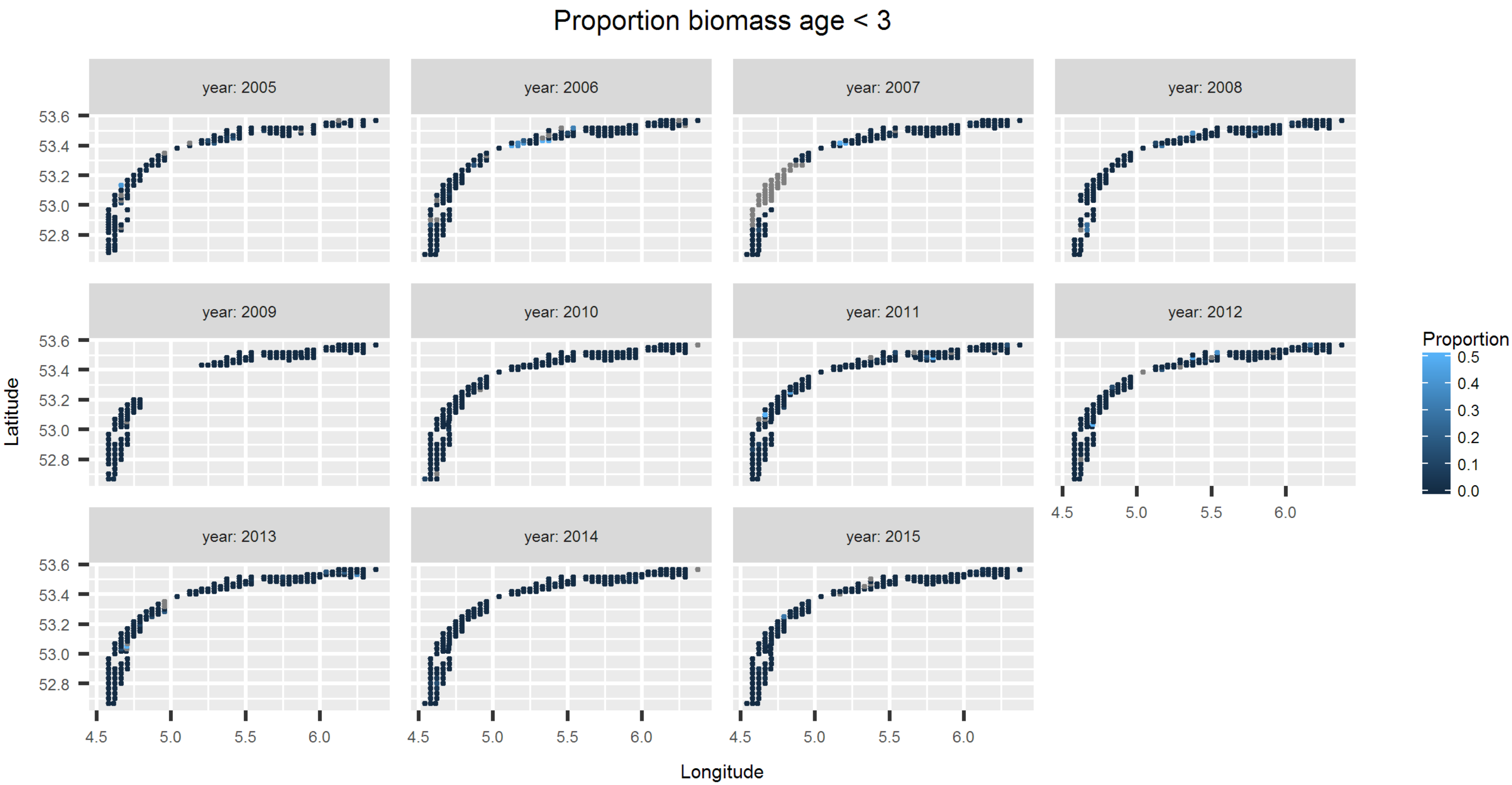

Figure 2 Proportion of biomass (in relation to total biomass per station and year) of species with average age lower than 3 years (based in Bolam et al., 2014).

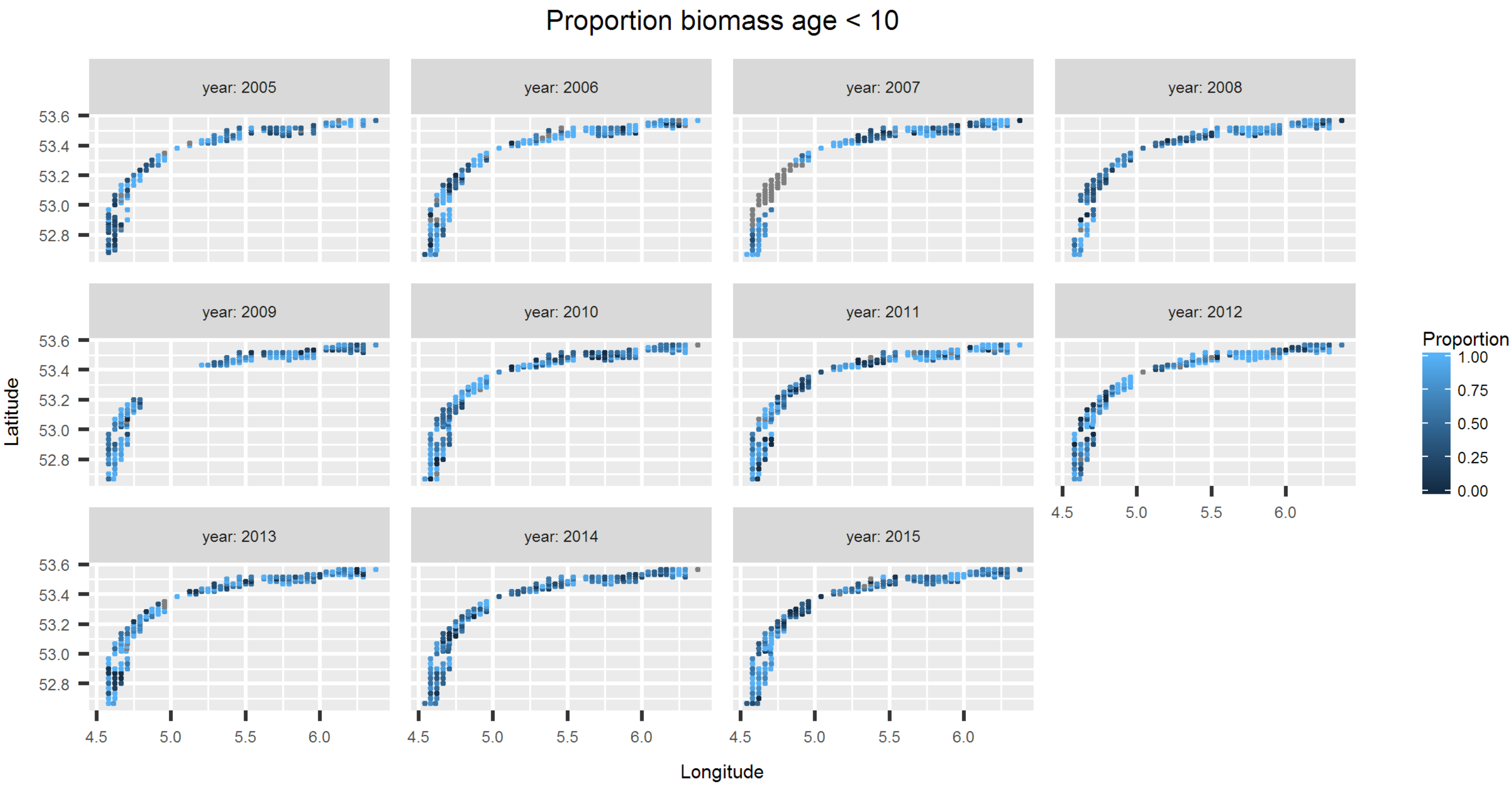

Figure 3: Proportion of biomass (in relation to total biomass per station and year) of species with average age lower than 10 years (based in Bolam et al., 2014).

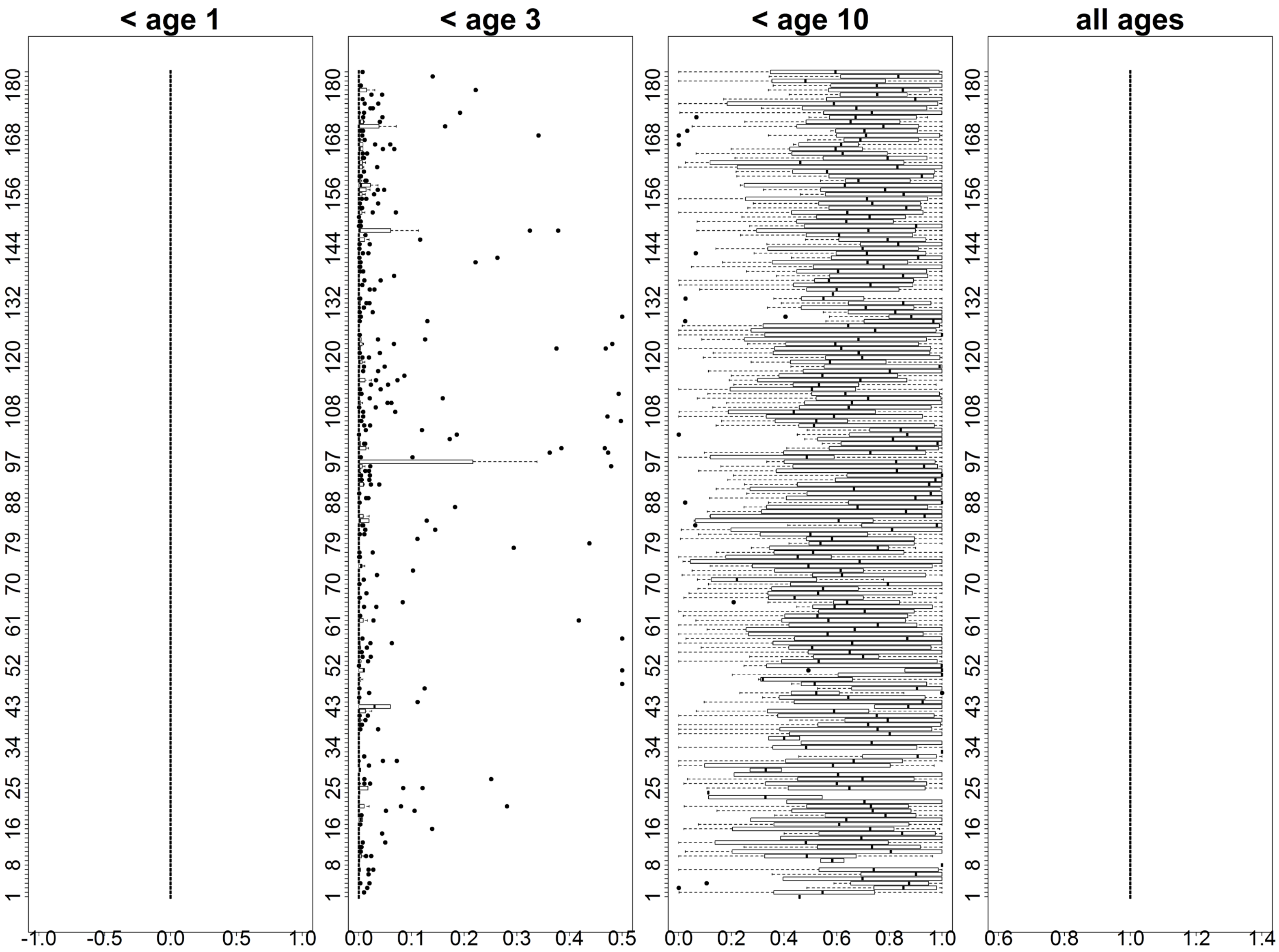

Figure 4: Boxplot showing the 25, 50 and 75 percentiles of biomass proportion by age (lower, mid and top limits of the box) and upper and lower whiskers showing the min(max(x),Q+1.5 IQR) (with x being the biomass proportion, Q the 25 or 75 percentiles and IQR the interquartile range). In the Y axis the station number is shown

2.1.2.2 Environmental drivers

The structure of the sea floor in terms of granulometry and silt content is shown respectively in Figures 5 and 6 for each survey station (In Figure 11 the numeric values per station are shown in a boxplot with the other environmental factors). The southern and western stations within the Noordzeekustzone presented the larger grain size, above 600 µm, while for stations in the eastern area it was around 200 µm. In accordance with the average estimated granulometry, the percentage of silt content (defined by the portion of the sediment below 63 µm grain size), was zero in most stations with the exception of some stations in the eastern area of the Noordzeekustzone.

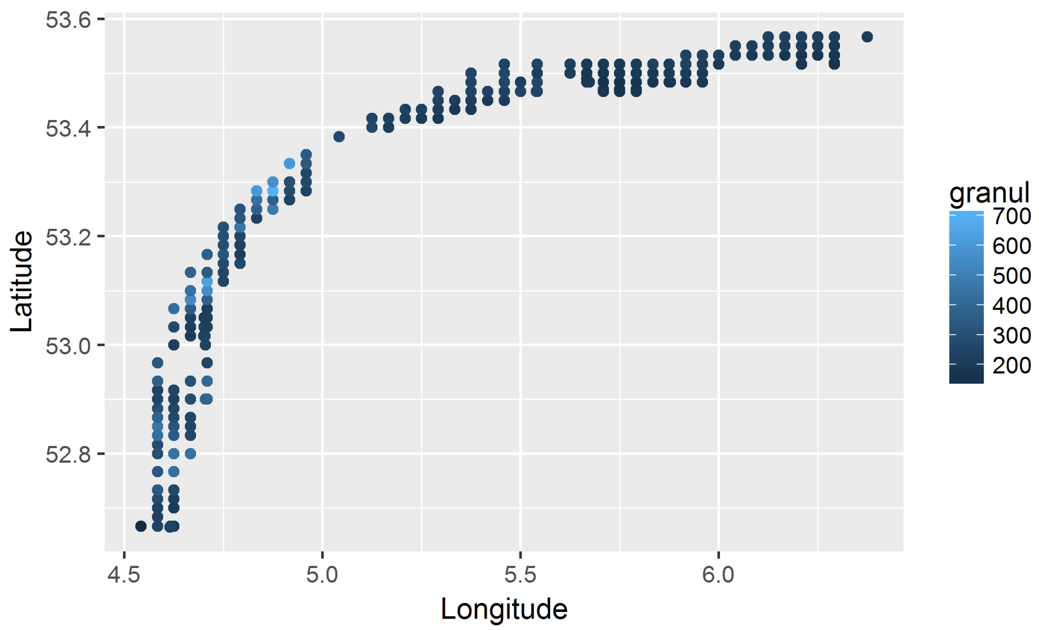

Figure 5: Mean granulometry (in µm) per sampling station.

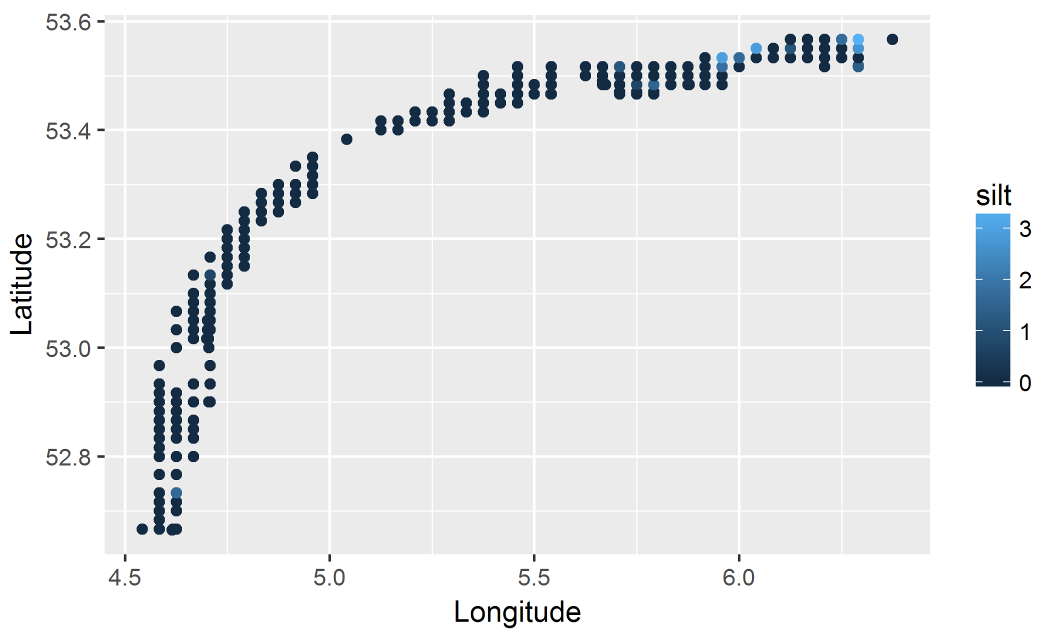

Figure 6: Mean silt content as percentage of particles below 63 µm grain size.

The shear stress was estimated, as indicated in the material and methods section, using the model GETM/GOTM (Tiessen et al, 2012). This model produces estimates of the shear stress as result of the tidal movement, which is in turn is modelled with dependency on depth, among other factors. For this reason, the resulting map with values of average shear stress per survey station showed a very similar pattern as that of the average depth by station (Figure 7 and 8 respectively; Figure 11 with the value per station in a boxplot). Shear stress was higher in the shallower areas closer to the islands in the Noordzeekustzone, and especially in the channels between the islands.

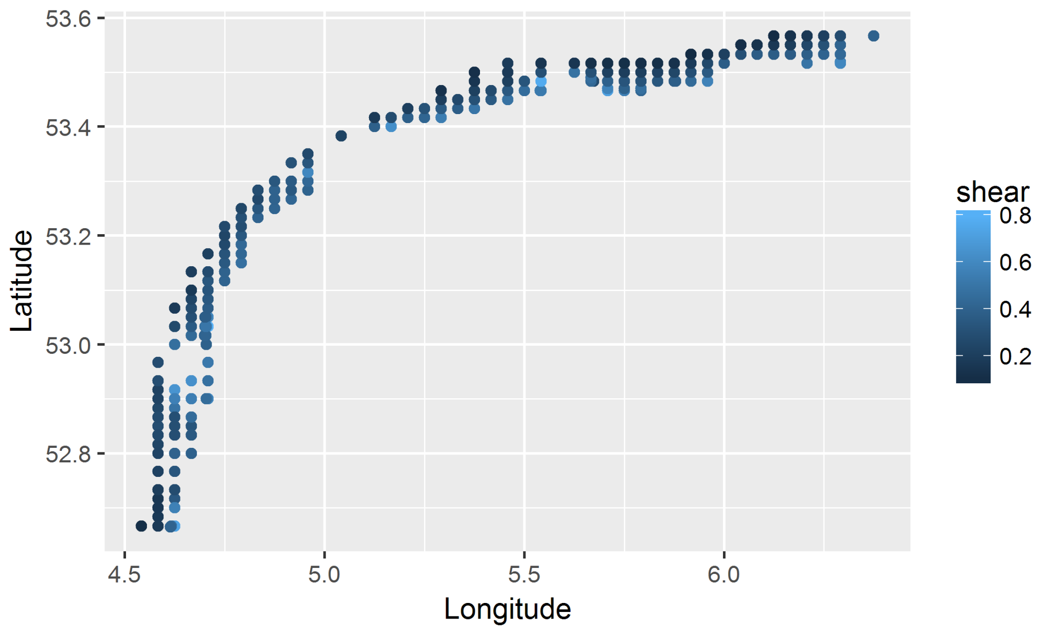

Figure 7: Average shear stress (in Newtons/m²) per sampling station.

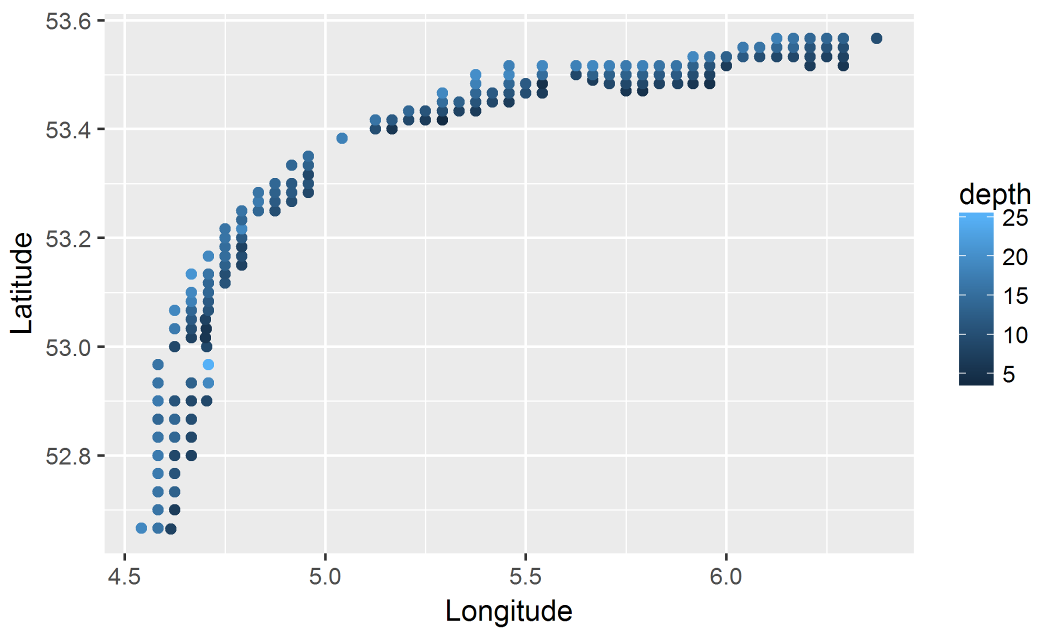

Figure 8: Mean depth (m) per sampling station.

The average wind speed in the Noordzeekustzone was between 7.5 and 8 m/s most years (Figure 9), with the exception of years 2007, 2008 and 2015, when the wind speed was higher (8.4 m/s in 2008), and year 2010, when the average wind speed was much lower (7.2 m/s). The maximum wind speed was between 22 and 24 m/s most years, but in years 2007 and 2013 it reached higher values (29.3 m/s in 2013).

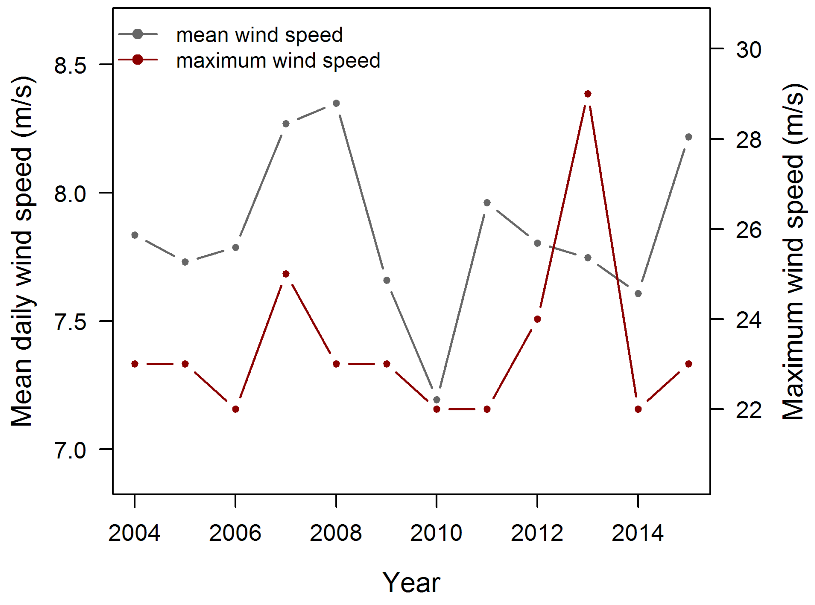

Figure 9: Mean and maximum wind speed (m/s) in the Noordzeekustzone area over the period 2004-2015.

2.1.2.3 Trawling intensity

The cumulative fishing effort showed important changes over the study period. All the different time frames considered (half, one, two and three years prior to the survey) to estimate the cumulative effort (in trawling hours/year) showed an increase in trawling intensity over the study period 2004-2015 (Figure 10), peaking between 2012 and 2014 (depending on the cumulative effort time series). The increase in fishing effort was different spatially (as an example, Figure 11 shows values of one year of cumulative effort; Figure 12 shows a boxplot with the range of values over the study period). For the one year cumulative effort estimate, from years 2005 to 2009, values were between 1 and 3 hours/year in most survey stations. During this period, a slight increase was detected in the stations located in the eastern part, where the effort was between 2 and 4 hours/year. However, it was from 2010 when the increase in the trawling intensity was higher. The increase started in the north-eastern part of the Noordzeekustzone, with effort above 4 hours/year in several stations, and progressed over time towards western and southern areas. The highest and more spread trawling intensity was observed in year 2013, when some stations reached values as high as 7 hours/year.

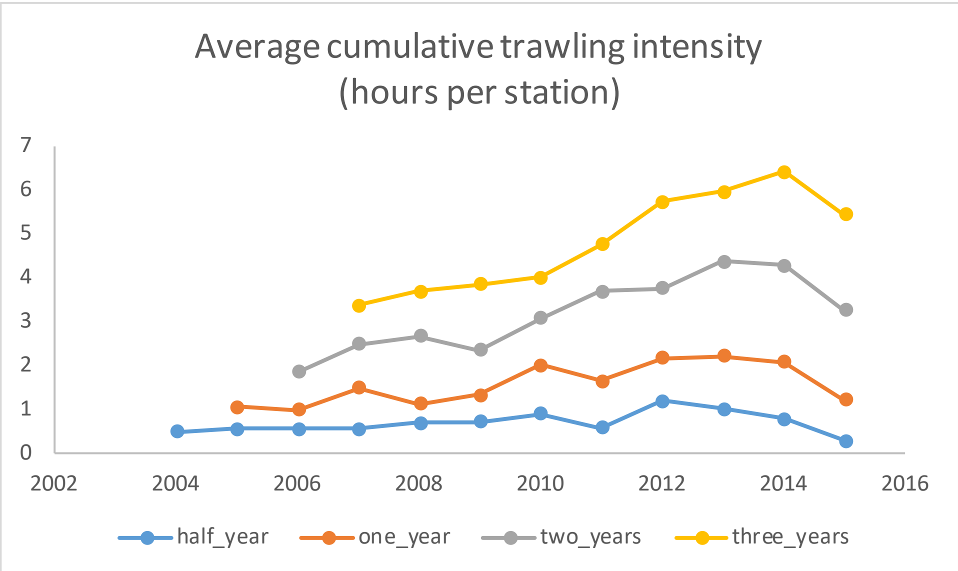

Figure 10: Cumulative trawling intensity per station (hours/year; averaged over all the stations).

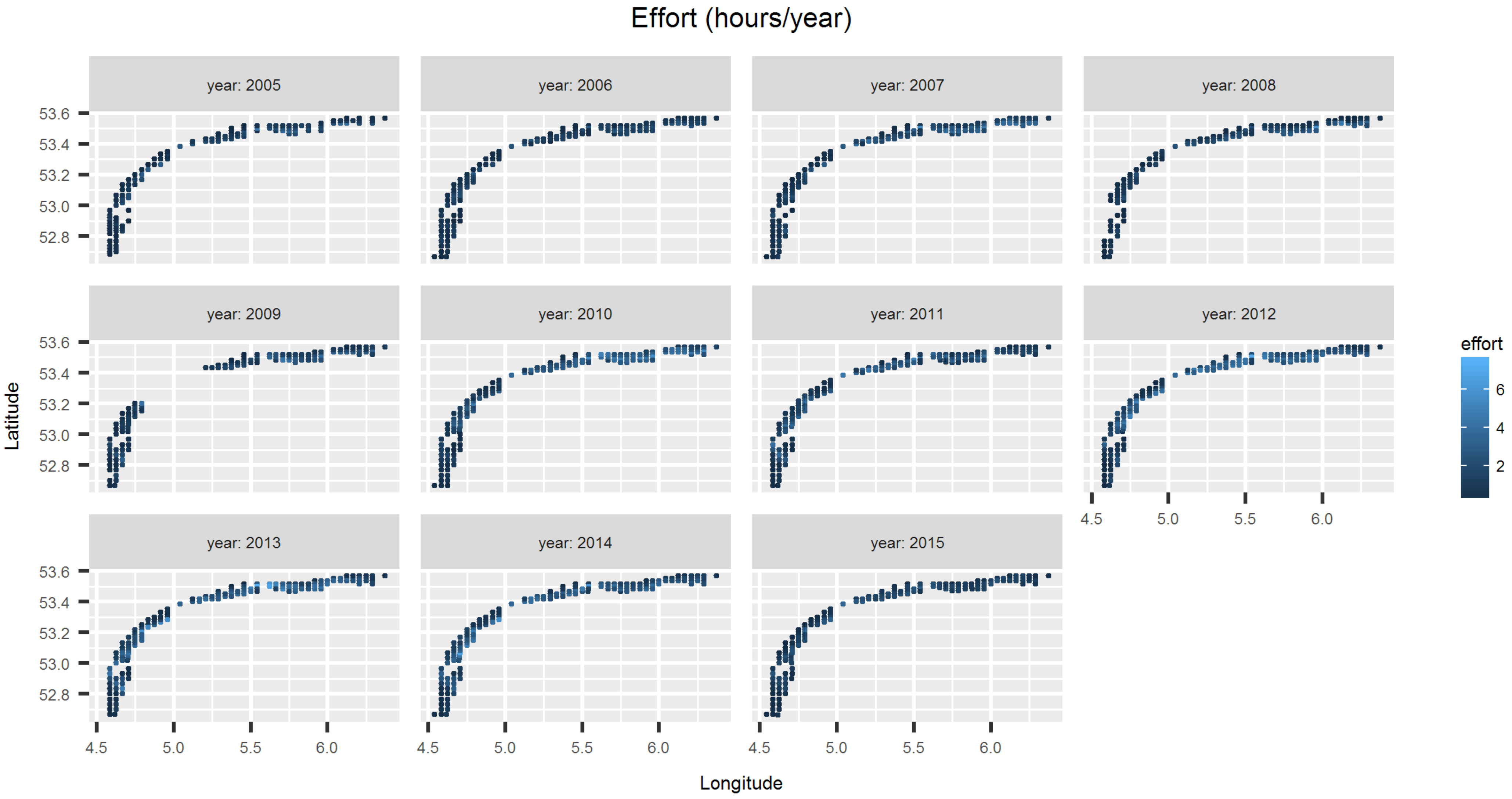

Figure 11: Shrimp trawl fleet fishing effort (in hours) per sampling station in the Noordzeekustzone.

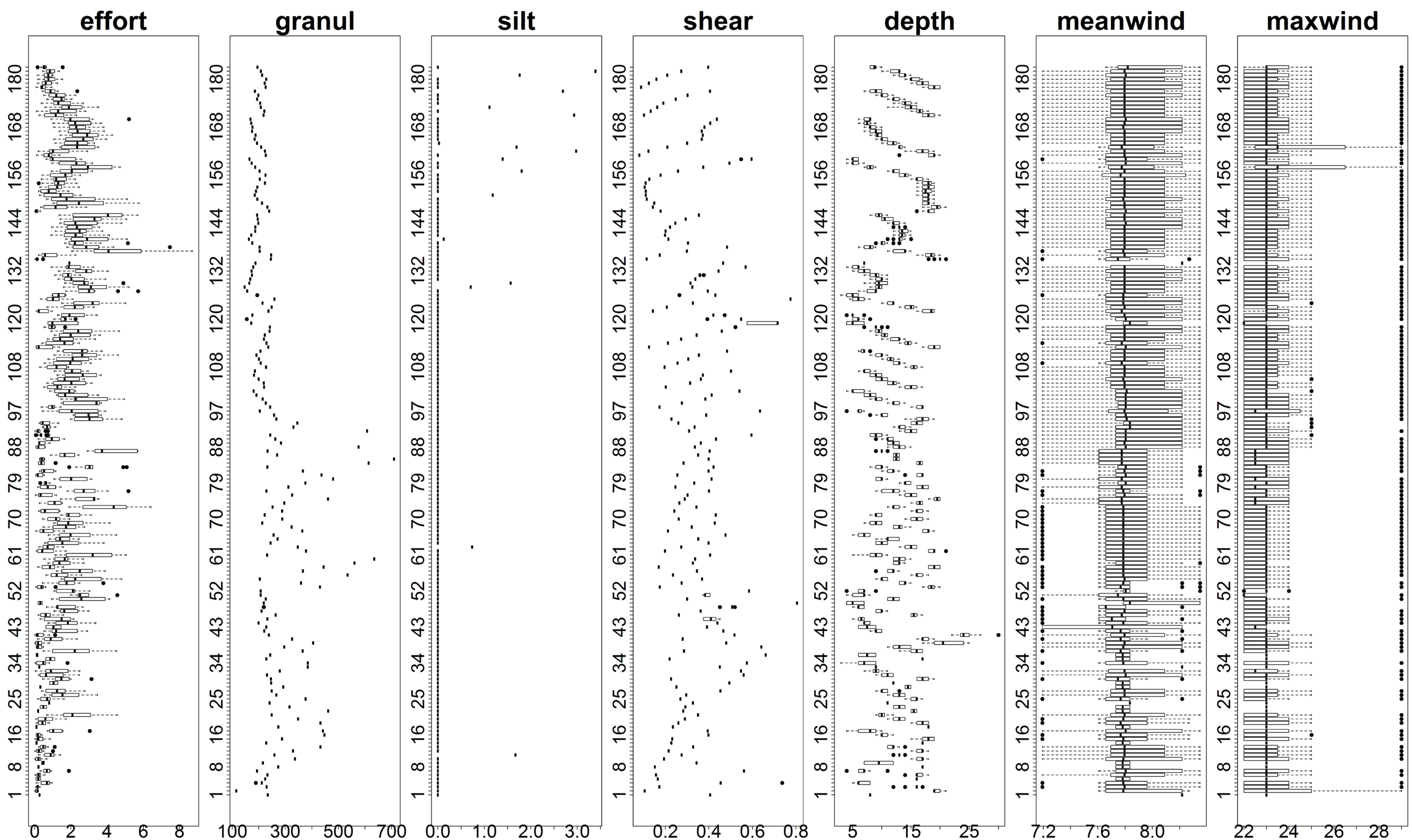

Figure 12: Boxplot showing the 25, 50 and 75 percentiles of values of all the explanatory variables considered in this study (lower, mid and top limits of the box). The upper and lower whiskers show the min(max(x),Q+1.5 IQR), with x being the value of the explanatory variable, Q the 25 or 75 percentiles and IQR the interquartile range. In the Y axis the station number is shown.

2.1.2.4 Correlation between candidate explanatory drivers

The Pearson correlation coefficient between pairs of candidate explanatory factors was estimated (Figure 13). Values were below 0.5 for all pairs of factors described above, with the exception of depth and shear stress. As already mentioned, shear stress estimates are strongly based in depth, and, despite it seems that the logarithm of the negative depth was used in the GETM/GOTM model (plot depth-shear stress in Figure 13), still the linear correlation was high (pearson=0.75). Although low, the bottom depth showed some positive correlation with fishing effort and granulometry. For this reason, the average depth per station was removed from the set of candidate explanatory variable that was used in the modelling exercise.

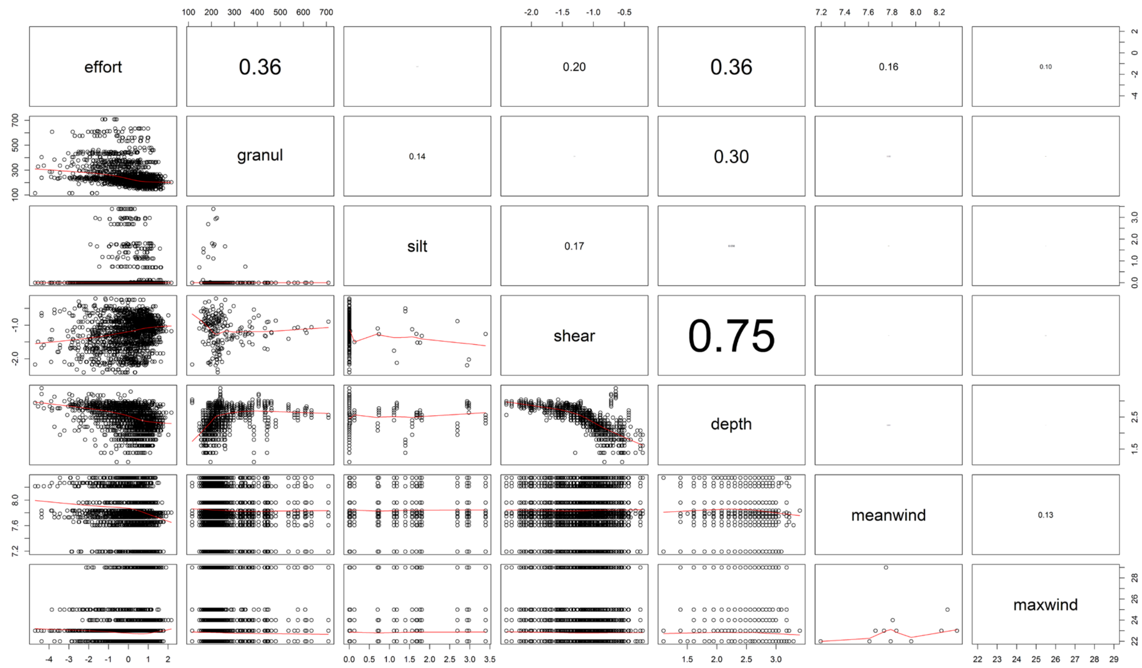

Figure 13: Correlation analysis of all independent variables used in the analysis.

2.2 Methodology

The methodology described by ICES-WKBENTH (2016) was used in this study to assess 1) the changes in the benthic community longevity structure over the study period; 2) evaluate the impact of different environmental factors, with special attention to fishing effort. The benthic community structure was represented by the ogive of cumulative biomass with longevity, and changes over time in the L_{50} (longevity at 50% accumulated biomass) were interpreted as changes in the community longevity composition.

The cumulative biomass is expressed as a logistic function of longevity that is affected by habitat characteristics (sea floor structure, shear stress, depth) and bottom trawling. It is expected that the impact of trawling can be expressed as the reduction in biomass of long-lived taxa given the observed trawling intensity of a grid cell relative to the untrawled situation.

The following logistic regression was fitted using a mixed effect model:

cumB ~ intercept + longevity + sea floor structure + depth + shear stress + fishing effort + ε_1*+ (random(station intercept/replicates) +* ε_2*)*

A mixed effect model was used to take account of the dependency of the cumulative biomass (cumB) estimates for each surveyed station in the benthic survey. ε_1 represents a binomial error. ε_2 represents the normally distributed error of the random effect on the intercept by station and the replicates nested within the stations. Fishing effort, depth and tidal shear stress were log-transformed to improve the model fit. A value of 10^{-2} was added to avoid taking the log of zero.

The random mixed effect model was estimated using library lme4 in R version 3.02, and the steps defined in Zuur et al (2009) were followed to select the best combinations of explanatory variables both in the fixed and the random models.

As a synoptic indicator summarizing the changes in the cumulative biomass ogive, the longevity at which the 50% of the biomass in a given survey station was estimated.

3 Results

3.1 Mixed modelling

The modelling exercise was limited to the period 2004-2015 due to the lack of VMS data before 2004. Several different combinations of variables where used for both the fixed effect and the random effect models within the mixed modelling exercise. In order to explore the cumulative effect of trawling intensity on the benthic community, the fishing effort was estimated for a half, one, two and three years previous to the development of the annual benthic survey, which as indicated above, takes place mostly from May to July.

As a first step, the effort was focused in finding the best random model. Following the recommendations from Zuur et al (2009), the fixed model was set with all the candidate explanatory variables presented in the previous sections (including 1st order interactions) and the model was fit several times using different configurations in the random model. The lowest Corrected Akaike Information Criteria (hereafter AICc) was obtained when the random model included the effect of longevity in the slope and the effect of the replicate (Station in a given year) in the intercept.

This random model setting was then maintained in further steps. Next, the structure of the fixed effect model was changed considering different combinations and interactions of explanatory factors. Four different groups of models were evaluated, depending on the time period for which the effort was calculated: half, one, two or three years before the survey (Table 2). When half, two and three years of fishing effort were considered, the model with the lowest AICc was:

CumBiom ~ loglong + logeffort + logmeanwind + logmeanwind:logeffort + (1 + loglong | station/repl)

Hereafter this model will be called model A.

When trawling intensity was represented by the fishing effort in one year, the model with the lowest AICc included the longevity and granulometry in the fixed model (Table 2). Hereafter this model will be called model B.

CumBiom ~ loglong x loggranulometry + (1 + loglong | station/repl)

However, even in this case (one year of fishing effort) the model A was the second best model, with an AICc only one point higher than the AICc in model B. This small difference technically means no differences between the models. Hence, due to the consistent better fit of the model A, and especially when longer time periods of cumulative impact of fishing effort were considered, the model A, with longevity, mean wind and fishing effort as explanatory variables is considered the model that better explained the changes over time in the benthic community cumulative biomass.

In Table 3 the coefficients and p-values for model A are shown. Since the resulting fit was very similar for model A no matter how many years of cumulative fishing effort was used in the model fit, for the sake of simplicity in Table 3 only the diagnostics of the model when one year effort is presented. In relation to the main effects, the longevity presented a highly significant positive effect in the cumulative biomass of the benthic community; the fishing effort showed a significant negative effect, while the mean wind had a non-significant positive effect (but close to significance). The interaction of fishing effort with mean wind speed had a significant positive effect in the cumulative biomass.

Table 2 Fixed effect models fitted during the modelling exercise. The corrected Akaike Information Criteria AICc is presented. The colors range from red to green, meaning lowest to highest AICc value on a column by column basis.

fixedmodel	Half year	One year	Two years	Three years
loglong	9342.5	8642.6	7916.4	6975.4
loglong + logeffort	9342.6	8643.7	7918.2	6977.3
loglong + shear	9344.5	8644.3	7917.9	6977.4
loglong + logmaxwind	9342.7	8642.6	7916.4	6971.2
loglong + logmeanwind	9341.1	8641.4	7915.2	6972.1
loglong + silt	9343.7	8644.2	7917.9	6976.7
loglong + loggranul	9339.3	8638.3	7913.7	6972.4
loglong x logeffort	9341.7	8645.6	7919.7	6978.9
loglong x shear	9343.6	8639.3	7913.2	6973
loglong x logmaxwind	9344.4	8644.5	7918.4	6973.2
loglong x logmeanwind	9341.6	8642.2	7914.8	6971.6
loglong x silt	9345.6	8646.2	7919.8	6978.7
loglong x loggranul	9339	8638.2	7914.2	6972.8
loglong + logeffort + logmeanwind	9340	8642.1	7917	6973.9
loglong + logeffort + logmeanwind + logmeanwind:logeffort	9336.5	8639.2	7907.5	6968.4
loglong x logeffort + logmeanwind	9339	8643.9	7918.6	6975.5
loglong x logeffort + loggranul	9340.1	8642.1	7914.9	6975.6
loglong x logeffort + loglong x logmeanwind	9340.1	8644.8	7918.2	6975
loglong x logeffort + loglong x loggranul	9341.2	8642.1	7914.2	6974.6
loglong + logeffort + logmeanwind + loggranul	9339.3	8639.4	7912.7	6971.2
loglong x logeffort + logmeanwind + logmaxwind	9340.3	8644.9	7919.1	6972.8
loglong x logeffort + logmeanwind + silt	9340.2	8645.5	7920.1	6976.9
loglong x logeffort + logmeanwind + shear	9341	8645.7	7919.8	6977.5
loglong x logeffort + logmaxwind	9342.3	8645.9	7919.6	6974.8

Table 3 Coefficients, standard error, z-value and p-value of the model with the lowest AICc, with longevity, mean wind and one year of cumulative fishing effort as explanatory factors.

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-14.2863	2.37826	-6.01	1.89E-09
loglong	4.93444	0.09493	51.98	2.00E-16
logeffort	-4.60883	2.10677	-2.19	0.0287
logmeanwind	2.04059	1.1476	1.78	0.0754
logeffort: logmeanwind	2.2638	1.02321	2.21	0.0269

The effect of effort and mean wind in the benthic cumulative biomass with longevity, as indicated by the significant interaction, are strongly interdependent. When the mean annual wind speed is high, the increase in fishing effort produces an decrease in the cumulative biomass-longevity curve (Figure 14). The opposite is observed when the mean annual wind speed is lower, i.e. the increase in effort produced an increase in the cumulative biomass-longevity curve, that means and increase in the proportion of young species in relation to the old species.

In relation to the effect of the mean wind in the cumulative biomass ogives, as shown in Figure 15, the effect is dependent on the level of fishing effort. As the fishing effort increases, the effect of wind becomes more positive for long-living species, which is shown by the displacement of the ogive toward older ages when the wind is more intense.

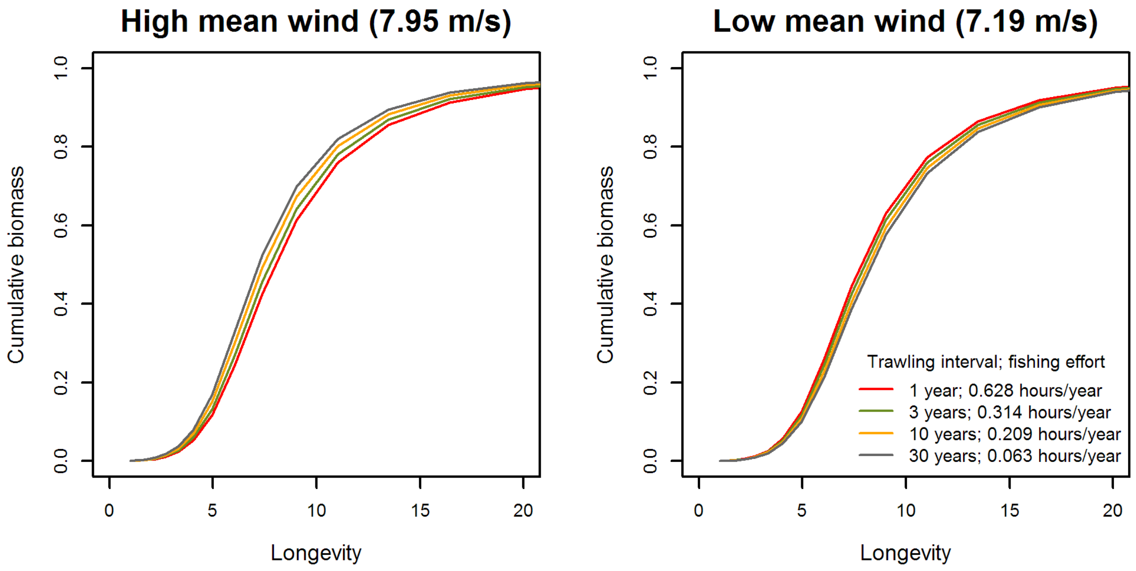

Figure 14: Cumulative biomass – longevity curves predicted by model A at different levels of fishing effort (hours/year and equivalent trawling interval) depending on the mean annual wind speeds (m/s). The

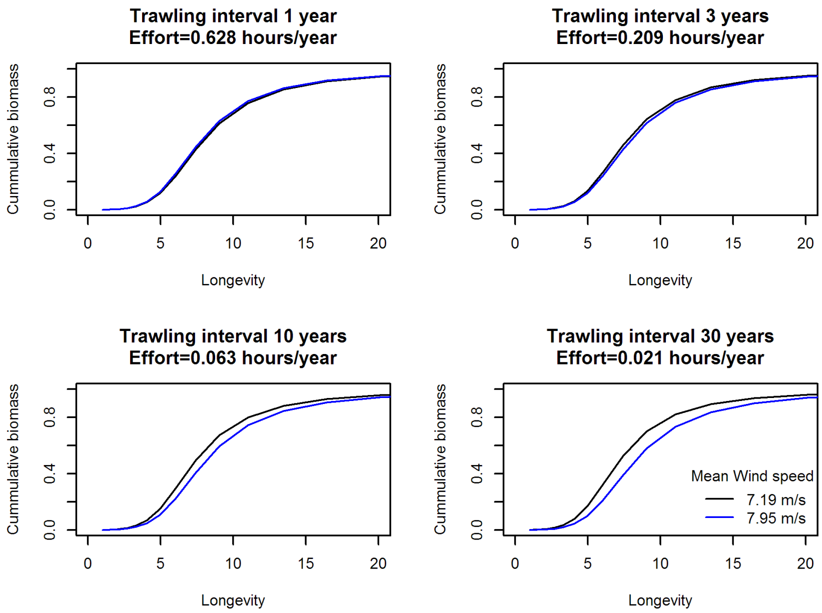

Figure 145: Cumulative biomass – longevity curves predicted by model A at different levels of mean annual wind speed (in m/s) depending on the fishing effort (hours/year and equivalent trawling interval).

3.2 Benthic community longevity indicator

The average cumulative biomass ogive with longevity for all the stations is shown in Figure 19 for all years (in this case the ogives were produced using the best model when one year of cumulative effort was used, i.e. the model B). These cumulative ogives did not show a clear trend in the displacement of the curves over time towards lower or higher longevities. However, in general the ogives from the early and the later years were somewhat higher than the ogives of intermediate years (especially years 2009-2012). The L_{50}, longevity at which the cumulative biomass ogive reach the 50%, was selected as the indicator that could be used to track, in a synoptic way, the changes in the cumulative biomass ogive over time. In Figure 20, the L_{50} estimated for all the four different modelling exercises, with half, one year, two and three years of cumulative fishing effort is presented. The best model (as described above) for each modelling exercise was used to estimate the L50 on each case. All the four models showed a very similar pattern in L50 over time. With the exception of 2006 and 2009, the L50 was around 8 years until 2010, when it declined from 2011 to 2013 to values around 7.6 years. In 2014 there was a marked increase to an L50 close to 8.5 years and decreased slightly in 2015. The relationship between the annual estimated L50 and the average trawling intensity was low for all the different time ranges of cumulative effort, with the highest Pearson correlation coefficient found for the two years cumulative effort (Pearson=0.434).

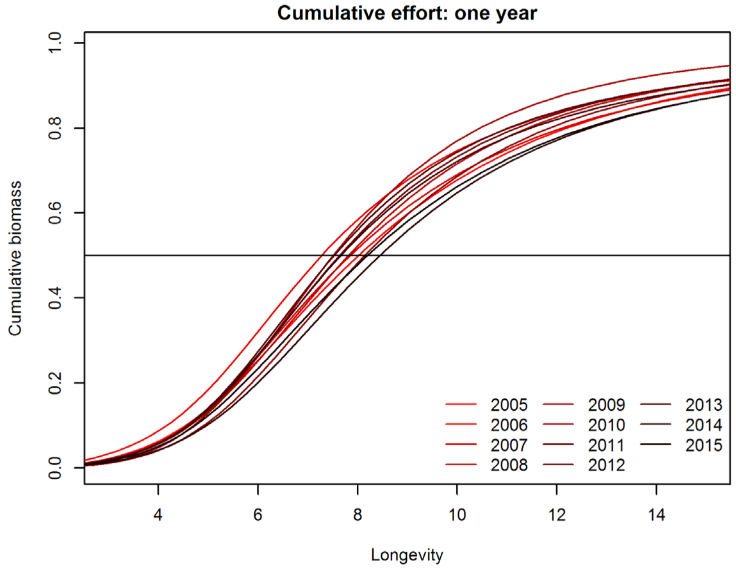

Figure 15:

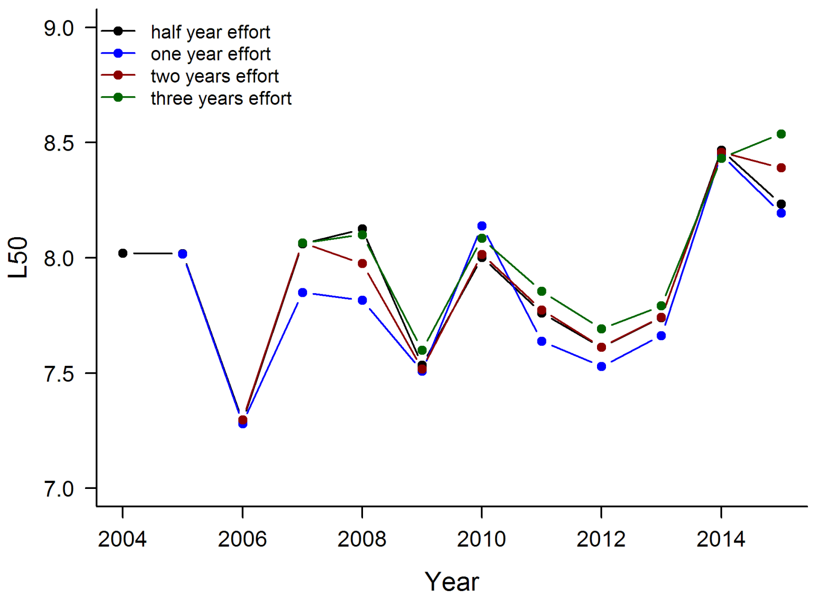

Figure 16:

4 Discussion

The methodology employed in this study has already been used in a previous study in the North sea (ICES-WGBENTH, 2015; Rijnsdorp et al. *in prep.*) where it was shown that trawling impact negatively affects the median longevity of the benthic community, which can then be used as an indicator to assess the impact of trawling in relation to other environmental drivers on the seafloor ecosystem. In addition, the method allows estimating the sensitivity of the benthic ecosystem to those environmental and human factors. The approach was found a useful method to derive transparent and empirically based indicators of the impact of trawling on seafloor habitats, which directly relates the trawling intensity with relevant biological traits. This study (ICES-WGBENTH, 2016) was based on the idea that any factor increasing the mortality and altering the stability of the benthic community will have the strongest negative impact on the long-lived and so-called K strategists, and hence will favour (in a relative sense) the development of fast-reproducing and short-lived species (so-called r-strategists). In agreement with this reasoning, their analysis showed that bottom trawling effort in the North Sea had a negative effect on the longevity distribution of benthic biomass – in other words, that intensively trawled areas on average had a higher proportion of short-lived species and lower median community longevity. This effect was stronger for relatively stable areas, with low natural disturbance of the seafloor.

The data we have analysed shows an important and clear increase in trawling intensity from 2005 to 2015, peaking in 2012-2013. The cumulative biomass for longevity groups of ages 1-3 and age 3-10, and hence the cumulative biomass ogive, did not show such a marked pattern. However, in general the cumulative ogives and the L50 (the longevity at the median of the longevity biomass distribution) showed higher values in the early and late years, while lower values in the period 2009-2013. The fit models showed that granulometry was potentially an important factor determining the longevity distribution of the benthic community. However, it was fishing effort, mean wind and the interaction of both factor what showed the more persistent effect in the different modelling exercises performed.

The interaction term between fishing intensity and mean wind means that the effects of fishing and wind in isolation depend on the intensity of the other. More specifically, our results show that in years with low average wind speed, there is a small but negative effect of trawling on longevity, corresponding to the findings of Rijnsdorp et al. (*In prep.*) and ICES WKBENTH (2016). However, in years with higher wind speeds, this pattern reverses and increased trawling intensity actually is associated with a benthic community consisting of *more* long-lived species. Similarly, we see that in intensively trawled benthic communities, increased average wind leads to less biomass of long-lived species, while in little-trawled communities, increased wind speed actually increases median longevity.

Both fishing activity and natural disturbance such as wind are factors that can potentially lead to perturbation of the benthic community in shallow waters like those considered in this study (Rijnsdorp et al, 2015). For the data analysed here, these factors have similar effect on the benthos, but the direction of the effect depends on the intensity of the other: in absence of wind, higher fishing intensity causes reduced longevity and in absence of fishing, increased mean wind causes a reduced longevity. Conversely, with relatively strong winds, more fishing causes an increase in longevity, and so does a higher mean wind speed in heavily fished areas. In a way, this analysis extends that of Rijnsdorp et al to shallow coastal areas with very high natural disturbance and shows that at some level of natural disturbance, the relationship between fishing intensity and longevity reverses.

We hypothesize that the mechanism behind this reversal is that under extreme natural disturbance, the ‘fast recovery’ strategy of r-selected species simply fails, and the only mechanism that works in these conditions is not fast recovery but reduced vulnerability. These relatively invulnerable species are generally hard, large species, which are also long-lived (They are, essentially, K-selected species). Trawling in such communities only acts to further strengthen the selection towards long-lived K-strategists. Further analysis is needed to confirm or refute this hypothesis, which is beyond the scope of the current study.

5 Conclusions and recommendations

In this study we find clear evidence that intensive shrimp trawling is associated with a reduction in the longevity of the benthic invertebrate community. However, the direction and intensity of that impact is determined by the wind regime in the area, which we take as a proxy for the degree and/or frequency of natural disturbance of the seafloor. The entire Noordzeekustzone area is subject to strong natural disturbance, and it has often been suggested that trawling has no effects in such areas. Our analysis shows otherwise. Even within this highly dynamic area there is a clear gradient along the magnitude of natural disturbance, in the effect of shrimp fishing. At the lower end, we find that shrimp trawling truncates community longevity, while at the higher end shrimp trawling actually enhances longevity. The mechanism for this reversal remains to be studied. To our knowledge, this is the first study where a clear effect of shrimp trawling on the benthic ecosystem has been found in empirical data.

This study shows a statistically significant effect of an admitted economic activity on the seafloor in a Natura2000 area where protection of seafloor habitat is one of the key reasons for the protection. The admission of shrimp trawling in this area has been granted based on an appropriate assessment which concluded that there are no known significant effects of the activity on the seafloor habitat. The *statistically significant* results of this study indicate that there *are* effects and hence warrant further study to determine significance in the sense of the natura2000 framework.

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Justification

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The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of Wageningen Marine Research.

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Signature:

Date: 11 December 2019

Approved: Drs. J. Asjes
Manager Integration

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