Predicting benthic fauna biomass in the Voordelta under different hypothetical fisheries regimes

Author(s): Niels Hintzen, Ulrika Beier

Wageningen University & Research report C083/19

WAGENINGEN UNIVERSITY & RESEARCH

Predicting benthic fauna biomass in the Voordelta under different hypothetical fisheries regimes

Could an expected increase in benthic fauna have occurred within an area protected from demersal trawling if shrimp fisheries should not have increased?

Author(s): Niels Hintzen, Ulrika Beier

Wageningen Marine Research
IJmuiden, September 2019

CONFIDENTIAL no

Wageningen Marine Research report C083/19

WAGENINGEN
UNIVERSITY & RESEARCH

Keywords: PMR, Benthos, fisheries regimes, modelling.

Client: Rijkswaterstaat WVL
Attn.: Mennobart van Eerden
Postbus 17
8200 AA, Lelystad

This report can be downloaded for free from https://doi.org/10.18174/499289
Wageningen Marine Research provides no printed copies of reports

Wageningen Marine Research is ISO 9001:2015 certified.

Contents

Summary

The aim of this study is to evaluate if an increase in benthic biomass and longer-lived species in the Voordelta area could have been possible if the shrimp fishery would not have increased over the study period. At the instigation of the bottom protection area, there were no signs yet of a very active shrimp fishing fleet, let alone that shrimp fisheries would expand substantially in magnitude. For this reason, the current study evaluates the 'what-if' specific changes in the fishery had not happened, how would benthic biomass have developed over time.

The study uses the PMR benthic monitoring data and assigns longevity classes to each of the species found in the monitoring data. Cummulative longevity distributions are calculated and a statistical framework is used to estimate how these distributions are affected by fishing, wind and substrate. The resulting statistical model estimates are used in a population model in which we can simulate biomass development per longevity class under a number of fishing scenarios.

Five scenarios were evaluated and shown in the figure below, demonstrating that restricting fishing activity by any kind of fleet would have resulted in maximum 5% change in biomass in any particular year. Even if fishing effort would have continued at similar levels as the 2004-2005 baseline situation, including a closure of the bottom protection area in 2008, there would have been a mimimal increase in biomass in the Voordelta area. As demersal fishing has declined more rapidly in recent years than expected (in comparison with the 2004-2005 baseline), there is no marked difference between the expected current state of benthos biomass in the Voordelta and the 04-05 baseline scenario.

1 Introduction

Seabed trawling is recognized as being the major source of physical disturbance to the seabed with profound impact on biota (Eigaard et al. 2017, Hiddink et al. 2017, Kaiser et al. 2002). It can therefore be expected that a reduction in trawling activities should improve conditions for, e.g., benthic fauna, and lead to increases in biomass and diversity (Hiddink et al. 2006, van Denderen et al. 2014).

In 2008, a marine protected area of 250 km^2, the "Bodembeschermingsgebied (BBG)", was installed within the "Voordelta" area south of where the river Meuse meets the Dutch coast (Figure 1). The reasons for protecting this area were to compensate for the effects of "Tweede Maasvlakte", i.e., the reclaiming of land from the sea by building the Rotterdam port extension port as well as the supporting infrastructure. To compensate for habitat loss caused by the newly constructed land, with the purpose of improving the bottom habitat and living conditions for fish and benthic fauna in the remaining area, the c. 25000 ha protected area (BBG) was closed for flatfish beam trawl fishery carried out by vessels with a motor capacity exceeding 260 hp (191 kW). However, shrimp fishery carried out by vessels with a motor capacity up to 300 hp (221 kW) was still allowed within the protected area (except for some areas used by birds for foraging that are closed at certain times of the year, or even year-round for all vessels).

Demersal trawlers aiming for flatfish use either beam trawls with tickler chains attached to the beam which is dragged along the seabed, or beam electric pulse trawls with electrodes replacing the tickler chains, or demersal otter trawlers dragging otter boards to increase the area covered by the bottom trawl. Traditionally, the most important fisheries in the Voordelta have been different types of demersal trawling for flatfish. Besides total protection in the BBG, in the last decade the flatfish fishery has decreased more than twofold in the Voordelta area, while the shrimp fishery operating with slightly smaller ships with comparatively lighter trawls has increased about threefold in the whole Voordelta, including the protected area (Machiels & Hintzen, 2018).
By closing the protected area for demersal trawling it was expected that the diversity in the benthic community should increase locally, including an increase in long-lived organisms, as well as an increase in the benthic biomass by at least 10%. The intention was that this anticipated biomass increase should then counteract the negative effects on amounts of fish and other organisms as food for birds, as caused by the habitat loss from constructing the Tweede Maasvlakte (Rijnsdorp et al. 2006). However, as there was no increase recorded in benthic biomass within the protected area during the time period 2008-2017, possible explanations for this have been searched for. While the demersal trawl fishery has decreased, the shrimp trawl fishery has increased, also within the protected area. The shrimp trawl fishery has previously been viewed as having minor effects on benthic fauna as its lighter gear does not penetrate as deeply into the sediment as the beam trawl (normally used for flatfish). However, recent studies have shown that also shrimp fishery affects benthic fauna composition and biomass (Perez-Rodriguez and van Kooten 2018 *in prep*). In this study, similar in design as the current one, cumulative longevity of the benthic community was studied in the coastal areas of the North Sea (Noordzee kustzone) in relation to environmental conditions such as wind, substrate type, natural seabed disturbance and fishing.

The aim of this study is to evaluate if an increase in benthic biomass and longer-lived species could have been possible if the shrimp fishery would not have increased over the study period. Furthermore, it provides the simulation tool to evaluate different fisheries scenarios in order to evaluate the efficacy of conservation plans making use of generic understanding of longevity distribution in benthic communities and their interaction with fisheries as well as the persistence in aggregation and distribution of fishing fleets in the study area. Three aspects are key to studying this: 1) assessing the longevity composition of the benthic community within the Voordelta and evaluating benthic biomass over time, 2) model the impact of fishing and environmental conditions on benthic biomass development over time and 3) assessing the persistence of spatial fishing patterns in the Voordelta to allow for future predictions of the impact of fishing on the benthic community (see Hintzen et al. 2019 for more background on methodology).

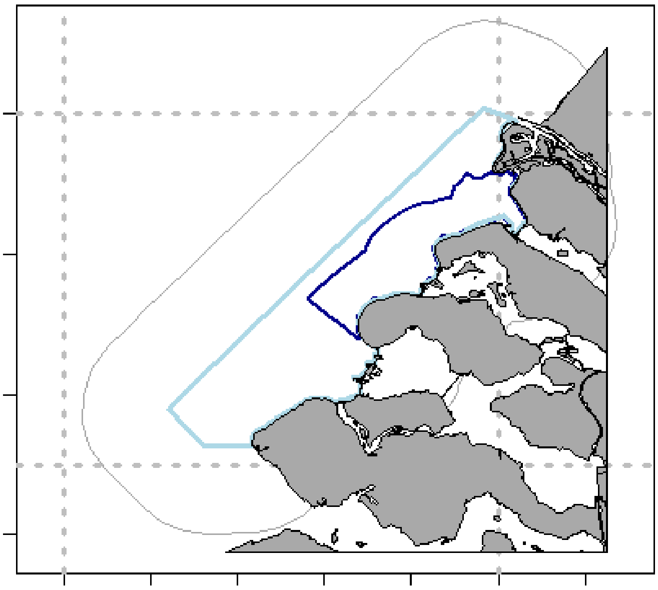


Figure 1. Map of part of the Dutch coast including the entire Voordelta area (in this study referred to as as SS2, inside the light blue line), and the protected Bodembeschermingsgebied area (BBG, in this study referred to as SS1, inside the dark blue line). The area in between the light blue line and the dark blue line is the rest of the Voordelta area (VD-, in this study referred to as SS3).

2 Materials and Methods

2.1.1 Assessing the longevity composition of the benthic community

With the use of both a box corer and dredge, sediment samples were taken at multiple stations located in the Voordelta to determine the benthic species composition. Stations were sampled during autumn/winter of the years 2004, 2005 and from 2009 onwards till 2016 (excluding 2014). From this survey, we extract per station and year the total species biomass (expressed per m^2) as response variable. This survey lists by year and station the biomass caught for each species. In order to determine the longevity composition of the entire Voordelta each species is linked to a database containing information on their longevity. In this database (Bolam et al. 2014, available online), the following classes in lifespan are defined: less than one year, between one and three years, between three and ten years and over ten years. For each survey station and year combination biomass is summed over these four longevity classes (i.e. class 0-1, 0-3, 0-10 and 0 - 10 > together). This provided us with the necessary link to estimate the longevity composition of the benthic community in the Voordelta. This approach was chosen as it matches scientific approaches published (Rijnsdorp et al. 2018). We do explicitly assume that the benthic community has been stable (no introduction or extinction) during the study period and that changes in the longevity composition are due to a number of co-variates, i.e. fishing effort, wind speed, grain size, silt content and water depth. Vessel Monitor by Satellite (VMS) data is used to estimate the fishing effort in the vicinity of the sampling station, calculated as the cumulative amount of swept area within a 100m radius around a sampling station that has been touched by a fishing gear during one full year prior to sampling. Trawl tracks at high spatial resolution are reconstructed from VMS data using interpolation techniques to allow for a more precise estimation of surface area fished (Hintzen et al. 2010). The proportion of the gear that affects either the surface or subsurface of the seabed is taken into account (Eigaard et al. 2016) and therefore results in two fisheries related covariates: effort surface (the lighter part of the gear + the heavier part of the gear taken into account), effort subsurface (only the heavier part of the gear taken into account). For beamtrawling, the entire width of the gear is assumed to have subsurface impact while for shrimp trawls, around 50% of the gear width is assumed to have subsurface impact. Fishing is hence represented by the co-variate surface effort or subsurface effort. Wind speed information is taken from the KNMI data portal and Hoek van Holland has served as the most relevant station to inform the influence of wind in the area. Both maximum and average wind speeds, averaged by day, are taken into account.

2.1.2 Model the impact of fishing and environmental conditions on benthic biomass development over time

Model fitting procedure, similar to Rijnsdorp et al. 2018, was applied to the dataset available here. The model, a GLM with binomial response implemented in R, tests which co-variates have most explanatory power on the longevity composition. The number of co-variates and interactions among them to include were tested using the AIC criteria and check whether the model was able to converge. Residuals were investigated to confirm appropriate statistical fit. Fitting the statistical model provides us with parameter estimates that describe the impact each co-variate has on the explanatory variable, i.e. how much would a percent change in wind speed alter the longevity distribution in the Voordelta. These parameters were used to model longevity distribution and predict benthic biomass using a population dynamics approach (ICES 2017, WKBENTH). This approach simulates over time the longevity composition under different fishing effort scenarios (while maintaining the other co-variates) and calculates the biomass of the VD benthic composition in relation to its maximum carrying capacity (which equals the situation with no fishing). Five different scenarios are evaluated: 1) status-quo (i.e. as observed in the field), 2) a scenario with no shrimp fishing, 3) a scenario with no demersal fishing, 4) a scenario in which we maintain the 2004/2005 average fishing intensity for the demersal and shrimp fleet but limit the demersal fishery beyond 2008 to be taken outside the BBG and 5) a scenario without any fishing. With this approach, we were also able to evaluate the impact of a change in the other co-variates while maintaining the other co-variates, such as wind.

2.1.3 Assessing the persistence in spatial use of the Voordelta

For the spatial and temporal analyses of fishing activities, VMS (containing information of vessel location, speed and direction) and logbook (containing information of gear type and targeted species) data were used. Data representing fishing vessels operating in the Voordelta during 2006-2017 were cleaned and checked for errors according to established procedures at WMR (Hintzen et al. 2012). The fleets selected for analyses were defined as shrimp trawlers (SHR), and demersal trawlers targeting flatfish (DTR), respectively. The DTR trawlers were selected as those using either of the following gears: beam trawls, pulse trawls and otter trawls. The pulse and beam trawlers were treated as one group as there is no scientific underpinning to differentiate the two types yet. Data was classified into three selected areas; the protected area (BBG), the entire Voordelta, and the Voordelta excluding the protected area. Trawl tracks were reconstructed using an interpolation routine (Hintzen et al. 2012).
Within the selected areas, effort was estimated as aggregated swept area per year, for the two different fleets. To investigate whether effort of the different fleets was depending on the distance to shore, the three areas (VD, BBG, and VD-) were further divided into subareas. These were defined as being within 3 nautical miles, within 5 nm, and outside 5 nm distance to shore (shore being defined by an EEZ shapefile available online).
The interpolation of trawling tracks (according to above) was used to project intermediate positions used for the estimation of aggregation, based on two hours interval pings (Hintzen et al. 2019). Aggregation is the degree to which fishers cluster in space and time. When fishers show random behaviour, aggregation equals to zero. Aggregation can be estimated using a negative binomial distribution fitted to the frequency distribution of the number of times all gridcells in an area have been trawled. The aggregation parameter is a reformulation of the over-dispersion parameter in a negative binomial. All interpolated GPS positions were projected onto a grid measuring ~20m by 20m, i.e., 0.00029 decimal degrees longitude by 0.00018 decimal degrees latitude at 53° latitude. The calculated annual aggregation parameters within the selected areas were used to see whether the efforts and the aggregation patterns for the two different fleets within the selected areas had changed over time. Persistence in the aggregation and spatial use of the area is needed to be able to predict the distribution of the fishing fleet on the benthic community under different scenarios.
Additionally, data on landings of plaice and shrimp for the North Sea as well as for the Netherlands, and TAC (Total Allowable Catch / sum of quota) for plaice in the North Sea for the same time period were retrieved from ICES. Finally, statistics on mean yearly prices in the Netherlands of plaice and shrimp were retrieved from Statistics Netherlands (CBS).
The persistence of the fishing fleet is studied to allow (at a later stage) designing more complicated spatio-temporal fishing scenarios. Evaluating other fishing scenarios could shed light onto the question if benthic biomass could have increased to a larger extend if fishing would have been limited overall or limited to fish in other areas. To design realistic spatial-temporal scenarios, we require an understanding of the spatial use of the area by the fishing fleet, which is being addressed by the two elements of this study: aggregation and distribution from the coastline.

3 Results

3.1.1 Assessing the longevity composition of the benthic community

In total, data from 165 stations were included, taking only stations that were sampled throughout the entire time-series, summing to 2750 observations over 4 longevity classes. The model has been fitted for the entire Voordelta. The best fitting model can be described as a relationship between cumulative biomass being explained by the longevity classes in the data, the average wind speed at the stations, the grain size at the stations, the associated subsurface effort by fishing around each of the benthic stations and interactions between these factors:

*Cumulative biomass ~ intercept + longevity class + average wind speed + grain size + subsurface effort + longevity * grain size + longevity * subsurface effort + average wind speed * subsurface effort + [random effect on longevity class | station/year]*

An intercept adjusts overall scaling of the co-variates to the cumulative biomass.

Table 1: Co-variates and their interactive terms of the statistical model including the estimated parameter values, their significance and contribution to the AIC selection criteria (Delta AIC).

Co-variates	Estimate	Pr(>|z|)	AIC (adding terms)	Delta AIC
Intercept	-1.302	0.001		
Longevity classes	8.048	0.000	59228.1	
Average wind speed	0.235	0.004	59190.7	-37.4
Grain size	0.562	0.000	59161.5	-29.2
Subsurface effort	-0.781	0.012	59158.5	-3
Longevity classes * grain size	-0.443	0.000	58955.6	-202.9
Longevity classes * subsurface effort	0.28	0.000	58757.5	-198.1
Average wind speed * subsurface effort	0.527	0.029	58754.8	-2.7

Surface effort was not included in the final model as it was less significant in the model selection than subsurface effort (including both is not an option as they refer to the same type of process and leads to statistically unstable results when included. Note however that each vessel has a subsurface effort, though usually lower that the total surface effort). Subsurface effort also includes fishing gears that are relatively light.

The table above (Table 1) lists all co-variates and their interactions in decreasing order of influence on model fit. As such, the longevity distribution of benthic species in the Voordelta is to a large degree explained by average wind speed (i.e. wind speed likely being an approximation for natural disturbance affects what species can and cannot survive in more or less disturbed areas). Thereafter, grain size determines the longevity distribution as well, since specific species prefer specific habitats. The benthic community living on muddier sediment has a different longevity distribution compared to communities living on coarser habitat. Fishing itself, as represented by subsurface effort, does not have a profound overall effect in explaining the longevity distribution in the Voordelta. Fishing effort, in interaction with longevity does, however. This implies that the explanatory value of fishing on the longevity distribution plays an important role within each longevity class, but not across. In other words, fishing effort is scaled differently between longevity classes. The same rationale can be applied to grain size, i.e. different longevity classes respond differently to grain size and hence their interaction is highly significant.

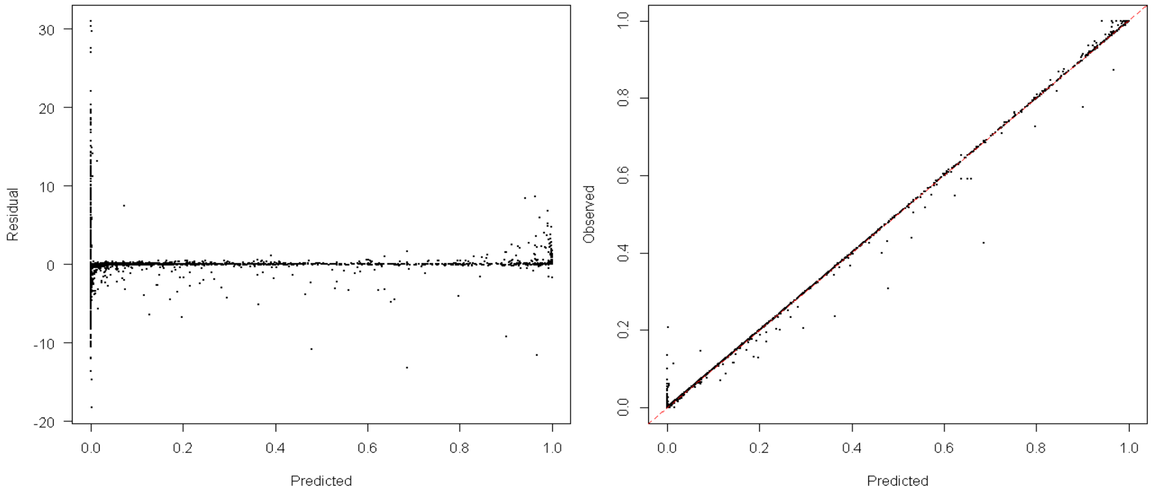


Figure 2: Left: residual plot of the final fitted model. The model predicts the longevity classes as a binomial distribution (between 0 and 1). For each of the predicted contribution for each longevity class a residual with the observation is calculated. Predictions vs residuals are given here and show no unexpected / undesired pattern. Right: Observed contribution of longevity classes in the data vs predicted contribution of longevity classes as obtained from the fitted model. A 1:1 red dashed line indicates the a-priory expected relationship between predicted and observed. The model fits well to this a-priory expectation.

The figures above (Figure 2) show residuals as well as predicted vs observed. These figures illustrate that the model fits well.

When using the fitted model to predict the longevity composition we can show the observed longevity distribution over time. This shows (Figure 3 left) that the longevity composition of slightly longer living species has increased over time while the subsurface effort has stayed more or less stable. The subsurface contribution of shrimp trawlers is much lower than that of traditional beam trawlers. The overall fishing effort (reported in earlier PMR reports as total surface area trawled, here divided into surface and subsurface where surface = surface + subsurface) is given as well to reflect the impact of the increasing shrimp fishery.

Although the longevity composition shifts to slightly longer lived species, the variability herein is large. Note as well that longevity <3 can increase under two scenarios: either due to an increase in species with higher longevity or due to a reduction in species in the highest longevity class. Since longevity classes <1 and > 3 contain very little biomass, for illustration purposes the contribution of longevity <3 is most informative.

Figure 3 right shows how the longevity distribution would have changed if average wind speeds would have been constant throughout the study period at either the highest value of the time-series (maximum) or lowest value of the time-series (minimum). In this scenario, all other processes such as fishing effort was maintained at the observed value. Results show that longevity is predicted to go down if wind speeds would have been higher while a markedly larger increase in longevity class <3 was to be expected if wind speeds would have been low.

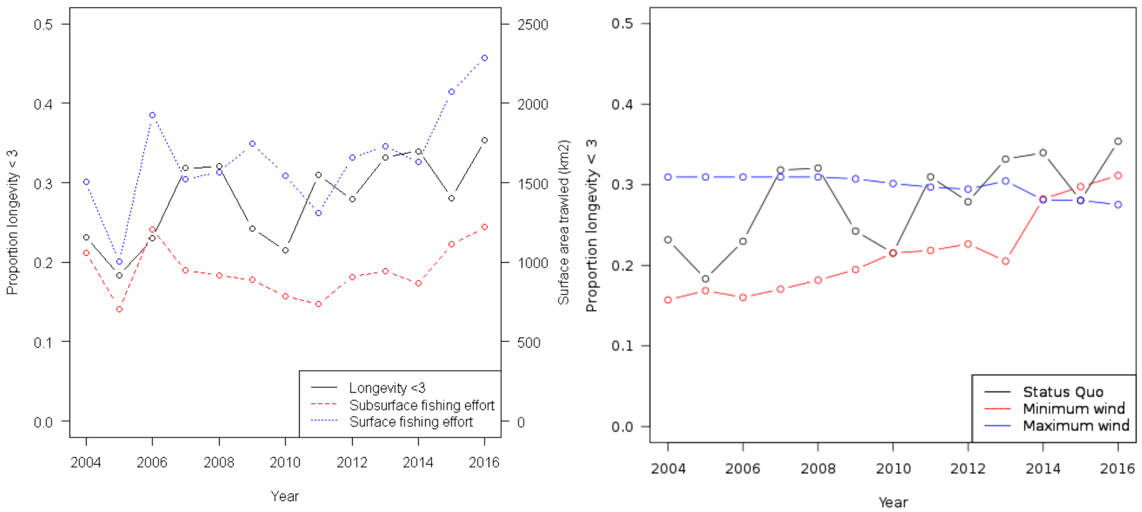


Figure 3: Left: Longevity composition over the years as estimated by the statistical model vs the fishing effort (swept-area of surface and surface+subsurface abbrasion, right-hand axis). Right: Longevity composition over the years as estimated by the statistical model for observed wind speeds, minimum wind speeds (from observed) assumed over the entire time-series and maximum wind speeds assumed over the entire time-series.

3.1.2 Model the impact of fishing and environmental conditions on benthic biomass development over time

The estimated longevity distribution was used in a biomass dynamic model which allows us to evaluate biomass development over time in the Voordelta (e.g. simulating recovery, mortality, in relation to carrying capacity). The biomass dynamic model is parameterized such that only a change in fishing effort can be evaluated and e.g. not how a change in average wind speed would alter the results. For this reason, if there would be no fishing, the benthic community would be at its carrying capacity, here scaled to the maximum value of 1. In each of the 3 other scenarios listed in Figure 4 we evaluated the reduction in biomass relative to carrying capacity when one of the three types of fishing would be absent. Under the actual observed fishing effort from 2004-2016 the biomass reduction compared to carrying capacity ranges between 2-5 percent. In other words, biomass in the Voordelta would have increased by as much as 2-5 percent if fishing would have stopped since 2004. Figure 4 shows that the trends in biomass development are characterized by two processes: 1, a reduction in fishing by demersal trawlers (where the full gear-width has a subsurface impact) and 2, an increase in shrimp trawling (where due to the lighter gear, only 50% of the gear-width has a subsurface impact). The 04/05 baseline scenario shows the reduction in biomass from carrying capacity if the fishing fleets had not changed in behaviour and magnitude from the 2004/2005 situation, while the BBG is closed from 2008 onwards for demersal trawlers. In this scenario, shrimp fishing does not increase and beam trawling does not decrease as observed in the status-quo situation. This scenario results overall in the lowest biomass density of all scenarios tested but is from 2007 similar to the status-quo scenario (from 2005 to 2006 there was a sharp increase in shrimp fishing effort).

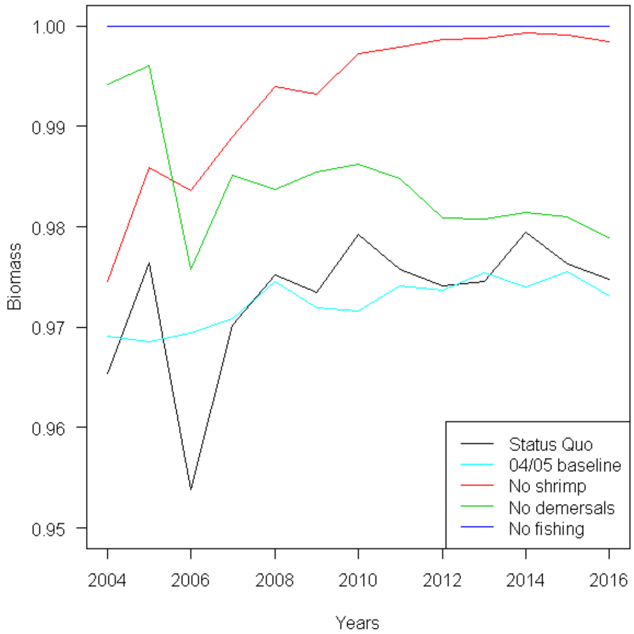


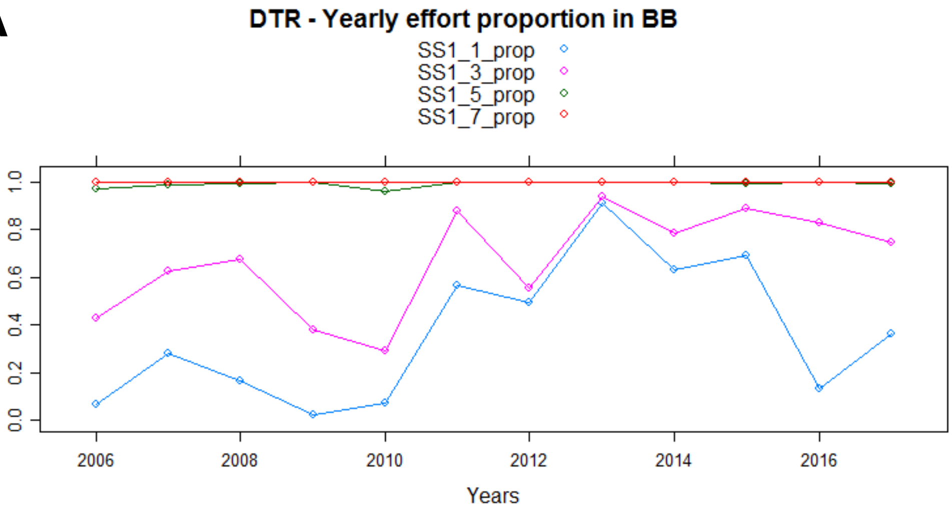
Figure 4: Estimated biomass of the benthic community in the Voordelta per year under four different scenarios: status quo, no shrimp fishing during the entire time-period, no demersal fishing, or no fishing at all (note that y-axis starts at 0.95).

3.1.3 Assessing the persistence in exactly the same spatial use of the Voordelta

3.1.3.1 Effort

Within the protected area (SS1) and during 2006-2017, the effort of the demersal trawlers was mainly occurring within 3 nautical miles to shore (Figure 5a), although the proportional effort depending on distance to shore has been varying (Figure 5a, pink line fluctuating between 0.4 and 0.9) where since 2011 a larger proportion of fishing took place than in the years before. Especially in the area within 1 nautical mile to shore, the proportional effort of demersal trawlers increased to a maximum of >80% in 2013, coinciding with the lowest total yearly effort, and the proportional effort closest to shore decreased thereafter. In the period towards 2013 less fishing outside the Voordelta takes place and a hotspot just north of Domburg became more important which affects the calculation of proportion of fishing close to the coastline. The shrimp trawling effort has in proportion been fairly evenly spread in terms of distance to shore within the protected area, although mostly occurring outside 1 nautical miles and within 4 nautical miles to shore (Figure 5b). Overall effort of the DTR fleet decreased over the study period while the opposite is true for the shrimp trawlers.

A



B

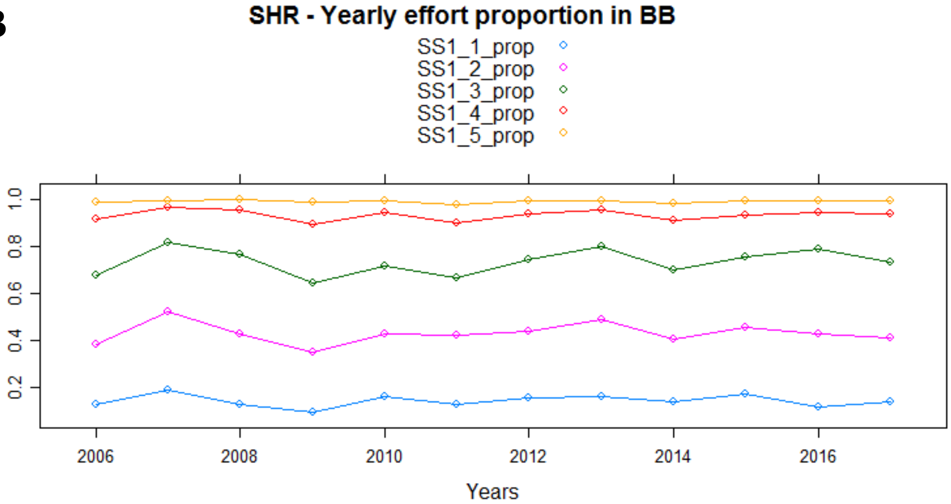


Figure 5: Proportion of fishing effort (swept area) depending on distance to shore within the protected Bodembeschermingsgebied area (SS1) during 2006-2017 by A) demersal flatfish trawlers (DTR), and B) shrimp trawlers (SHR). Numbers after area (SS1) in the legend depict distance to shore (nautical miles).

Outside the protected area and within the Voordelta (SS3), the effort of the demersal trawlers was allocated mainly 3 to 7 nautical miles from the coast (Figure 6a). The proportion of effort occurring within 5 nautical miles to the coast decreased moderately during 2006-2017 (Figure 6a). Within SS3, the most fishing effort by shrimp trawlers occurs between 1 and 4 nautical miles distance to the coast (Figure 6b). Over the entire time period, the yearly effort proportions or the shrimp trawlers depending on distance to shore have been relatively regular and stable between years (Figure 5b).

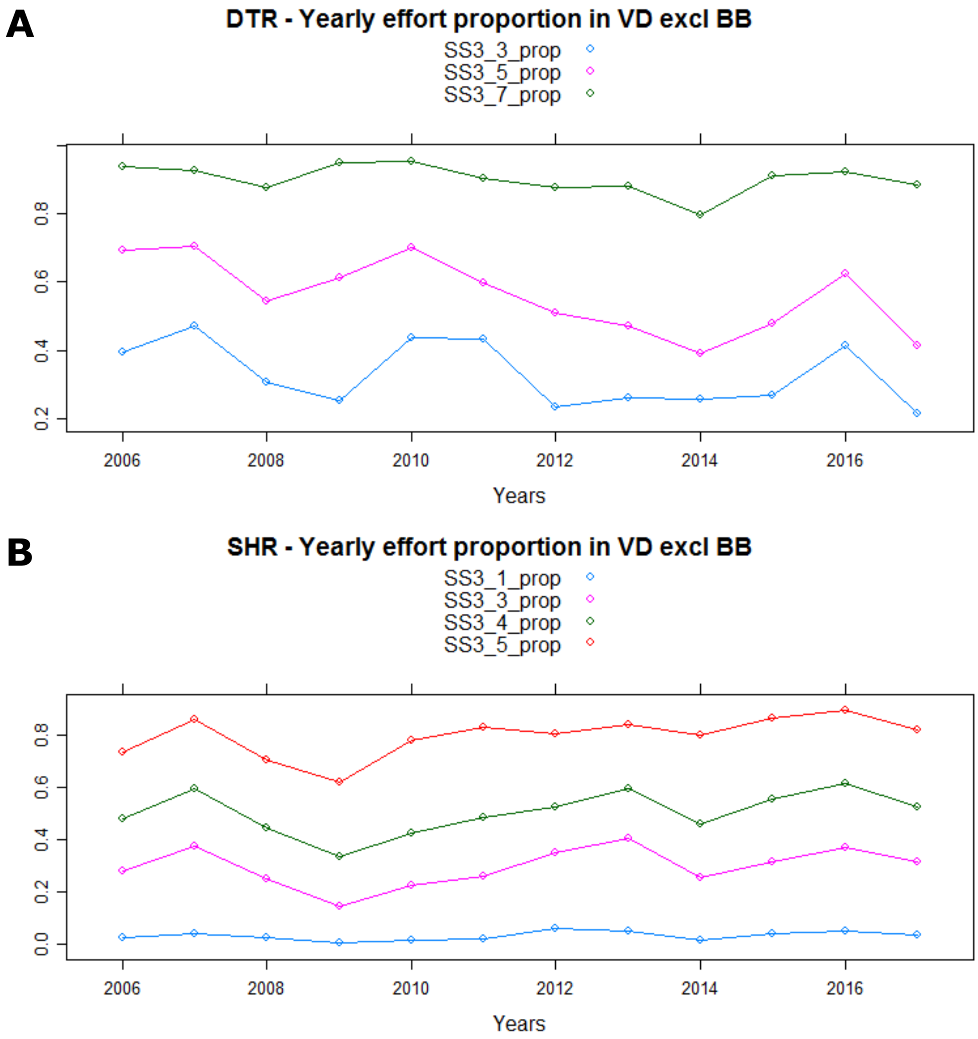


Figure 6. Proportion of fishing effort (swept area) depending on distance to shore within Voordelta excluding the protected Bodembeschermingsgebied area (SS3) during 2006-2017 by A) demersal flatfish trawlers (DTR), and B) shrimp trawlers (SHR). Numbers after area (SS1) in the legend depict distance to shore (nautical miles).

3.1.3.2 Aggregation

For demersal trawlers within the protected area (SS1), overdispersion (β), i.e., degree of aggregation was relatively low and with a small declining trend over the study period 2006-2017 (Figure 7) [a value of 0 for aggregation indicates no aggregation, i.e. random behaviour]. The degree of aggregation of the demersal trawlers outside the protected area could generally be viewed as low to moderate. For shrimp trawlers, the degree of aggregation was much higher compared to the demersal trawling fleet. The degree of aggregation of the shrimp trawling fleet was comparatively higher within the protected area (SS1) compared to outside (SS3), and also varied between years. In the area outside the protected area (SS3), the degree of aggregation of the shrimp trawling increased after 2013. Within the protected area, the same was true after 2014 (Figure 7).

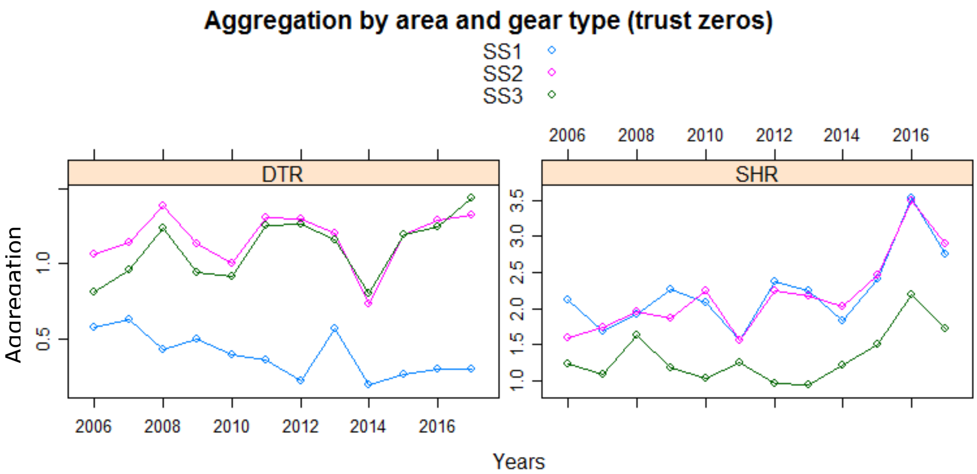


Figure 7. Aggregation within the Bodembeschermingsgebied area (SS1), the entire Voordelta area (SS2), as well as the Voordelta excluding the protected Bodembeschermingsgebied area (SS3) during 2006-2017 by demersal flatfish trawlers (DTR), and shrimp trawlers (SHR), respectively.

3.1.3.3 Landing value of plaice and shrimp

The price development of plaice and shrimp has differed during the studied period. The annual mean price for plaice has been relatively stable, fluctuating between 1.3 and 2.0 € per kilo. In 2017, the price of landed plaice was close to the price in the beginning of the period, i.e., 1.9 € per kilo. The annual mean price of shrimp has been more variable. It declined until 2011, when it was 2.0 € per kilo, and then increased to a relatively stable level, fluctuating between 4.2 and 3.7 € per kilo in the period 2012 till 2015. In 2016, the mean annual price of shrimp increased substantially to 7.4 € per kilo in 2016, slightly decreasing to 7.3 € per kilo in 2017 (Figure 8).

Multiplying the Dutch landings from the Netherlands with the mean annual price at the auction gives a rough figure of the annual value of these fisheries on a national basis. The mean annual value of plaice was in in the period 2006 till 2015, 41 million €, and increased during the last two years to ~57 million €. The value of shrimp varied more compared to that of plaice; it increased in 2012 to 73 million €, and reached a maximum in 2016 when it was >115 million €. In 2017, the value of the Dutch shrimp fishery was lower but at its second highest level: 88 million €. Noteworthy is the seemingly concurrent development in shrimp value and level of aggregation in Voordelta, although a clear link was not found in this study.

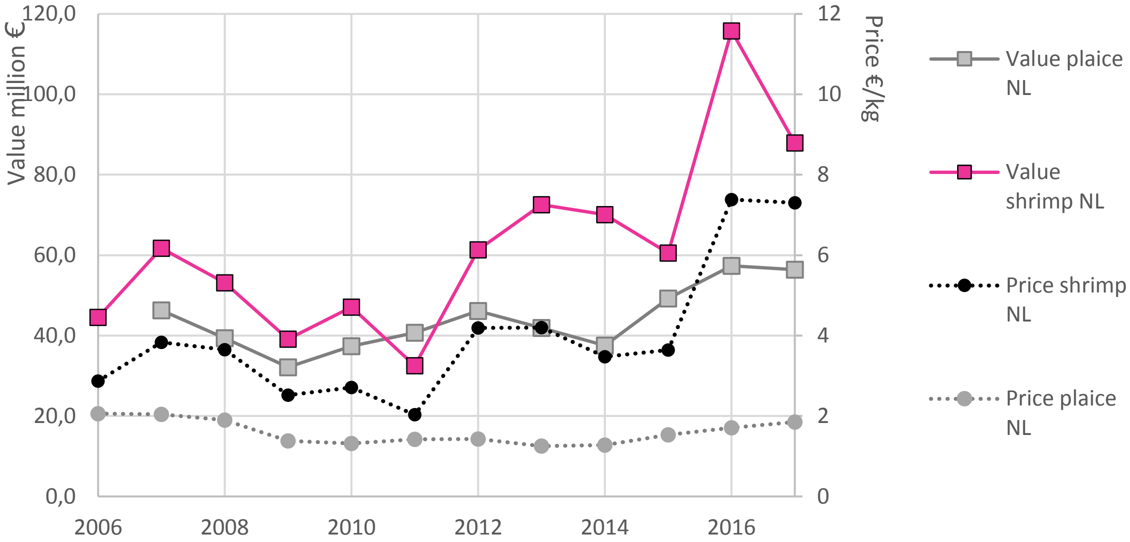


Figure 8: Dutch value of landed plaice (most important flatfish in volume for the Dutch cutter fleet) and brown shrimp calculated as mean yearly price within the Netherlands multiplied by Dutch landed amount, as well as mean yearly price per kilo of plaice and brown shrimp during 2006-2017 (data from Statistics Netherlands (CBS) and ICES).

4 Conclusions and recommendations

Fishing data and the associated effort linked to benthic stations is derived from VMS data. Since VMS data is generally collected at a 2h interval rate, there is uncertainty associated with the exact allocation of fishing effort and hence influences our analyses here where we link fishing effort to an impact on the benthic community. For this reason, we made use of algorithms (parameterized and validated on higher-interval data) to interpolate VMS data and we use aggregated values over a longer time-period (i.e. a year) to counter potential biases originating from the 2h interval rate of ship positioning.

Benthic sampling shows that over the years the overall longevity composition of the benthic community has somewhat increased towards longer lived species. There is, however, substantial variation in this value as it represents an average over the entire Voordelta which contains a variety of different habitats characterised by grain size, silt content and also fishing effort. Overall, however, there seems to be an increase in biomass of species in the <3y longevity class in the Voordelta while biomass on the other hand has not increased over the study period.

A decrease of disturbance of the sea floor may increase the survival of long-lived species that are associated with lower productivity, and hence leads to lower biomass levels (Tulp et al. 2016). If the effort of demersal trawlers which penetrate deeper into the bottom decreases, this may be directly beneficial for long-lived species living deeper in the sediment, i.e., leading to lower biomass production.

The amount of disturbance of the top benthic layer (epi-fauna) has increased over time while the deeper layers (in-fauna) have received relatively stable disturbance. The stabilisation is due to a decline in demersal trawls being compensated for a rapid increase in shrimp trawling. The impact per unit swept-area is much lower for shrimp trawls than for demersal trawls and hereby cancel out the diverging trends in effort over time that show a decline in beam-trawl and a rapid increase in shrimp trawl. If both gear types would have had a similar bottom impact, overall swept-area impact would have increased as shrimp trawl effort increased more rapidly than the decline in beam trawling.
The scenarios of what biomass development over time could have been are simple in design but illustrate clearly that the increase in shrimp trawling has had a profound impact. If shrimp trawling would not have increased from ~2004 levels (where it was very low compared to demersal trawling), it would have been likely that biomass had increased. This is illustrated in Figure 4 where modelled community biomass increases substantially if no shrimp fishing would have taken place. Although the impact is profound, the absolute change in community biomass would have amounted to only 2-3% maximum. Even if fishing had remained the same as was observed in 2004-2005, establishing the BBG in 2008 would have resulted in only a minor improvement of overall biomass in the area of ~0.5%. As such, the decline of the beam trawl fleet has been beneficial for benthos biomass development in the Voordelta area, although this positive effect on benthos biomass has to a large extend been counteracted by the increasing shrimp fishery.

The discards from the shrimp fishery, which has increased, causes a constant supply of carcass and carrions as food for scavengers (Tulp et al. 2010). If scavengers thereby would increase, benefitting from the increase in shrimp discards, this may also cause a greater predation rate on benthic fauna by these scavengers with an indirect result of a reduction in biomass.

It should be noted, however, that fishing effort by itself has little explanatory value (only in interaction with longevity). Wind speed (as a single factor in the model) had the largest impact on the longevity composition of the benthic community as shown in the statistical model and figure 3. Hence, if natural disturbance would have been different during the study period, it is likely that the benthic community composition would have changed to a larger degree than fishing could have attributed to. In other words, if wind speeds would have been much higher, hereby causing higher wave velocities that in turn affect sea bottom stress, one could have expected a different benthic composition in the Voordelta.

The distribution of fishers in the Voordelta is difficult to predict from key indicators such as distance to the coast and aggregation of effort. Especially the increase around 2014-2015 in aggregation is difficult to explain since no alternative management measures were taken at that stage. The declining trend in aggregation and effort of the demersal fleet makes it nearly impossible to predict what may happen in the future if one would like to evaluate biomass composition under current fishing effort regimes in 10 years' time. However, at the same time, the effort operated by this fleet is low and likely contributes little to the benthic disturbance. However, the stability in space and aggregation of the shrimp trawlers allows to predict how a 2-fold increase in effort would translate into swept-area ratios at a grid-cell scale. Given the recorded aggregation of a factor ~2 in the Bodembeschermingsgebied, this would imply that areas previously trawled only once (before doubling fishing efforts), would be trawled 3 times after effort has doubled. Areas previously trawled 9 times would be trawled on average 14 times. This relationship is key to predict trawling intensities if shrimp trawling effort continuous to increase in the Voordelta, and to estimate local effects to the benthic community in more detail.

The change in aggregation from 2014 onwards however makes it more difficult to predict the most likely future distribution and aggregation of the shrimp fleet. There seems, however, to be a correlation between the value of shrimp in the Netherlands and the change in aggregation. It is unclear however how these two may interact and provide a mechanism to predict aggregation for the future or reconstruct spatial fishing scenarios based on different assumptions other than listed in Figure 4.

5 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. This certificate is valid until 15 December 2021. The organisation has been certified since 27 February 2001. The certification was issued by DNV GL.

Furthermore, the chemical laboratory at IJmuiden has EN-ISO/IEC 17025:2017 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2021 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation. The chemical laboratory at IJmuiden has thus demonstrated its ability to provide valid results according a technically competent manner and to work according to the ISO 17025 standard. The scope (L097) of de accredited analytical methods can be found at the website of the Council for Accreditation (www.rva.nl).

On the basis of this accreditation, the quality characteristic Q is awarded to the results of those components which are incorporated in the scope, provided they comply with all quality requirements. The quality characteristic Q is stated in the tables with the results. If, the quality characteristic Q is not mentioned, the reason why is explained.

The quality of the test methods is ensured in various ways. The accuracy of the analysis is regularly assessed by participation in inter-laboratory performance studies including those organized by QUASIMEME. If no inter-laboratory study is available, a second-level control is performed. In addition, a first-level control is performed for each series of measurements.
In addition to the line controls the following general quality controls are carried out:

- Blank research.
- Recovery.
- Internal standard
- Injection standard.
- Sensitivity.

The above controls are described in Wageningen Marine Research working instruction ISW 2.10.2.105. If desired, information regarding the performance characteristics of the analytical methods is available at the chemical laboratory at IJmuiden.

If the quality cannot be guaranteed, appropriate measures are taken.

References

Bolam et al. (2014) Sensitivity of macrobenthic secondary production to trawling in the English sector of the Greater North Sea: A biological trait approach, Journal of Sea Research 85: 162-177

Eigaard, O. R., et al. (2017). "The footprint of bottom trawling in European waters: distribution, intensity, and seabed integrity." ICES Journal of Marine Science 74(3): 847-865.

Ellis, N., et al. (2014). "Scaling up experimental trawl impact results to fishery management scales — a modelling approach for a "hot time"." Canadian Journal of Fisheries and Aquatic Sciences 71(5): 733-746.

Hiddink, J. G., et al. (2006). "Cumulative impacts of seabed trawl disturbance on benthic biomass, production, and species richness in different habitats." Canadian Journal of Fisheries and Aquatic Sciences 63(4): 721-736.

Hiddink, J. G., et al. (2017). "Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance." Proceedings of the National Academy of Sciences Jul 2017, 201618858; DOI: 10.1073/pnas.1618858114

Hintzen, N.T.; Piet, G. J.; Brunel, T.; (2010). Improved estimation of trawling tracks using cubic Hermite spline interpolation of position registration data. Fisheries Research 101: 108-115

Hintzen, N. T.; Bastardie, F.; Beare, D. J.; Piet, G. J.; Ulrich, C.; Deporte, N.; Egekvist, J.; Degel, H. (2012). "VMStools: Open-source software for the processing, analysis and visualisation of fisheries logbook and VMS data." Fisheries Research 115-116: 31 - 43.

Hintzen, N. T., Coers, A., Hamon, K. (2013). "A collaborative approach to mapping value of fisheries resources in the North Sea (Part 1: Methodology). " Report number C001/13, IMARES, Ijmuiden. 24 pp.

Hintzen et al. (2019). Persistence in the fine-scale distribution and spatial aggregation of fishing, ICES Journal of Marine Science. https://doi.org/10.1093/icesjms/fsy144

Holland, D. S. and J. G. Sutinen (1999). "An empirical model of fleet dynamics in New England trawl fisheries." Canadian Journal of Fisheries and Aquatic Sciences 56(2): 253-264.

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

Kaiser, M. J., et al. (2002). "Modification of marine habitats by trawling activities: prognosis and solutions." Fish and Fisheries 3(2): 114-136.

Machiels & Hintzen (2018). Visserij activiteit in en rond Natura 2000 natuurbeschermingsgebied voordelta. PMR rapportage.

Rijnsdorp, A. D., et al. (1998). "Micro-scale distribution of beam trawl effort in the southern North Sea between 1993 and 1996 in relation to the trawling frequency of the sea bed and the impact on benthic organisms." ICES Journal of Marine Science 55(3): 403-419.

Rijnsdorp,A. D., van Stralen, M., Baars, D., van Hal, R., Jansen, H., Leopold, M., Schippers, P., en E. Winter, 2006. Rapport Inpassing Visserijactiviteiten Compensatiegebied MV2. Wageningen IMARES, IJmuiden. Rapport C047/06. 123 pp.

Rijnsdorp, A. D.,Bolam, S.G. ,Garcia, C.,Hiddink, J. G., Hintzen, N.T. ,van Denderen, P. D. ,van Kooten, T. ,(2018) Estimating sensitivity of seabed habitats to disturbance by bottom trawling based on the longevity of benthic fauna. Ecological Applications 28 (5) : 1302-1312

Pérez Rodríguez, A., van Kooten, T. (2018). "Shrimp fishery and natural disturbance affect longevity of the benthic invertebrate community in the Noordzee-kustzone Natura 2000 area. " *In prep.(?)*

Poos, J.-J. and A. D. Rijnsdorp (2007). "The dynamics of small-scale patchiness of plaice and sole as reflected in the catch rates of the Dutch beam trawl fleet and its implications for the fleet dynamics." Journal of Sea Research 58(1): 100-112.

Tulp, I., T. Leijzer en E. van Helmond (2010). Overzicht Wadvisserij, deelproject A, bijvangst garnalenvisserij eindrapportage. Imares, rapport nr: C102/10.

Tulp, I., Tien, N. and van Damme, C. (2016). "PMR Monitoring natuurcompensatie Voordelta - Ontwikkeling vis in de Voordelta na instelling bodembeschermingsgebied ter compensatie van de aanleg Tweede Maasvlakte." Wageningen University & Research Rapport C089/16. http://edepot.wur.nl/393791

van Denderen, P. D., et al. (2014). "Habitat-Specific Effects of Fishing Disturbance on Benthic Species Richness in Marine Soft Sediments." Ecosystems **17**(7): 1216-1226.

Justification

Report C083/19
Project Number: 4316100065

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: S.T. Glorius
Researcher

Signature:

Date: 16 September 2019

Approved: Dr. ir. T.P. Bult
Director

Signature:

Date: 16 September 2019

Wageningen Marine Research
T +31 (0)317 48 09 00
E: marine-research@wur.nl
www.wur.eu/marine-research

Visitors' address

- Ankerpark 27 1781 AG Den Helder
- Korringaweg 7, 4401 NT Yerseke
- Haringkade 1, 1976 CP IJmuiden

With knowledge, independent scientific research and advice, **Wageningen Marine Research** substantially contributes to more sustainable and more careful management, use and protection of natural riches in marine, coastal and freshwater areas.

Wageningen Marine Research is part of Wageningen University & Research. Wageningen University & Research is the collaboration between Wageningen University and the Wageningen Research Foundation and its mission is: 'To explore the potential for improving the quality of life'