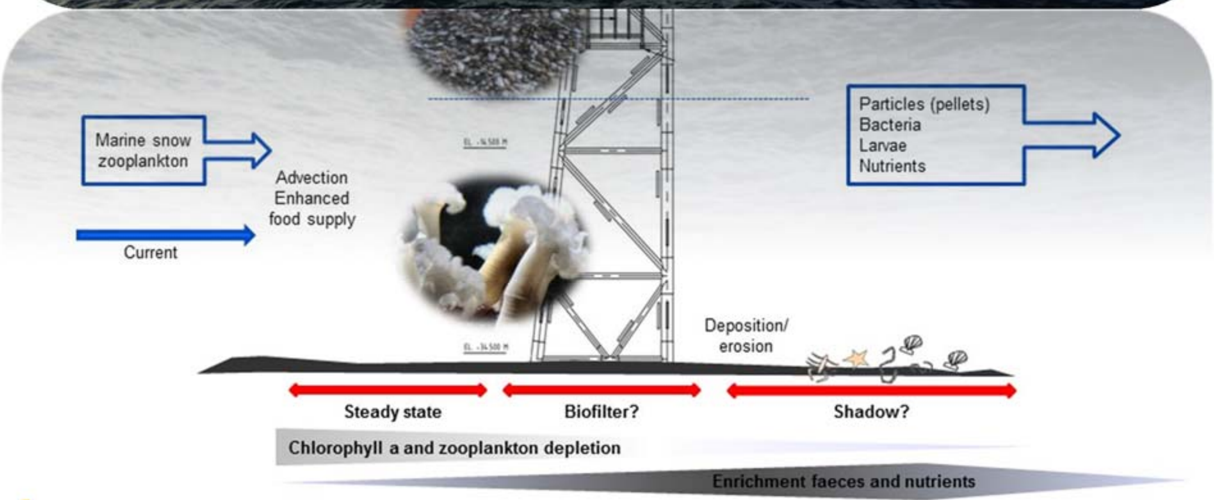
Measuring the SHADOW of an artificial structure in the North Sea and its effect on the surrounding soft bottom community



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Summary

Artificial structures in the North Sea, offering substrate for rich and diverse epifauna communities, form small oases in the North Sea, which is mainly characterised by the presence of soft sediments. In most cases these communities are dominated by active and passive suspension feeders, which attract higher trophic levels forming reef like systems. Very little is known about the effect these filter feeders have on local carbon cycling. On the basis of the high number of suspension feeders which can be up to 500-fold the biomass of the surrounding benthic soft bottom community, observed on man-made structures like oil and gas platforms and windfarms, we hypothesized that the epifauna acts as a biofilter. This biofilter casts a “shadow” on the immediate surroundings, hereby affecting the soft-bottom community directly around the platform, and also the more distant pelagic environment behind the platform. This hypothesis is based on the assumption that the biofilter will deplete (primary-produced) organic matter and zooplankton in the water column and will produce faeces, release nutrients and dissolved organics as well as larvae. In this way, the epifauna will alter the local particle flux and the physico-chemical conditions in the water column, while through the production of larvae the epifauna community will contribute to the persistence of rare and endangered species throughout the heavily trawled North Sea.

To examine whether a “shadow” effect is present around oil and gas platforms, two cruises were carried out to gas platform L7A, situated in the southern North Sea at 40 m water depth. Based on hydrographic current models of the wider North Sea the “shadow” area was defined in the direction of the strongest current within a tidal cycle. Accordingly, a sampling scheme was designed with stations in the assumed “shadow” and at reference sites. Along transects moving away from the platform the water column structure, as well as concentrations and fluxes of particulate and dissolved matter, were sampled using a CTD-Rosette system. To establish whether a shadow effect affected the bottom fauna, in situ sediment community respiration was measured at different distances from the platform and sediment and fauna was collected, the latter for assessment of species richness and standing stock. Based on ROV footage provided by TOTAL, the density of epifauna on the platform was estimated and the most abundant species were identified.

A dense epifauna coverage was present on the platform. The main species were *Mytilys edilus* observed in the top 4 m below the sea surface and *Metridium Senile*, which was found below 10 m water depth towards the bottom. The species richness (amount of different species) observed in the sediment was the similar in all directions, however, large differences were seen in abundance (individuals m^{-2}). In the area potentially affected by the platforms’ shadow, the abundance increased with increasing distance, while abundance in the reference areas showed an opposite trend. This is in line with a similar trend, observed in the in-situ respiration, showing an increase away from the platform in the area affected by the shadow as opposed to a decrease in the reference area. Also organic matter concentrations in suspended particulate matter and in surface sediment showed an increase away from the platform in the shadow area, which corresponded with highest amounts of silt found near the platform. Although silt and organic matter concentrations were much higher in the direction of the shadow, the quality of the organic matter was higher at the reference sites. This fits with the trends observed in oxygen consumption (respiration) and observed faunal abundances.

These observations suggest that the platform, providing substrate for epifauna, plays a major role for at least local carbon cycling, which is expressed in organic matter respiration and

faunal abundances. The more distant effect through the potential enhanced release of nutrients, although still feasible, has not been proven with the current set of observations. Moreover, our present observations do not yet allow disentangling the impacts by the epifauna attached to the structure and the impact of the platform itself, or potentially a combination of these two factors. Currently a model is developed, in which the hydrodynamics, geochemical and mechanistic descriptions of faunal activity are coupled. This model will also be applied to observations from a platform in the North Sea in a deeper water setting. It is hypothesized that the shadow effect on the sediments will be less pronounced in deeper water, due to general attenuation of particle fluxes with depth. Impact on the water column and nutrient fluxes might however have a similar, or even larger impact due to the impact of the structure itself on local hydrodynamics. In this model it is also taken into account that the epifauna on the deep platform might strongly differ from the shallow platform, influencing biofilter capacity of the community. So far we can conclude that man-made structures affect their surroundings, although it remains questionable whether this effect will have an imprint on the wider North Sea, since trends are only observed locally (several 100's m) around the structure and the amount of oil and gas platforms is scattered. Model quantification will allow extrapolating these numbers to a basin-wide scale.

Introduction & Background

Artificial structures like oil and gas platforms, pipelines and more recently wind turbines offer hard substrate for sessile epifauna in the North Sea which is primarily covered by soft sediments (Krone et al., 2013). Decades of chronic bottom trawling has further diminished the already sparse substrate for sessile epifauna. Artificial structures therefore are oases for sessile epifauna amidst of a desert of soft and disturbed sediment. The epifauna growing on artificial structures can attain a biomass of up to 500-fold the biomass found in nearby soft sediment (Picken et al., 2000) and consists mainly of filter- and suspension-feeders (van der Stap et al. 2016). So far little is known about the effects of these local biomass extremes on concentrations of nutrients and particles in the water column and on the benthic ecosystems in their direct vicinity. Based on modelled data of chlorophyll a depletion around a wind turbine (Maar et al., 2009) and the wake of particles observed around windfarms (Baeye and Fettweiss, 2015), we hypothesized that the presence of a high number of suspension-feeders on oil and gas platforms will act as biofilter, simultaneously depleting the suspended nutritious matter in the water column and enriching the environment by the excreted pseudo-faeces, dissolved nutrients (like $NH4+$) and larvae. This biofilter therefore can cast a so called shadow over the immediate surroundings, altering concentrations and fluxes of particles and nutrients (Figure 1). This in turn might affect the benthic community, due to limited availability of high quality food. In addition we hypothesize that artificial structures might form stepping stones by offering suitable substratum to species that would otherwise be absent (e.g. Mytilus, cold-water corals). They therefore may act as factors facilitating the dispersal of epifauna in the North Sea (Adams et al., 2014; De Mesel et al., 2015).

Our general hypothesis is that **the fouling community on artificial structures in the North Sea cast a shadow in the water column and on the seafloor in their immediate vicinity.** This was translated in the following specific hypothesis**:**

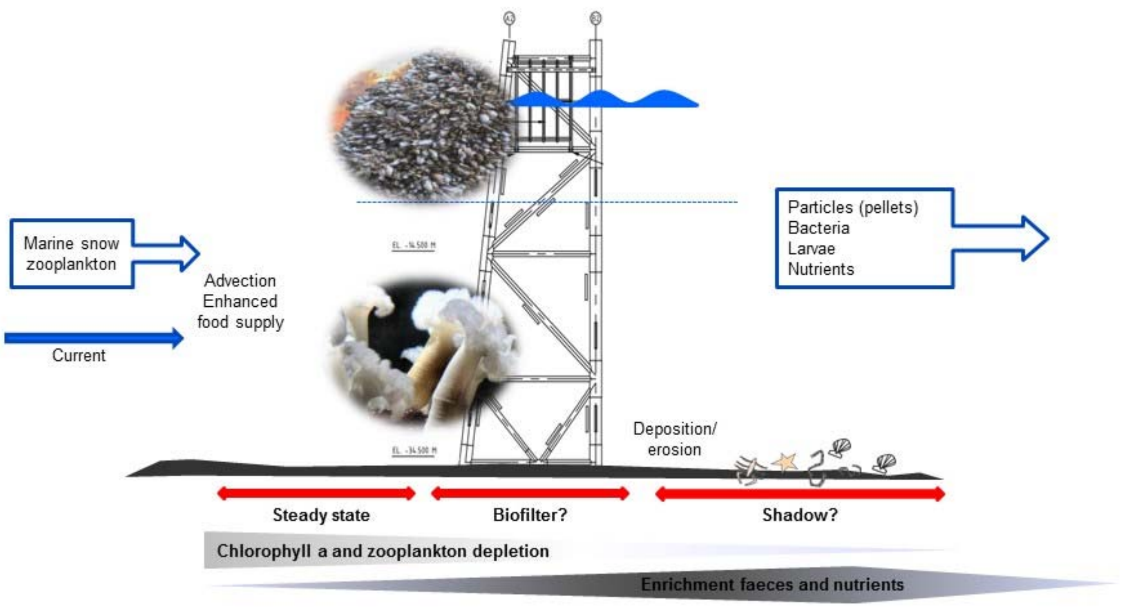

Figure 1. Schematic representation of potential processes occurring near a platform.

1. The epifauna on oil/gas platforms act as biofilter retaining nutritious particles from the water column causing depletion in the water column in the wake of the platform
2. Uptake of particles and subsequent excretion and deposition of pseudo-faeces and faeces by the fouling community will cause a change, i.e. enrichment/depletion, in the sediment and benthic community in the wake of the platform
3. The platform community forms a source of larvae produced by local sessile organisms, which is measurable as higher larvae numbers present in the wake as compared to reference water column outside the wake

Study area

Platform L7A is situated in the southern North Sea and is owned by Total (Figure 2). The first gas was produced in 1988 and at present the platform is no longer in use. Crucial for the selection of this particular platform for the current study is that non-toxic substances were used during drilling operations in the past (Duineveld et al. 2007). Discharges of toxic drilling wastes around platforms typically have long-lasting effects on the sediment and its community (Kroncke et al. 1992). L7A is situated in the shallow part of the North Sea at 35 m water depth near the southern border of the Oyster grounds. The bottom fauna within the 500 m (non-trawling) zone around the platform was investigated earlier in 2007 by NIOZ. This non-trawling zone around the off shore installation forms a refuge for vulnerable soft bottom fauna and within this zone anthropogenic influences like fisheries are minimal (Duineveld et al. 2007).

Available data supported by actual measurements showed that tidal current vectors at L7a formed an elongated SE-NW ellipse with very short intervals of low speeds in transverse directions. The net current was oriented NW and the presumed shadow was therefore defined as the sector between 0^o and 90^o N compass direction with the main axis at 45^o and secondary 225^o. Reference sites were selected along perpendicular directions 135^o and 315^o compass.

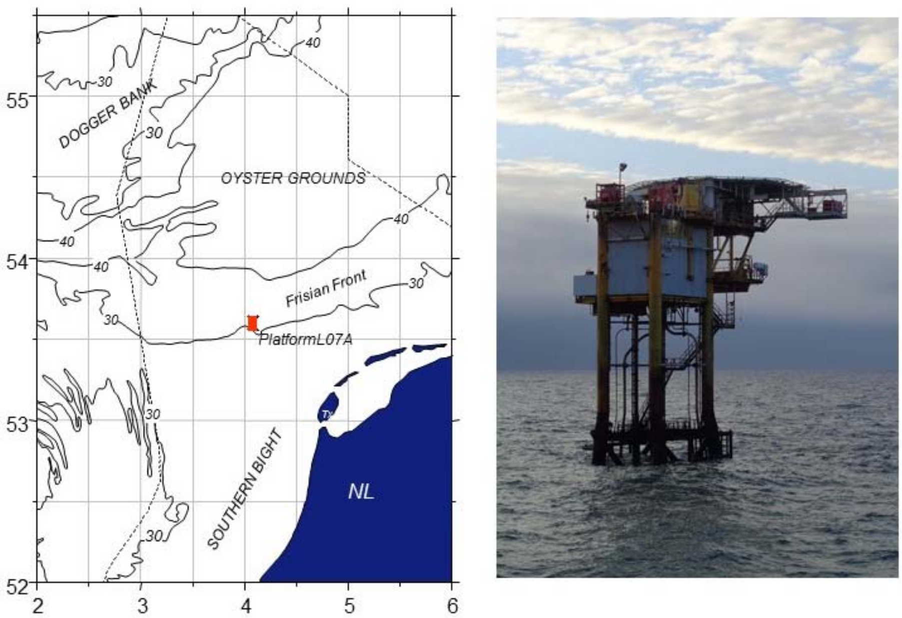

Figure 2. Location of platform L7A in the southern North Sea. Sampling stations are presented in Appendix A.

During the cruise samples were taken within the shadow of the platform (direction of the strongest currents) and at reference sites outside the shadow mainly within the 500 m non-trawling zone to exclude the effect of trawling (Bergman et al., 2014) (See Appendix A).

Methods

Cruises

Two cruises were carried out within the framework of the INSITE project. During the first cruise (7-12 May 2016) with the RV Pelagia the area around the L7A platform was sampled along transects in the shadow and at reference sites. The main objectives of this cruise were:

- To measure concentrations of particles (organic matter, larvae) and solutes (nutrients, dissolved organic matter) around L7A
- To search for trends in the activity, diversity and standing stock of the benthic community around L7A by means of in-situ respiration measurements, box core sampling, and underwater video
- To assess the species composition of propagules in the water column around L7A at the time of the cruise (CTD water sampling). Because of the short timeframe, propagule sampling was extended over the subsequent 7 months using a sediment trap mounted in a mooring (see below)
- To deploy a mooring with sediment trap in and outside the presumed shadow of the platform, to measure particle fluxes (incl. propagules) over a longer period. The moorings were recovered during a short 2 days cruised with the VOS Sweet in 2-3 December 2017.

Field sampling

Underwater video imaging

Video-images of the seafloor around platform L7A were made using a tethered camera system attached to a specifically designed frame, holding a downward looking HD digital video camera, a forward looking camera, a power-supply and modem, UW lights, and a set of parallel Oktopus™ laser pointers. The camera system is connected to an optical fibre cable that allows real time transmission of video images. The major purpose of the video transect made during the cruise was to estimate coverage and density by large epifauna and to identify bioturbation patterns. The fixed distance (30 cm) marked by the lasers in the images forms a mean to estimate coverage per square meter. During the cruise one transect was carried out, starting and ending outside the 500 m non-trawling zone and crossing the platform at 100 m distance.

Sediment sampling

Box core samples were collected along transects in 4 different directions (SW, SE, NW and NE). Each transect consisted of 4 box core samples taken at 150 m distance apart. All bottom samples were collected with a NIOZ box corer (K16) equipped with a stainless steel cylindrical core of 30 cm in diameter and 55 cm height and a trip valve sealing the box. When the box corer came on deck, the valve was carefully opened and if present the overlying water was siphoned off. The surface of the box core was photographed and a description of the species composition and other characteristics was made (e.g. height of sediment and/or sediment characteristics, living/fossil species). A sub core was taken for sedimentological and radionuclide analyses, which were stored in the fridge at 4 °C. Three surface samples were collected for OM measurements and three syringes were pushed into the sediment to collect material for e(nvironmental) DNA. The eDNA samples will be analysed for metazoan organisms, and more specifically meiofauna. Meiofauna diversity has been shown to respond to changes in organic enrichment. All these samples were stored at -20 °C. The box core samples were sorted for living macro-organisms, whereby the whole sample was sieved over a 1 mm sieve. All live organisms were sorted and identified during the cruise. All fauna was stored in ethanol for later analysis.

In-situ respiration measurements

During cruise 64PE409 two ALBEX landers with respiration chambers were deployed at three different distances from the platform, i.e. 100, 300 and 700 m, along a transect in the "Shadow" and another perpendicular transect in the reference direction. The ALBEX landers consisted of an aluminium tripod equipped with 12 glass Benthos™ floats, two IXSEA acoustic releasers and a single 250 kg ballast weight. The landers were deployed and recovered with a floating line, which was kept at the surface with 5 little floats. An Iridium beacon was attached to the frame to locate it in case of unexpected surfacing. Each lander carried three NIOZ made benthic chambers (144 cm^2) equipped with recording Rinko™ oxygen sensors (optodes). Movements of the chambers in- and out of the sediment and closure of the valves were pre-programmed and incubations lasted typically for 10 hours. Upon return, the oxygen concentrations measuring by the Rinko™ optodes were converted to fluxes over a surface area, and flux data from the three replicate chambers were averaged. Additional data on water column characteristics were collected in combination with the deployments of the landers for respiration measurements. For this purpose, the landers were equipped with a Nortek Aquadopp™ current meter, an ALEC™ optical backscatter sensor, a LISST™ Acoustic Backscatter Sensor (ABS) to monitor near-bed current and suspended particle load. Furthermore, the lander that was deployed in the "Shadow" was equipped with a McLane particle pump, which filtered 3L of near bottom water at hourly interval over pre-weighted GFF filters.

Mooring deployments

The moorings that were deployed for long term measurements consisted of a bottom weight of 400 kg, which was connected to two releases. Along the mooring wire an Aquadopp current sensor and a Lisst ABS sensor with data logger were mounted at 10 m above the bottom. Immediately above the current sensor a Technicap PPS4/3 sediment trap was mounted with a rotating carrousel with 12 bottles that were filled with a preservative (pH buffered $HgCl_2$ solution or DMSO). The sediment trap was programmed at a 14 day interval. At 12 m above the bottom and 16 m below the sea surface an Alec turbidity sensor was attached to the wire. In addition little nets with living pre-weighed and pre measured *Mytilus edilus* were attached to the wire at 4, 12 and 24 m above the bottom, respectively. These muscles will be used for a growth experiment, whereby growth and biomass of the muscles at different heights in the water column will be monitored.

Water column characteristics

During the cruise the CTD-rosette sampler was equipped with 22 Noex bottles of 12 litre, a Seabird™ 911 CTD with auxiliary sensors for oxygen, fluorescence (Chelsea Aqua 3) and turbidity (Transmissometer and Wetlabs FLNTU). Data were acquired using the SeaBird SBEdata Processing –Win 32 software. CTD profiles were recorded along several transects in- and outside the "Shadow". CTD profiling was mainly performed during the flood which is the period with strong currents in NE direction at the study site. Effects of the platform were expected to be most explicit during flood tide. During CTD profiling water samples were collected at three different depths, i.e. as close as possible to the seabed, at mid water depth and at the surface. The water samples were subsampled for analysis of DIC, DOC, nutrients and silicate. Other subsamples were filtered over pre-weighed GFF filters to measure the amount of suspended matter in the water column. These filters will be also used for measurements of organic matter, N and carbon and nitrogen isotopes. Three times 10 L of water was filtered over a 50 µm sieve to collect samples for eDNA (propagules). These samples were frozen at -80 °C.

Laboratory methods

Sediment samples

In the laboratory sediment cores were opened, described and scanned with an XRF core scanner. Sub samples were taken with syringes at 5 cm intervals to determine porosity. The core was sliced in 1 cm slices, which were freeze dried for further analysis of grainsize with a Coulter counter and Corg-N and C and N isotopes analysis. Inorganic C was removed prior to the analysis by reacting samples with 2 M HCl twice (4 and 12 hours). The samples were then rinsed two times with demineralized water, freeze-dried and ground in an agate mortar. In-house and international standards were used and the average standard deviation of all measurements was <1%. C and N contents were determined using Flash 2000 Organic Elemental Analyser, (Thermo Scientific Bremen, Germany) and stable isotopes, a Delta V advantage Isotope Ratio Mass Spectrometer (Thermo Scientific Bremen, Germany).

C and N analysis

Suspended particulate matter samples collected from the water column with CTD or McLane pump and surface sediments were measured for their organic carbon, nitrogen content and C, N stable isotopes on a Flash 2000 Organic Elemental Analyser and a Delta V advantage Isotope Ratio Mass Spectrometer (Thermo Scientific Bremen, Germany), respectively. For C_{org} content and $\delta^{13}C$ values, filters were acidified, prior to the analyses, with 37 % fuming HCl in a desiccator container for 12hrs and subsequently were dried overnight at 40°C.

Environmental DNA

Sediment samples were taken from all 16 box cores with a 1.5 cm radius mini corer. The 0-2 cm, 2-3 cm and 5-6 cm layer were separated as starting material for the DNA extractions. DNA extractions were performed on a 10 g subsample using the Powermax Soil DNA isolation kit (MoBio) following the kits instructions. A 400bp fragment of the 18s rRNA gene was amplified using a polymerase chain reaction from all DNA extracts. All forward and reverse primers were extended with 12nt unique barcodes. All samples were pooled in equimolar quantities together blank PCR controls. The pooled sample was submitted for sequencing at USEQ (Utrecht, Netherlands) on an Illumina MiSeq using the 2x 300bp V3 kit.

Raw reads were quality trimmed and filtered and merged. Quality filtered reads were de-multiplexed according to both their unique forward and reverse barcodes using QIIME. Operation Taxonomic UNITS (OTUs) were found using a 97% similarity cut off in VSEARCH.

Taxonomic assignment was performed against the SILVA 18s rRNA database using the RDP classifier in QIIME. OTUs of all samples will be used in further community analysis.

Modelling

A one-dimensional model will be developed to determine the “shadow” effect induced by the platform, using different sub-models to describe the various processes. The model which will be used for the growth simulation of *Metridium* at the bottom and *Mytilus* top of structure is adapted from the model developed by Meire et al. (2013). In addition, a physical and a biogeochemical sub-model that comprise water column physics and pelagic biogeochemical dynamics, respectively, will be incorporated to the final integrated model (Meire et al., 2013). For the solution of the model, ReacTran (Reactive Transport Modelling in 1D, 2D and 3D) R-package will be used (Soetaert & Meysman, 2009).

Results

Water column

Water column at time of sampling (May 2017) was stratified with relatively low concentrations of chlorophyll and turbidity above the thermocline, and increasing below the thermocline to maximum levels near the seafloor. Shifts were observed in height of the turbidity and fluorescence maximum, depending on the period within the tidal cycle, showing increased mixing during high current speeds (Figure 3). Current speeds varied between 0.05 m s^{-1} to 0.4 cm s^{-1} during one tidal cycle.

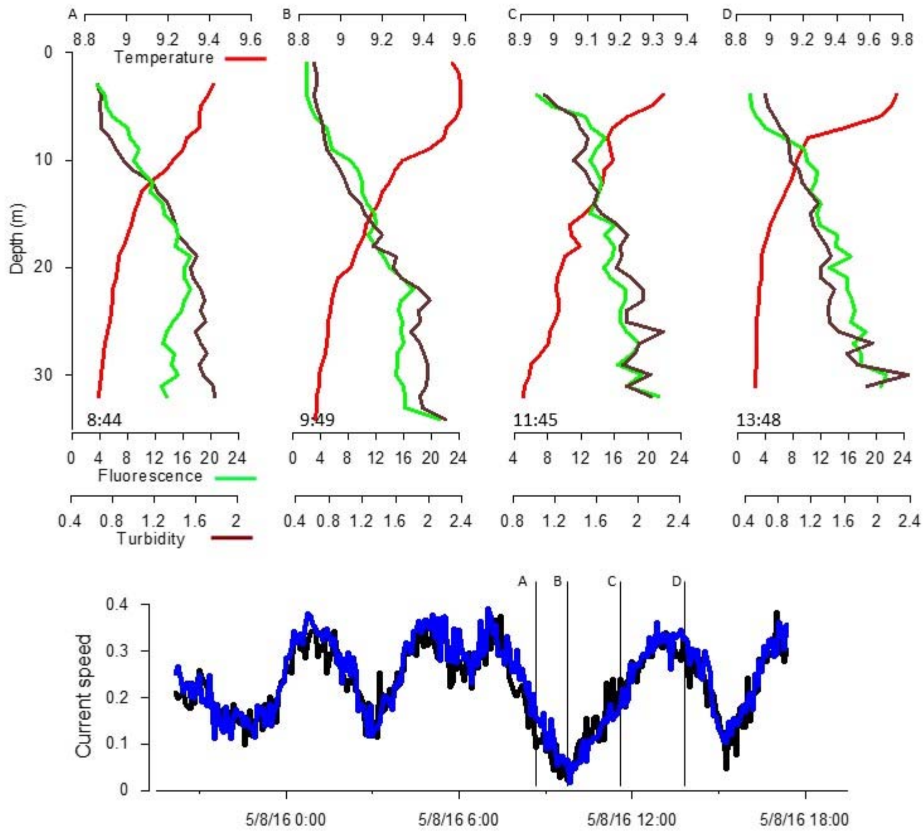

Figure 3. CTD profiles recorded at different times within a tidal cycle. A turbidity and fluorescence maximum was observed below 10 m water depth. Current data of 24 hour deployment are shown as recorded by a bottom lander.

A Corresponding trend was found in the percentages organic carbon (TOC) of suspended particulate matter (sPOM), i.e. increasing concentrations towards the seafloor at both shadow and reference stations (Figure 4). Along the shadow transect, %TOC increased moving away from the platform, while no significant trend was observed at the reference stations, **due to the relatively high percentages TOC closest to the platform**. D13C values of SPM varied around -19 ‰, being of mainly marine origin. Large differences were observed between δ15N values measured in the shadow and reference. The suspended organic matter along the reference was markedly more depleted in δ15N than the sPOM along the shadow transect. **This points to presence of reworked sPOM along the shadow transect**. Inorganic nutrients showed no trends apart from ammonium (NH4), which were relatively low close to the platform along the reference transect. No such trend was found in the shadow direction.

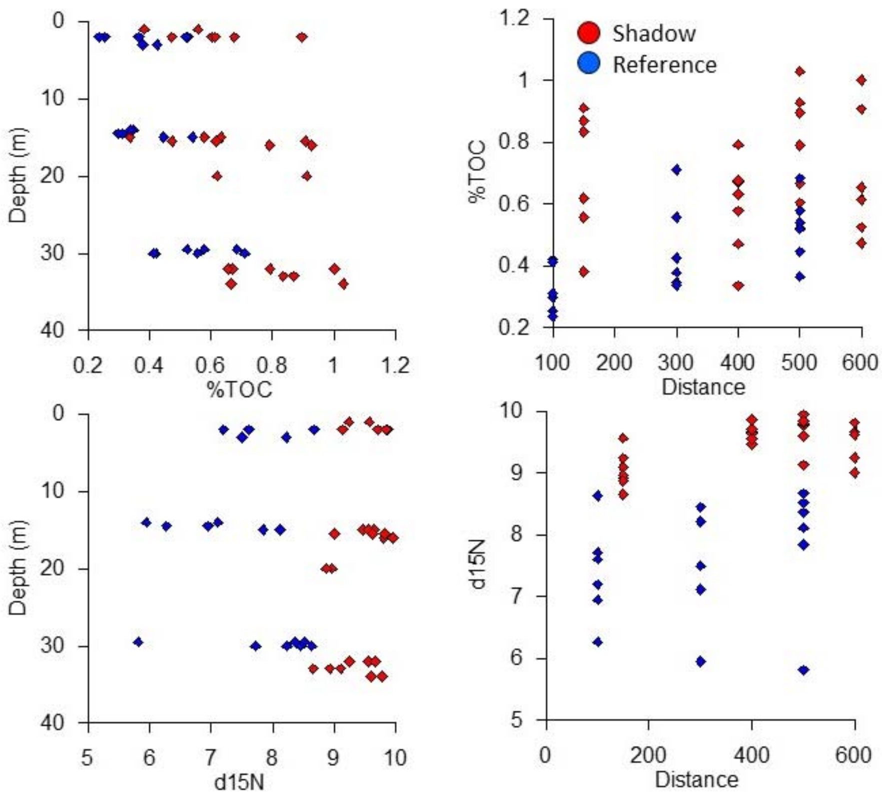

Figure 4. TOC content and δ15N of suspended matter samples along the shadow and reference transects.

Surface sediment

TOC of surface sediment showed distinct trends along the SW and NE transects which are respectively covered by ebb and flood that passes the platform. **On both shadow transects low TOC values were found close to the platform and increasing concentrations away from the platform.** No such trends were found in reference directions SE and NW (Figure 5). The sediment in the area mainly consisted of sand and silt. Highest amounts of silt were observed in the shadow direction (27.7-40%), while lowest values were observed in the SW direction (19.2-27.7%). Removal of TOC and carbonates showed that a large part of the silt fraction consists of TOC, corresponding to the elevated concentrations of TOC in the NE shadow direction.

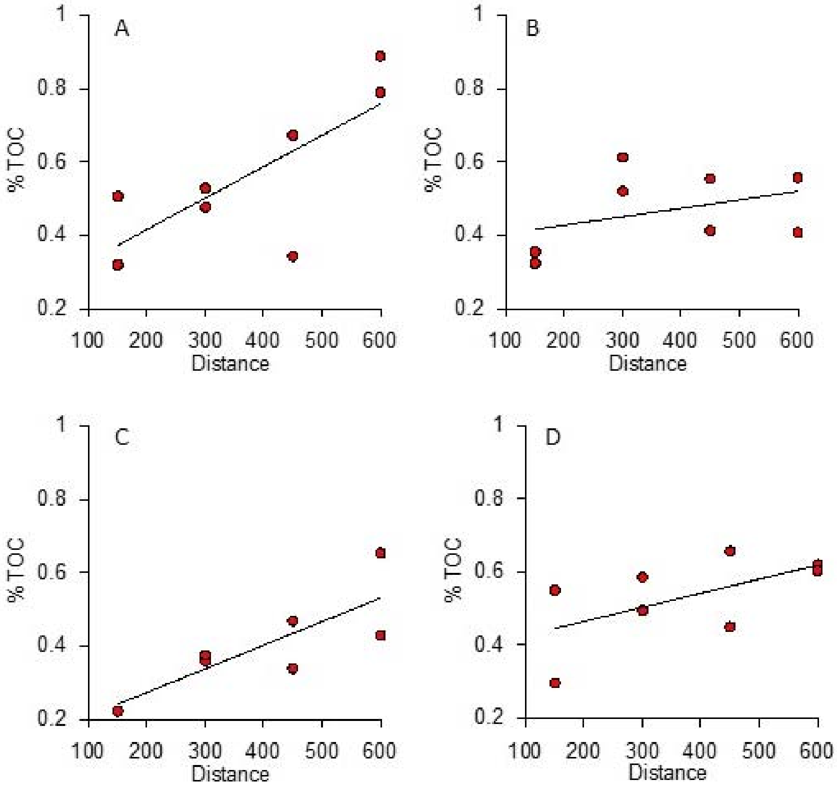

Figure 5. TOC content of surface sediments along the 4 different transects. Transect A and C are situated in the "shadow", the other transects are considered reference.

Fauna

Fouling community, composition and biomass and model input

On the basis of video clips recorded by an ROV during inspection surveys of L7A in 2015 (data kindly provided by Total), a gross interpretation of the fouling community was made. Two dominant species were present on the underwater structure of L7A, i.e. the blue mussel *Mytilus edulis* and the plumose anemone *Metridium dianthus* (Figure 6). The upper 4 m of the underwater structure was covered with mussels followed by a zone of ~5 m which was sparsely populated. The lower 25 meter was densely covered with anemones. Percentage coverage was estimated from video footage collected during the 2015 surveys. On the basis of estimates of density and average body size, in combination with the underwater surface area taken from technical drawings (~1810 m^2), the total number and biomass of the fouling community and its species was estimated for the different depth zones. Estimates for the daily supply of phytoplankton (food *Mytilus*) at the location of L7A expressed in g C/m3 were derived from runs of the European Regional Seas Ecosystem Model ERSEM) model (data kindly provided by P. Ruardij). Daily supply of zooplankton being the documented food source of *Metridium*, were taken from Broekhuizen et al. (1995) These numbers will be used as input for modelling consumption and excretion by the fouling community at L7A.

Figure 6. Fouling community on the piles of platform L7A. Left photo Metridium Senile and right photo, Mytilus edilus.

Macrofauna

Macrofauna was sampled along 4 transects (Appendix A) on each of which 4 box cores were taken. Samples were identified, counted and weighed on board. Macrofauna abundance and species richness was significantly lower on the transect SW of the platform. During ebb this transect is covered by water that has passed platform L7A. There were no distinct differences in average abundance and species richness between the three remaining transects. The two reference transects (SE and NW of L7A) had highest abundance nearest to the platform while the NE transect in the supposed shadow had increasing abundance of macrofauna with distance from the platform. This pattern was also apparent in the distribution of total biomass (ash-free dry weight), i.e. the reference transects had highest biomass values near L7A while the NE transect had lowest value near L7A and increasing values with distance.

Analyses of species composition using the PRIMER software tools MDS and ANOSIM underscored the deviating composition of macrofauna on the SE transect. This was primarily due to lower abundance of the ophiuroid *Amphiura filiformis* and the horseshoe worm *Phoronis* spec. on all 4 stations of the SW transect. Both organisms rely for their food on suspended and recently settled organic matter and are thriving at high organic food input. The macrofauna collected on NE transect which is supposedly in the flood shadow of L7A did not differ significantly from the fauna on the reference transects (ANOSIM tool).

In-situ community respiration

Respiration rates of the sediment community values were measured in triplicate at 3 stations along a NE transect (Shadow) and 3 along SE transect (Reference). Replicate measurement at single stations showed substantial variation which is most likely explained by the heavily bioturbated sediment inhabited by large deep-burrowing crustaceans (*Upogebia* spp., *Callianassa subterranean*). A multiple-comparison by means of Box-Whisker boxplot (Figure 7) showed significantly lower respiration rates at the station (st36) closest to the platform on the Shadow transect. Differences between the other stations were statistically not significant.

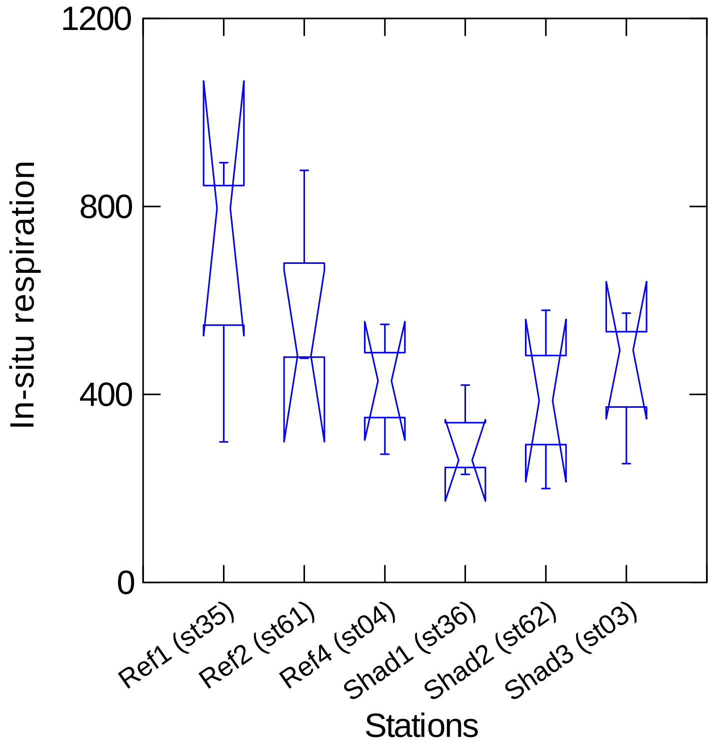

Figure 7. Box-Whisker box plot showing in situ respiration rates along the shadow and reference sites. Lander stations are shown in Appendix A.

Mooring data

At the end of the May 2016 cruise two moorings were placed close to platform L7A to measure particle concentration and flux over longer periods in the presumed shadow and at a reference position 300 m SE of L7A. Upon retrieval both moorings appeared almost fully overgrown with mussels, sea urchins and hydroids. This unexpected heavy fouling made recovery of the moorings cumbersome and had serious implications for the data. The instrument data (turbidity, fluorescence) showed that in less than 4 weeks after deployment, the overgrowth had begun to interfere with the readings so that only 4 weeks of clean data were collected. The fluorescence records from the top sensors suggest a small but consistent lower signal at the Shadow mooring, notably in the first week when chlorophyll levels in the upper water column were relatively high. The mussel growth experiment showed different growth patterns at different depths in the water column. Strongest growth was observed near the bottom and surface, while mid water depths showed lowest growth rates. Growth rates in shadow were slightly less compared to the reference site.

Discussion

The INSITE project "SHADOW" started with the following hypothesis, based on literature and recent observations mainly made in windfarms (Maar et al. 2009; Baeye and Fettweis, 2015): *The epifauna on oil/gas platforms act as biofilter retaining nutritious particles from the water column causing depletion in the water column in the wake of the platform*. The data collected within the project revealed significant differences between shadow and reference sites, which are consistent with the above hypothesis. Evidence that the platform causes depletion of the food resources in the sediment consists of differences in the distribution of macrofauna around the platform, which is depauperated on the SW transect, and the trends in carbon and nitrogen contents of the surface sediment on the SW and NE shadow transects, with lowest values being observed near the platform. Long-lived macrofauna as well as sediment carbon integrate and reflect food supply over longer periods (i.e. years). In-situ sediment respiration rates measured in the NE shadow were low near L7A and increased outward pointing to depletion of labile carbon in the vicinity of L7A. Respiration rates vary seasonally with production and temperature in the overlying water column, and hence reflect short-term food availability.

Uptake of particles and subsequent excretion and deposition of pseudo-faeces and faeces by the fouling community will cause a change, i.e. enrichment/depletion, in the sediment and water column in the wake of the platform. We did, however, not find evidence for enrichment of the benthic environment around L7A, with data instead pointing to depletion in the shadow direction (see above). We did find indications that the water column in the wake of the platform differed in composition. Evidence also consists of a marked difference in $\delta 15N$ of the suspended organic matter in the shadow. Potentially this indicates the addition of organic matter from the filter feeders attached to the platform and hence trophic level. Also concentrations of organic carbon of the suspended matter (sPOM) differed between shadow and reference transects, with distinct trends of increasing sPOM levels in both shadow transects away from the platform. This might reflect the enhanced uptake of food particles by the attached filter feeders. Alternatively, the structure as such might act as an obstacle in the tidal flow, resulting in increased amounts of fine materials settling in the direction of the strongest currents and hence diluting the locally produced fresh organic matter. The moorings, which were unfortunately rapidly overgrown, showed during the first few weeks a fluorescence signal at the shadow side which was lower compared to the reference site. This is in line with the here inferred depletion in fres organic matter at the shadow side.

A model is developed, in which the hydrodynamics, geochemical and process-based descriptions of faunal activity are coupled. This model will be applied to observations from a platform in the northern North Sea, in much deeper water. It is now hypothesized that the shadow effect on the sediments in such a setting will be less pronounced, due to general attenuation of particle fluxes with depth. However, impact on the water column and nutrient fluxes might have a similar, or even larger, impact due to the effect of the structure itself on local hydrodynamics. This model also takes into account the observation that the epifauna on the deep platform strongly differs from the shallow platform, influencing biofilter capacity of the community.

The combined data point at overall depletion of food resources (carbon) in water column and sediment within the shadow of L7A, and a marked drop in quality of the organic matter in the water column, which most likely reflects the input of reworked organics (faeces) being released by the fouling community. **These observations confirm our initial hypothesis and**

suggest that the platform, providing substrate for epifauna, plays a major role for at least local carbon cycling.

Conclusions & Recommendations

So far we here conclude that man-made structures affect their surroundings, although it remains questionable whether this effect will have an imprint on the wider North Sea. Trends are only observed locally (several 100's m) around the structure and the amount of oil and gas platforms is scattered. Still, this might rapidly change in the future, with the introduction of many new to-be-build wind farms over the coming years. Wind farms are characterized by a much denser grid of closely spaced structures, which likely will re-enforce each other, including potential positive and negative feed backs of shadow effects.

Our present observations do not yet allow disentangling the impacts by the epifauna attached to the structure and the impact of the physical presence of the platform itself (e.g. turbulence), or potentially even a combination of these two factors. It is hence recommended that data is collected in a wider area of the North Sea, including data very close to structures, enabling the quantification of the impact of man-made structures in areas characterized by different environmental conditions (e.g. depth, hydrodynamics, epifauna). These should also include a time component, which can be achieved by long term monitoring. With respect to epifauna, life habits (e.g. food, metabolism) of the dominant epifauna will strongly influence potential shadow effects. So far the focus in field and model studies has been mainly on *Mytilus edilus*, however in many parts of the North Sea this is not the most common species observed, as in the case of platform L7A. The scarcity of information on fouling species other than *Mytilus* requires more detailed studies on their life habits for reliable model construction. Field data will be crucial for the accurate parameterization of different processes relevant for new and existing models targeting the impact of man-made structures in the marine environment. All these parameters potentially influence shadow effects and hence the relevance of man-made structures in the marine realm for biogeochemical cycling and impact on the benthic and pelagic communities.

Outreach & Products

A Dutch television crew of the program "Jules Unlimited" made an item about the research carried out during the recovery cruise of the moorings. The program was broad casted several times on national Dutch television.

A theme session, titled "Introducing man-made structures in marine systems: assessing ecological effects, knowledge gaps and management implications" was organized at the ICES annual science meeting (Conveners: Silvana Birchenough (Cefas), Jennifer Dannheim (AWI), Furu Mienis (NIOZ)), Fort Lauderdale 18-21 September 2017.

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Appendix A. Maps with stations that were sampled during the RV Pelagia cruise in May 2016. A. CTD stations (Yellow), CTD stations with samples (Blue), B. Lander and mooring stations, C. Box core stations.