

# Acoustic analysis of seabed at the Luchterduinen wind farm zone

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**April 2020**

## ***Abstract***

In this project the seabed of the Luchterduinen wind farm (North Sea, Netherlands Continental Shelf) has been investigated towards indicators for presence of biogenic reef structures based on acoustic data. The wind farm went operational in 2015 with 42 wind turbines spread over an area of about 5 km by 7 km. Multibeam echosounder (MBES) bathymetry and side-scan sonar (SSS) backscatter data were acquired in April and May 2020 as well as in August 2020 in the wind farm.

The MBES bathymetry data revealed a seabed morphology with two dominant bedform types covering the entire wind farm. The water depths range between 13 and 27 m (LAT). Mega ripples with a wavelength between 3 and 8 m and wave heights around 15 cm are superimposed on the larger sand waves with a wavelength between 300 and 850 m and heights up to 3 m. Paulsen et al. (2016) estimated the average migration speed of sand waves for the Hollandse Kust Zuid, an area next to Luchterduinen, between 0.7 and 3.0 m/year. This would lead to a minimum sand wave cycle (crest to crest) of 100 years for the Luchterduinen area.

The mega ripples are only interrupted by the monopiles and their scouring protection. The side-scan data shows that the scouring protection reaches an extent with a radius of about 20 m around the monopile. The inner circle of the scour protection consist of larger rocks ( $d_{50} = 40$  cm, causing high backscatter and acoustic shadows) and the outer circle is covered with a bit finer material (only high backscatter). Between the monopiles the backscatter is lower and appears to be very consistent across the entire wind farm. Acoustic shadows are mostly caused by mega ripples. A few single boulders, debris or man-made structures were visible as well. Often it is difficult to distinguish between these features based on the acoustics and only ground truthing would yield to a clear conclusion. Video data around the turbine shows that a variety of different biota is located around the monopile. However, the side-scan data does not indicate that the biota and hard structures continue towards the areas in between the monopiles. It rather shows a homogenous distribution of mega ripples consisting of sand between the monopiles across the entire wind farm.

The assumption of the presence of sand is based on the combination of the acoustics and video data from two wind turbines showing sand as the main sediment type on the seabed. In addition, an acoustic study conducted in Hollands Kust Zuid (HKZ) (Gaida, 2020), indicates sand as the dominant sediment type as well. Since specific acoustic patterns, which are expected

for biogenic reefs, are not visible in the SSS images, the acoustic results rather plead for the non-existence of biogenic reefs in the area between the monopiles at the Luchterduinen wind farm. In case nature enhancement structures are planned to be placed in the area between the monopiles, the seabed dynamics of moving mega ripples and in particular sand waves should be considered. Therefore, they should not be located in the trough very close to the crest, otherwise the sand waves are likely to migrate over the structures (see migration rates above). Based on the acoustic results, there is no reason to expect biogenic reefs in this area. In case a ground truthing campaign will still be carried out, the lee side of the monopile is probably the most promising location, since the shear stress is lower and calmer condition can be found, which might be the preferred location for reef-building species in the Luchterduinen area. In addition, the SSS backscatter images indicate for these areas an increased backscatter. However, it is more likely that the material of the filter layer is moved with the current and deposited in this area causing the increased backscatter.

### ***Introduction***

Offshore wind farms are expected to have a positive effect on the development of mature, rich benthic communities and potentially biogenic reef habitats in the North Sea. Since bottom contacting fishing gear, like beam trawling, is forbidden within and around the wind farm, the pressure on benthic organisms will be reduced and the likelihood for the maturation of certain species and the benthic community as a whole in that area is higher. Also newly placed hard substrate, such as the monopile and the scour protection, can act as an artificial reef habitat harboring reef building, reef associated and reef benefitting species. Reef habitats are largely lost over the last centuries due to overexploitation and habitat destructing activities such as trawling.

In order to assess the development of marine habitats in the wind farm, in particular biogenic reefs, acoustic measurements are highly suitable. These measurements, conducted after the wind farm went operational (2015), are able to provide an extensive overview of the seabed state at the given time. In this study, acoustic measurements were conducted around 5 years after the wind farm went operational. This work locates the hard substrate within the Luchterduinen wind farm and searches indicators of the reef-building species *Lanice conchilega* and *Sabellaria spinulosa* through analysis of multibeam backscatter and side scan sonar data. These reef forming species widely occur in the North Sea and they may have established reef structures in the absence of trawling activities. Since the acoustic sensors provide an extensive but only indirect measurement of the seabed properties, ideally ground truthing on specific location should be added via a video camera or grab sample device to verify species presence expected based on the acoustic results. However, in case that no ground truthing data is available such as in this project, acoustic measurements still allow a search for acoustic anomalies in the regular patterns of sand waves and mega ripples. Such acoustic anomalies can indicate the presence of hard substrate or biogenic reefs located in a sandy environment.

### ***Research goals***

Within this project we acoustically evaluate the seabed in the Luchterduinen area based on multibeam echosounder (MBES), side-scan sonar (SSS) data and where possible ground truth data. We aim to provide the following information about the seabed of the study area:

General goals:

1. An indication on the possible presence of tubeworms (i.e. *lanice conchilega* or *Sabellaria spinulosa*), shell material, gravel and stones and the presence of benthic biodiversity.
2. Tailored advice on where nature enhancement structures are most optimal, considering the mapped spatial distribution of sediments and biodiversity (hotspots)
3. Information on locations which can be considered for future ground truthing and biological research (validating data/results, e.g. via ROV/Dropcam) .

Based on the project goals, the following research questions are defined:

Research questions:

1. Are reef-building tubeworms present in the Luchterduinen wind farm and can they acoustically be discriminated from the surrounding sediments?
2. What sediments and habitats do we identify and do we observe a homogenous or heterogenous distribution?
3. Can we based on acoustic data identify suitable locations for nature enhancement structures?

**Study area**

The Luchterduinen wind farm is located about 10 km from the Dutch Coastline in the North Sea (Figure 1). The majority of the Luchterduinen wind farm is surrounded by the HKZ wind farm. The water depth ranges between 13 and 27 m (LAT). The wind farm consist of 42 wind turbines (WTG) founded on a monopile foundation where the majority is protected with a scour protection consisting of a filter layer and an armour layer. The armour (upper) layer consists of rock material (Limestone) with a weight between 10-200 kg and a thickness of 1.2 m thick (average) and a d50 value of 399mm. The average extent of this layer is 18.2 m. The filter layer is ~0.5m thick and has an extent of 27.4 m. Two WTGs do not have scour protection (i.e., WTG 40 and 32).

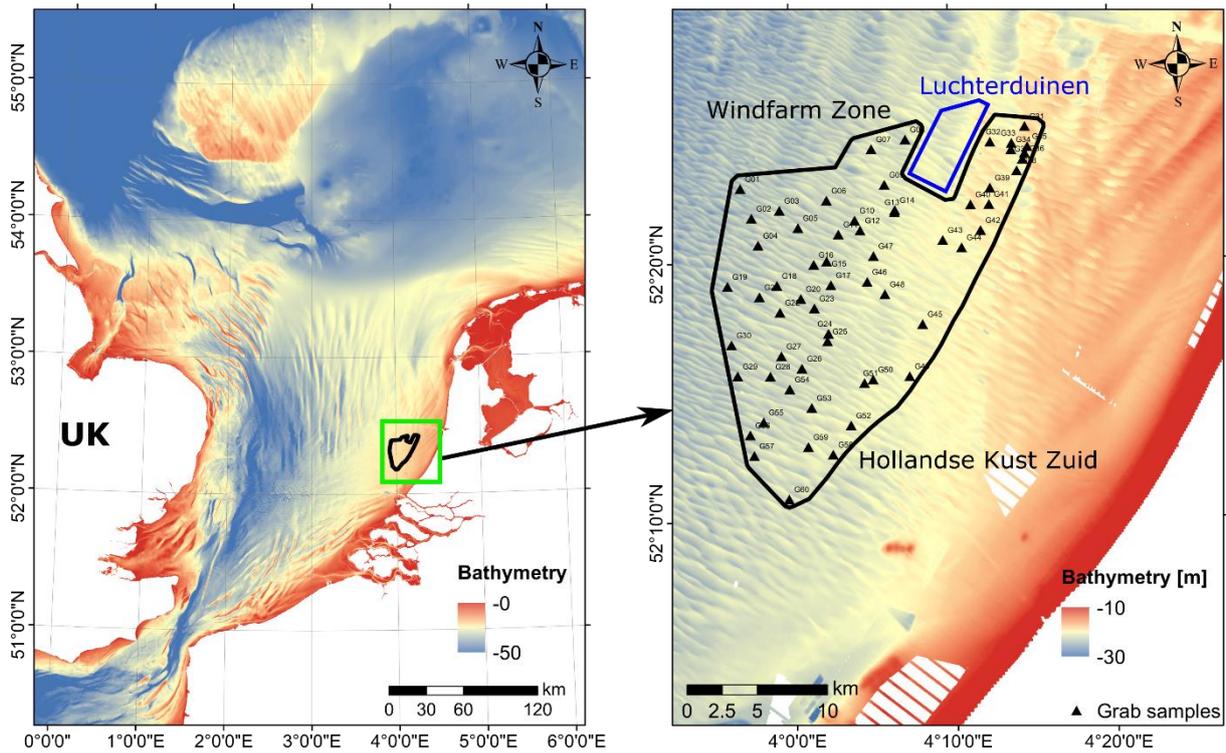


Figure 1 (Left) Bathymetry of the North Sea (EMODnet, 2018) including location of HKZ and Luchterduinen. Grid cell size is 178 m. (Right) Detailed bathymetry map of HKZ and Luchterduinen. Grid cell size is 25 m. Triangles indicate grab samples taken in HKZ.

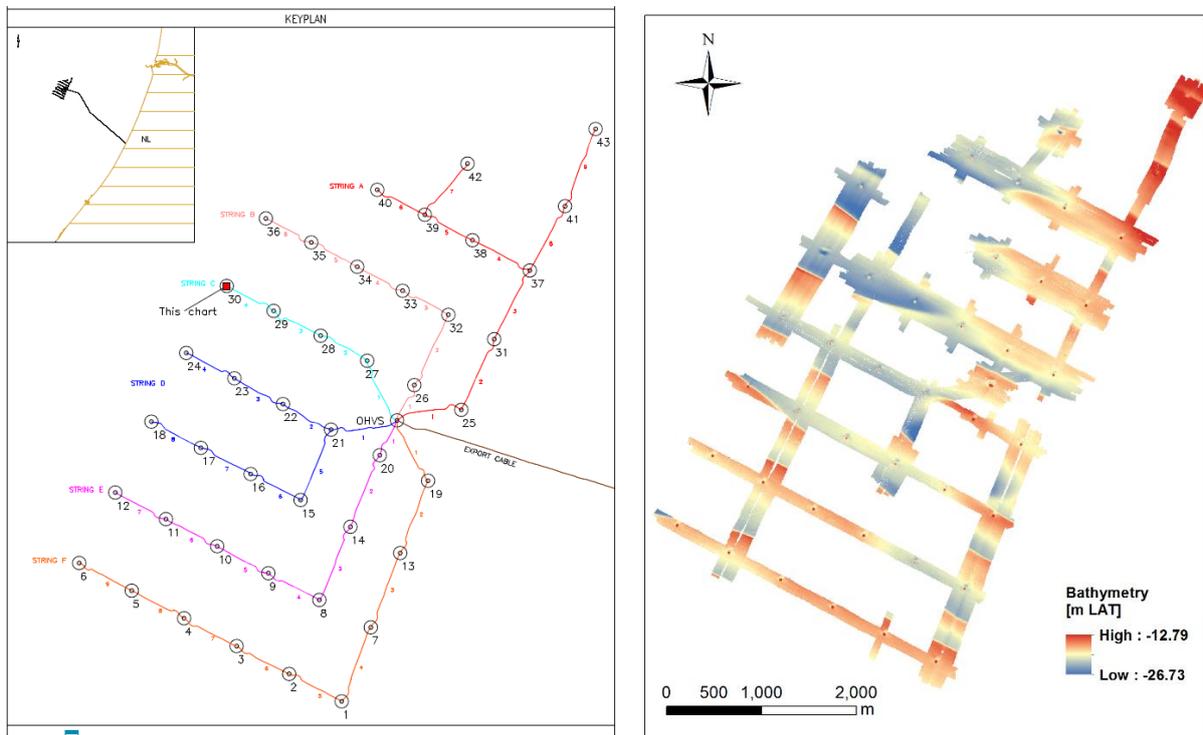


Figure 2 (Left) Overview of 42 Wind turbines (WTG) in the Luchterduinen wind farm. (Right) Detailed bathymetry map acquired with an R2Sonic 2024. Grid cell size is 50 cm.

## Data

Within this project MBES bathymetry measurements and SSS backscatter measurements were analyzed. The MBES data was acquired between the 5<sup>th</sup> and 8<sup>th</sup> of May 2020 and the 31<sup>st</sup> of July and 6<sup>th</sup> of August 2020 and the SSS data was acquired between the 5<sup>th</sup> and 8<sup>th</sup> of May 2020 and 1<sup>st</sup> and 4<sup>th</sup> of August 2020. The surveys have been carried out by the geophysical company DEEP. An R2Sonic 2024 MBES with a center frequency of 400kHz and an EdgeTech SSS with a frequency of 900 (high frequency channel) and 600 kHz (low frequency channel) were used. The seabed coverage of the MBES data is shown in Figure 2 (right).

Ground truthing only exists within a small radius around the monopile. An ROV equipped with a video camera has taken video clips from the monopile and the scour protection around the 24<sup>th</sup> of June 2019. Two wind turbines (WTG 30 and 42) have no scour protection, which yielded to recordings of the original sediment. As shown in Figure 3 (left and middle) the natural seabed consists of sand and shell fragments. As can be seen from Figure 3 (right) Figure 3, a high amount of biota has been settled on the scour protection around the monopile.



Figure 3 Video footage recorded with the ROV camera from WTG 30 without scour protection. (Left) Sandy seabed with small amount of shell fragments around 5 m from the monopile, (middle) sandy seabed with a high amount of shell fragments around 8 m from the monopile, (right) high amount of biota attached to the monopile.

## Results

### Seabed morphology

The Luchterduinen wind farm zone possesses a diverse seabed morphology with two dominant bedforms. The seabed morphology can be described by the length, height, steepness and asymmetry of the bedforms and the seabed dynamic by the growth and migration of the bedforms.

Mega ripples with a wavelength between 3 and 8 m are superimposed on sand waves with wavelengths varying from 300 to 850 m (e.g., Figure 5 and Figure 5). The orientation of the sand waves and mega ripples is relatively equal, with a general orientation perpendicular to the shore and a migration towards the north-northeast. Mega ripples reach heights of up to 30 cm. Sand wave heights vary between 1.5 and 3 m in the Luchterduinen area. On the crest of the sand waves, the mega ripples have a slope of up to 11 degrees, whereas in the trough of the sand wave the slope is more gentle with around 4 degrees. This observation can be seen in Figure 4, where the slope map indicates steeper slopes (yellow colors) on the crest than in the trough (greenish colors). The mega ripples vary between straight and curved crested. The slope of the sand waves reaches values of up to 15 degrees. An example of the morphology

representative for the western part of the Luchterduinen areas is given in Figure 4 and Figure 5.

Due to the lack of a proper time series of MBES measurements, an accurate estimation of the migration rate of the mega ripples was not feasible. However, existing literature indicates a migration rate for mega ripples in the decimeter scale per day; with up to 50cm/day for mega ripples with a height of 50 cm (Wever, 2014). With decreasing bedform height the migration rate increases. Sand waves are consequently more temporally stable. Still, modelling studies have indicated sand wave migration between 0 and 10 m/year for the North Sea (Nemeth et al., 2002). Paulsen et al. (2016) have classified for example the HKZ as dynamic based on the sand wave migration. They estimated the average migration speed between 0.7 and 3.0 m/year. Considering the minimum sand wave wavelength of 300 m and the maximum migration speed of 3 m/year, a full sand wave cycle (crest to crest) of 100 years can be expected for the Luchterduinen area. Based on the orientation of the mega ripples and sand wave, the migration direction is towards the north-east.

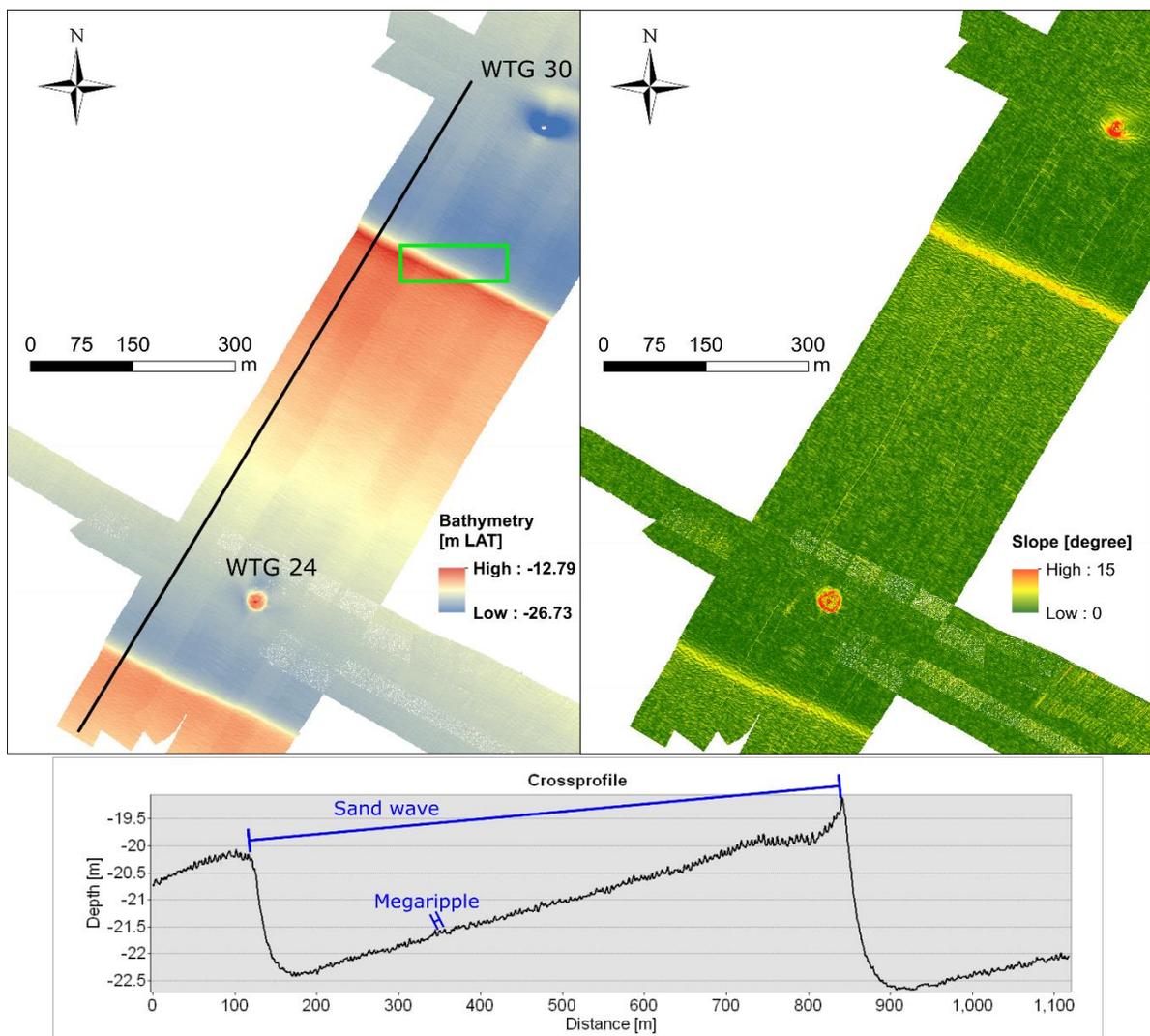


Figure 4 Subset area in the western part of Luchterduinen. WTG 24 and 30 are shown. WTG 24 is surrounded with scour protection material and WTG 30 has no scour protection. (Top left) Bathymetry, (top right) slope and (bottom) cross profile showing mega ripples superimposed on sand waves. The grid cell size is 50 cm. Figures are created with the geo analysis software ArcGIS (Esri).

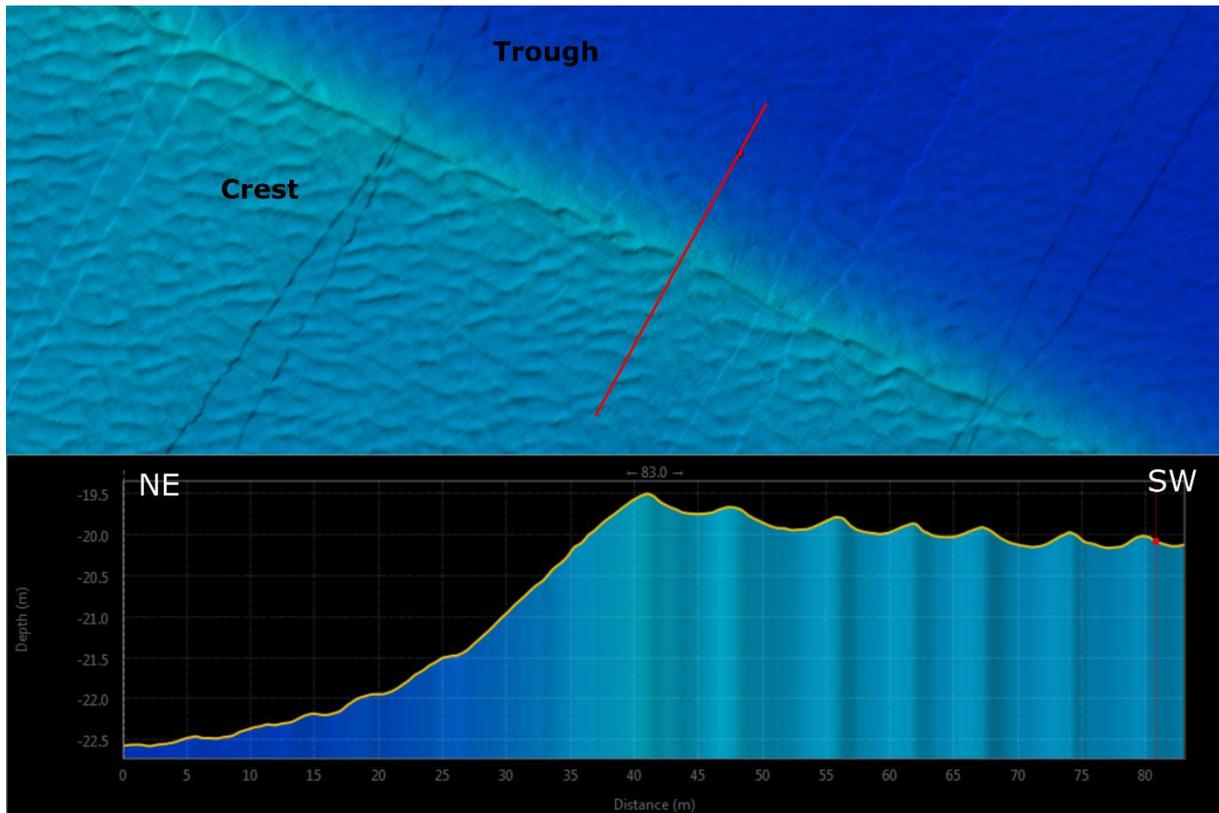


Figure 5 Subset area located between WTG 24 and 30. Area is indicated by green polygon in Figure 4 (Top) Bathymetry with a grid cell size of 50 cm. Red line indicates location of cross profile. (Bottom) Cross profile showing mega ripples superimposed on sand wave. Figures are created with the hydroacoustic software Qimera (QPS).

### **Acoustic description of sediment distribution and presence of biogenic reefs**

Figure 6 shows the processed SSS backscatter mosaic consisting of all individual track lines sailed in the Luchterduinen wind farm area. The SSS backscatter is very consistent with medium backscatter values across the entire wind farm. This indicates a homogeneous distribution of similar sediment types. Based on the video footage around the wind turbine without scouring protection, indicating a sandy seabed (Figure 3), and the distribution of mega ripples across the entire wind farm, which are very typical for sandy sediments in the North Sea, it can be assumed that the seabed of the entire wind farm is covered with sandy sediments. Also the grab samples taken in the HKZ close to the Luchterduinen area (see Figure 1), revealed sandy sediments, which substantiate this assumption. Figure 7 shows a typical side-scan image acquired in the Luchterduinen wind farm. Here, mega ripples, causing high acoustic backscatter (lighter color) with the side facing the sonar and an acoustic shadow (dark colors) with the side pointing away from the sonar, are superimposed on the larger sand wave. The monopile with the scour protection are located on the crest of the sand wave. The large rocks of the scour protection are visible via the acoustic shadow. The finer material of the filter layer is detectable via the high acoustic backscatter and the formed circular pattern, which allows to distinguish this artificial material from the original sediment. The SSS data does not reveal acoustic patterns, which are typical for the presence of biogenic reefs like *Lanice conchilega* and *Sabellaria spinulosa* as found in other studies in the North Sea (Figure 10).

Furthermore, the MBES bathymetry does not indicate any elevations on the seabed, which could have given a hint for the presence of reefs structures. Only a few locations with an increased backscatter compared to the surrounding environment or certain features, like boulders, debris or man-made structures, causing an acoustic shadow are visible in the areas between the monopiles. For example, the elongated feature visible in Figure 8 (top), with a height of 0.11 m and a length of 5 m, could represent a boulder or man-made structure. The high backscatter patch with an extent of 80 m by 6 m in Figure 8 (bottom) could represent a sedimentary variation, like a gravel, shell fragment or reef patch within a sandy environment, or artificially dumped material for a pipeline or cable protection. The MBES bathymetry reveals that this patch is covered with the widely distributed mega ripples without any height elevation, which rather indicates an increased amount of shell fragments causing the high backscatter anomaly. Unfortunately, no data from overlapping track lines exist to fully exclude an artifact as a cause for the backscatter anomaly. Furthermore, Figure 9 shows that the material of the filter layer is moved N-NE with the current in the same direction as the mega ripples, indicated by an increased backscatter. This region, the lee side of the monopile, could also be a preferred location for reef-building species, since the shear stress is lower and calmer conditions are found. That means the increased backscatter, could also be a combination of the filter material and a reef-building species, like *Lanice conchilega*. Even though, that in general no clear acoustic indication for the presence of biogenic reefs in the Luchterduinen wind farm could be found, the lee side of the monopile is probably the most promising location for ground truthing. As a final remark, the data quality of the processed SSS images, in particular for the data acquired parallel to the mega ripples, is high as demonstrated in Figure 7 and Figure 9. In both images, one can identify the individual rocks, distinguish between the armour and filter layer of the scouring protection or count the mega ripples

Considering the consistent backscatter across the entire wind farm without any findings of acoustic patterns, typical for biogenic reefs, the acoustic results rather plead for the non-existence of reef structures in the area between the monopiles at the Luchterduinen wind farm. The continuous distribution of mega ripples, clearly visible in the MBES bathymetry and SSS backscatter, might also be a hint for the non-existence of reefs otherwise the mega ripples would be interrupted.

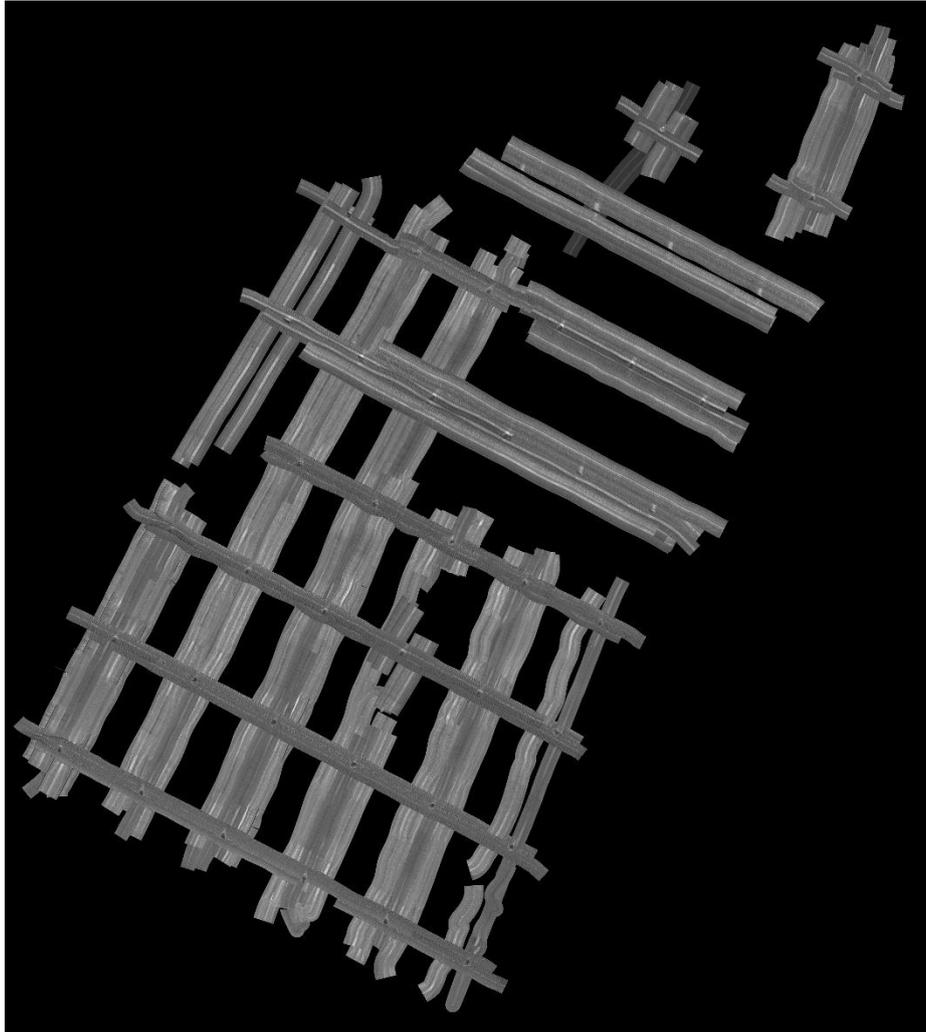


Figure 6 SSS backscatter mosaic of the entire Luchterduinen wind farm area. The grid cell size is 50 cm.

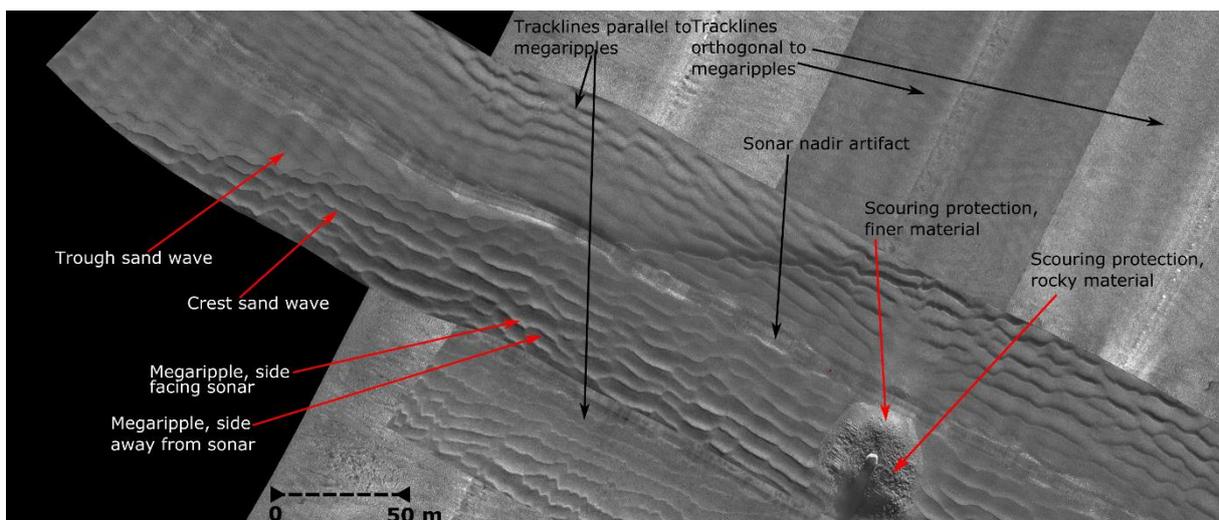


Figure 7 Processed SSS backscatter mosaic around WTG 6 consisting of three NE-SW (orthogonal to mega ripples) and two NW-SE (parallel to mega ripples) orientated track lines. NW-SE orientated track lines are on top. The grid cell size is 10 cm. This acoustic image represents the typical acoustic patterns in the Luchterduinen area: mega ripples superimposed on larger sand wave. Mega ripples generate acoustic high reflectivity spots as well as acoustic shadows. Clearly visible is the scouring protection and the monopile.

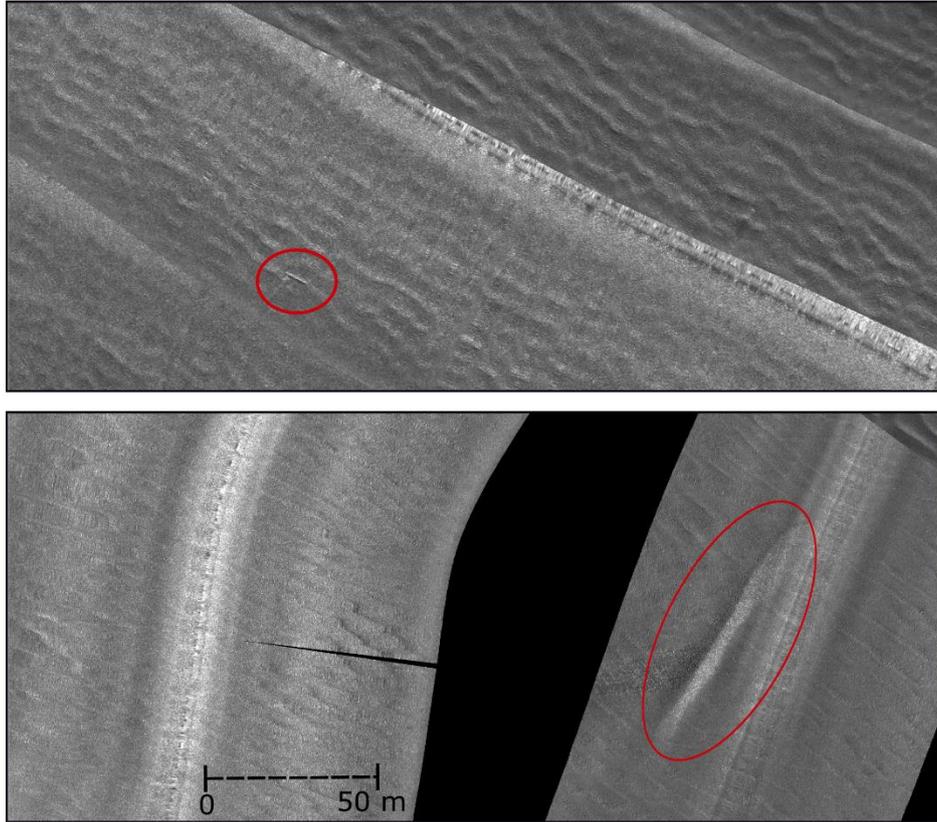


Figure 8 SSS backscatter anomaly indicating (top) feature like boulder or man-made structure and (bottom) sedimentary variation like gravel or shell fragment patch or artificially dumped material for pipeline/cable protection.



Figure 9 SSS image of WTG 4 and surrounding seabed. Individual rocks of amour layer are clearly visible as well as the finer material of the filter layer. Filter layer material has still a larger grain size than the surrounding sandy sediments causing higher backscatter (lighter colors). Therefore, it can be distinguished from the surrounding sandy sediments. Material of filter layer is moved N-NE with the current in the same direction as the mega ripples, indicated by an increased backscatter. This image shows the high quality of the data. The grid cell size is 10 cm.

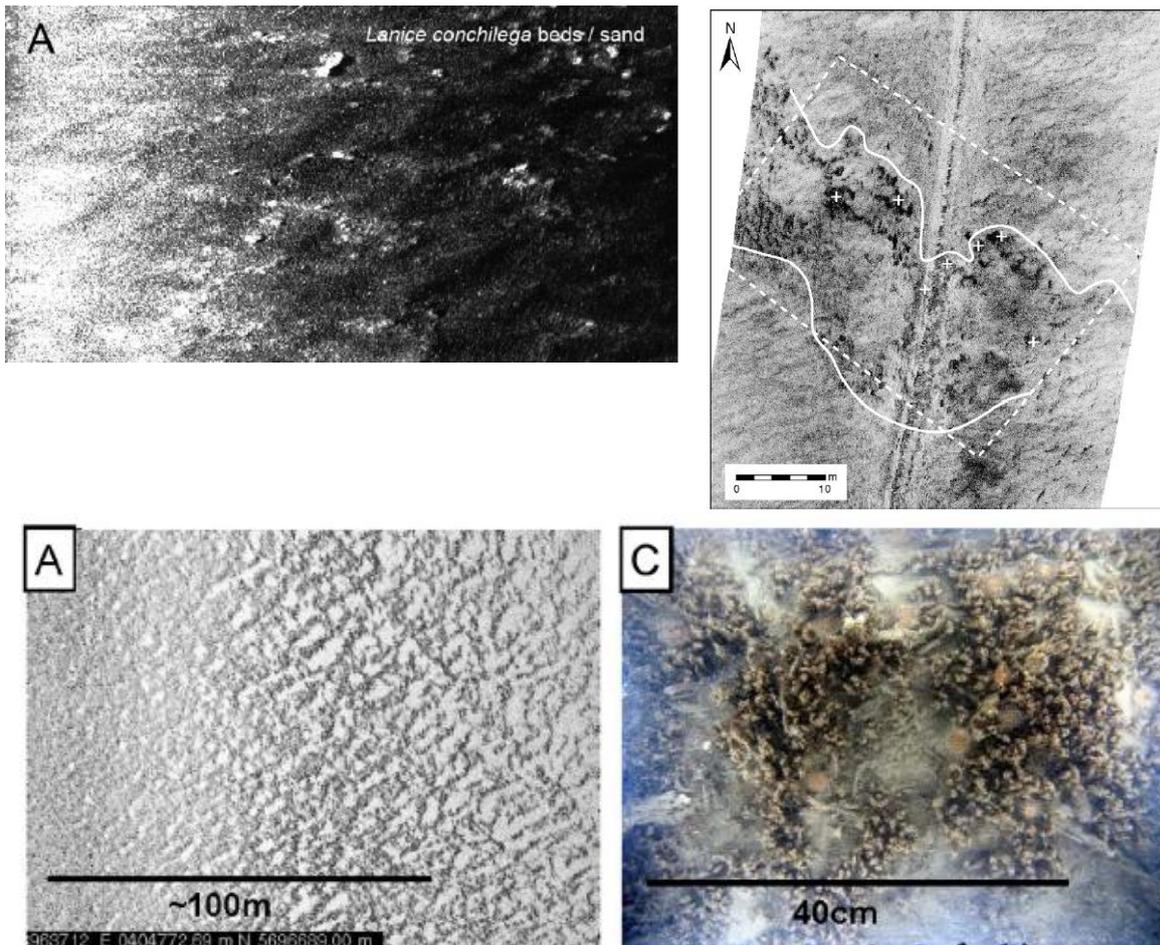


Figure 10 Literature examples of acoustic patterns resulting from biogenic reefs found in SSS images. (Top left) Coolen et al. (2015): *Lanice conchilega* found at the Dutch Borkum Reef Grounds. (Top right) Degraer et al. (2008): *Lanice conchilega* found in the Belgian North Sea at the Trapegeer Stroombank. (Bottom) Pearce et al. (2014): *Sabellaria spinulosa* found in Western North Sea, South-East of England; (left) SSS image, (right) video recording at the location of the acoustic pattern indicating the reefs.

## Literature

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