HARBOUR PORPOISES AND THE CONSTRUCTION OF NORD STREAM 2 GAS PIPELINE

Assessment of the impact on porpoises in the Natura2000 Hoburg's Bank and Midsjöbanks, Swedish Baltic

Scientific Report from DCE – Danish Centre for Environment and Energy No. 398 2020

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Jakob Tougaard
Emily T. Griffiths

Aarhus University, Department of Bioscience

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Authors: Jakob Tougaard & Emily T. Griffiths
Institution: Aarhus University, Department of Bioscience, section for Marine Mammal Research

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Abstract: The Nord Stream 2 gas pipeline crosses the marine protected Natura2000 area Hoburgs bank and Midsjöbanks, where a critically endangered population of porpoises aggregate during the summer months. Measurements of underwater noise during construction in 2019 supported the Environmental Impact Assessment (EIA), which concluded that significant impact on harbour porpoises was unlikely, by showing that the noise generated from the pipelaying vessel and support ships, rock placement, and trenching was comparable to or lower than expected. Passive acoustic monitoring for porpoises showed that harbour porpoises were detected at low rates before, during, and after pipeline construction. Habitat loss was assessed by the same model used in the EIA, based on AIS data from the Natura2000 area. While the cumulative impact from all Nord Stream 2 vessels was 25% compared to the impact from commercial shipping in the same period and hence appreciable, the temporary habitat loss caused by construction was very small in absolute terms, less than 0.01% of the total area. Therefore, nothing in the results of the monitoring program indicate that porpoises were adversely affected beyond the low and negligible impact anticipated in the impact assessment.

Keywords: Harbour porpoise, noise assessment, underwater noise, acoustic monitoring, porpoise detection, pipelaying, rock placement, trenching.

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Preface

This report was commissioned by Nord Stream 2 as a follow-up to the monitoring program completed during construction of the Nord Stream 2 pipeline through Swedish Economic Exclusive Zone. The report is intended as a comprehensive presentation of the assessment of impact on porpoises performed before construction began and the post hoc evaluation after completion of the monitoring. It therefore draws heavily on the environmental impact assessment report (Rambøll, 2016), background reports (Sveegaard et al., 2017; Teilmann et al., 2017; Tougaard and Sveegaard, 2017), and the noise monitoring report (Stöber and Thomsen, 2019). These reports should be consulted for technical details regarding assessment methodology and monitoring program.

Drafts of this report have been commented by Rambøll and Nord Stream 2 supplemented by input from Swedish Authorities prior to completion of the final version. Conclusions remain the responsibility of the authors, however.

Summary

Nord Stream 2 recently constructed a gas pipeline through the Swedish part of the Baltic Sea. During the environmental impact assessment (prior to construction) particular focus was paid to the possible negative impacts on harbour porpoises. Harbour porpoises in the Baltic Proper are distinct from porpoises in the Western Baltic; the population size is very low and the status is assessed as critically endangered. In the summer months, the Baltic Proper population of porpoises aggregate in the Natura2000 area Hoburg's Bank and Midsjöbanks likely for breeding and nursing, which designates it as critical habitat. The pipeline route discussed in this report was constructed through this area.

In the impact assessment, it was clear that underwater noise was the only real concern with respect to impact on porpoises. The most significant sources of underwater noise were considered to be the pipe laying vessel and support ships, and particularly noisy single activities including rock placement before the pipe is laid down and trenching of the pipe into the sediment.

Based on measurements performed during previous construction works, including the Nord Stream pipeline in 2012, it was predicted that noise emissions from the pipe laying vessel, as well as from rock placement and trenching, would be comparable to or lower than the noise from commercial vessels also using the habitat area. The main difference to the commercial ships is the slower speed of the pipe laying vessel and trenching plough.

Based on these assumptions, together with precautionary assumptions on reactions of porpoises to ships, the temporary habitat loss caused by construction of the pipeline was modelled. The results showed that the construction would constitute a significant increase of the habitat loss caused by the commercial ships in the area. However, the absolute magnitude of the habitat loss was predicted to be very low, therefore leading to the conclusion of the impact assessment that the Nord Stream 2 pipeline could be constructed without affecting the Baltic Proper porpoise population or the integrity of the Natura2000 area. The measurements underlying this conclusion came from surveys performed during the construction of the Nord Stream pipeline and these recordings were limited in frequency range to only the very low frequencies, where porpoises have poor hearing. To close this gap in knowledge, an ambitious monitoring program was designed in dialog with the Swedish authorities, which obtained full bandwidth recordings of both ambient noise and construction related noise during construction of Nord Stream 2 through the Natura2000 area. In addition to measuring underwater noise the presence of harbour porpoises was also monitored by deployment of passive acoustic detectors (C-PODs) in different distances from the pipeline route.

The detailed results of this monitoring program is presented in the monitoring report (Stöber et al., 2020), but several conclusions can be drawn from the results, with implications for evaluating the actual impact on porpoises due to construction activities. These are summarized as:

- Underwater noise radiated from the pipe laying vessel (Solitaire) and support ships was as expected comparable in level and frequency content to noise radiated from commercial cargo ships in the area.
- Underwater noise from rock placement was likewise lower than or comparable to ship noise and with comparable frequency spectrum.
- These observations support the precautionary assumption used in the impact assessment that porpoises would not react to the pipe laying vessel, support ships, rock placement and trenching beyond 1 km from the vessel.
- Pipe laying operation during Nord Stream 2 construction was faster than during construction of Nord Stream, which was used as input to assessment of impact. This means that the time spent inside the Natura2000 area was lower for construction of Nord Stream 2 than what was assumed in the impact assessment.
- These results lead to the conclusion that the actual temporary habitat loss due to pipe line construction was not larger than what was anticipated in the impact assessment and most likely smaller.
- This conclusion was supported by rerunning the habitat loss model used for the impact assessment with the traffic data from the actual construction of Nord Stream 2.
- Harbour porpoises were detected at low rates throughout the monitoring program, which extended from before the pipelaying vessel arrived to the Natura2000 area until after it left. The low detection rate was anticipated based on the very low density of porpoises in the Baltic Proper and indicate that porpoises did use the Natura2000 area also when construction took place.
- Although detection rates are too low to allow for any kind of robust statistical analysis, these detections are consistent with the low level of disturbance anticipated in the impact assessment.
- Therefore, nothing in the results of the monitoring program indicate that porpoises were adversely affected beyond the low and negligible impact anticipated in the impact assessment.

Although this may seem as a vague non-conclusion, given the very low abundance of porpoises in the central Baltic Sea and challenging conditions for field work, this is a significant achievement, both practically and analytically. The measurements obtained will also remain a valuable addition not only to the knowledge about impact of pipeline construction on harbour porpoises, but also on the general acoustic soundscape of the central Baltic Sea.

1 Background

Nord Stream 2 is constructing a gas pipeline through the Baltic Sea, from the Russian part of Gulf of Finland to the coast of Mechlenburg-Vorpommern, Germany. The route passes between Hoburg's Bank and Midsjöbanks in the central Baltic Sea, an area identified as important habitat for the critically endangered harbour porpoise (*Phocoena phocoena*) of the Baltic Proper (Carlén et al., 2018). For this reason and others, the banks and surrounding areas have been designated as a marine protected area under the EU Habitats Directive (Hoburg's Bank and Midsjöbanks Natura2000 site).

The possible impact on harbour porpoises from constructing and operating the gas pipeline was assessed in the environmental impact assessment (Rambøll, 2016), background report (Sveegaard et al., 2017) and follow-up to questions from the Swedish authorities (Tougaard and Sveegaard, 2017). The key factor in these assessments was the underwater noise generated by construction of the pipeline. The primary concern was that the noise could potentially disturb and / or displace porpoises from the protected area.

An ambitious monitoring program was launched in order to document the actual levels of underwater noise generated by the pipe laying operation and, if possible, the disturbance on the harbour porpoises in the Natura2000 area. Now that the construction and associated monitoring is completed, it is possible to compare the anticipated impact with the measured levels. This analysis is presented below.

2 Introduction

The Baltic Prober is home to a small, but distinct population of harbour porpoises (*Phocoena phocoena*). This population is genetically and morphologically distinct from the population inhabiting the Western Baltic and Danish Straits called the Belt Sea population (Galatius et al., 2012; Huggenberger et al., 2002; Sveegaard et al., 2015). While the Belt Sea population is considered to be in favourable conservation status (Fredshavn et al., 2019; SLU Artdatabanken, 2020), the population in the Baltic Proper is estimated to consist of some 500 individuals (Amundin, 2016) and is assessed as critically endangered (Hammond et al., 2016). The large-scale acoustic monitoring program SAMBAH mapped the distribution of porpoises in the Baltic Proper and confirmed the presence of this isolated population (Amundin, 2016; Carlén et al., 2018). Furthermore, the study demonstrated that the animals aggregate in the summer months in the waters on and around Hoburg's Bank and Midsjöbanks (**Figure 2.1**). Due to these findings and others, the banks and surroundings have been designated as a marine protected area (Hoburg's Bank and Midsjöbanks Natura2000 site).

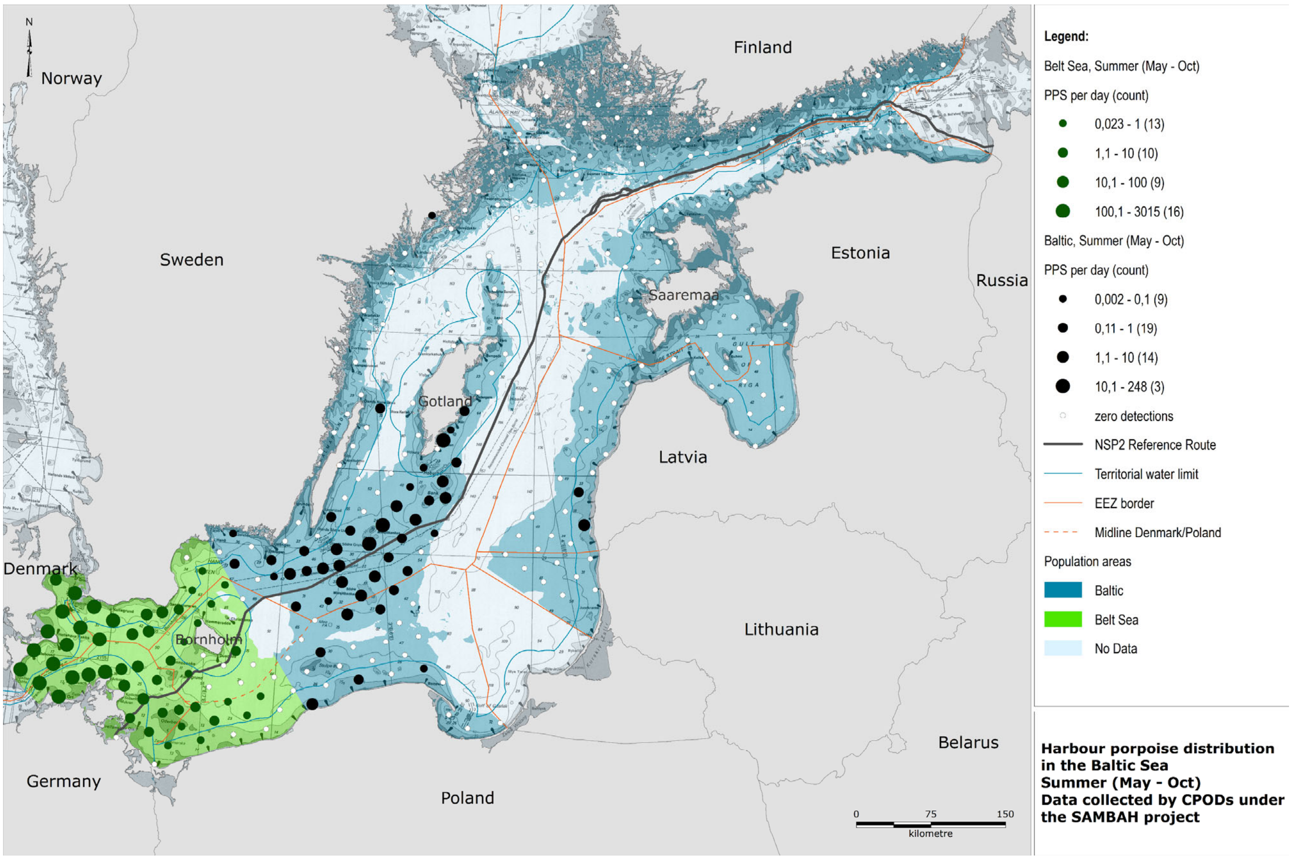


Figure 2.1. Summer distribution of porpoise detections in the Baltic Sea. Only the blue and green shaded areas were monitored. Each dot (black and white) represents an acoustic monitoring station deployed between 2011 and 2013. Black dots indicate stations with porpoise detections where the size of the dot scaled to represent the density of 'porpoise positive seconds per day'. White dots indicate no porpoise detections at that station. The area highlighted in green is assumed to be primarily populated by the Belt Sea population, while the blue area is believed to contain the majority of the breeding distribution of the remaining Baltic Proper porpoise population. From Teilmann et al. (2017); based on data from Amundin (2016)

As the Nord Stream 2 pipeline (together with the earlier Nord Stream pipeline) passes right through this core protected area for the endangered porpoise population, due concern was raised over possible negative impact from construction and operation of the pipeline on the porpoise population. The possible impact was addressed and assessed in the background reports to the environmental impact assessment (EIA, Sveegaard et al., 2017; Tougaard and Sveegaard, 2017), summarized below for the construction phase.

2.1 Anticipated effects of construction

Underwater noise was considered the only likely source of impact on porpoises during construction of the pipeline, as no other emissions were expected from the pipe laying vessel and support vessels. As sound propagates very well in water and porpoise reactions to underwater noise in general (reviewed by Tougaard et al., 2015), ship noise in particular (Dyndo et al., 2015; Wisniewska et al., 2018), are well known, it was expected that porpoises would demonstrate avoidance behaviour as the pipe laying vessel and support vessels entered porpoise habitat.

Ships are powerful sources of underwater noise particularly in the lower frequencies (below 1 kHz), although there are ultrasonic components at higher frequencies (extending beyond 100 kHz) at close range (Hermannsen et al., 2014). The noise can potentially affect porpoises in several ways. The risk of direct injury and damage to porpoise's health and hearing was assessed as being very unlikely, even under very precautionary assumptions (Sveegaard et al., 2017). Therefore, the main effects of ship noise are behaviour alteration (deterrence) and interference with the perception of other sounds (masking). However, masking was dismissed as an insignificant effect for porpoises due to the low frequency emphasis of ship noise coupled with the ultrasonic nature of the echolocation and communication sounds of porpoises (Tougaard and Sveegaard, 2017). Additional effects include physiological effects, such as elevated stress hormone levels and cardiovascular responses, but such effects have not been quantified in marine mammals in ways that allow any robust assessment.

2.1.1 Sources of underwater noise from pipeline construction

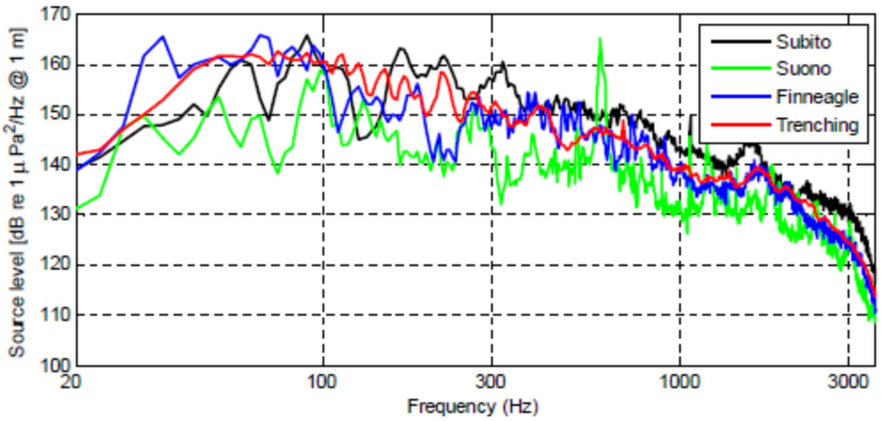
The main factors anticipated in the impact assessment to affect harbour porpoises during construction were:

- Underwater noise radiated from the pipe laying vessel.
- Underwater noise radiated from support vessels to the pipe laying operation.
- Deposition of rocks around pipe line (rock placement) and trenching (ploughing) of the pipe line into the seabed.

Measurements from construction of the Nord Stream pipe line (Johansson and Andersson, 2012) indicate that noise levels from a pipe laying vessel (Castoro Sei) is comparable to the noise emitted from cargo vessels. The main difference between the two types is that the pipe laying vessel is stationary (on a short time scale of minutes to hours), whereas cargo vessels move with speeds between 10 and 20 knots, which means that the pipe laying vessel will spend more time inside the Natura2000 site than a passing cargo ship.

Johansson and Andersson (2012) also concluded that the source level of a trenching operation is lower than pipe laying itself, i.e. lower than, or comparable to that of a passing cargo vessel (**Figure 2.2**). As for the pipe laying vessel, the main difference is that the source in case of trenching moves slower than a normal ship, which means that the time the source is in a given area is extended (albeit not as much as for the pipe laying vessel).

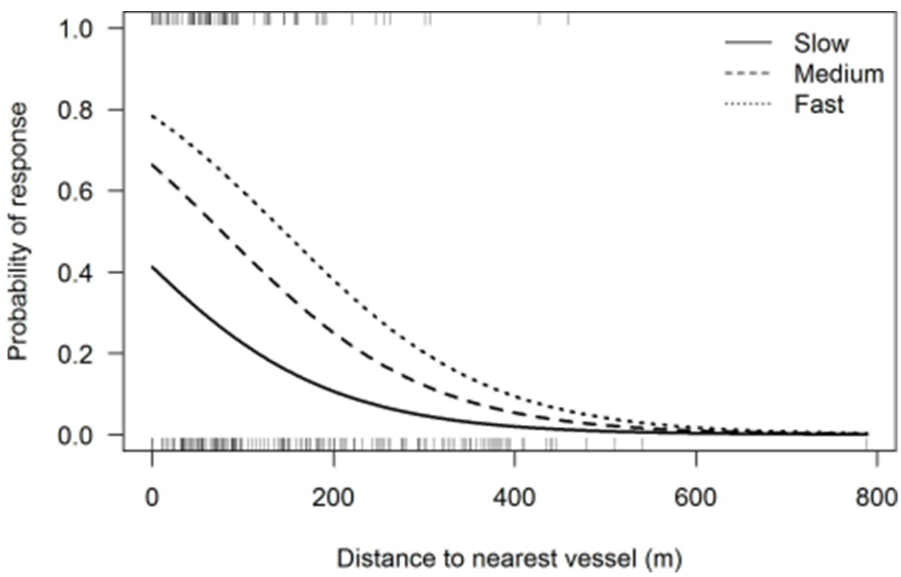
Figure 2.2. Estimated source power density spectrum (i.e. back-calculated to 1 m from source) of trenching operation (red) and three cargo vessels recorded during construction of the Nord Stream gas pipeline. From Johansson and Andersson (2012). The peak around 600 Hz in the spectrum from Suono (green) is a strong tonal component, possibly a singing propeller blade.



2.1.2 Effects of noise on porpoises

Although no information is available on reactions of porpoises to pipe laying and trenching operations *per se*, noise measurements from those activities indicate it would be reasonable to use reactions to normal cargo vessels as a proxy in assessment of impact. Although these reactions are also poorly studied, there is at least some information available. A study on harbour porpoises in captivity indicated that they respond predominantly to noise at higher frequencies, above 1 kHz (Dyndo et al., 2015) and a second study on a free-swimming, wild porpoise indicate cessation of swimming activity and foraging as reaction to ship noise, strong reactions to the noise from a fast ferry, although no distance to the ship was given (Wisniewska et al., 2018). One recent and central study from the Strait of Istanbul indicated that harbour porpoises react to passing ships (presumably because of hearing the underwater noise) at distances some hundred meters from the ship (Bas et al., 2017, Figure 2.2)).

Figure 2.3. Figure from Bas et al. (2017), showing probability that porpoises would react to a passing ship at different ranges from the ship.



Therefore, it was anticipated that reactions to the pipe laying operation and trenching operations would be on a similar scale, i.e. within 1 km of the operation, or more likely less.

2.1.3 Quantifying the anticipated disturbance to the Natura2000 site

Based on the assumption that all porpoises within 200 m of the pipe laying vessel and support ships are displaced (precautious assumption based on Bas et al. 2017, **Figure 2.3**), the disturbance anticipated from construction of Nord Stream 2 was modelled by Tougaard and Sveegaard (2017). In this modelling, the actual track of the pipe laying vessel and support ships during construction of the Nord Stream pipeline were used as input to the model and compared to a background level modelled from actual ship traffic in the Natura2000 site in 2014 (**Figure 2.4**).

The disturbance to porpoises inside the Natura2000 area was quantified in time (percent of time a point in the map is disturbed) and in space (percent of total area disturbed at a particular point in time. These disturbance ratios can be combined into a disturbance index H, which expresses the fraction of the Natura2000 area which is disturbed by the presence of vessels, averaged across time and space and thus a measure of the average habitat loss during the construction period. H was estimated for commercial ships, based on AIS data from February and July 2014, as 0.02%, whereas the contribution from the Nord Stream construction vessel and support ships was estimated to be 0.005%.

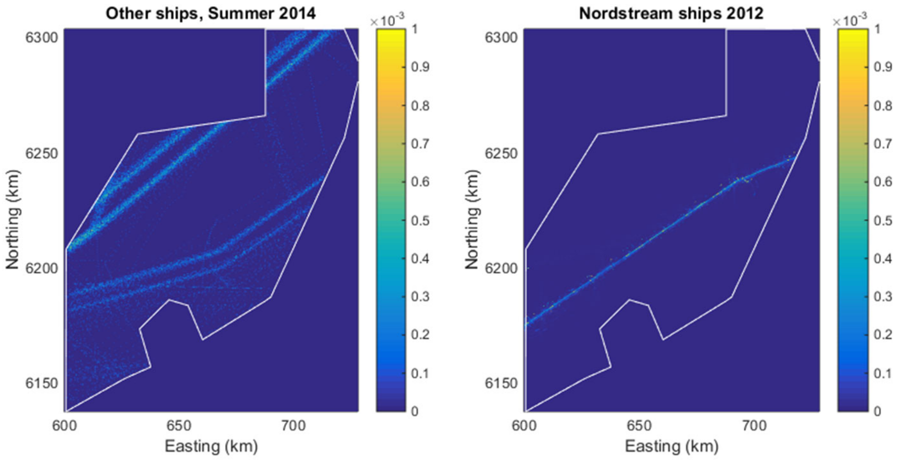


Figure 2.4. Predicted disturbance from commercial ships (left) and Nord stream construction period (right) in the Natura2000 site. Scale indicates fraction of time the area was expected to be unavailable to porpoises due to presence of vessel noise. From Tougaard and Sveegaard (2017); based on actual ship information (AIS-data).

This means that the construction of the pipeline added significantly to the baseline level of disturbance in the habitat area (an increase by 25%), but as the overall level of disturbance was very low, the impact of this increase on harbour porpoises was considered negligible. The disturbance index H of the combined effect of commercial ships and Nord Stream construction was 0.025%, i.e. a prediction that on average 1/4000th of the Natura2000 area would be unavailable to porpoises due to ship noise. It was therefore concluded that only a minor disturbance and displacement was to be anticipated by the construction, below levels, which would compromise the integrity of the Natura2000 site (Sveegaard et al., 2017; Tougaard and Sveegaard, 2017).

3 Monitoring of noise and porpoises

In order to test and validate this assertion of low impact on porpoises by the construction activities, an ambitious monitoring program was designed in discussions between Nord Stream 2 and the Swedish authorities. It aimed to build upon the results and experience from monitoring during construction of Nord Stream (Johansson and Andersson, 2012) and to test central assumptions underlying the assessment for Nord Stream 2 (Sveegaard et al., 2017; Tougaard and Sveegaard, 2017). Key features of the monitoring program thus were:

- Expansion of recording bandwidth of noise recorders to include ultrasonic frequencies. During monitoring for Nord Stream the recording bandwidth was limited (for technical reasons) to 3 kHz, precluding any conclusions about noise in the ultrasonic range, likely to affect porpoises more than the low frequency part (Dyndo et al., 2015; Tougaard et al., 2015)

- Concurrent monitoring of harbour porpoises by deployment of passive acoustic porpoise detectors (C-PODs)

Emphasis was put on documenting changes to the soundscape and characterisation of the contribution from the pipe laying operation and rock placement. Trenching was considered secondary and not included in the Nord Stream 2 monitoring program, as this activity was considered adequately described by the existing data showing that it produced less noise than pipelay (Johansson and Andersson, 2012).

Technical description of the measurements and full results can be found in the separate report of the monitoring program (Stöber et al., 2020), but are briefly outlined here.

Four stations in the Baltic Sea (A, B, C and D, Figure 3.1) South of Gotland and East of Öland in the Natura2000 were selected to monitor background noise, passing vessels, pipeline construction activities and presence of harbour porpoises. Station A was 25 km away from the pipe laying activity. These stations were deployed at different times of the year. There is data from stations A, B, and C during the Winter Deployments (13-01-2019 – 22-03-2019), stations A and B during the Spring Deployment (22-03-2019 – 18-05-2019), and stations A, B, and D during the Autumn Deployment (25-08-2019 – 17-12-2019). Data collected at different stations during different seasons is reflective of difficult field conditions and not experimental design. Using a custom mooring, each station contained multiple SM3M or SM4M recorders (Wildlife Acoustics, Maynard, MA, USA) and CPODs (Chelonia Ltd., Cornwall, UK).

Both CPODs and Wildlife Acoustic data loggers were used to assess harbour porpoise presence around the site before, during, and after construction. CPODs are fully automated with their own proprietary software to detect porpoise echolocation while the acoustic logger data, recorded with sampling rate of 384 kHz, was processed in the PAMGuard (Scottish Oceans Institute, Scotland, Gillespie et al., 2008). Output from both of these device types was analysed and compared in the final report (Stöber et al., 2020), where details on analysis can also be found. As C-POD and Pamguard detectors operate on different principles the data are not expected to be identical, although a high consistency is expected in low-noise conditions, such as the Baltic Sea (Sarnocinska et al., 2016).

Logger data was also used to measure ambient noise and construction activity source levels. Sound pressure levels for each sensor was estimated and transmission loss for the site was calculated.

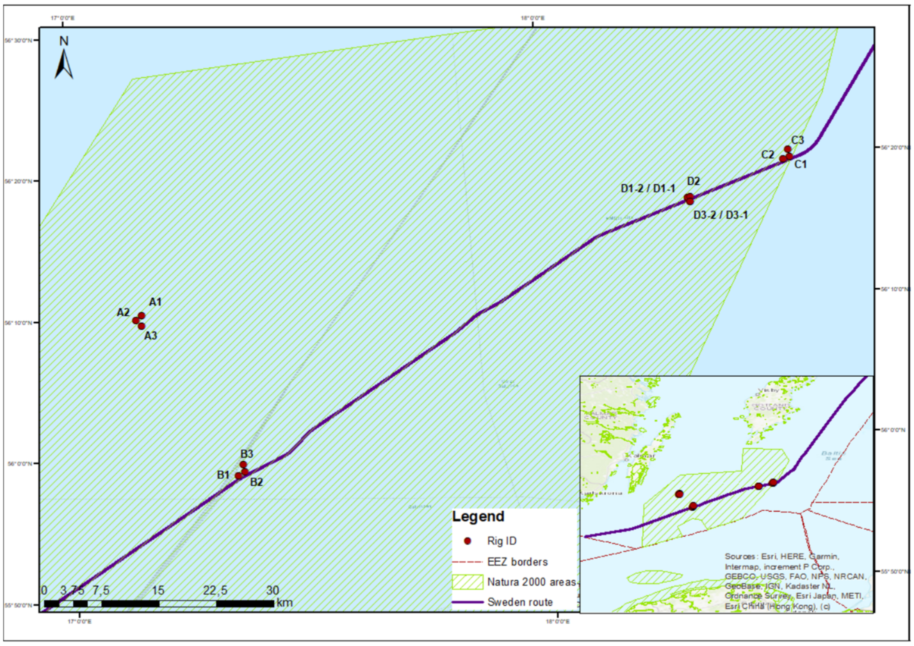


Figure 3.1. Map of stations with recording instruments deployed. From Stöber et al. (2020).

3.1 Ambient noise

An example of recording of ambient noise and porpoise detections is shown in Figure 3.2 and illustrates the fluctuating noise level over an 8 day period. Broadband sound pressure level fluctuated between roughly 110 and 130 dB re. 1 µPa (middle panel) and the main energy was located at frequencies below 1 kHz (lower panel).

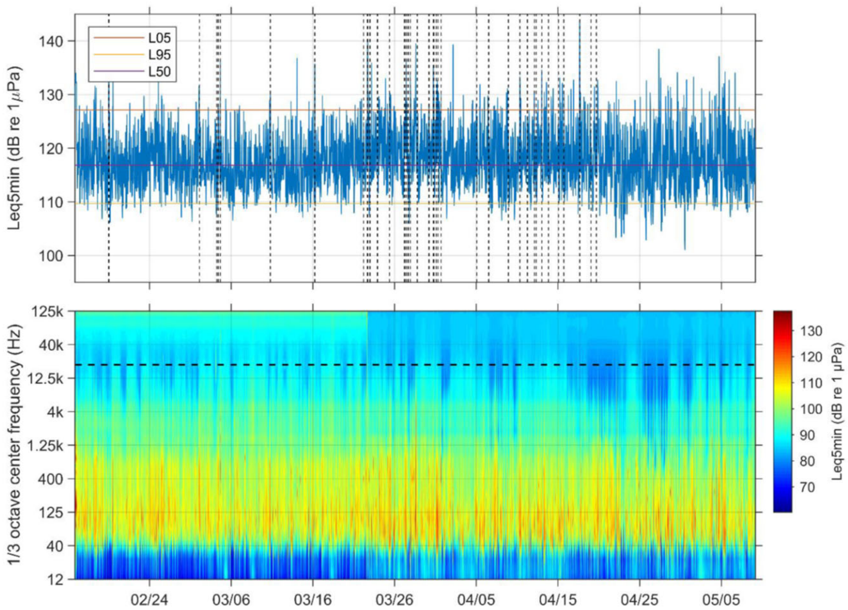


Figure 3.2. Recording of ambient noise (consisting of natural ambient noise and contribution from cargo ships) from station A1 over a period of 90 days.

3.2 Noise from pipe laying vessel

Figure 3.3 shows recordings of noise for a 2-week period, during which the pipe laying vessel Solitaire passed the recording station B, substation B2 (closest approach on the 25th September). The noise level increased steadily during the days leading up to closest approach and reaches a maximum broadband level of about 140 dB re. 1 µPa, 10-30 dB above the natural ambient, at a distance of about 500 m from the recording station. During the passage, the noise was elevated above ambient in a wide frequency range. Most energy was at low frequencies, but at closest approach energy was detectable up to at least 100 kHz (bottom panel).

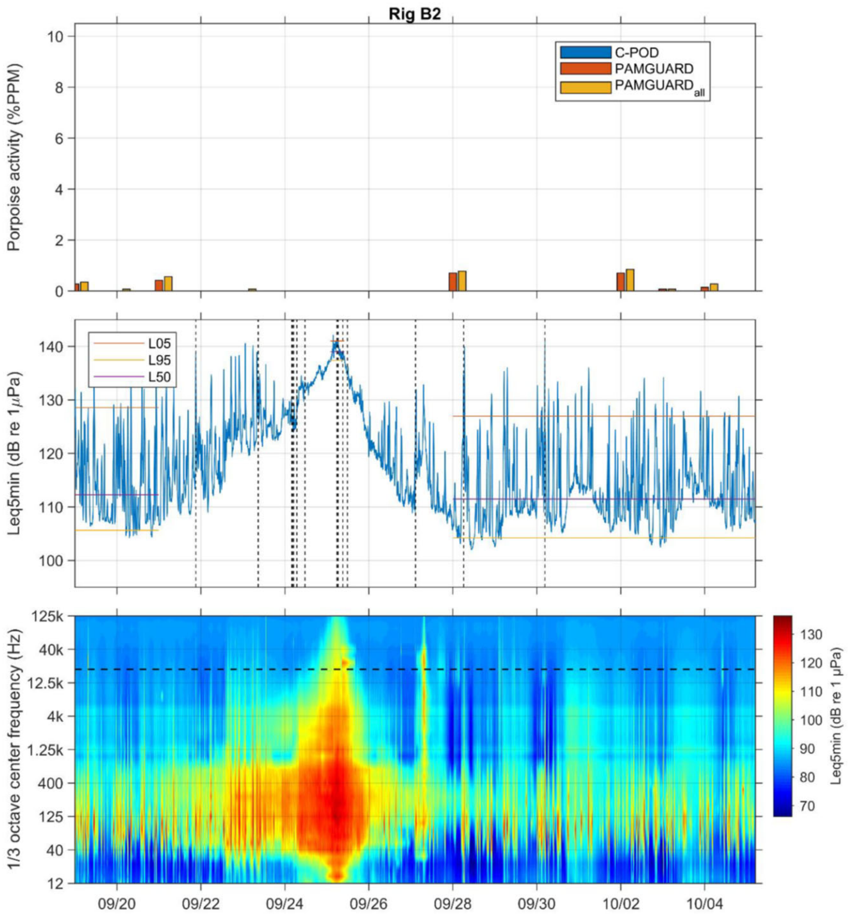


Figure 3.3. Recorded noise from the pipe laying vessel, Solitaire, and support vessels, displayed as total sound pressure (middle) and spectrogram (bottom), together with detections of porpoise positive minutes (PPM) from CPODs, PAMGuard (at least five clicks per minute), and PAMGuard$_{all}$ (all minutes with clicks) (top). Closest approach of the pipe laying vessel Solitaire was approx 600 m on the 25th September.

During this 2-week monitoring period a few detections of porpoise signals were made (upper panel), none of them during the time when the pipe laying vessel noise was above ambient, however. These detections are indicative of porpoises visiting the area both before and after the passage of the pipe-laying vessel. Other recordings of pipe laying noise (from the passage during laydown of the first pipe in spring 2019) were consistent with the measurement above, but did not record any porpoise signals.

Figure 3.4. Solitaire, the pipe laying vessel used on the Midsjöbanks.

The background noise before arrival of the pipe laying vessel (**Figure 3.5**, left) was dominated by natural wind and wave generated noise, distant shipping and an occasional ship passing close to the recording station. Peak energy in the unweighted spectrum was around 100 Hz, in line with what is normally seen in deep water (e.g. Richardson et al., 1995). However, when the recording was weighted according to the hearing curve of porpoises (Southall et al., 2019; Tougaard and Beedholm, 2019; Tougaard et al., 2015), the highest levels were found in the range 10-50 kHz.

The overall appearance of the noise spectra, both the unweighted and the weighted, for the noise during passage of the pipe laying vessel (**Figure 3.5**, right) is very similar to the background spectrum with respect to location of peaks and maximum levels. There are important differences, however. Perhaps most noteworthy is the strong and narrow peak around 25 kHz, which is only very faintly recognisable in the background noise recording. This peak is due to either echosounders or other navigational equipment used on the pipe laying vessel and / or other ships. The pulsed nature of the signals can be seen in a close-up of two types of sound identified in the recordings, shown in **Figure 3.6**. The signal at 38 kHz (**Figure 3.6**, bottom) is almost certainly an echosounder, as 38 kHz is a commonly used frequency for navigational echosounders. The source of the 25 kHz signal is unknown, but because of its regular pattern is likely from an anthropogenic source.

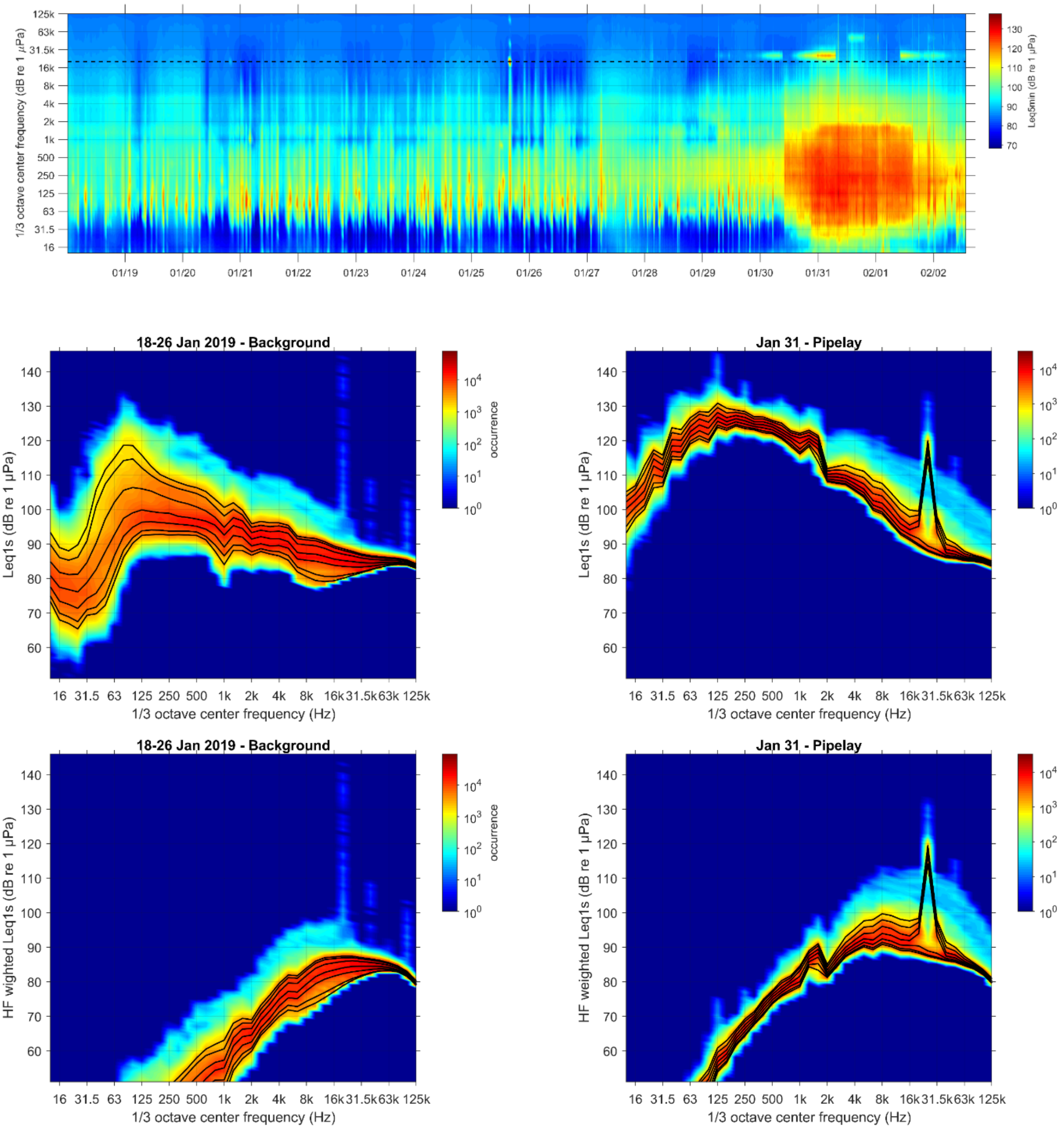


Figure 3.5. Comparison of noise recording prior to arrival of pipe laying vessel (left) and during closest approach of the pipe laying vessel to the recording station (right). Top shows long-term spectrogram, mid panel shows 1/3 octave frequency spectra and bottom panel shows the same frequency spectra weighted with the inverse hearing curve of harbour porpoises (Southall et al., 2019; Tougaard and Beedholm, 2019; Tougaard et al., 2015). Solid lines indicate exceedance levels (upper percentiles), from bottom and up: L_{95}, L_{90}, L_{75}, L_{50}, L_{25}, L_{10} and L_5.

A second important difference between the noise spectra in Figure 3.5 is that while the higher exceedance levels (L_5 and L_{10} are comparable, the remaining exceedance levels are higher during passage of the pipe laying than during the background recordings. This is due to the slow speed of the pipe laying vessel, which means that for the duration of the passage of the recording station (about 2 days), the pipe laying vessel completely dominates the soundscape, whereas the background situation is a mix of more silent periods dominated by wave noise and distant shipping, and shorter periods, where passing ships dominate (each lasting on the order of one hour, not shown in figures).

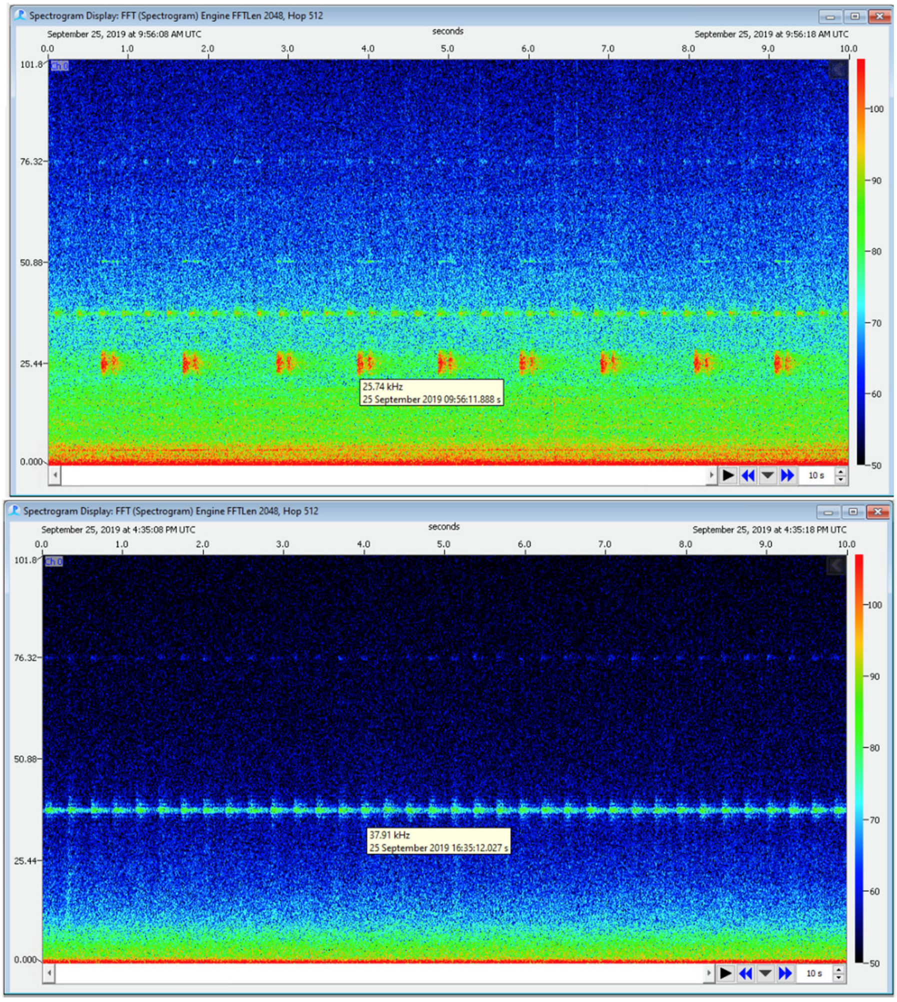


Figure 3.6. Detailed spectrograms in 10-second sections of recordings containing powerful narrow-band pulsed signals, visible as the strong, narrow peaks in the frequency spectra in **Figure 3.5**.

3.2.1 Source levels

Based on measurements of the received level of noise at the location of the recording station and estimates of the distance between closest ship and recorder (obtained from AIS data), the source level 1 m from the ship was estimated by DHI for the pipe laying vessel as well as several of the support ships. Source levels were back-calculated by assuming a transmission loss of 17log(r), where r is the distance in meters, following Johansson and Andersson (2012). These source levels are shown in **Table 3.1**.

Table 3.1. Measurements of broadband sound pressure levels from the pipe laying vessel Solitaire on several stations and occasions. Values given both as actual measured level (RL, Received level) and level back-calculated to 1 m from the source (SL, source level). Data from (Stöber et al., 2020).

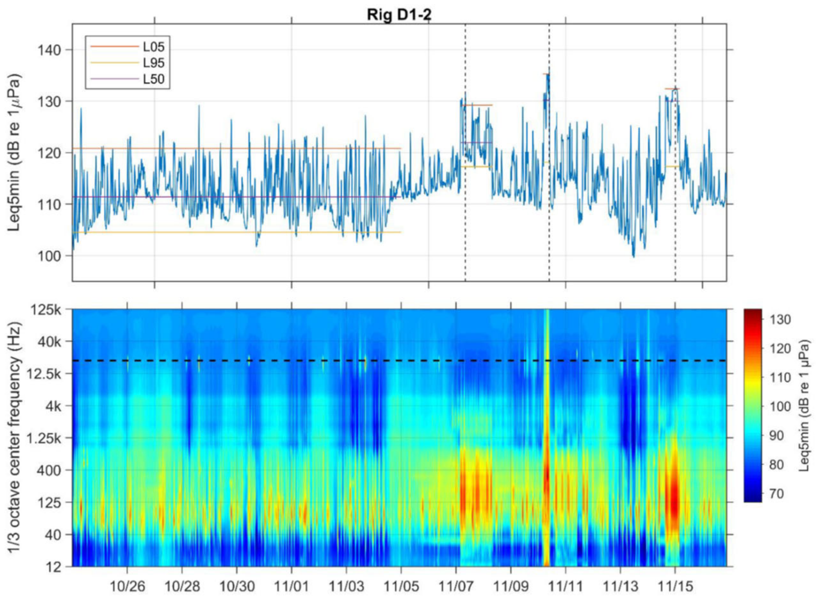
	Station	Distance (km)	RL (dB re. 1 µPa)	SL (dB re. 1 µPa)
Solitaire	B3	1.5	136.1	190.1
	B3	0.5	414.2	186.4
	B2	0.6	142.6	189.8
	C1	1.2	133.6	186.0
	C1	0.5	.139.5	185.3
	C1	1.5	135.6	189.6
	D1-1	0.3	141.8	183.1
	D3-1	0.3	147.0	190.0
Median				188.0

3.3 Noise from rock placement

A single instance of rock placement was documented in the recordings, shown in **Figure 3.7** as the peak on the 10th November. This is a much shorter event that the pipe laying, but measured broadband noise levels are slightly higher. The sound was measured at the same time on two closely spaced recorders (D1-2 and D3-2), 370 and 270 m from the rock placement vessel (Rockpiper), respectively. Received broadband levels were 136.8 dB re. 1 µPa and 137.5 dB re. 1 µPa, respectively, which were back-calculated into source level estimates of 180.5 dB re. 1 µPa and 178.8 dB re. 1 µPa, respectively. Though these events were recorded at different locations, they are spatially close enough to be comparable (> 0.1 km). The distance over which the rock placement sounds were measured were roughly a factor 10 smaller than the source level measurements on the pipe laying vessel, indicating that it had a comparable or smaller effect than the pipe laying and other passing vessels.

No porpoise signal were detected in the days before or after the rock placement.

Figure 3.7. Recording of noise over a 24 day period. The peak on 10 November is due to rock placement. L05= upper 5th percentile, L50=median, and L95= lower 5th percentile.



3.4 Acoustic detection of porpoises

It was anticipated that reactions to the pipe laying operation and trenching operations would be on a similar scale, i.e. within 1 km of the operation. When this is coupled with the very low abundance of harbour porpoises in the Baltic and the small detection range of porpoise detectors (C-PODs, on the order of some hundred meters; Kyhn et al., 2008), this means that the statistical power of a monitoring program to detect effects of the pipeline construction is bound to be very low. This is true, even factoring in that the Midsjöbanks has some of the highest densities of porpoises for the Baltic proper (Amundin, 2016; Carlén et al., 2018). There is a low probability of porpoise presence within the detection range of the monitor stations (some hundred meters) at the same time as the pipe laying or trenching vessel, were effects can be expected (less than a kilometer).

Table 3.2 summarizes the detections of porpoise signals at the different stations, further illustrated in Figure 3.8. The porpoise detections are aggregated into porpoise positive minutes, where a porpoise positive minute indicate that at least one porpoise click (but often more) were detected in that particular minute. The reason behind this aggregation is that porpoise clicks occur in short trains of many clicks, which means that simply counting clicks will result in unbalanced data, where a single event, which may contain hundred clicks or more can bias and dominate any statistical analysis of the data (Carstensen et al., 2006). Due to the very low occurrence of porpoises in the Baltic and hence very low detection rates, the porpoise positive minutes were further aggregated into porpoise positive days (Verfuss et al., 2007), where one porpoise positive day equals a 24 h period with at least one porpoise positive minute.

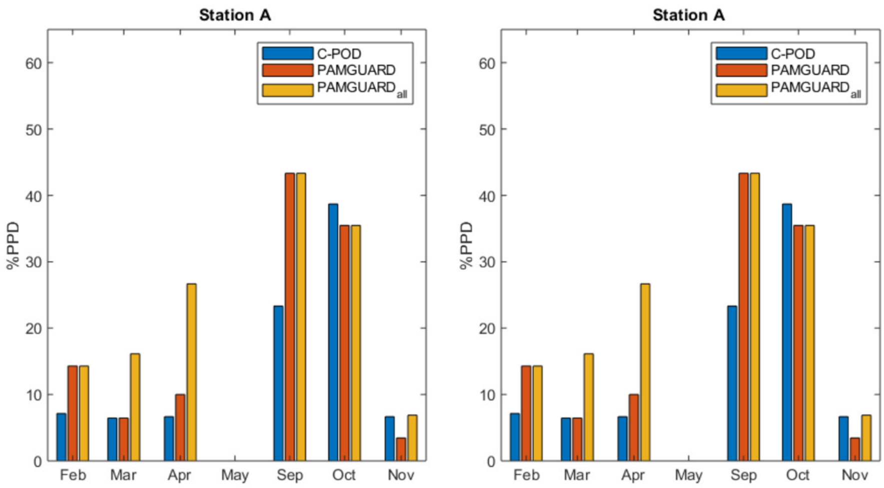


Figure 3.8. Summary of CPOD and PAMGuard (two settings) detections'.Y-axis (%PPD=% Detection Positive Days) represents the percentage of days within each month where porpoises were detected in at least one minute during the day. A PAMGuard count constitutes a minute with at least 5 porpoise clicks, whereas a PAMGuard-all count indicates a minute with one porpoise click or more.

Table 3.2. Summary of days with positive porpoise minutes (PPM) during the three monitoring deployments over the four stations. Lines in gray represent data not available to be accurately summarised. Numbers are collected from Figures 4-25, 4-26, and 5-4 in Stöber et al. (2020). CPOD = CPOD, WA = Wildlife Acoustics

Station	Deployment Dates (2019)	Detection Date range (2019)	CPOD (days)	PAMGuard All (days)
A1	15/02 – 22/03	19/02 – 19/03	2	5
A1	22/03 – 18/05	22/03 – 29/04	3	9
A2	12/01 – 22/03		0	0
A2	22/03 – 18/05		4	~35
A2	25/08 – 17/12 (CPOD) 01/09 – 29/11 (WA)	29/08 – 27/11 (CPOD) 6/09 – 27/11 (WA)	23	26
B1	12/01 – 22/03		4	?/~55
B1	22/03 – 18/05		3	?/~25
B1	25/08 – 17/12		13	?/~100
B2	12/01 – 22/03		3	?/~55
B2	22/03 – 18/05		5	?/~25
B2	25/08 – 17/12 (CPOD 19/09 – 10/05 (WA)	17/10 – 20/11 (CPOD) 19/09 – 4/10 (WA)	6	8
B3	13/01 – 22/03	2/01	0	1
B3	22/03 – 18/05	25/03 – 16/05	6	15
B3	25/08 – 17/12		19	?/~100
C1	14/02 – 18/05	16/02 (CPOD) 23/02 (WA)	1	1
C2	14/02 – 18/05		0	?
D1-1	24/08 – 17/12	1/09 – 11/10	2	0
D1-2	24/08 – 17/12	1/09 – 11/10	2	0
D2	24/08 – 17/12		3	?
D3-1	24/08 – 17/12	1/09 – 11/09	2	0
D3-2	24/08 – 17/12	1/09 – 11/09	2	0

As expected, very few porpoise detections were recorded during the three monitoring periods, including in the presences of pipe-laying activity. Harbour porpoises were detected at low rates throughout the monitoring program, in and outside the pipe laying area. The low detection rate was anticipated based on the very low density of porpoises in the Baltic Proper. However, even the low detection numbers indicate that porpoises did use the Natura2000 area regularly, also when construction took place. This reinforces the prediction that the construction of Nord Stream 2 did not have a significant negative impact on porpoise behaviour.

The two stations with the most comprehensive data were stations A and B (Table 3.2), where station A was placed 25 km away from the construction site and B was along the pipeline path (Figure 3.1). Stations C and D were reported to record low levels of porpoise activity (Stöber and Thomsen, 2019). Both stations A and B recorded the highest levels of positive porpoise minutes (PPM) during September and October, and station B also had spikes in March and April. (Figure 3.8) The only times PPM activity spikes coincided with periods of intense pipe lay is in September. However, as predicted by the EIA, PPM decreased during times when pipe lay activity noise was loudest. This is likely because porpoises demonstrated avoidance in the presence of loud ships (Figure 3.2).

From the results available in the DHI report (Stöber et al., 2020), full broadband data processed in PAMGuard resulted in more porpoise positive minutes (%PPM) than CPODs alone. This is consistent with other comparative research (Clausen et al., 2018; Jacobson et al., 2017; Sarnocinska et al., 2016), even though the broadband recordings were duty cycled and not continuous. However, because the CPOD and PAMGuard Click Detector employ different algorithms, using both can improve our understanding of true porpoise vocal behaviour. Thus, using the full broadband recordings gives a better understanding of the Natura2000 area soundscape in respect to porpoises.

Importantly, detections were not dramatically different between CPODs and PAMGuard, when aggregated into porpoise positive days, and therefore results from either instrument can be considered representative of porpoise activity. With both instruments there was minimal activity recorded at station D, both before and after pipe laying and before rock placement activities. After rock placement, only CPODs were still recording at that station for an additional month. With the CPODS, no porpoises were detected during this period.

4 Modelled disturbance from Nord Stream 2

The same methodology used in assessment of disturbance from Nord Stream (Tougaard and Sveegaard, 2017) was applied to AIS data collected during the construction of Nord Stream 2 through the Natura2000 area.

AIS-data was separated into ships considered part of the construction work (**Table 4.1**) and other ships. Data were further truncated to the two periods where the pipe laying vessel (Solitaire) was inside the Natura2000 area: 11/1-23/2 (south pipe) and 1/9-10/10 (north pipe). AIS-positions within the Natura2000 area and in these two periods were selected and separated into individual tracks. Two positions, which were separated by 12 hours or more, were considered to be from separate tracks. Within each track, positions were interpolated every 10 minutes, to adjust for different transmission and reception rates of different ships. Positions were transformed from latitude/longitude (WGS84) to Universal Transverse Mercator (UTM zone 33N) by Matlab function wgs2utm (Matlab 2017b) and interpolation performed on UTM coordinates assuming plane projection.

Table 4.1. Ships participating in the Nord Stream 2 construction work in the Natura2000 area. It is indicated whether the ship was part of construction of the north pipe (autumn 2019) and/or south pipe (winter 2019).

MMSI-number	Name	North pipe	South pipe
209029000	THOR	x	
211260260	Bugsier 19	x	x
232006679	Standard Princess	x	x
232008761	Standard Supplier	x	
232012423	Standard Provider		x
244010945	Symphony Performer	x	
244060802	Symphony Provider	x	x
244962000	Nordnes		x
248596000	Fortitude	x	x
249110000	Pioneering Spirit	x	
249118000	Solitaire	x	x
257038470	Alegria	x	x
257380000	Sea Goldcrest	x	
257867000	Far Solitaire	x	x
258032000	Normand Poseidon	x	
258135000	Felicity	x	
259006000	Stril Explorer		x
259866000	Normand Naley		x
304068000	Fairplay 27		x
311000229	Havila Phoenix	x	
311000470	Bourbon Topaz	x	
311070200	Solvik Supplier	x	
370603000	Mintaka I		x

For each of the two study periods (south pipe and north pipe) the disturbance from ships were assessed in 10 minute steps in a spatial raster grid covering the Natura2000 area. The resolution of the grid was 50x50 m. For each 10 minute snapshot, the position of all vessels inside the Natura2000 area was found and all raster cells within 200 m of a vessel (Nord Stream 2 associated or other) were marked as “disturbed”. In this way, the percentage of disturbed cells inside the Natura2000 area was found for each snapshot. This is shown in **Figure 4.1**.

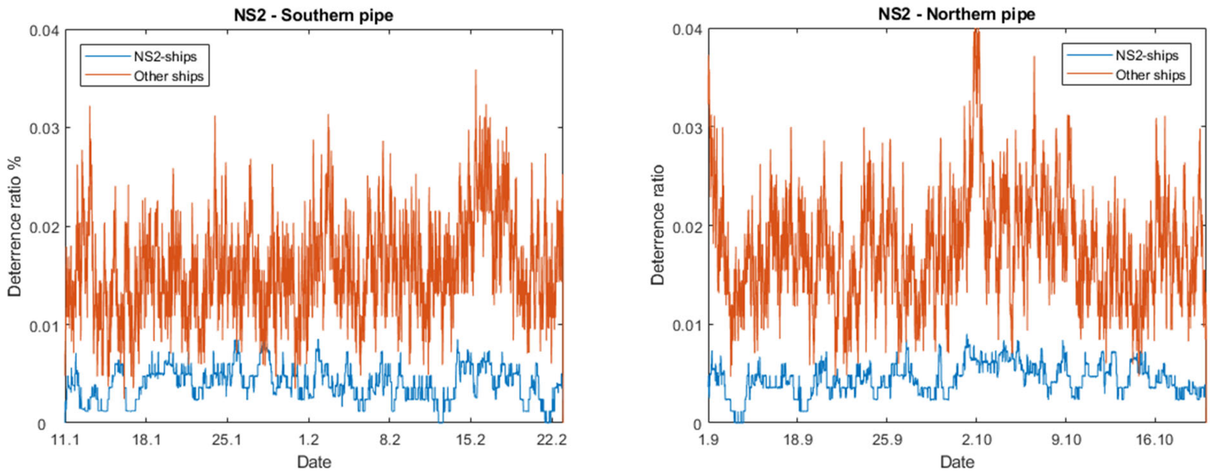


Figure 4.1. Deterrence ratio (percentage of area disturbed) from ships inside Natura2000 area during construction of the southern and northern pipe, respectively, and separated into Nord Stream 2 ships and other ships.

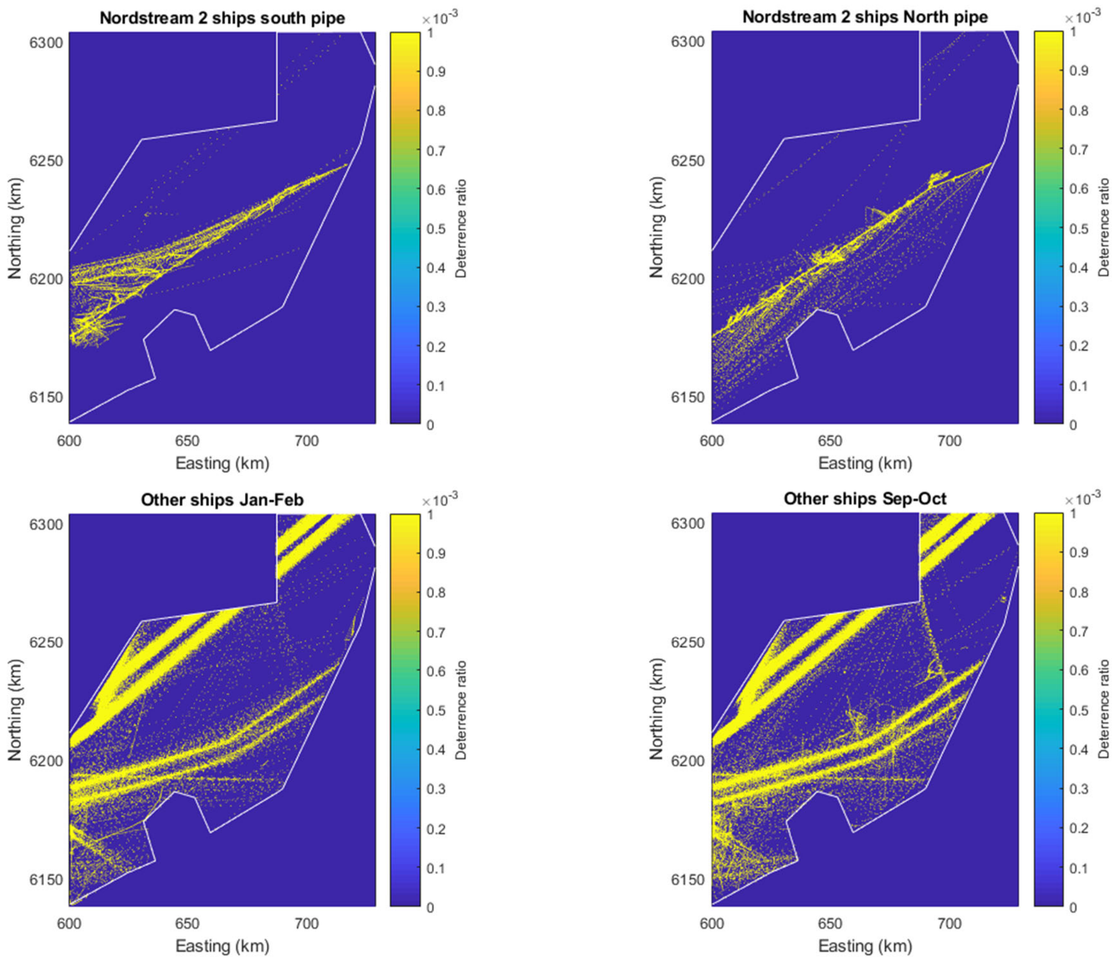


Figure 4.2. Disturbance of the Natura2000 area due to ships, related to North Stream 2 vessels and other ships. The colour of each grid cell indicate the percent of time the cell was disturbed and thereby considered unavailable for porpoises during the construction period. Projection UTM zone 33N.

The disturbance can also be expressed spatially, as in **Figure 4.2**, where the mean disturbance is calculated for each grid cell. A high value therefore indicate that the particular grid cell was disturbed due to the presence of ships for a larger part of the time compared to surrounding grid cells. For Nord Stream 2 vessels the pipeline corridor is clearly seen, together with tracks relating to service vessels going to and from the pipe laying vessel. For the other ships, the two main shipping routes (northern coastal route and central deep-water route), each with an inbound and an outbound track, are clearly visible.

Overall disturbance to the Natura2000 area can be quantified in the same way as was done in the EIA (Tougaard and Sveegaard, 2017), expressing the average deterrence index for the entire area, for each of the two construction periods, shown in **Table 4.2**. The index should be understood as the average fraction of the Natura2000 area unavailable to harbour porpoises due to the presence of ships (related to Nord Stream 2 and others). The increase due to the construction of the pipeline expresses how much larger the disturbed area was during construction relative to what it would have been, had the pipeline not been constructed.

Table 4.2. Deterrence index for the Natura2000 area during construction of Nord Stream 2.

	South pipeline	North pipeline
Nord Stream 2 vessels	0.004%	0.004%
Other vessels	0.016%	0.018%
Total	0.020%	0.022%
Increase due to pipeline	25%	25%

These figures can be compared to the corresponding estimates based on the construction of Nord Stream in 2014. Mean deterrence index for Nord Stream vessels was estimated to be 0.005% and other vessels 0.020% / 0.021% for winter and summer, respectively. The mean impact per day from constructing Nord Stream 2 was thus lower than the mean impact from construction of Nord Stream, but as the impact from other ships was also lower in 2019 compared to 2014, the cumulative increase in impact due to construction of the pipeline remains the same: 25%. As ship traffic in the Baltic has not decreased from 2014 to 2019, the decrease in impact from other ships in the same period cannot be explained by fewer ships. It may be a reflection of a higher speed (not tested), which would mean shorter time spent within the Natura2000 area, but could also simply be related to the uncertainty associated with AIS data, which is expected to vary in the degree of completeness.

The construction time of the pipeline is not included in the indices in **Table 4.2**, as these are expressed as daily means. The time the pipe-laying vessel and support ships were inside the Natura2000 area (43 and 39 days for south and north pipe, respectively) should be compared with the 68 days for a single pipe during construction of Nord Stream (Tougaard and Sveegaard, 2017). Thus, although the daily disturbance from constructing Nord Stream 2 was roughly identical to the daily disturbance from constructing Nord Stream, the cumulative impact over the construction period was roughly 40% lower, as the construction speed was more than 1.5 times higher for Nord Stream 2 than for Nord Stream.

5 Discussion

The Natura2000 area Hoburg's Bank and Midsjöbanks is an important habitat for the critically endangered Baltic harbour porpoise (Carlén et al., 2018) and it is therefore imperative to assess impact of human activities in the area, both prior to permitting and preferably also through direct monitoring during the actual activities. However, due to the very low abundance of harbour porpoises in the area, it is practically impossible to collect enough direct observations of animals (either through visual surveys or passive acoustic monitoring) to give any confidence to subsequent statistical analysis of the data. We are therefore left with an indirect assessment, where instead of measuring the impact on the animals directly, we test the validity of the assumptions that went into the Environmental Impact Assessment (EIA). The conclusions of the EIA are thereby considered valid, if the assumptions are supported by direct measurements.

5.1 Validity of assumptions behind the assessment

The monitoring program documented that the noise levels produced by the pipe laying vessel was comparable to levels measured during pipe laying for the Nord Stream pipe line and to cargo ships in general. The average source level of the Solitaire vessel was 188 dB re. 1 µPa (**Table 3.1**), which is in the upper end of the values reported for various cargo ships by McKenna et al. (2012) (**Figure 5.1**). As this was the assumption behind the impact assessment, the measurements therefore indicate that the noise exposure and hence likely disturbance to porpoises during passage of the pipe laying vessel through the Natura2000 site was within the anticipated levels.

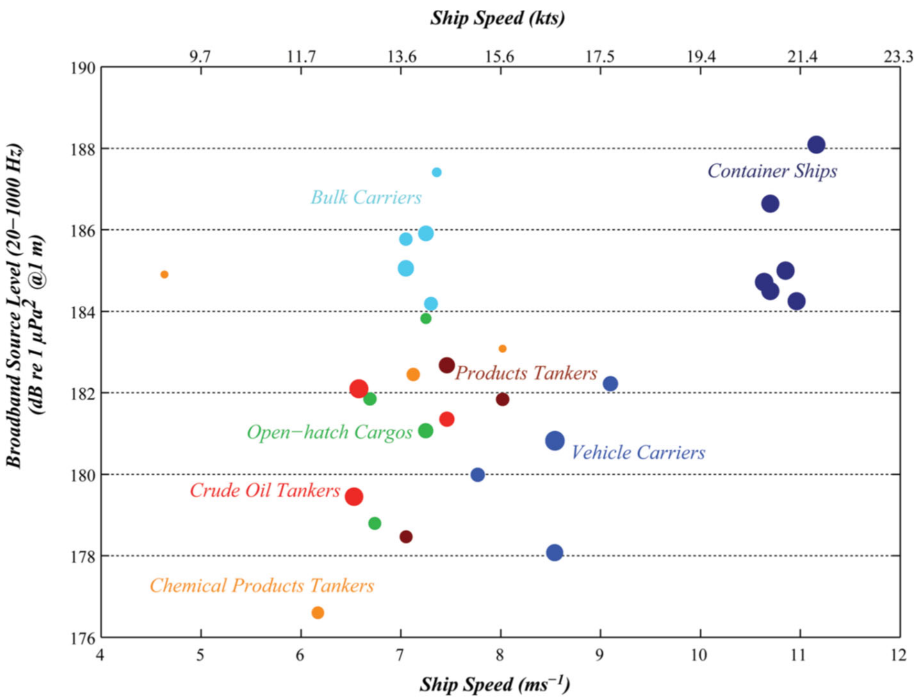


Figure 5.1. Broadband source levels reported for different commercial vessels by McKenna et al. (2012).

5.2 The actual impact on porpoises

Detections of harbour porpoises were scarce throughout the entire monitoring period (Stöber et al., 2020), as anticipated from the general low abundance of porpoises in the Baltic Proper. However, the presence of porpoises was clearly documented on numerous occasions, supporting the previous observation that the Midsjöbanks is an important habitat for the Baltic porpoises (Carlén et al., 2018). The number of detections were too low, however, to allow for a proper statistical analysis with any appreciable statistical power to be conducted. All that can be concluded with certainty is that porpoises were in the area both before and after passage of the pipe laying vessel.

Modelling of the disturbance to porpoises from the pipe laying vessel and support ships were undertaken in the impact assessment. Based on data from construction of the Nord Stream pipeline, it was estimated that the disturbance caused by the pipeline construction would be negligible, affecting on average less than 1/1000 of the habitat area at any one time. Similar modelling of disturbance based on the actual data from Nord Stream 2 construction strongly supported this conclusion. The mean daily disturbance (roughly 1/4000 of the habitat area) was very close to the predicted level, supporting the conclusion that actual impact on porpoises was very low and within anticipated levels.

Construction speed was higher for Nord Stream 2 than anticipated from Nord Stream data, which means that although the daily disturbance to the habitat area was as anticipated in the EIA, the cumulated impact was roughly 40% lower than the estimate from the EIA, based on the (precautionary) assumption that construction speed would be the same as for Nord Stream.

All in all these observations supports the assumptions on which the original assessment was made, indicating that with respect to harbour porpoises the immediate integrity of the Natura2000 site was not compromised by the construction of the pipeline.

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HARBOUR PORPOISES AND THE CONSTRUCTION OF NORD STREAM 2 GAS PIPELINE

Assessment of the impact on porpoises in the Natura2000 Hoburg's Bank and Midsjöbanks, Swedish Baltic

The Nord Stream 2 gas pipeline crosses the marine protected Natura2000 area Hoburgs bank and Midsjöbanks, where a critically endangered population of porpoises aggregate during the summer months. Measurements of underwater noise during construction in 2019 supported the Environmental Impact Assessment (EIA), which concluded that significant impact on harbour porpoises was unlikely, by showing that the noise generated from the pipelaying vessel and support ships, rock placement, and trenching was comparable to or lower than expected. Passive acoustic monitoring for porpoises showed that harbour porpoises were detected at low rates before, during, and after pipeline construction. Habitat loss was assessed by the same model used in the EIA, based on AIS data from the Natura2000 area. While the cumulative impact from all Nord Stream 2 vessels was 25% compared to the impact from commercial shipping in the same period and hence appreciable, the temporary habitat loss caused by construction was very small in absolute terms, less than 0.01% of the total area. Therefore, nothing in the results of the monitoring program indicate that porpoises were adversely affected beyond the low and negligible impact anticipated in the impact assessment.

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