Port of Rotterdam

PROJECTORGANISATIE MAASVLAKTE 2

Effect Monitoring for Maasvlakte 2

Underwater sound during construction and the impact on marine mammals and fish

Effect monitoring for Maasvlakte 2: Underwater sound during construction and the impact on marine mammals and fish

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Contents

1 Introduction

1.1 Background and objective

The Soil Removal Permit for the construction of Maasvlakte 2 includes a provision (article 3(6)(c)(7)) requiring the permit-holder (the Port of Rotterdam Authority) to conduct 'sound measurements to determine the actual levels of sound generated by sand dredging, sand transportation and sand discharge'. The results of this monitoring activity will help to answer evaluation question 9c in the Monitoring and Evaluation Programme established by the competent authorities: 'Is the behaviour of marine mammals and fish affected by the underwater sound produced as a result of the dredging, transportation and discharge of the sand to the extent that populations of marine mammals and fish are affected?' The Maasvlakte 2 Construction Monitoring Plan approved by the relevant competent authorities includes the monitoring component in fact sheet Z5 and annex 7.

The Maasvlakte 2 Construction Monitoring Plan describes, in response to this question, a monitoring strategy that consists of 'measuring[1] the acoustic source levels of a trailing suction hopper dredger using a monitoring vessel on location during sand dredging, sailing to the discharge area, bottom discharge ('dumping'), rainbowing, and pumping the sand ashore. On the basis of acoustic source levels (from characteristic dredgers) determined by means of measurements, a numerical model will be used to calculate acoustic contours weighted on the basis of the hearing frequencies of the marine mammals (harbour porpoises and seals) calculated for the vicinity of the work'. A more detailed description of the measurement strategy drafted at the request of the Port of Rotterdam Authority by TNO Sonar and Acoustics has been included in Annex 7 of the Maasvlakte 2 Construction Monitoring Plan.

TNO conducted measurements of underwater sound in 2008 and 2009. The results were set out in two reports containing the data and describing the background sound measured in 2008 and 2009, as well as the underwater sound as generated during the various phases of the dredging cycle by the dredgers (Dreschler et al., 2009; De Jong et al., 2010). The latter measurements were conducted in 2009. Additional model calculations were then made to establish a picture of the possible impact on marine mammals and fish. The results of these calculations were then described in a third report (Ainslie et al., 2012).

The present report describes the principal results of the research and discusses those results against the background of the effects predicted in the Environmental Impact Assessment and the evaluation question contained in the Monitoring and Evaluation Programme.

[1] Strictly speaking, source levels cannot be measured directly in the field; they have to be calculated using 'inverse' modelling based on field records of underwater sound (see also section 3.2.3). Nevertheless, this report often refers to 'measured' source levels since the measurements were specifically intended to determine as well as possible (= as close to the source as possible) the underwater sound generated by the dredgers during the various activities.

1.2 Report structure

After the introduction describing the background and aims of the present report, Chapter 2 describes the effects of underwater sound during the construction of Maasvlakte 2 on marine organisms, as predicted in the Environmental Impact Assessment and the Appropriate Assessment. This description will look first at the chain of effects (section 2.1) and then in greater depth at the specific issues addressed by the research covered by this report (section 2.2).

Chapter 3 describes the activities conducted for the purposes of answering the questions to be addressed by the research. In succession, it will examine how the various steps in the chain of effects have been stated as specific research issues (section 3.1), and then describe the research (section 3.2).

Chapter 4 summarises the results of the completed research. First of all, it sets out the results of the baseline measurements in 2008 (4.1), the results of the measurements of the background sound and the underwater sound generated by the dredgers in 2009 (4.2). Section 4.3 presents the sound maps established on the basis of these measurements, after which section 4.4 looks at the possible impact that the underwater sound associated with the dredging activities has on fish and marine mammals.

The principal conclusions of the research conducted by TNO can be found in Chapter 5. Chapter 6 contains the ‘final evaluation’ of underwater sound in relation to the construction of Maasvlakte 2. Section 6.1 shows that the research and the associated data constitutes compliance with the requirements of the permit granted under the Dutch Soil Removal Act. Section 6.2 provides an assessment of whether the working plan included in the Maasvlakte 2 Construction Monitoring Plan has been implemented correctly and the findings are appraised on the basis of the effect contours predicted in the Environmental Impact Assessment and the Appropriate Assessment. Section 6.3 examines the relevance of the results of the research for answering question 9c of the Monitoring and Evaluation Programme for the construction of Maasvlakte 2. Strictly speaking, this final item is not required by the monitoring obligation imposed on the Port of Rotterdam Authority by the permit granted under the Dutch Soil Removal Act.

The report concludes with a bibliography and an annex.

2 Research area on the basis of effects predicted in EIA/AA

2.1 The chain of effects

During construction, the number of vessels in the area (in particular dredgers) increases and so the sound level rises locally. The rise in sound levels during the construction of Maasvlakte 2 could disturb fish and marine mammals.

To determine the effects of underwater sound generated by dredgers on fish and marine mammals, the Environmental Impact Assessment (EIA) and the Appropriate Assessment (AA) assume on the basis of Thomsen et al. (2006) that the behaviour of marine mammals is affected when the sound level is 75 dB or more above the hearing threshold. There was no firm empirical proof available for the adoption of this threshold value. There were indications based on the results of empirical studies that zones of responsiveness calculated using this theoretical threshold value are comparable with the zones of responsiveness found in other research (Thomsen et al., 2006). In the calculations conducted for the EIA and the AA, the reactions of fish and marine mammals were stated in terms of distance to the source.[2] The hearing threshold was determined using research summarised by Nedwell et al. (2004) examining the audibility of underwater sound for a range of fish and marine mammal species. The sound calculations are based on the calculated source emissions from a type of dredging vessel that is representative for the equipment that will be deployed during the construction of Maasvlakte 2. The results of the calculations and the description of the methods used can be found for all scenarios in the Environmental Quality Annex of the Construction EIA and Annex 3 of that document.

On the basis of the best knowledge available at the time[3] model calculations were made for the EIA and the AA. It emerged from these calculations that the sound level below the water in the vicinity of dredgers can exceed the hearing threshold of fish and marine mammals. At a distance of more than a few hundred metres away from the vessel, however, it is thought that the stated threshold value of 75 dB above the hearing threshold is not exceeded (Vertegaal et al., 2007; Vellinga, 2007). On that basis, it was concluded in the EIA and the AA in 2007 that the area affected is negligible in size by comparison with the total space that is used by the animals as feeding grounds and migration areas.

2.2 Research area

The sound calculations for the EIA and the AA were based on the data available at the time for the trailing suction hopper dredger Gerardus Mercator, which was considered to be a representative vessel for the construction work on Maasvlakte 2. However, the data were relatively limited because they

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[2] Section 5.4.4, page 120 of Nature Annex in MV2 Construction EIA.

[3] Ongoing developments and the increased availability of data mean that the calculations would not now (in 2012) be conducted in the same way.

related only to sound during dredging and not during transportation or discharging. Nor was it clear to what extent the conditions in which the data had been obtained were comparable with the situation in the planning area prior to dredging and the construction of Maasvlakte 2. To estimate any possible effects on marine organisms, it was necessary to obtain more precise information about actual sound production during dredging, transportation and discharge for the construction of Maasvlakte 2.

The research conducted in the context of the provision included in the permit focused on finding answers to the following questions:

- What is the source level of the underwater sound during the various phases of the dredging cycle of the deployed dredgers?
- How do these levels relate to the background sound?
- To what extent are the effect contours (determined on the basis of the source levels and weighted on the basis of the hearing sensitivity of the relevant species) related to the contours predicted in the EIA and the AA for a possible impact on marine organisms?

3 Study of underwater sound

3.1 Formulation of permit provision for the purposes of the research

The Port of Rotterdam Authority does not have any extensive expertise in the field of the recording underwater sound levels or processing measurement data and has therefore asked TNO to elaborate a measuring strategy for the monitoring requirement stated in the permit. The strategy has been included in full as Annex 7 in the MV2 Construction Monitoring Plan.

To comply with the permit conditions, the measuring strategy proposed the following measurements:

- Continuous registration of background sound at a fixed location for one week prior to the start of the construction work (T0 measurement): measurement series 1;
- Continuous registration of the background sound (at a fixed location) and the underwater sound as a result of the construction work over a period of one week in 2009; this includes recordings of the various phases of the dredging cycle and of the various types of trailing suction hopper dredgers (TSHDs) deployed during the work: measurement series 2;
- Continuous registration of the background sound (at a fixed location) and the underwater sound generated by the construction work over a period of one week in 2010; this includes recordings of the various phases of the dredging cycle and of the various types of trailing suction hopper dredgers (TSHDs) deployed during the work: measurement series 3.

Another important component of the measuring strategy established by TNO was the decision made in consultation with the Port of Rotterdam Authority and the competent authority to combine field measurements with the acoustic modelling of sound propagation. This makes it possible to predict underwater sound levels in an area that extends beyond the measuring location itself. The modelling works in two ways:

- <u>Inverse modelling</u>: calculating backwards to determine the sound level at the source (in other words, the dredgers during different parts of the dredging cycle) on the basis of the underwater sound determined at the measuring location; this is the part of the research that focuses specifically on compliance with the requirements of the permit (determining source levels for TSHDs);
- <u>Modelling from the source</u>: here, on the basis of one or more sources, sound levels are calculated for the entire three-dimensional space below the surface of the water; on the basis of these calculations, sound maps can be drawn up and – if necessary - weighted according to the animal's hearing characteristics.

3.2 Completed research

3.2.1 Measurements

Measurements of the background sound prior to the construction of Maasvlakte 2 (the baseline measurements) were conducted in the week of 8 to 15 September 2008 at a fixed location (designated as Z in Figure 3-1). During this week, recordings were made over a period of 5.5 consecutive days 2 m above the seabed and over a period of more than three days in the same period at a height of about 7 m above the seabed (total water depth was approximately 20 m). A six-second sample was recorded every minute. The monitoring setup used in 2008 is shown schematically in Figure 3‑2. The basic principles and further details for the baseline measurements can be found in Dreschler et al. (2009).

From 22 September to 5 October 2009 (inclusive), sound recordings linked to the various phases of the dredging cycle were made at a range of locations. The approximate locations of the monitoring stations are shown in Figure 3-1. In addition, as in 2008, background sound was measured at a fixed location. In 2009, a stand-alone measuring system was used for this purpose: SESAME (Shallow water Extendible Stand alone Acoustic Measuring System). A schematic overview of the physical approach to the measurements in 2009 can be found in Figure 3‑3. The basic principles and further details for the measurements in 2009 can be found in De Jong et al. (2010).

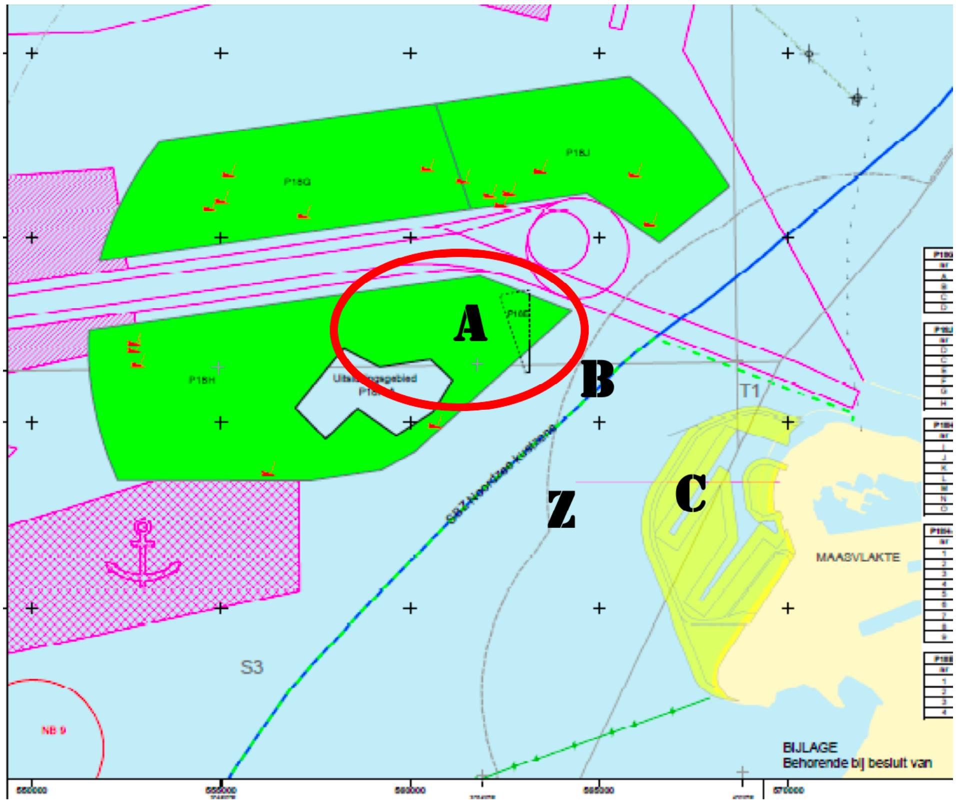


Figure 3‑1 Map showing the future Maasvlakte 2 (C, lime green) and the approved sand dredging areas/borrow areas (green). The red oval shows where sand was actually dredged for the construction of Maasvlakte 2. The large letters show the sites where recordings of underwater sound were made. Z: background sound, A: sand dredging, B: transport of sand (transit), C: construction area (bottom discharge, rainbowing and pumping ashore).

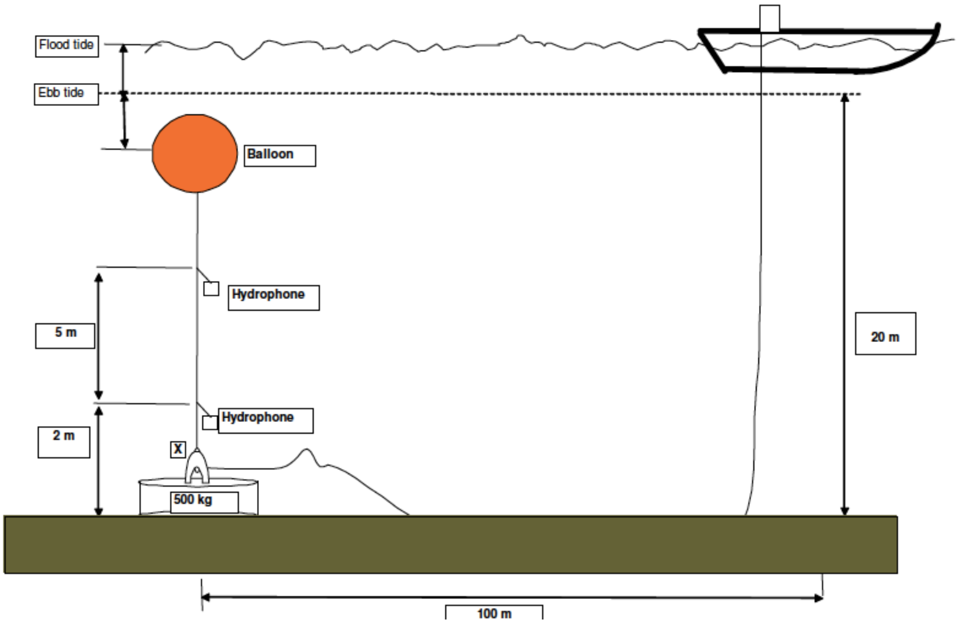


Figure 3‑2 Schematic representation of the fixed monitoring set-up during the baseline measurements in 2008 at location Z_{2008}

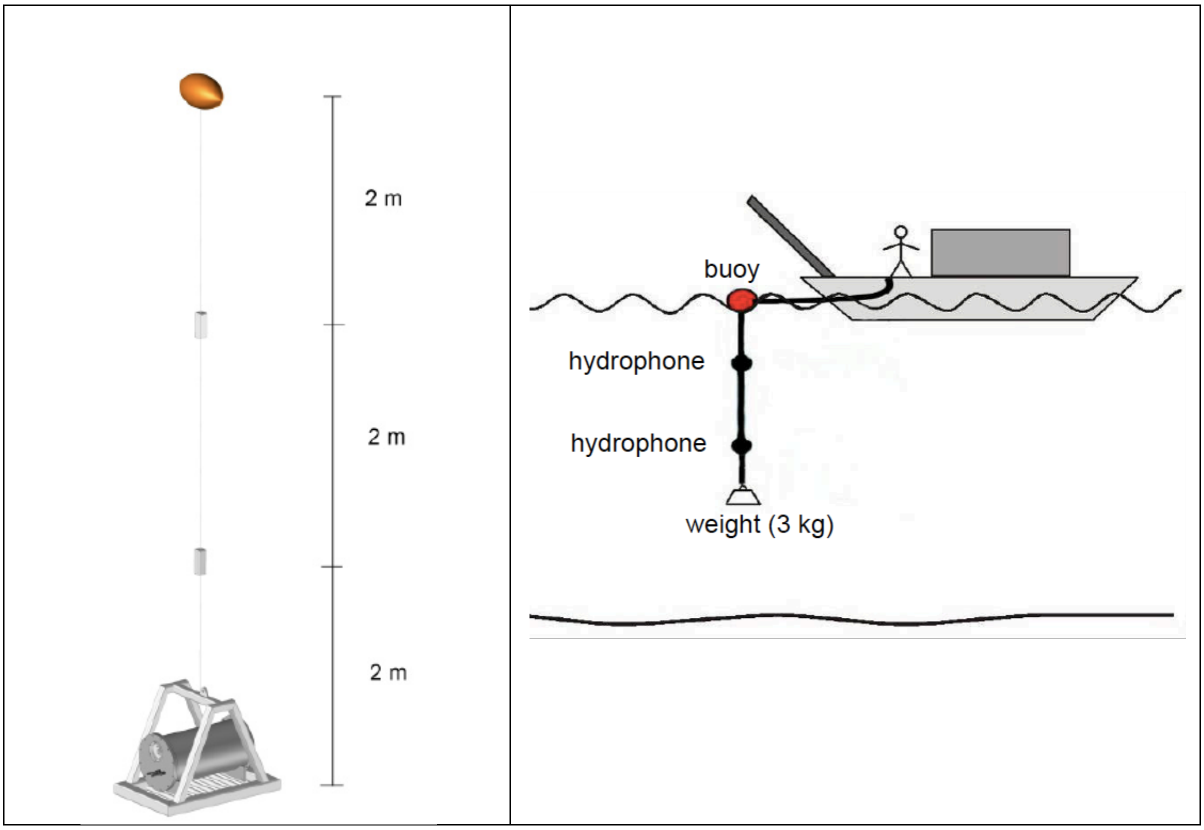


Figure 3‑3 Schematic representation of the fixed monitoring set-up, SESAME, used in 2009 to record background sound at location Z_{2009} (left) and the mobile set-up for measuring the sound level of the various parts of the dredging cycle involving working TSHDs (right)

When the Maasvlakte 2 Construction Monitoring Plan was drafted, it was assumed that sand dredging would be gradual (approximately 60 million m^3/year). On the basis of that scenario, it was not immediately clear whether it would also be possible to make recordings of all the components of the dredging process in the first monitoring week in 2009. This applied in particular to the process of pumping ashore. However, once work started in January 2009, it became clear that the contractor, PUMA, was working very energetically and that sand was being dredged very quickly. During the measuring week in 2009, it was found that all the different phases of the dredging cycle, including pumping ashore, were in place to such an extent that measurements were possible. In consultation with the competent authority, therefore, it was concluded that compliance with the Maasvlakte 2 Construction Monitoring Plan had been achieved and that a third measurement series would not generate any additional information and was therefore not necessary (see Intermezzo, Representativeness of measurements in 2009).

Intermezzo

Representativeness of measurements in 2009

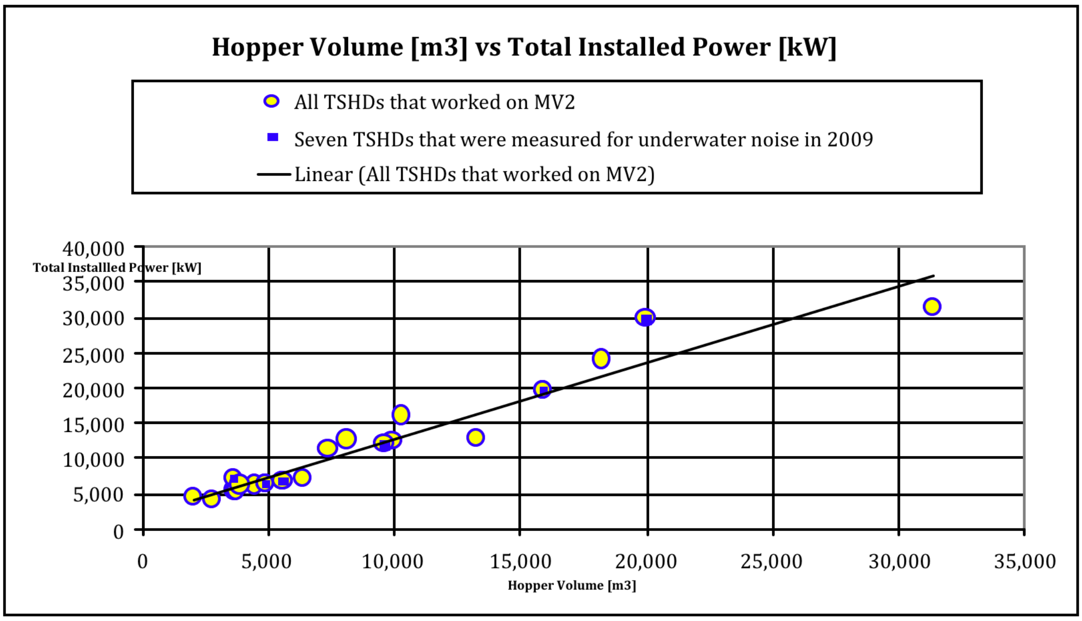
During the measurements conducted over a period of one week in October 2009, seven TSHDs were at work. Recordings were made for all seven vessels of the sound produced under water, and of the following phases of the dredging cycle: dredging, transit with load, bottom discharge, rainbowing, pumping ashore, transit without a load.

To provide an indication of the representativeness of these seven vessels, all 21 TSHDs deployed on the construction of Maasvlakte 2, including the seven monitored vessels (marked with a blue dot), are shown in the figure below. Two of them are virtually identical sister ships. The figure plots the total installed power (kW) and the capacity of the ships (m^3). The figure shows that the seven vessels monitored are a representative selection of those working on Maasvlakte 2.
The table below from De Jong et al. (2010) contains an overview of the phases of the dredging cycle that were monitored. It can be seen that all phases of the cycle were recorded, albeit not always as frequently. However, it can be assumed that an adequately representative picture has been established of the entire range of sound pressure levels associated with the work done because:

- The sound generated by both the largest and smallest vessel was measured;
- The sound below the water is not determined by the equipment used for the various activities such as pumping ashore and rainbowing but by the cavitation of the propellers and bow thrusters.

Additional monitoring of ships engaged in bottom discharging or pumping ashore, the phases in the dredging cycle for which relatively few data have been collected, will not therefore generate any additional information.

Weeks 39 & 40 in 2009	
Action	**number of events:**
Transit: fully loaded	**16**
Transit: empty	**16**
Dredging port side	**15**
Dredging starboard side	**10**
Rainbowing	**13**
Pumping ashore	**2**
Bottom discharge ('dumping')	**2**



3.2.2 Measures and units for underwater sound

A range of measures and units are used to describe the underwater sound to which animals can be exposed. This study used the following acoustic measures with the associated units:

- Source Level: the sound pressure level in one-third-octave bands at 1 metre from the source; unit: dB re 1 μPa^{2}m^2 (in older literature, also dB re μPa at 1m or dB re μPa–m);
- Broadband Sound Pressure Level: the time-averaged quadratic sound pressure level for continuous sound (such as ship sound) or the average sound pressure level during the duration of the pulse in the case of pulse sounds (such as pile-driving sound); unit: dB re 1 μPa^2;
- Sound Exposure Level: the total, quadratic sound pressure level integrated over a given period of time; is used as a measure for both continuous and pulse sounds; unit: dB re 1 μPa^{2}s.

3.2.3 Processing of measurement data (modelling)

The acoustic data collected using the hydrophones were converted into sound pressure levels (SPL) per one-third-octave band (1/3-octave band), with a frequency range of 20 Hz to 80 kHz (2008) and 12.5 Hz to 160 kHz (2009). The different calculation steps required to do this are described in section 4.2 of the first TNO report (Dreschler et al., 2009).

The source levels corresponding to the various phases of the dredging cycle were determined using 'inverse modelling'. This means that the sound levels measured for each 1/3-octave band at various distances from the dredger were back-calculated to the sound level at the source (in other words, the dredger). A detailed description of how these calculations were made and the underlying assumptions are set out in Chapter 4 of the TNO report (De Jong et al., 2010).

The next step was to calculate how sound from a particular source (a dredger) spreads into the area around Maasvlakte 2 and how the energy of that sound changes with distance. The ultimate aim here is to determine the extent to which the activities of the dredgers result in changes in the 'soundscape'. The background sound and the source levels determined on the basis of the various measurements conducted in 2009 constituted the basis for these calculations. The AQUARIUS propagation model developed by TNO (previously known as ANOMALY) was used to calculate sound levels at every point in the three-dimensional space. In the model, the seabed - a sandy one in the case of the Maasvlakte - is one factor that determines sound transmission. The model was validated by comparing spectra of measured sound levels with model values (see section 2.5 in the TNO report by Ainslie et al., 2012). Sound maps were made for two characteristic points in time during the construction of Maasvlakte 2. In addition, an animation fim was produced showing these points in time, and how the 'soundscape' in the area around the Maasvlakte can change over a period of 24 hours.

3.2.4 Underwater sound during construction of MV2 in relation to fish and marine mammals

Underwater sound can affect marine organisms in different ways depending on the sound pressure level and the frequency (see, for example, Richardson et al., 1995; Kastelein et al., 2008). The literature generally distinguishes between zones of responsiveness, ranging from a zone in which the sound is heard but where the animal does not respond to a zone in which severe physical harm or even death can occur. In between, there are zones in which behaviour is affected, with the animal swimming away from the sound or being attracted to it, and a zone where the animal's hearing may be affected temporarily or permanently (temporary hearing threshold shift = TTS, and permanent hearing threshold shift = PTS respectively). In addition, there can be masking effects in some animals. This is the situation in which the frequency range, and level, of the non-natural sound is comparable to the sounds produced by the animals or their prey. This can be a particular problem for animals that track their prey using echolocation, the harbour porpoise being one example. Ship sounds are relatively low-frequency sounds and there is no overlap with the very high frequency of the vocalisations used by harbour porpoises (in the 120 kHz range) and so this does not play a role.

In the study conducted by TNO for the Port of Rotterdam Authority, the main criterion adopted for affecting animals was the sound exposure level, with the possibility of a temporary rise in the hearing threshold (TTS). This is a generally accepted approach because it can be concluded on the basis of the considerations in Southall et al. (2007) that there will be no avoidance in seals at lower levels.[4] The values derived by Southall et al. (2007) for continuous sound, with the SEL being weighted for the specific hearing sensitivity of the animals, have been adopted for harbour porpoises and seals. 'M-weighting' (Southall et al., 2007) was used here. Alongside TTS, the values thought to result in a permanent increase in the hearing threshold (PTS) have been taken into account for harbour porpoises and seals.

There are no thresholds for fish relating to harm after exposure to continuous sound generated by, for example, shipping. The criteria proposed by the US Fish Hydroacoustic Working Group (FHWG) relate to pulse sounds generated by pile driving (Oestman et al., 2009). There is a distinction here between small fish (< 2 grams fresh weight) and larger fish (> 2 grams fresh weight). It is not clear to what extent these values can be applied to continuous sound. The threshold values for continuous sounds are often slightly higher than for pulse sounds and so the application of these criteria to continuous sound would produce a 'worst case' description of the possible effects.
An overview of the thresholds used can be found in Table 3‑1.

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[4] The threshold of 75 dB above the hearing threshold that was adopted in the EIA and the AA for an impact on behaviour has not been validated further since the appearance of the publication by Nedwell et al. (2003) quoted by Thomsen et al. (2006). More recent publications about the impact of underwater sound on marine organisms have also stopped using this value.

Table 3‑1 SEL thresholds, in dB re 1 μPa^{2}s for risk of PTS and TTS. Thresholds for harbour porpoise and seal from Southall et al. (2007) and for fish from Oestman et al. (2009). M_{Hf} = M-weighting for 'high frequency cetaceans' (including harbour porpoise); M_{pw} = M-weighting for 'pinnipeds in water' (seals).

Species (or group)	PTS risk threshold	TTS risk threshold	weighting
harbour porpoise	215	195	M_{hf}
seal	203	183	M_{pw}
fish > 2 g	-	187	none
fish < 2 g	-	183	none

When estimating the possible impact on marine organisms of vessels engaged in dredging, two scenarios were initially considered:

- A stationary ship dredging sand and an animal swimming past at a given speed (1 m/s relative to the ship);
- A dredging vessel sailing past an animal during transit from dredging to discharge area, with the animal remaining at a given distance from the sailing ship (speed relative to the swimming speed of the animal = 7 m/s).

In these scenarios, the total SEL was calculated as a function of distance with respect to the ship. Both these scenarios first looked at the situation in which sound is propagated equally in all directions (spherical spreading). This approach provides an initial impression of the order of magnitude of the effects and the impact on the level of exposure (SEL) of the source level, distance with respect to the source, and swimming or sailing speed. An animal swimming past a ship at a given distance and at a speed relative to the vessel of 1 m/s is exposed for a period of time that is seven times as long as it would be in the case of a stationary animal past which a dredging vessel sails at a speed of 7 m/s at the same distance. This difference in relative speeds between the animal and the ship is reflected in effect distances which, when a dredging vessel sails past a stationary animal, are an order of magnitude less than in the situation in which the animal swims past a vessel dredging sand (Table 3‑2). More precise, more realistic calculations using the AQUARIUS propagation model were therefore only made for the scenario with an animal swimming past a dredging vessel.

Table 3‑2 Distance with respect to a dredging vessel fitted out with a 'receiver', with the exposure levels listed in the first column being exceeded. Result of 'first impression' calculations assuming 'spherical spreading'.

SEL (dB re 1 μPa^{2}s)	SL = 200 dB re 1 μPa^{2}m^2		SL = 190 dB re 1 μPa^{2}m^2	
	v = 1 m/s	*v* = 7 m/s	*v* = 1 m/s	*v* = 7 m/s
195 dB	10 m	< 3 m	< 3 m	< 3 m
185 dB	100 m	14 m	10 m	< 3 m
175 dB	1000 m	140 m	100 m	14 m

The relationship was calculated for three depths between the distance from the swimming animal to the vessel dredging sand, and the total sound exposure level. The resulting values were compared with TTS and PTS thresholds.

In addition, sound maps were produced that could be used to derive, for every point in the area of 15 x 15 km studied, the sound exposure level for fish and marine mammals assuming they are present at that point for a period of 24 hours. These maps were made for animals close to the surface of the water (at a depth of 1 m) and for animals close to the seabed (+ 1 m). However, in reality, marine organisms are always on the move. Calculations were therefore made to establish the sound exposure level received by harbour porpoises and seals swimming along straight, north-south, lines for a period of 24 hours through the area, and the proportion of animals for which the thresholds for TTS (or PTS) are exceeded. This included modelling the situation in which only normal shipping traffic is present, as well as the situation in which the dredgers were actively working on the construction of Maasvlakte 2. Furthermore, the theoretical situation was modelled in which only the TSHDs for the construction of Maasvlakte 2 were present.

4 Results

4.1 Baseline measurements 2008

During the baseline measurements preceding the start of the construction work on Maasvlakte 2, levels of background sound were measured at a fixed location (Z_{2008}), which was less than 5 km from the borrow area (this is the area where the sand was dredged) and the future Maasvlakte 2. In this area, typical sound pressure levels per 1/3-octave band at 100 Hz, 1 kHz and 10 kHz respectively were 114 ± 6, 105 ± 6 and 90 ± 6 dB re 1 μPa^2 (Figure 4‑1). The corresponding spectrum levels were, respectively, 100 ± 6, 82 ± 6 and 57 ± 6 dB re 1 μPa^2/ Hz (see Figure 5.2 in Dreschler et al., 2009). The grey lines in Figure 4.1 show the results of the individual measurements. The coloured lines represent a range of statistical parameters that are described in detail in section 5.1 of the TNO report from Dreschler et al. (2009).

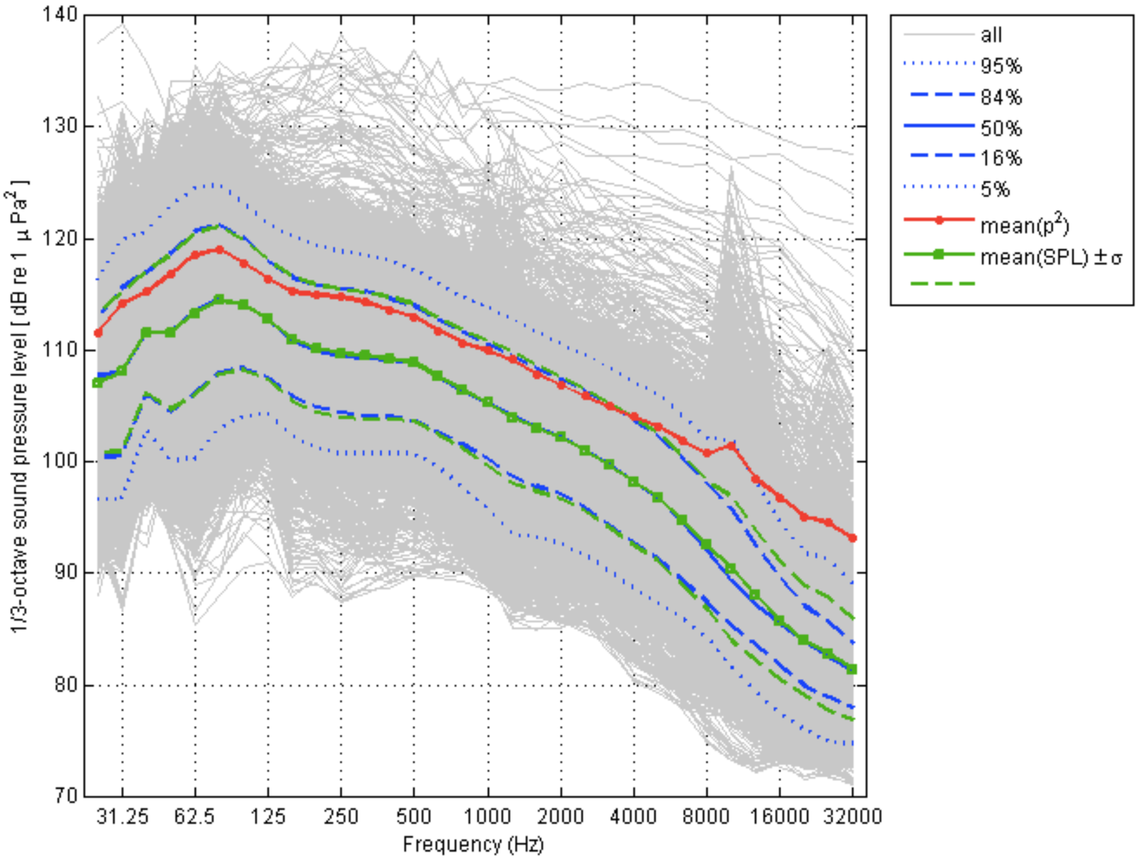

Figure 4‑1 Sound pressure levels (SPL) per 1/3-octave band. The results of all individual measurements are shown by the grey lines. The blue dotted, interrupted and continuous lines show P_5, P_{16}, P_{50}, P_{84} en P_{95}. The average values for the sound levels for all measurements are shown by the red line and the green continuous line (± 1 standard deviation in interrupted green line).

At frequencies between 50 Hz and 10 kHz, the measured sound pressure levels proved to be significantly affected by variations in shipping traffic. The effect was also perceptible at higher frequencies, but much less so. The effects associated with frequency started to decline from a frequency of approximately 5 kHz onwards. The wind also affected the measured sound pressure levels. At higher frequencies, there was a strong positive correlation between wind speed and measured sound pressure levels: above approximately 10 kHz, sound caused by the wind, for example as a result of breaking waves, can be a significant component of background sound.

4.2 Source levels in phases of dredging cycle and background sound, 2009

Sound recordings were made of all phases of the dredging cycle in 2009. Using the method described in De Jong et al. (2010), they were converted to 'dipole'[5] source levels (SL). The maximum values for these source levels for the different activities are shown in Figure 4‑2. It can be seen in the figure that dredgers produce most sound as they move from the borrow areas to the discharge area and vice-versa (at a speed of 16 knots). During the sand dredging, comparable levels were produced although the levels in most 1/3-octave bands were a few decibels lower. During pumping ashore and rainbowing, the maximum source level at frequencies between 500 Hz and 10 kHz was comparable with that of a vessel dredging sand but substantially lower than at frequencies outside this range. The lowest source levels were measured during the bottom discharging of sand at frequencies above 1 kHz and at frequencies of 500 Hz and less during rainbowing. At a frequency of approximately 100 Hz, the source level for all phases of the dredging cycle is comparable, with the exception of rainbowing. In all probability, the production of underwater sound by dredgers is primarily caused by cavitation linked to the propellers and bow thrusters.

As in 2008, background sound measured from a fixed location was also dominated in 2009 by sound from shipping traffic. The sound levels measured in 2009 were generally higher than those found in 2008 (Figure 4‑3). There was a strong correlation with the distance to dredgers and it is probable that the dredgers in transit contributed most to the underwater sound found at the location (see also section 4.3). The dredgers sometimes sailed very close to the fixed SESAME monitoring station and the variations in the background sound measured in 2009 were much higher than the variations measured in 2008.

At frequencies exceeding 10 kHz, the wind – and therefore the sound generated by waves – determined the measured sound levels, except when a dredging vessel was sailing past. In the frequency range between 100 Hz and 10 kHz, a negative correlation was found between wind speed and background sound. This is probably the result of an increase in propagation loss as waves get higher since, in those circumstances, sound is dissipated more.

[5] Ainslie e.a., 2012:"Source level" is a quantitative measure of the sound radiated by an underwater source in idealised conditions. The term can take on many different meanings. For example, the sound radiated by a monopole (point omnidirectional source) is characterised by the monopole source level (MSL, a property of point source that can be combined with propagation loss (PL) from point source propagation model to predict sound pressure level: SPL = MSL – PL). Also relevant is the dipole source level (DSL), the equivalent quantity for a point source combined with its surface reflected image. The DSL is especially relevant for surface ships because of the inseparable nature of these from the sea surface. At high frequency, DSL exceeds MSL by about 3 dB. At low frequency, MSL exceeds DSL by an amount that increases with decreasing frequency.

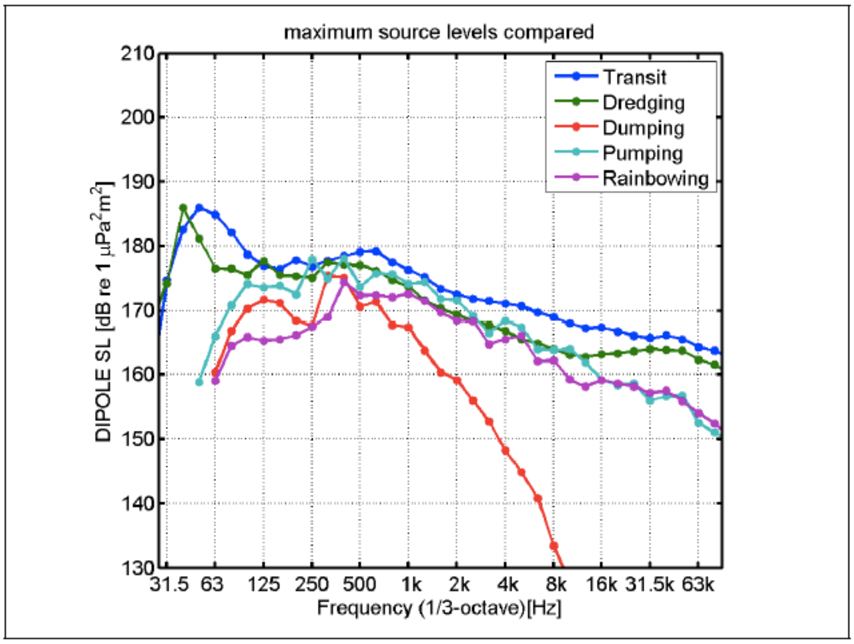

Figure 4‑2 Maximum dipole source level spectra for the various activities of dredgers during the construction of Maasvlakte 2 (dumping=bottom discharge).

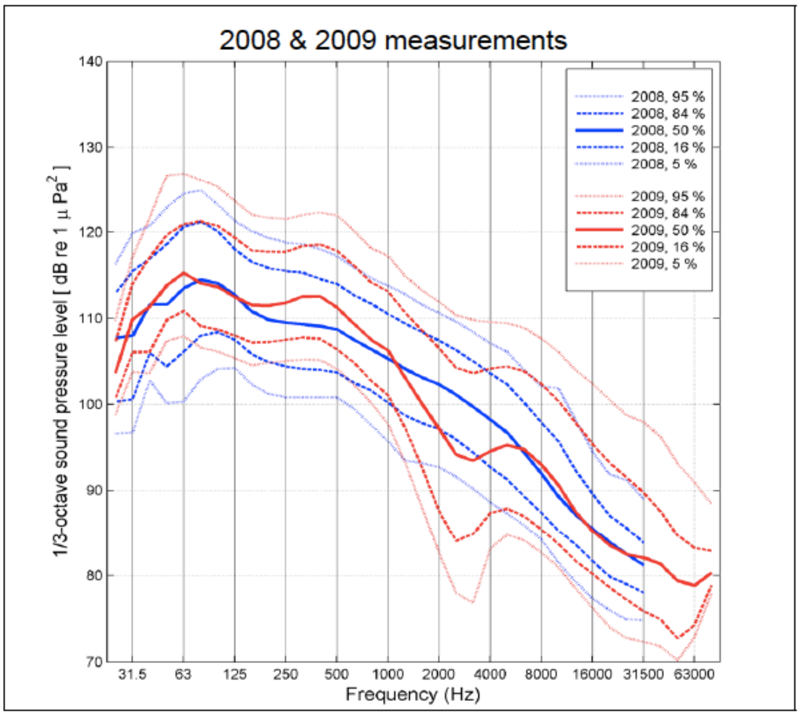

Figure 4‑3 Sound pressure levels (SPL) per 1/3-octave band at a fixed station in the area between the borrow area and the Maasvlakte 2 construction area in 2008 (blue lines) and 2009 (red lines). The dip in the 2009 curves at 3 kHz may be the result of the night-time presence of large numbers of small fish with a swim bladder (see De Jong et al., 2010, section 6.4.2)

4.3 Sound maps

The first step in the production of sound maps involved the validation of the AQUARIUS propagation models by using the model to calculate the contribution of source levels to background sound and comparing the results with the background sound measured with SESAME. It emerged that the AQUARIUS model predicted the measured sound spectra reasonably well but systematically underestimated measured values at frequencies below 500 Hz and overestimated the values at frequencies between 700 Hz and 30 kHz. Since most sound energy is located in the lower frequencies, this may result in the total, broadband sound pressure level being underestimated by approximately 6.6 dB. Raising the sediment sound speed used in the model from 1760 m/s (medium sand) to 1960 m/s (coarse sand) reduced this discrepancy to 3.5 dB (compare figures 8 and 9 in the TNO report from Ainsley et al., 2012).

The validated AQUARIUS model was used to produce sound maps for two points in time on 29 September 2009. For each of the two points in time, a map was produced for a depth of 1 m above the seabed and for a depth of 1 m below the water surface. Table 4‑1 contains an overview of the input data used in the model. The results of the calculations - in the form of four maps - can be seen in Figure 4‑4.

Table 4‑1 Input data for calculations of sound maps

Parameter	**Value**
Sediment sound speed	1960 m/s*
Wind speed	0 m/s*
Source level	selected on the basis of the best match with activity and speed (data from Automatic Identification System)
Depth	1 m above the seabed, representative for animals located somewhere in the water column, with the exception of the upper metres (depending on the frequency) 1 m below the water surface, representative for animals that swim close to the surface
Time	29 September 2009 11.04 (dredging vessel 1 close to SESAME)** 29 September 2009 12.02 (dredging vessel 7 close to SESAME)**

* These parameters were selected in such a way that the sound was propagated relatively well, resulting in 'worst case' effect distances. At wind speeds exceeding approx. 4 m/s and lower sediment speeds, dissipation and absorption prevent sound from travelling as far.

** Figures with source levels for the observed dredgers during the execution of various phases of the dredging cycle have been included in Annex 1 accompanying this report.

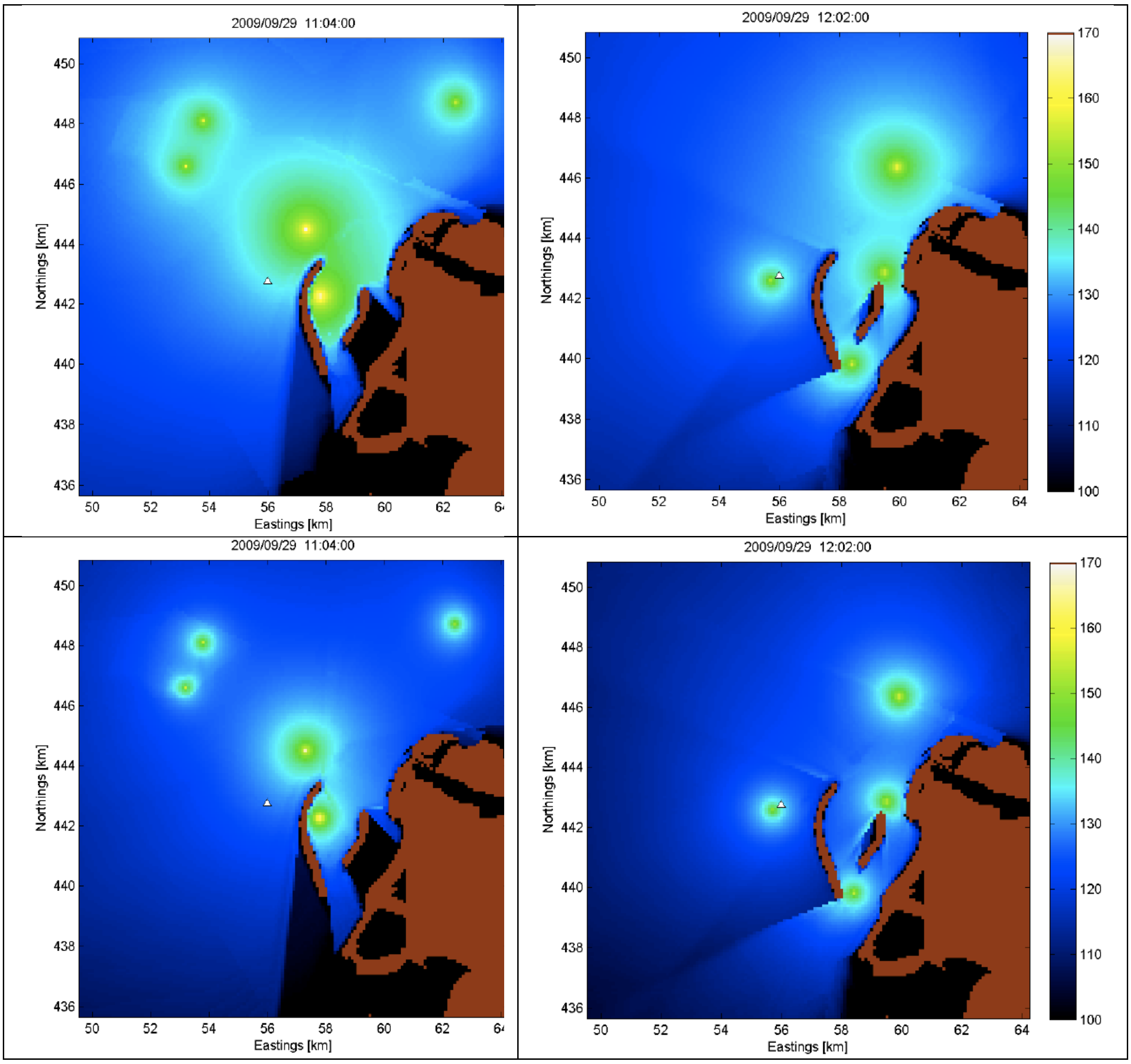

Figure 4‑4 Sound map for dredging vessel 1 close to the fixed monitoring station SESAME (sound source to the north of the banana-shaped sandfill in the left-hand panels) and for dredging vessel 7 close to SESAME (sound source close to SESAME in the right-hand panels) 1 m above the bed (top panels) and 1 m below the surface (bottom panels). In the right-hand panels, dredging vessel 1 is at work at the southern tip of the 'banana'. The colours show the broadband sound pressure level (dB re 1 μPa^2). The white triangle shows the location of SESAME.

The maps in Figure 4-4 show how sound generated by the activities of two dredgers in the Maasvlakte 2 area was propagated under water at two points in time. The area measures 15 x 15 km. Background sound caused by, for example, wind and waves or other shipping and harbour activities has not been included in the calculations for these maps. The yellow circles show the locations of the various dredgers. The spread of the sound is shown in circles because the vessels are effectively considered to be point sources. The resulting contours with the same sound level can be seen as the worst-case scenario because the calculations are based on a wind speed of 0 m/s and a sediment sound speed that is appropriate for coarse sand.

A film was made for a depth of 1 m above the seabed covering the total of 15 min before dredger 1 sailed past SESAME through to 15 min after dredger 7 sailed past. The film can be found on the DVD accompanying the TNO report (Ainslie et al., 2012). The DVD also includes films showing the variations in the soundscape below the water around Maasvlakte 2 at the two depths in question on 29 September 2009 (0.00 to 24.00 hours) and what those soundscapes would have looked like in the absence of dredgers. Films were also made for the theoretical scenario in which only dredgers are active and in which there is no other shipping traffic. The sound maps in Figure 4‑4 are snapshots taken from these films.

4.4 Impact of dredging work on fish and marine mammals

4.4.1 Relationship between distance to dredgers and sound exposure level (SEL)

The AQUARIUS model was used to calculate the levels of underwater sound to which fish, harbour porpoises and seals were exposed to at various depths when swimming at a relative speed of 1 m/s in a straight line past a dredging vessel engaged in dredging sand. The calculations adopted the following worst-case principles:

- A total exposure duration of 24 hours; in reality, the hearing of an animal will recover, at least in part, over the course of those 24 hours but it is not known at what level this will be the case;
- The highest source level found in the study was used: the level generated by dredging vessel 1 sailing to and from the borrow area and the discharge area; it was assumed that this was also the maximum source level during sand dredging;
- Minimal propagation loss at higher frequencies (wind speed 0 m/s and sediment sound speed of 1960 m/s).

The results of the calculations are stated for depths of 1 m and 16 m in Figure 4‑5 and Table 4‑2. For harbour porpoises, the TTS risk thresholds are not exceeded at any distance from the dredging vessel. TTS may occur in seals if they swim past the vessel for a period of 24 hours at a depth of 16 m and a distance of 90 m or less. In the case of fish, the distances are 100 m or less for larger fish (> 2 g) and 400 m or less for small fish (< 2 g). The distances are shorter for animals swimming closer to the sea surface (Fig 4-5, top). They are 15 m for seals and 20 m for small fish. At this depth, the TTS risk thresholds are not exceeded for harbour porpoises and larger fish.

Table 4‑2 Distance to dredgers at which the TTS threshold (see Table 3‑1) is exceeded for harbour porpoises, seals and fish at a depth of 16 m (worst case). In all cases, the animal is moving at a speed of 1 m/s with respect to the dredging vessel. Total exposure duration of 24 hours.

TTS threshold	Harbour porpoise 195 dB re 1 μPa^{2}s	Seal 183 dB re 1 μPa^{2}s	Fish > 2 g 187 dB re 1 μPa^{2}s	Fish < 2 g 183 dB re 1 μPa^{2}s
Distance to dredging vessel	n/a	90 m	100 m	400 m

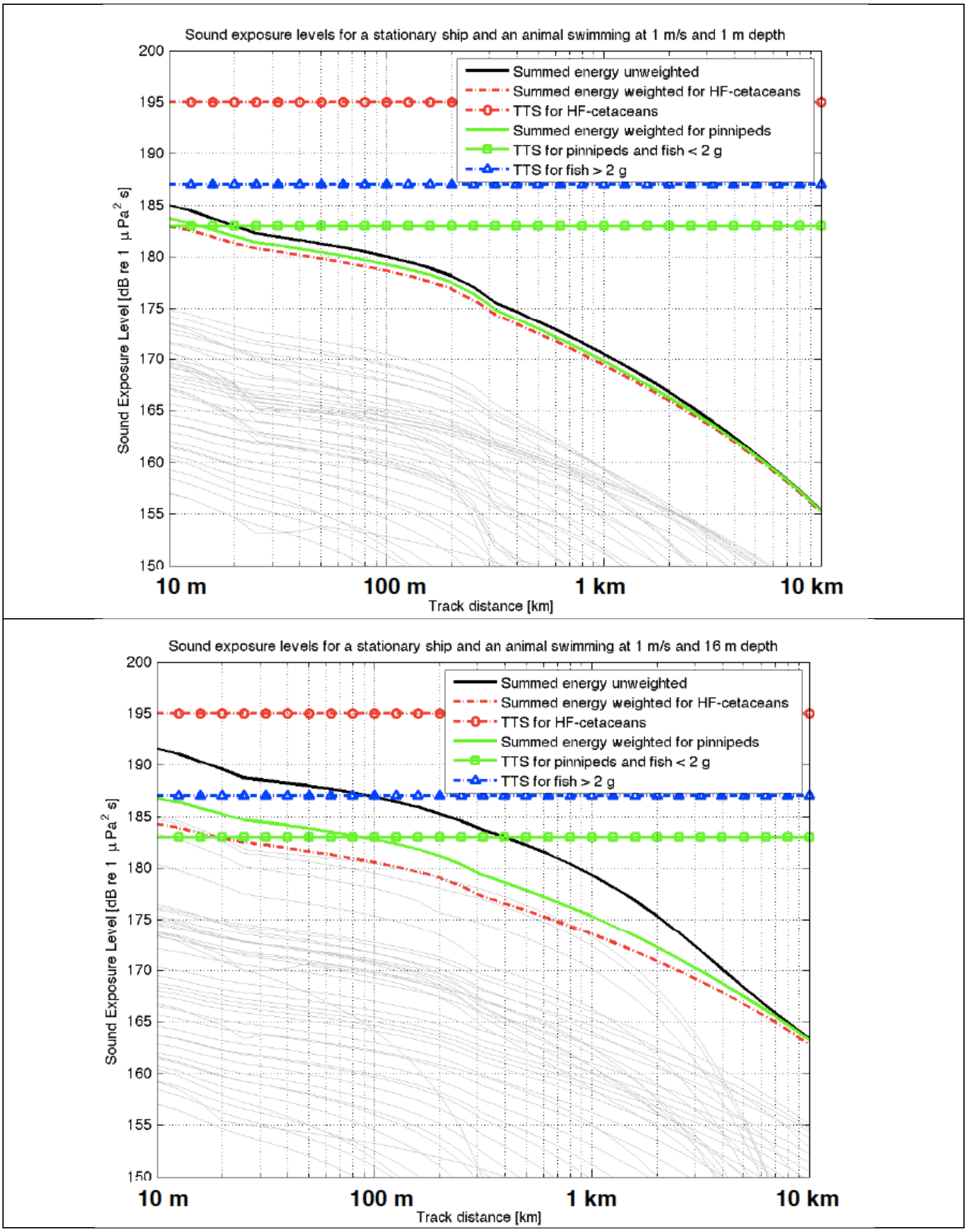

Figure 4‑5 Relationship between distance to dredging vessel and sound exposure level (SEL) in dB re 1 μPa^{2}s of a swimming animal with a relative speed with respect to the ship of 1 m/s at a depth of 1 m (top) and 16 m (bottom).

4.4.2 Sound exposure level (SEL) for stationary and swimming animals

The sound maps presented in section 4.3 and the accompanying films provide an accurate and representative picture of the changes in the soundscape during the construction of Maasvlakte 2. However, it is not possible to satisfactorily establish on the basis of these maps the level of sound to which the animals are exposed, whether they remain in one place or are swimming through the area. The results of the calculations presented in section 4.4.1 do indeed give an impression of the distance from a dredging vessel at which animals may suffer TTS but it is not possible to determine on that basis the probability that this will indeed actually happen. Actual exposure depends not only on the position of the animal with respect to the source and the propagation conditions but also on the animal's behaviour.

Maps weighted in accordance with an animal's hearing sensitivity give an impression of the total amount of sound to which an animal is exposed when that animal is located at a particular place in the area studied for a period of 24 hours (in other words, if the animal is not swimming). Maps have been made showing the 24-hour cumulative exposure (SEL_{24}) for the following situations (18 maps in total):

- Regular shipping, regular shipping + dredgers, dredgers only (3 possibilities);
- Depth 1 m below the surface and depth 1 m above the seabed (2 possibilities);
- Unweighted sound levels (fish), M-weighting for 'high frequency cetaceans', which include the harbour porpoise (M_{hf}) and M-weighting for 'pinnipeds in water' (including seals, M_{pw}) (3 possibilities).

The impact of the dredging and discharge activities on the soundscape as experienced by the various species and groups if they were to remain in a single location for a period of 24 hours can be read off by comparing the three left-hand panels (regular shipping) with the three right-hand panels (regular shipping + dredgers) in Figure 4-6 and Figure 4-7. Figure 4‑6 shows the situation 1 m above the seabed and Figure 4‑7 the situation 1 m below the surface. For the six corresponding maps which show only the impact of the dredging ships, the reader is referred to Annex A of the TNO report (Ainslie et al., 2012).

On the basis of the thresholds shown in Table 3‑1 at which fish, harbour porpoises and seals may suffer TTS in the area of 15 x 15 km studied, an area can been calculated where these risk thresholds are exceeded. Without the contribution of dredgers, this area is, 1 m above the seabed (worst case), 68 km^2 for small fish and 23 km^2 for large fish (30% and 10% respectively of the area of 225 km^2 studied). When the dredgers are present, these areas are 97 km^2 and 72 km^2 respectively (=43% and 32% of the area studied). The areas for seals and harbour porpoises 1 m above the seabed are, respectively, 10 km^2 and 0.0 km^2 assuming regular shipping traffic only, and 72 km^2 (seal) and 0.5 km^2 (harbour porpoise) (32% and 0.2% respectively of the area studied) when the contribution of dredgers is taken into account. These areas are much smaller for animals located close to the surface.

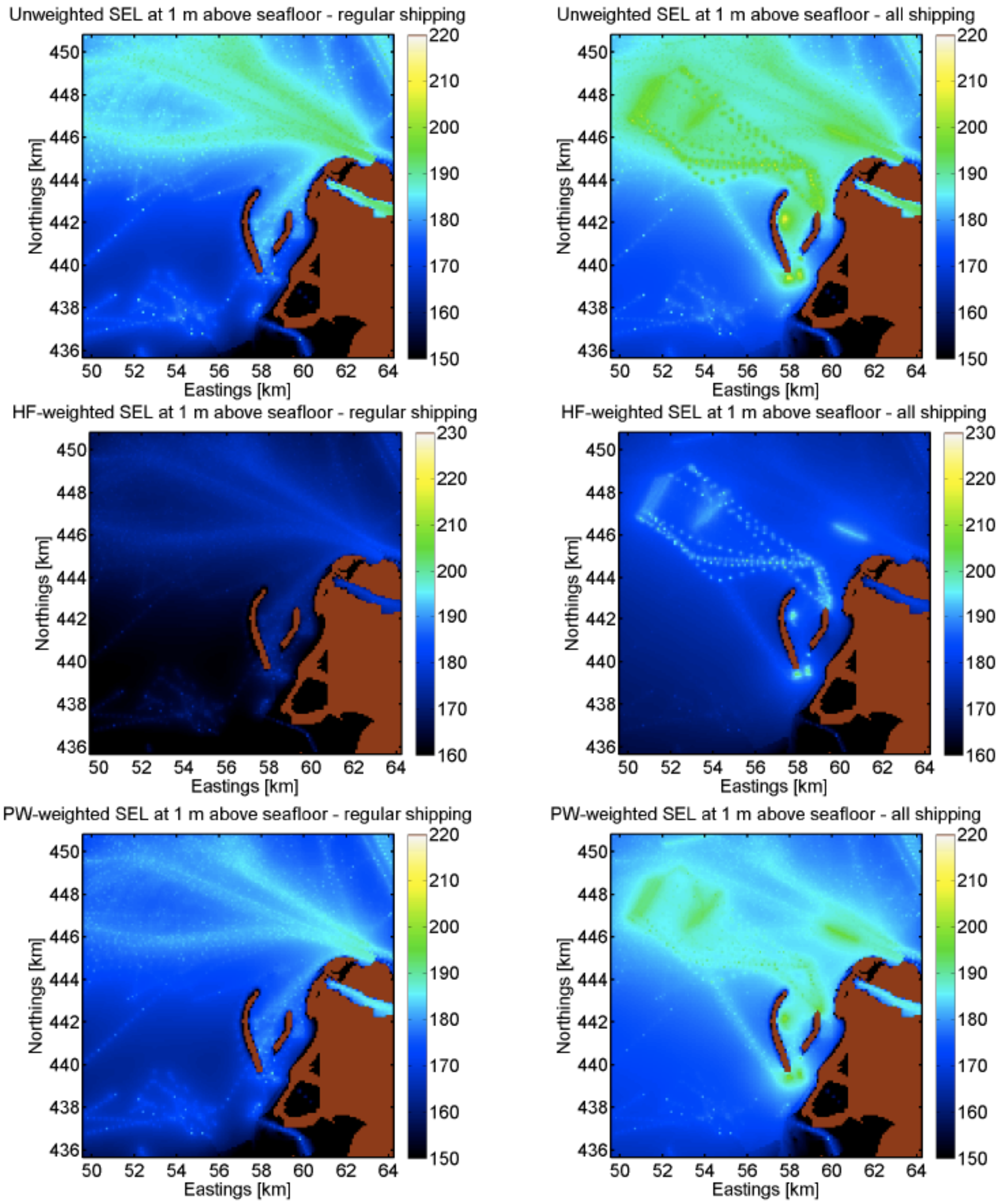

Figure 4‑6 Sound maps generated by regular shipping (left) and regular shipping + dredgers (right) at a depth of 1 m above the seabed. The figure shows the cumulative broadband sound exposure level (dB RE 1 μPa2s) for a period of 24 hours: non-weighted (top, representative for fish), M-weighted for 'high frequency cetaceans' (centre, representative for harbour porpoise) and M-weighted for 'pinnipeds in water' (bottom, representative for seals).

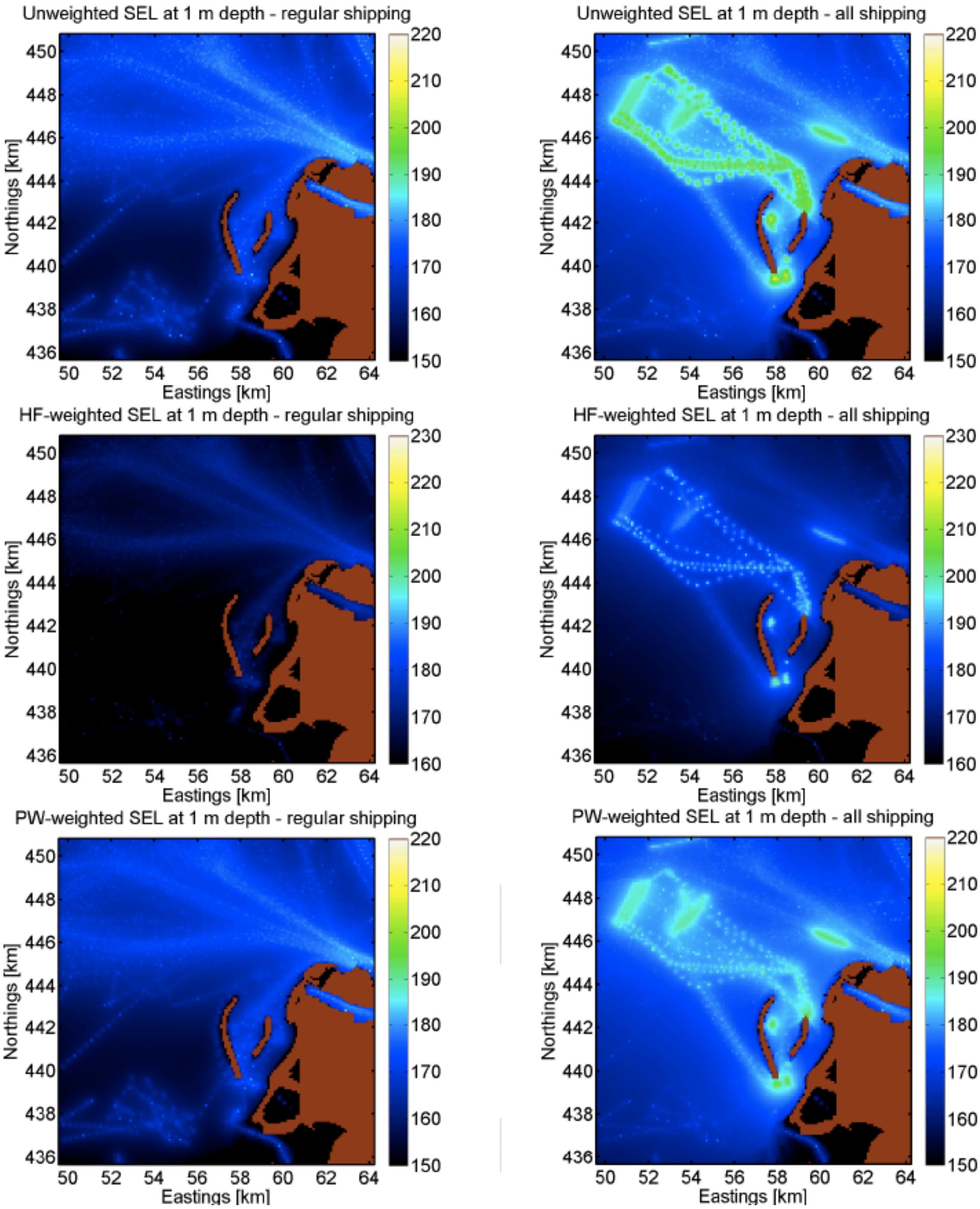

Figure 4‑7 Sound maps generated by regular shipping (left) and regular shipping + dredgers (right) at a depth of <u>1 m below the surface</u>. The figure shows the cumulative broadband sound exposure level (dB RE 1 μPa2s) for a period of 24 hours: non-weighted (top, representative for fish), M-weighted for 'high frequency cetaceans' (centre, representative for harbour porpoise) and M-weighted for 'pinnipeds in water' (bottom, representative for seals).

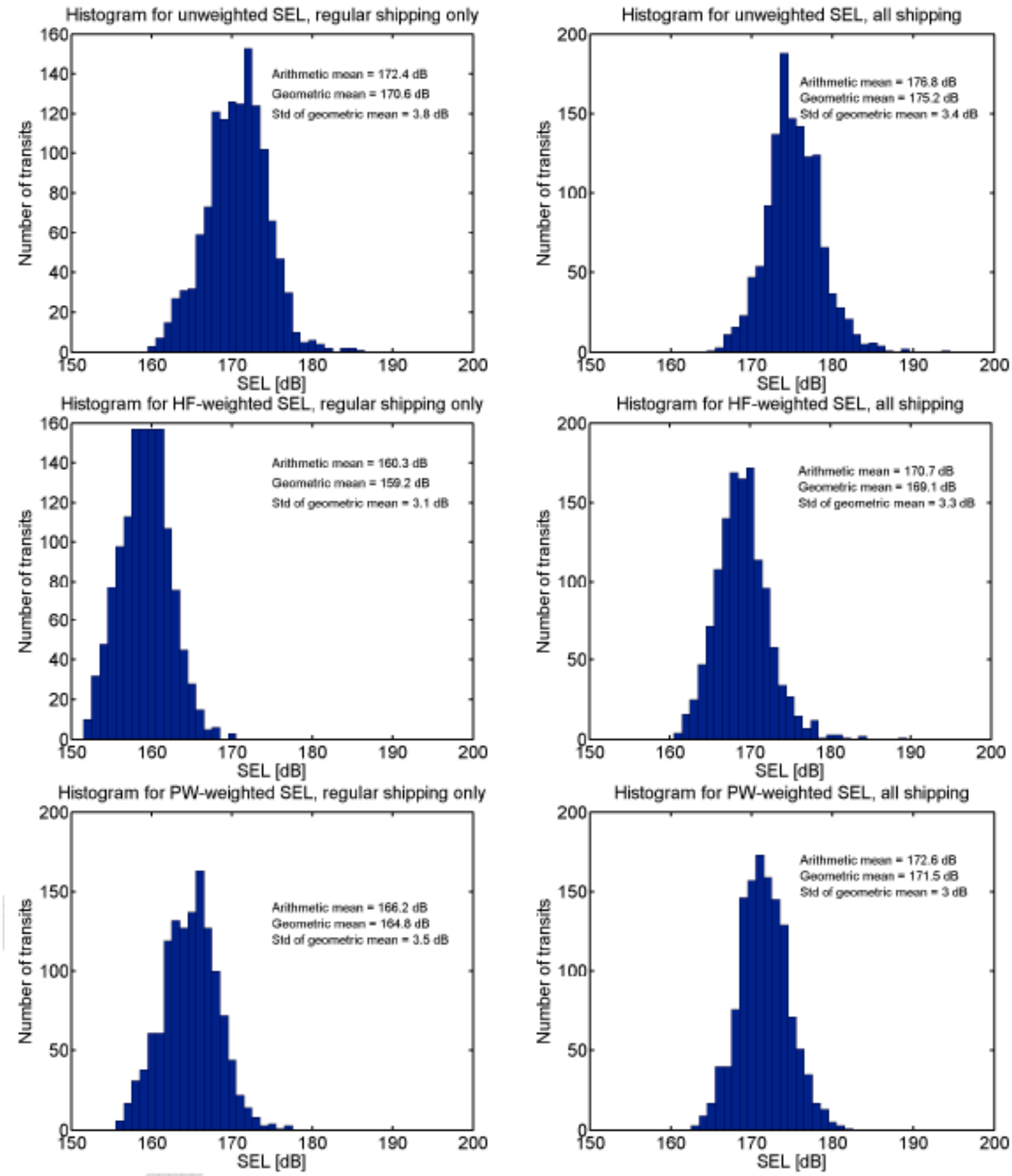

Figure 4‑8 Frequency distribution for sound exposure level (SEL) to which animals are exposed when they swim at a depth of 1 m above the seabed along a north-south line through the Maasvlakte 2 area for regular shipping traffic (left) and regular shipping including dredgers (right). Weightings: unweighted (top), M_{hf} (centre, relevant for harbour porpoises) and H_{pw} (relevant for seals).

Marine organisms are always on the move and so calculations were also made to determine the sound exposure level that harbour porpoises and seals[6] receive when swimming along a straight north-south line through the area. It is assumed here that 15 animals start to swim at intervals of 15 minutes from points situated at intervals of 500 m on a line on the southern edge of the area of 15 x 15 km between kilometre 50 and kilometre 57, proceeding northwards at a speed of 6 km/h. It was decided to adopt straight lines because all the animals then cover the same distance. The starting time for the first 15 animals was midnight on 28/29 September, after which a new group of 15 animals started out every 15 min until the end of the same day (midnight on 29/30 September 2009). The total sound exposure level was calculated for the animals during the 2.5 hours of all 1440 (24x4x15) transits.

Figure 4‑8 contains, for the three frequency weightings applied previously, histograms showing the calculated results for all 1440 transits. The average sound exposure level was also calculated for animals present in the Maasvlakte 2 area (swimming) for 24 hours. This involved calculating the average for the single transits 9.8 dB re 1 μPa^{2}s. This is the sound exposure level for an animal making the south-north crossing of 15 km without a break in a consecutive period of 24 hours ($10\log_{10}$ (6 km/h x 24 h / 15 km) = 9.8). Table 4‑3 contains an overview of the results of the calculations. A comparison of columns 4 and 5 shows that the TTS risk thresholds are not exceeded for swimming harbour porpoises and seals. In fact, fewer than 0.1% of the seals and even fewer of the harbour porpoises are exposed to a sound level that exceeds the TTS risk threshold.

Table 4‑3 Calculated SEL values for south-north transits (swimming speed = 6 km/h). S = regular shipping; S + D = regular shipping + dredgers

Shipping	weighting	threshold from Table 3‑1 SEL$_{TTS}$: dB re 1 μPa^{2}s	average (single transit) SEL: dB re 1 μPa^{2}s	24 hour exposure (several transits) SEL + 9.8: dB re 1 μPa^{2}s
S	none	n/a	172.4	182.2
S + D	none	n/a	176.8	186.6
S	M_{hf} (harbour porpoise)	195	160.3	170.1
S + D	M_{hf} (harbour porpoise)	195	170.7	180.5
S	M_{pw} (seal)	183	166.2	176.0
S + D	M_{pw} (seal)	183	172.6	182.4

[6] These calculations were not made for fish. However, they will generally swim more slowly than harbour porpoises and seals. When estimating the impact on fish, the worst-case approach can be adopted based on the results of the calculations for stationary animals (Figure 4‑6, Figure 4‑7 and accompanying text).

5 Conclusions TNO study

5.1 Measurements 2008 and 2009

- Prior to the construction of Maasvlakte 2, background sound was typically in 1/3-octave band sound pressure levels (SPL) of 114 ± 6, 105 ± 6 and 90 ± 6 dB 1 RE μPa^2 at frequencies of 100 Hz, 1 kHz and 10 kHz respectively. Corresponding average spectrum levels were 100 ± 6, 82 ± 6 and 57 ± 6 dB 1 RE $\mu Pa^2/Hz$ respectively.
- In the area around the future Maasvlakte 2, the background sound in virtually the entire measured frequency range up to 40 kHz was dominated by underwater sound from shipping. In a situation with little shipping and frequencies of more than 10 kHz, the wind is the main determinant factor.
- Sound pressure levels for the background sound measured in 2009 were, in general, slightly higher than during the measurements in 2008 and were closely correlated to the distance from passing dredgers to the SESAME monitoring station.
- A new method has been developed for the analysis of measurement data and to describe the various activities of dredgers.
- Dredgers produced most sound when they were travelling to and from the borrow and discharge areas. The next noisiest activity was sand dredging. During pumping ashore and rainbowing, the source levels in the frequency range between 500 Hz and 10 kHz were comparable with the level of vessels dredging sand, but significantly lower at higher and lower frequencies. Least sound was produced during the bottom discharge of sand.
- It can be assumed that the underwater sound generated by dredgers is mainly cavitation sound from the propellers and bow thrusters.

5.2 Validation of AQUARIUS propagation model

The measured sound pressure levels (SPL) were compared with the values predicted using the AQUARIUS model. This was done for two different dredgers, one sailing 330 m away from the fixed SESAME monitoring station and the other at a distance of 2250 m. The AQUARIUS model can predict the measured sound spectra reasonably well but it systematically underestimates measured values at frequencies below 500 Hz and overestimates the values at frequencies between 700 Hz and 30 kHz. The total, broadband sound pressure level can be underestimated by approximately 6.6 dB. Raising the sediment sound speed used in the model from 1760 m/s (medium sand) to 1960 m/s (coarse sand) can reduce this discrepancy to 3.5 dB. The calculations for determining possible effects on fish and marine mammals assumed the higher sound speed of 1960 m/s.

5.3 Impact of dredging sound on fish and marine mammals

- Possible effects on fish and marine mammals were established by comparing the 24-hour sound exposure levels for stationary animals and animals swimming past vessels dredging sand with the thresholds stated in the literature for effects on fish and marine mammals. Here, the thresholds for TTS (= temporary threshold shift) from Southall et al. (2007) were adopted for marine mammals, with the values published by the FHWG being adopted for fish (Oestman et al., 2009). These thresholds were not available during the drafting of the EIA and the Appropriate Assessment. At that time, the threshold adopted for the relevant species was the value postulated by Nedwell et al. (2003) for an effect on behaviour of 75 dB above the hearing threshold.

- The calculations for animals spending 24 hours 1 m above the seabed – which is not realistic for marine mammals because they have to breathe – produce the following results:
  - For fish, the size of the area affected increases from 23 km^2 to 72 km^2 as a result of dredging activities; the areas affected for smaller fish are 68 km^2 and 97 km^2 for regular shipping only and shipping including dredging respectively.
  - The area in which seals can suffer TTS is 10 km^2 in the scenario with regular shipping traffic only and 72 km^2 if there is also dredging activity.
  - For harbour porpoises, these areas are 0.0 and 0.5 km^2 respectively.

  The areas are much smaller for animals closer to the surface. The threshold value for a permanent threshold shift (PTS) was not exceeded in any of the cases studied or in any of the species in question.
- Seals swimming (once) on the seabed at a relative speed of 1 m/s or 3.6 km/h past a stationary vessel dredging sand will only suffer TTS if they are swimming 1 m above the seabed at a distance of 90 m or less; if they are swimming 1 m below the surface, this distance will be approximately 11 m. Harbour porpoises will not suffer TTS in any of the scenarios studied. The effect distances for fish are larger 1 m above the seabed: 100 m for fish weighing more than 2 g and 400 m for smaller fish. In the case of fish swimming closer to the surface - at a depth of 4 m - the distances will be 20 and 110 m respectively.

  The threshold value for a permanent threshold shift (PTS) was not exceeded in any of the cases studied or in any of the species in question.
- Harbour porpoises and seals repeatedly swimming backwards and forwards for a period of 24 hours at a realistic speed of 6 km/h 1 m above the seabed[7] will not suffer TTS, even in the presence of dredging activities representative for the construction of Maasvlakte 2.

5.4 Knowledge gaps

A major gap in our knowledge is the very limited availability of data about the levels at which behaviour is affected (these data are virtually non-existent) and data about other effects on hearing, whether temporary or permanent. This is the main reason TTS was adopted as the primary effect indicator. Data on this indicator are available, albeit limited. No effect measurements have been conducted yet in which animals are exposed to the types of continuous sound that is most relevant for the underwater sound generated by ships, in other words broadband sound with considerable energy at relatively low frequencies. This means that, despite the fact that new results from experimental studies of animals including harbour porpoises became available during the course of the TNO study, they could not be used because they related to pulse sound (Lucke et al., 2009) or other, higher, frequencies than those relevant to shipping sound (Kastelein et al., 2012).
Another gap in our knowledge is the lack of data about TTS recovery time and conditions. This can have important implications for determining the effects on animals swimming through an area with a range of

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[7] This is an unrealistic 'worst case'. Harbour porpoises and seals cannot stay underwater for 24 hours without breathing.

sound sources, mobile or otherwise, and the total length of time adopted for cumulative sound exposure (this was 24 hours in the TNO study).

6 Evaluation

6.1 Permit provision (article 3(6)(c)(7))

The provision in the Soil Removal Permit for the construction of Maasvlakte 2 required the Port of Rotterdam Authority to conduct 'sound measurements to determine the actual levels of sound generated by dredging, transportation and discharge'. This provision was formulated in the following terms in the Maasvlakte 2 Construction Monitoring Plan approved by the competent authorities: 'the acoustic source levels of a trailing suction hopper dredger using a monitoring vessel on location during sand dredging, sailing to the sandfill, bottom discharge, rainbowing, and pumping the sand ashore'.

Compliance with the permit was achieved by publishing the report on the baseline measurements and the TNO data report containing the results of the measurements of background sound and sound generated by dredging activities (Dreschler et al., 2009; De Jong et al., 2010). The reports provide a complete picture of the variation in the source levels generated by the different phases of the dredging cycle (see also Intermezzo, Representativeness of measurements in 3.2.1).

Furthermore, the last report from TNO, which was completed in November 2012, was accompanied by a DVD with a series of eighteen 24-hour films showing a day that was representative for the activities of the dredgers (29 September 2009). Those films show variations in the soundscape below the water over the course of those 24 hours in three situations and at two depths:

- Dredging activity only;
- Dredging activity and regular shipping;
- Regular shipping only.

The background to the calculations upon which the films were based has been described in the aforementioned TNO report (Ainslie et al., 2012).

6.2 Maasvlakte 2 Construction Monitoring Plan (fact sheet Z5)

6.2.1 Sound contours

The Maasvlakte 2 Construction Monitoring Plan describes how measurements of underwater sound in the field will be used to determine the source levels generated by a trailing suction hopper dredger during sand dredging, sailing to the sandfill, bottom discharge, rainbowing, and pumping the sand ashore. On the basis of these measurements of source levels (from characteristic dredgers), a numerical model was used to calculate acoustic contours weighted on the basis of the hearing frequencies of the marine mammals (harbour porpoises and seals) for the vicinity of the work.

As with unweighted sound (see section 6.1), films were also made in which the sound was weighted according to the specific hearing sensitivity of harbour porpoises and seals using the M-weighting proposed by Southall et al. (2007). The sounds were not weighted for fish because fish are actually sensitive to low-frequency sound of the kind produced by ships. The contours in the animation films showing broadband sound pressure level (SPL in dB re 1 μPa^2) provide a good picture of the spatial and temporal variations in the soundscape as it might be perceived by the three different species. To that extent, this constitutes the implementation of the measurement strategy set out in fact sheet Z5 of the

Maasvlakte 2 Construction Monitoring Plan. However, the mobility of the sound sources (in other words, the ships) means that it is not possible to derive on the basis of the films the extent of any effects or how those effects are related to the effect predictions in the EIA and the Appropriate Assessment.

6.2.2 Comparison with effects predicted in Environmental Impact Assessment and Appropriate Assessment

At the time, the EIA and the Appropriate Assessment concluded on the basis of now outdated assumptions that the behaviour of fish and marine mammals can be influenced at a distance of a few hundred metres from a dredging vessel (see section 2.1). The TNO study adopted different principles, criteria and calculation methods. With respect to the assessment of effects on animals, the most important of those was that any effects are measured on the basis of a cumulative sound exposure level that may result in a temporary hearing threshold shift (TTS onset). And it was decided to adopt this physiological criterion because of the lack of relevant thresholds for effects on behaviour. However, there are indications that, at sound levels below the TTS threshold, there are no changes in behaviour in certain marine mammal species, including the seal (Southall et al., 2007). In order to obtain an impression of effect contours, calculations were made to determine the extent to which fish, seals and harbour porpoises swimming past a vessel dredging sand at a relatively low relative speed of 1 m/s may suffer TTS (or PTS).

It emerged, on the basis of the Southall criteria, that:

- the thresholds for PTS or TTS are not exceeded for harbour porpoises;
- in the case of seals,
    - the threshold for PTS is not exceeded,
    - the threshold for TTS is exceeded at a distance of 15 m or less from the dredging vessel when the animals are swimming 1 m below the surface of the water,
    - the threshold for TTS is exceeded at a distance of 90 m or less from the dredging vessel when the animals are swimming 1 m above the seabed.

The effect contours calculated in this study are therefore lower for harbour porpoises and seals than the 'few hundred metres' mentioned in the EIA and the Appropriate Assessment.

The following contours were calculated for fish on the basis of the FHWG criteria for pile-driving sound:

- For fish heavier than 2 g, the criterion is exceeded at a distance of 100 m or less from the dredging vessel when the animals are swimming 1 m above the seabed; for smaller fish, this distance is 400 m;
- For fish heavier than 2 g, swimming 1 m below the surface of the water, the criterion is not exceeded; for smaller fish, the criterion is exceeded at a distance of 20 or less from the dredging vessel.

It can be concluded that the maximum effect contours calculated in the study for fish are of the same order of magnitude as those stated in the EIA and the Appropriate Assessment.

6.3 Evaluation question 9C in Maasvlakte 2 Monitoring and Evaluation Programme

This section looks at the question of whether, and if so, to what extent the results of the TNO study can contribute to answering evaluation question 9c in the Monitoring and Evaluation Programme drawn up by the competent authorities: 'To what extent is the behaviour of marine mammals and fish affected by the underwater sound produced as a result of the dredging, transportation and discharge of sand to the extent that populations of marine mammals and fish are affected?' The elaboration of any effects of a rise in underwater sound during the construction of Maasvlakte 2 on the behaviour of marine mammals and fish, and therefore on the populations of these animals, is not included in the planned monitoring approach adopted by the Port of Rotterdam Authority. However, on the basis of the results of the study, some conclusions can be stated that contribute to answering the evaluation question.

6.3.1 Research results relevant to answering the evaluation question

To establish a picture of the possible maximum effect distances, calculations were made to determine where, in the area of 15 x 15 km under study, thresholds for TTS would be exceeded if an animal were to remain stationary there for a period of 24 hours (and therefore be exposed to sound from ships passing by). The calculations were conducted for two depths and for scenarios with and without active dredgers. The maps showing the impact on fish and marine mammals are presented in Figure 4‑6 and Figure 4‑7. The size of the area in which the stationary animals could suffer TTS was then calculated. In the case of harbour porpoises, this proved to be an area of less than 1 km^2. For seals staying near the seabed for a period of 24 hours, the area was 10 km^2 in the scenario with regular shipping traffic only, extending to 72 km^2 in the scenario with regular shipping + dredgers. The areas for animals spending 24 hours at a single location close to the surface of the water were much smaller. For fish, a larger maximum size of the area affected resulted from the calculations (see section 5.3).

In reality, marine mammals never stay still for a long time in natural conditions; they are constantly swimming in order to feed and to move from one place to another. They also spend more time relatively close to the surface of the water than to the seabed because they cannot breathe underwater. Calculations were therefore made for the situation in which seals and harbour porpoises swam for a period of 24 hours at a realistic speed of 6 km/h along north-south lines in the area measuring 15 x 15 km (9.6 transits in 24 hours). To establish a worst-case scenario (the sound level is lower near the surface of the water) calculations were only conducted for animals swimming 1 m above the seabed for a period of 24 hours. In this rather unrealistic scenario, harbour porpoises and seals will not suffer TTS, even in the presence of dredging activities representative for the construction of Maasvlakte 2.

6.3.2 Conclusion

The evaluation question primarily addresses the issue of whether the normal behaviour patterns of fish and marine mammals are disturbed by the large increase in underwater sound levels during the construction of Maasvlakte 2. The next question is whether any effect on behaviour will result in a negative impact on the population.

The previous section showed, on the basis of the TNO study using the criteria of Southall et al. (2007), that the dredging work for the construction of Maasvlakte 2 does not have any negative impact on the hearing of harbour porpoises or seals. This means that these species, despite the fact that they can hear the ships, will not be hindered in their perception of the surrounding 'soundscape'. If that is the case, it is also reasonable to assume that they will behave (and feed) naturally. At this point, the possibility of an effect on the population can be excluded. For fish, the effect distances calculated on the basis of the criteria used are larger. The total sizes of the area affected (temporarily) are, however, very small by comparison with the size of the total area in which the animals live. The effect is therefore local.

The point that should be made with respect to this conclusion is that relevant knowledge about sound levels at which effects may occur as a result of exposure to continuous sound was relatively limited at the time of the study (and, indeed, it still is). Data are not available about the different responses of seals and harbour porpoises to sound that is representative for shipping sound. It is expected that this knowledge gap will not be remedied in the near future since the research programmes currently in place focus primarily on the effects of pulse sound generated by pile driving at sea, which is much louder than sound generated by shipping.

7 Literature

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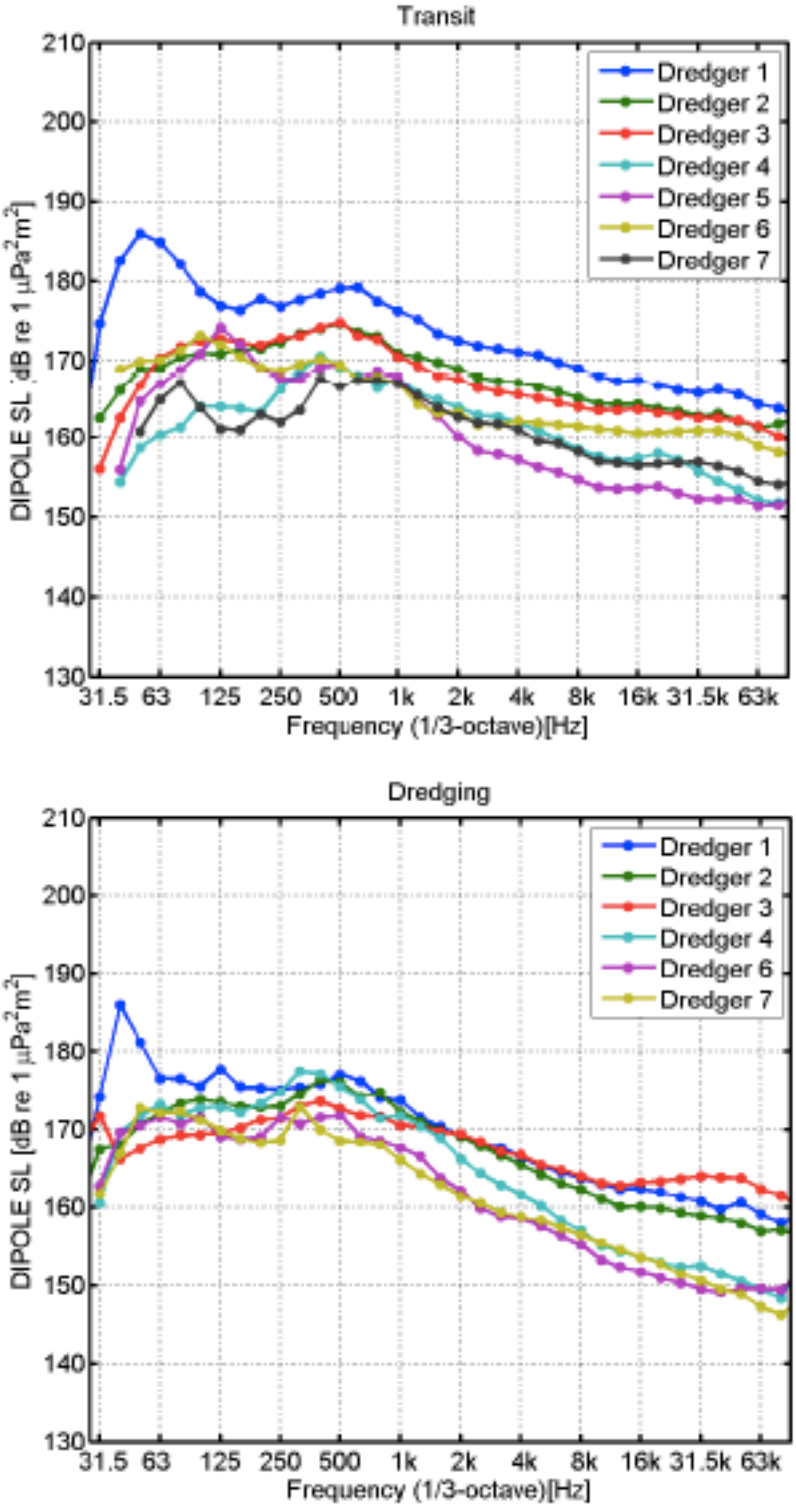
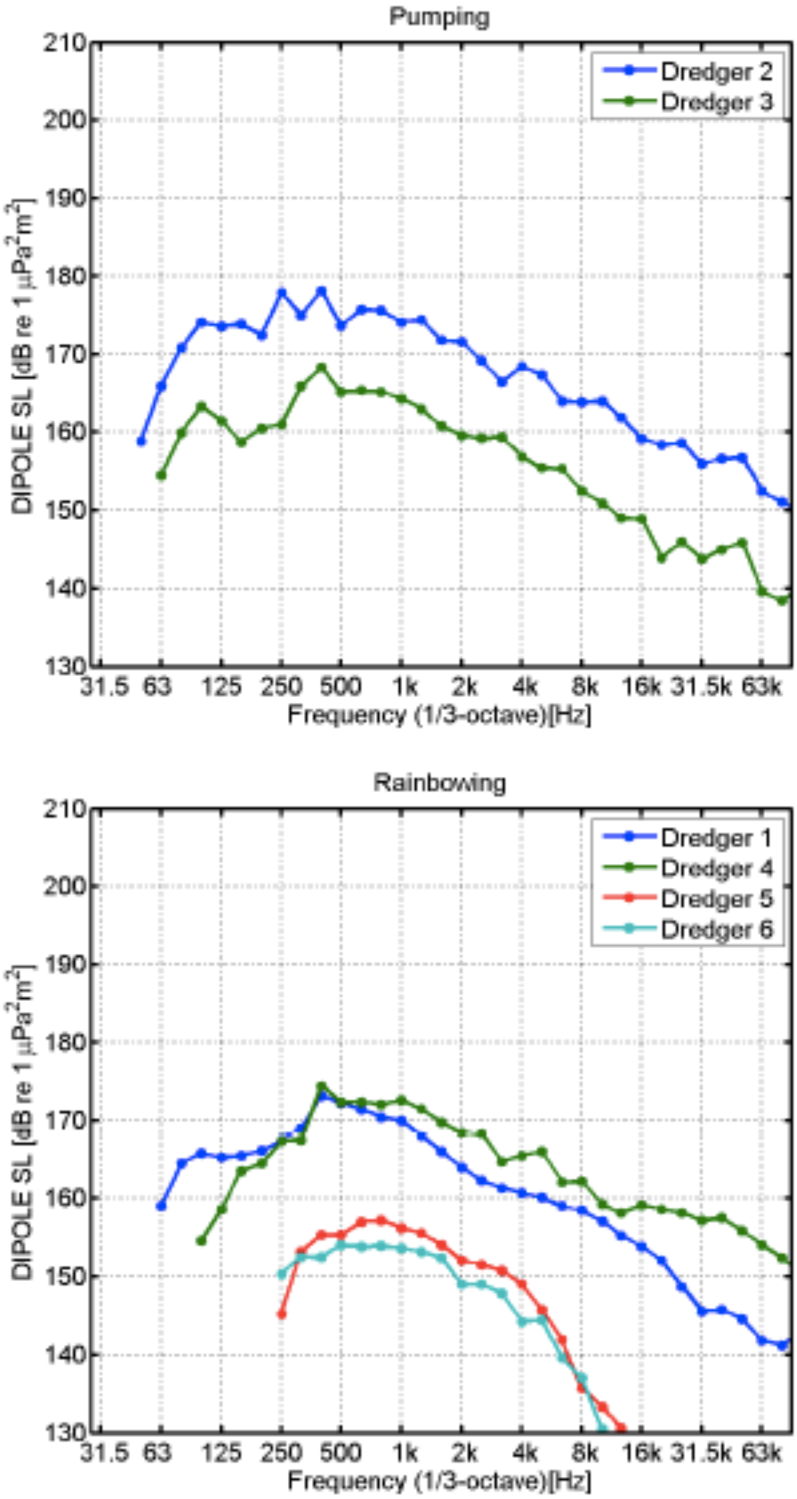
ANNEX 1



Annex figure 1 Dipole source level (dB re 1 μPa^2) in 1/3-octave bands from dredgers 1 to 7 during transit (top) and from dredgers 1 to 4 and 6 and 7 during sand dredging (bottom)



Annex figure 2 Dipole source level (dB re 1 μPa^2) in 1/3-octave bands from dredgers 2 and 3 during pumping ashore (top) and from dredgers 1, 4 and 5 and 6 during rainbowing (bottom)