EFFECTS OF BLADDERED FISH ON AMBIENT NOISE MEASUREMENTS CLOSE TO THE PORT OF ROTTERDAM

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Abstract: *Ambient noise in the frequency range 25 Hz to 80 kHz was measured at a site close to the Port of Rotterdam in September 2008, before construction began of a port extension known as 'Maasvlakte 2' [http://www.maasvlakte2.com/en/index/], and in September-October 2009 (during construction). Day-night differences are present in the 2009 measurements that were not observed in 2008. The largest diurnal change appears in third octave bands close to 3 kHz, in the form of an absorption band that appears only at night. The observations are consistent with scattering and absorption of sound by small bladdered fish, of length 3 to 5 cm.*

Keywords: *Shipping noise, absorption, fish bladder resonance*

1. INTRODUCTION

Ambient noise measurements were carried out close to the Port of Rotterdam during two one-week periods, the first in September 2008 and the second in September-October 2009. Dredging operations associated with a port expansion known as 'Maasvlakte 2' began in 2009 and continued throughout the 2009 noise measurements. Details of the 2008 and 2009 measurements are reported in [1] and [2], respectively. The present focus is on diurnal variations observed in the data of September-October 2009 and in particular on day-night differences associated with suspected biological activity.

The measurement location and conditions are summarised in Section 2, followed by a description of the noise measurements and the diurnal variations in Section 3. In Section 4 we provide our interpretation of the diurnal variations in terms of scattering and absorption of sound by small bladdered fish. Conclusions are given in Section 5.

2. MEASUREMENT LOCATION AND CONDITIONS

The location of the noise measurements is indicated by the letter 'Z' in Figure 1. In 2008 the background measurements were carried out at coordinates 51.96723º N, 3.91567º E (long., lat., WGS84). In 2009 the measurement platform was installed at coordinates 51.96522º N, 3.94677º E, about 2 km east of the 2008 measurements. This move was made for safety reasons, to avoid risk of collision with nearby ships, including fishing vessels. The water depth at the measurement site was about 20 m, and measurements were made at heights of 2 m and 4 m above the (sand) seafloor. All data presented are for the lower of the two hydrophones (2 m height). Meteorological measurements were made at a nearby site on land, indicated by the red cross in Figure 1. The recorded wind speed (one minute averages at height 4.5 m) varied mostly between 0 and 7 m/s, with occasional gusts up to 9 m/s. On most days, the air temperature was between 13 and 17 ºC and water temperature between 18 and 20 ºC, so on average the water temperature exceeded the air temperature by about 4 ºC. No precipitation was recorded.

The main shipping route into and out the Port of Rotterdam is indicated by the magenta tracks running roughly east-west, about one third distance from the top of the chart. During the 2009 measurements these routes were displaced slightly northward, to avoid the dredgers, which spent much of their time along the trajectory A-B-C south of the shipping lane. The green regions either side of the shipping lane indicate areas for which dredging activity was licensed. The locations of source level measurements associated with dredging, transport and dumping of the sand (see [2, 3]) are indicated by the letters 'A', 'B' and 'C', respectively.

3. AMBIENT NOISE MEASUREMENTS

3.1. Overview

Recordings of duration 6 s were made once per minute, corresponding to a 10 % duty cycle. The sampling frequency was 200 kHz. The measurements were filtered between 50 Hz and 80 kHz (-3 dB points) and processed into the 25 Hz to 80 kHz third-octave bands, with a correction for the filter characteristics. The sound pressure level in each third octave band for the period 25 September to 2 October 2009 is shown in Figure 2.

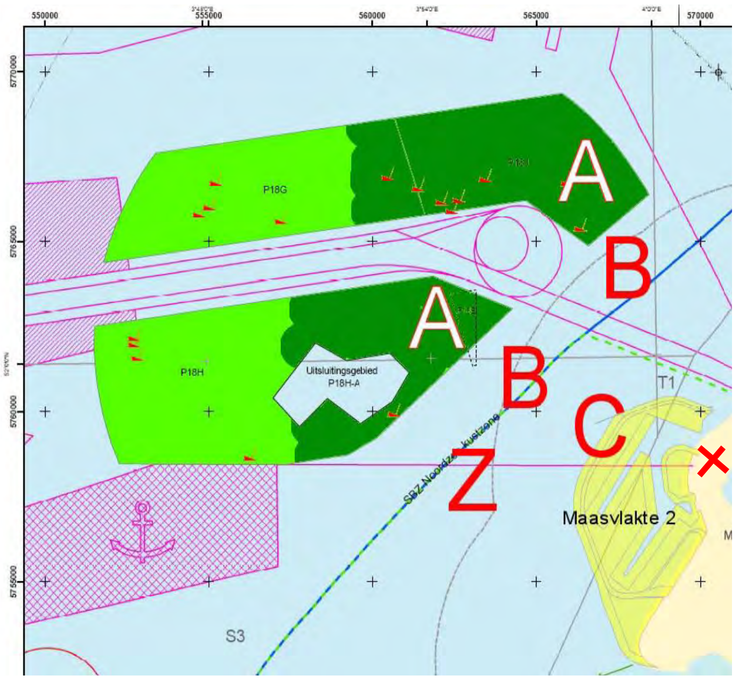

Fig.1: Area map with Maasvlakte 2 and the dredging areas (green). The ambient noise measurements were carried out at location Z. Other letters indicate the location of source level measurements of different activities. The approximate location of the meteorological measurements on land is marked with a red cross. The Port of Rotterdam is just off the map to the east (see Fig. 6). Tick marks are separated by 5000 m*; the total extent of the map is approximately 20* km *by 25* km.

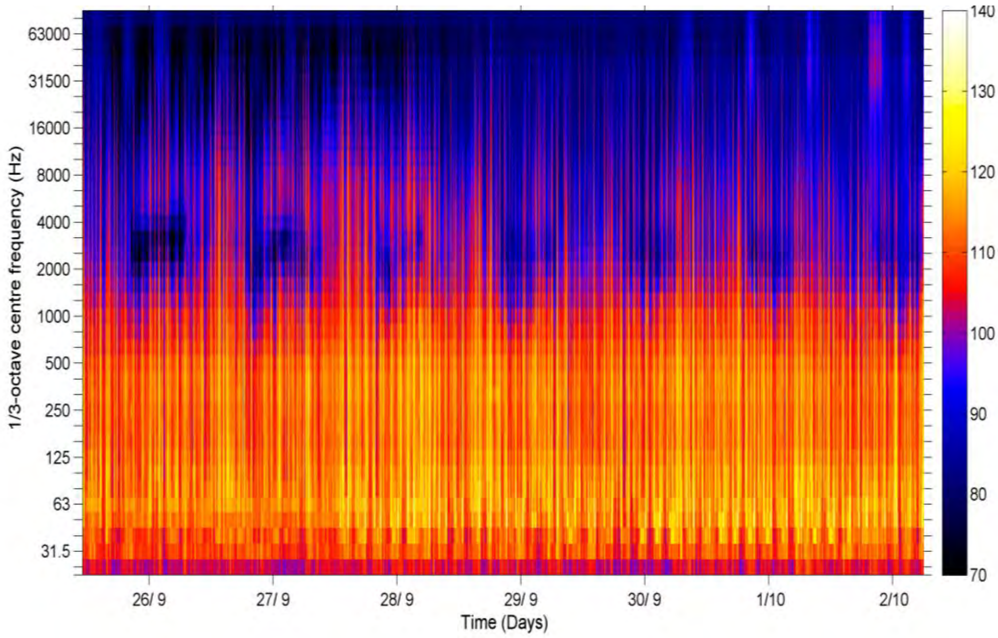

*Fig.2: Sound pressure levels [*dB re 1 μPa^2*] in 1/3-octave bands versus time for the selected data taking period, with a time resolution of one minute. The ticks on the time axis specify the beginning of each day at 00:00 local time (UTC + 2 hours).*

The third-octave band sound pressure level is plotted versus centre frequency in Figure 3. The results for all individual measurements are plotted in light grey. In the same figure the corresponding percentiles P5, P16, P50, P84, and P95 are drawn. Each percentile indicates the percentage of measurements for which the levels were below the value of the percentile: 5%, 16%, 50%, 84%, and 95%, respectively. The red line shows the mean square pressure in decibels. The green lines show the mean of the individual SPL measurements (geometric mean of the mean square pressure), one standard deviation above the mean and one standard deviation below it.

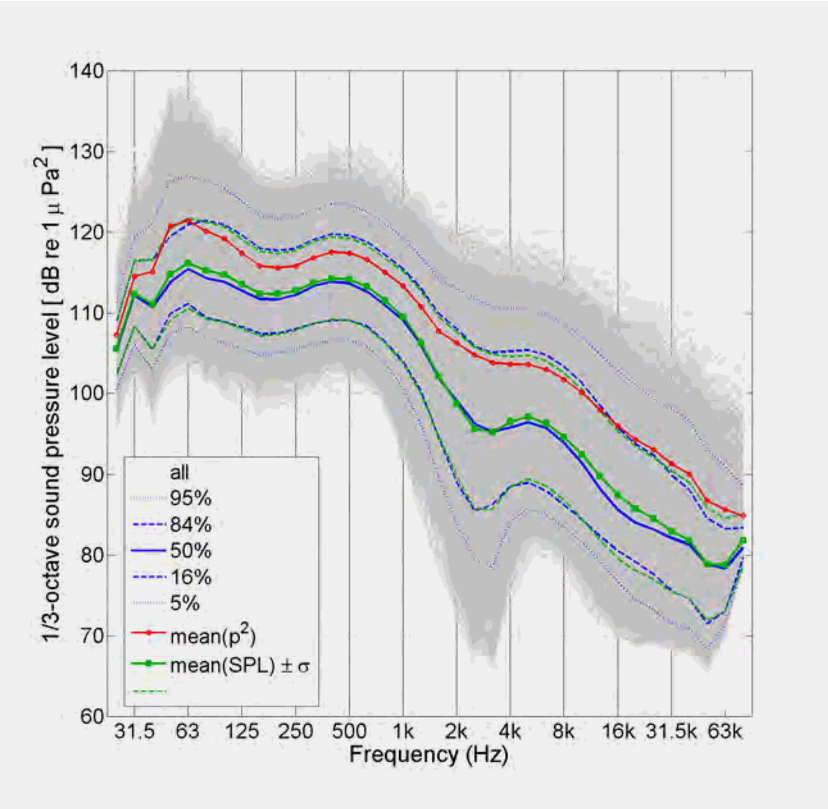

Fig.3: Sound pressure levels in 1/3-octave bands. The results of all individual measurements are represented by the light-grey lines. The blue dotted, dashed, and solid curves represent the percentiles P5, P16, P50, P84, and P95. The red and green curves represent average values of the noise levels for, respectively, averaging over the mean square pressures and averaging over corresponding levels in decibels. The green dashed curves represent the levels at ±1 standard deviation from the latter average.

3.2. Diurnal variations

Diurnal variations can be seen in the spectrogram of Figure 2 in the 1600-5000 Hz bands. This time dependence is illustrated for the 2500 Hz band in Figure 4, which for each time of day is averaged over about 6 days (duration of the spectrogram of Figure 2). Every day the levels are seen to increase around sunrise and to decrease around sunset. The rapid decrease (after averaging) between 19:30 and 21:00 local time is particularly striking. The quietest period occurs between 21:00 and 23:00, during which time the median level is 5 dB lower than the quietest noon measurement (P5). There are noise peaks at 07.00 and 19:00, coinciding approximately with dawn and dusk.

The percentiles for day-time and night-time measurements are compared in Figure 5. Measurements between sunrise and sunset are categorized as day-time measurements, and measurements between sunset and sunrise are categorized as night-time measurements. The dip around the 2500 Hz and 3150 Hz bands is clearly visible during the night and not during day time. For lower and higher frequencies the percentiles for day-time and night time sound pressure levels agree reasonably well.

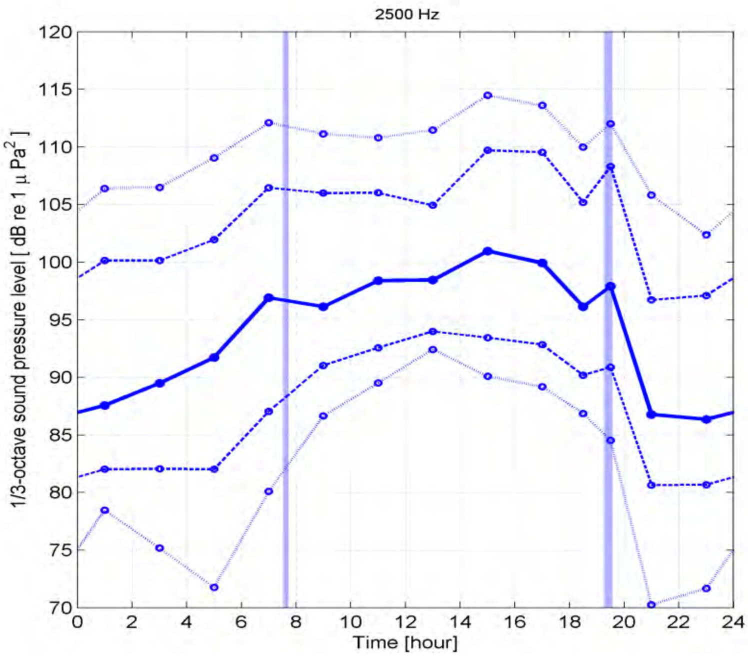

Fig.4: Percentiles of sound pressure levels in the 2500 Hz band as a function of the time of day. The curves represent the percentiles P5, P16, P50, P84, and P95. The percentiles are determined for time intervals of two hours combined from all days of the measurement period. The vertical light-blue bands indicate sunrise and sunset. The time is given in Amsterdam local time, which at the time of the measurements was UTC plus 2 hours.

4. INTERPRETATION OF DIURNAL VARIATIONS

In this section we advance the hypothesis that the diurnal variations in noise level around 3 kHz are caused by diurnal changes in propagation loss around this frequency. In 2008, a negative correlation was observed between SPL and wind speed across a broad frequency range between 100 Hz and 20 kHz [1], suggesting that the noise in this range of frequencies is not locally generated, but has travelled some distance, arriving at the hydrophone after perhaps several sea surface interactions. In 2009, a similar negative correlation was observed, except that this correlation vanished in the third octave bands close to 3 kHz, suggesting that local sources dominate at this frequency [2, 4], consistent with distant sources being heavily damped in the 2009 data.

We further suggest that the main cause of the diurnal changes in propagation loss is absorption and scattering of sound from fish bladders, combined with diurnal changes in the fish behaviour. A characteristic signature of absorption due to (bladdered) fish is a marked diurnal variation (due to their aggregation into shoals during the day and dispersal at night) and a broad absorption band around the bladder resonance frequency [5-9], both of which are present in the observed spectra.

The resonance frequency of a fish of length L at depth z (both in metres), for a bladdered fish, can be estimated using [10]

$$f_0(L) \approx (0.079\,\text{kHz})\frac{\sqrt{0.1z + 1.75}}{L}. \tag{1}$$

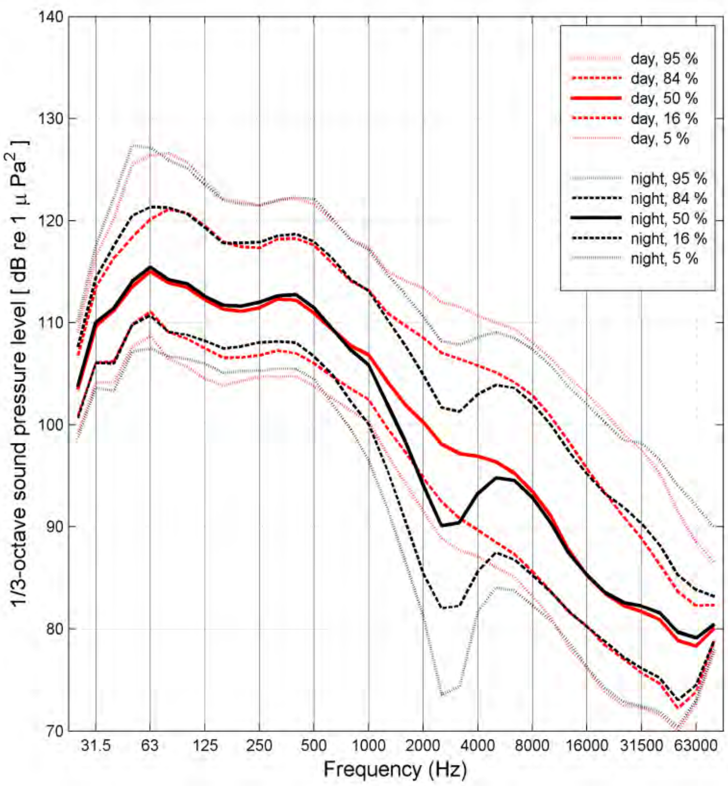

Fig.5: Comparison of the percentiles of day-time and night-time sound pressure levels. At frequencies around 2500 Hz the night-time percentiles are consistently lower than the day-time percentiles.

Therefore, for a given resonance frequency f_0 (in kilohertz), the corresponding fish length is

$$L(f_0) \approx (0.079\,\text{m})\frac{\sqrt{0.1z + 1.75}}{f_0}. \tag{2}$$

For example, in the depth range 0 to 20 m, the length of fish that would resonate at 3 kHz is between 3 and 5 cm. Candidate species of the right size and likely to have been present, although not necessarily in sufficient numbers, include sprat, juvenile whiting and juvenile herring. A survey of fish in 2007 revealed the presence of sprat, whiting and herring between April and October of that year [11], as illustrated by Figure 6, which shows the measured abundance distribution for sprat. A bottom trawl survey reveals that pelagic fish of length 5 to 10 cm (mostly juvenile herring and juvenile whiting, with some sprat) were present close to the seabed in the autumn of 2009 [12], but it is unclear what implications this might have for the density of these three species in the rest of the water column.

Assuming a radiation Q-factor of 30 and a group Q-factor of 2, a population of one fish per ten cubic metres would result in an attenuation of 2 dB/km.[10] This is sufficient to dampen sound from the main shipping lane, which was about 5 km away from the measurement platform. Sprat are regularly present in the region, at least in the spring [13].

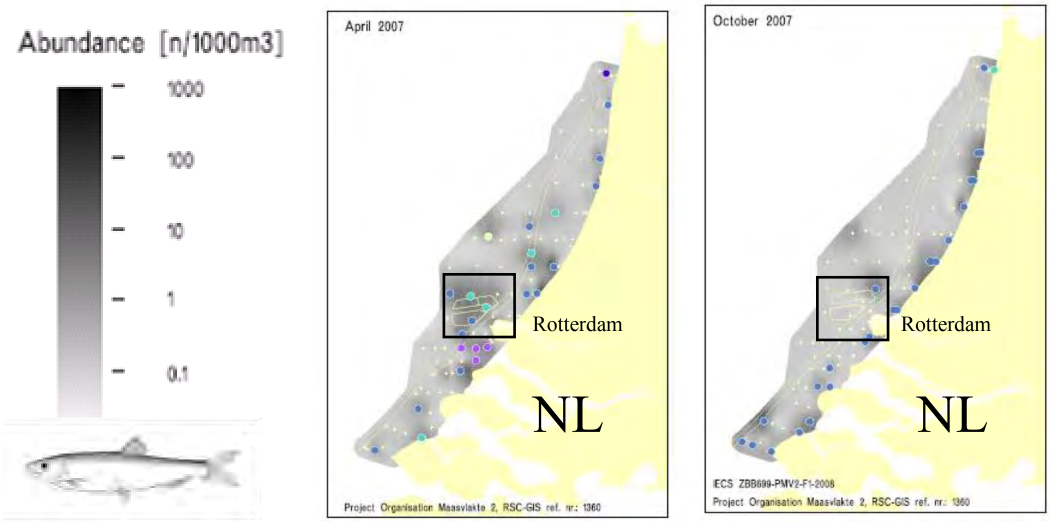

Fig.6: Measured distribution of sprat along the Dutch coastline for April 2007 and October 2007 [11]. The black rectangle indicates the Maasvlakte area (Fig.1).

5. CONCLUSIONS

Third octave band ambient noise measurements close to a shipping lane are presented in the frequency range 25 Hz to 80 kHz. Strong diurnal variations are observed at 3 kHz, with gradual increase around dawn and sharp decrease of about 10 dB at dusk. A negative correlation with wind speed is observed between 100 Hz and 20 kHz, except in third octave bands close to 3 kHz.

The negative correlation with wind speed observed in 2008 (see Sec. 4) indicates propagation from non-local (i.e., not overhead) sources, most probably from the shipping lane or from dredgers, or a combination of both. The diurnal variation suggests biological activity. The absorption band around 3 kHz is consistent with scattering from bladdered fish of length between 3 and 5 cm, the most likely candidates being sprat, juvenile whiting and juvenile herring.

Other authors have suggested that (passive) sound measurements might be used to classify fish [5, 14]. However, despite the considerable literature on the scattering and absorption of sound by fish, the authors are unaware of any previous measurement of an absorption band in ambient noise associated with fish.

6. ACKNOWLEDGEMENTS

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