REACTIONS OF COD (GADUS MORHUA) TO LOW FREQUENCY SOUND RESEMBLING OFFSHORE WIND TURBINE NOISE EMISSIONS

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1 ABSTRACT

The growing number of offshore wind farms will lead to an increase in anthropogenic noise in the sea. Many fish such as cod have good hearing abilities and use sound for intraspecific communication. Research is therefore necessary to identify and minimize any potentially negative effects of offshore wind turbine noise on fish.

Behavioural experiments were carried out in an annular concrete tank of 10 m in diameter to examine the reaction of cod to low frequency sound. The tank was divided into connected quarters to achieve a sound pressure difference of between 32 and 52 dB, depending on produced frequencies and sound levels. The fish could therefore avoid highest sound levels if they chose to. Pure tones from the frequency range of offshore wind turbine noise were artificially emitted at sound levels of 130 and 140 dB re 1 µPa.

The location of the fish in the 24-hour periods before, during and after sound production were compared showing significantly lower numbers of cod in the tank quarter containing the sound source in most experiments during sound production. Strongest reactions were observed at frequencies of 60 and 90 Hz.

From the results, at least short-term changes in distribution of cod, related to noise in the vicinity of offshore wind farms could be expected.

2 INTRODUCTION

The reasons for and effects of climate change have been frequently discussed among scientists and politicians around the world. The main preventive measure is the radical reduction of CO_2 emission as one of the major greenhouse gases. Using renewable energy such as wind turbines is one important way to reduce CO_2 emissions. Especially in densely populated regions such as Central Europe suitable onshore wind farm sites are limited and offshore wind farms that are more effective due to stronger and more predictable winds at sea will play an important part in electricity production. A number of offshore wind farms have already been installed mainly off the coasts of Denmark and the UK and further wind farms are planned or under construction.

A disadvantage of offshore wind farms is the fact that they add low frequency noise to the already existing anthropogenic noise level in the sea, which is likely to influence marine animals such as fish or marine mammals.

There is only limited knowledge about the hearing ability of fishes. The larger number of fishes are hearing generalists that are mostly restricted to detection of frequencies below 500 to 1000 Hz [1]. Some groups of fish known as hearing specialists developed special adaptations that widen the detectable frequency range and that lower the hearing threshold by up to 20 dB [2].

The hearing ability of cod is very good compared with that of other hearing generalists. In its most sensitive range between 60 to 380 Hz hearing is mostly restricted by background noise rather than hearing ability [3]. Additionally cod uses grunts for intraspecific communication during courtship or agonistic behaviour [4]. Therefore cod was chosen for the following behavioural experiments as an important North and Baltic Sea species that might be affected by the noise of offshore wind farms.

But especially in fish populations it is difficult to examine disturbing factors in the open sea. Reactions in the wild are a combined effect of a number of variable factors and the size of fish stocks is varying largely with time [5,6]. Additionally in the open sea behaviour of fish is difficult to observe. Therefore, fish were tested in tank-based experiments where a controlled sound pressure difference in defined sound fields could be created. This is seen as a first step to examine the behaviour of fish to anthropogenic noise.

3 MATERIAL AND METHODS

3.1 EXPERIMENTAL SETTINGS

Experiments were carried out in an annular concrete tank of 10 m in diameter 1.26 m deep. It was divided in connected quarters by sound barriers made from Styrofoam and plywood. Three of the sound barriers left a gap of 0.7 m to the outer wall to allow the fish to move around freely in the tank. The fourth barrier was as long as the circular radius (3.68 m) to avoid sound circulating in the tank. Figure 1 shows a sketch of the tank containing the sound equipment.

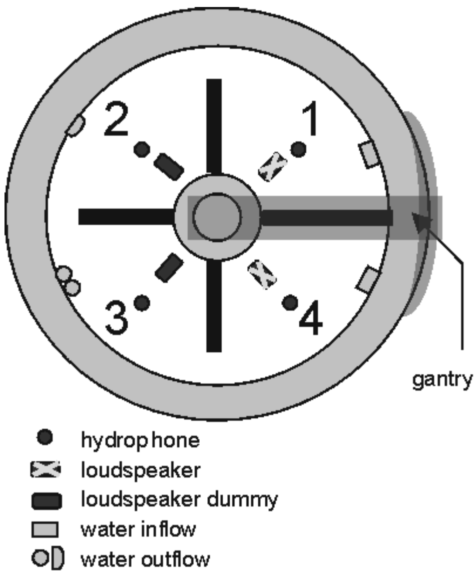

Figure 1: Sketch of the tank divided in connected quarters that were numbered anticlockwise.

For sound production two loudspeakers (Type J11-Audio-Frequency Transducers, USRL US-Navy) were located centrally in quarters 1 and 4 five centimetres above the tank bottom. Two loudspeaker dummies, made from plastic were placed in quarters 2 and 3. A hydrophone was positioned in the centre of every quarter but only the hydrophones in quarter 1 and 4 (TC4013 (Reson) and a 6050C (ITC)) were used for sound measurements.

It was decided to test single frequencies from the range of offshore wind farm noise to investigate whether those frequencies would cause behavioural reactions. The frequencies were chosen on the basis of offshore wind farm noise measurements and predictions [7,8] and biologically important frequencies for cod. Frequencies causing greater effects could be reduced by adaptation of future turbines if necessary. Sound was produced at frequencies of 25 Hz, 60 Hz, 90 Hz, 125 Hz and 250 Hz at sound levels of 130 and 140 dB re 1µPa. The sound levels were chosen on the basis of predicted levels of a 4.5-MW offshore turbine [8] showing maxima of about 140 dB re 1µPa@10m at some frequencies.

The sound pressure level in the tank was determined at 86 measurement points at four different water depths (0 m, 0.4 m, 0.8 m, 1.2 m from bottom) showing a sound pressure difference with high sound levels close to the sound source and much lower sound levels in large parts of the tank in all produced sound fields. Local sound pressure peaks and dips caused by interferences when reflecting sound waves join together again were not observed. A sound pressure difference of 32 to 52 dB depending on frequency and produced sound level was achieved and therefore the fishes could avoid highest sound levels by moving to other parts of the tank. An example for the sound field in the tank during sound production in quarter 1 is given in Figure 2. Measurements during sound production in quarter 4 showed comparable results. Sound levels decreased from the bottom of the tank to the water surface. The differences between bottom and surface generally came to 12 to 15 dB.

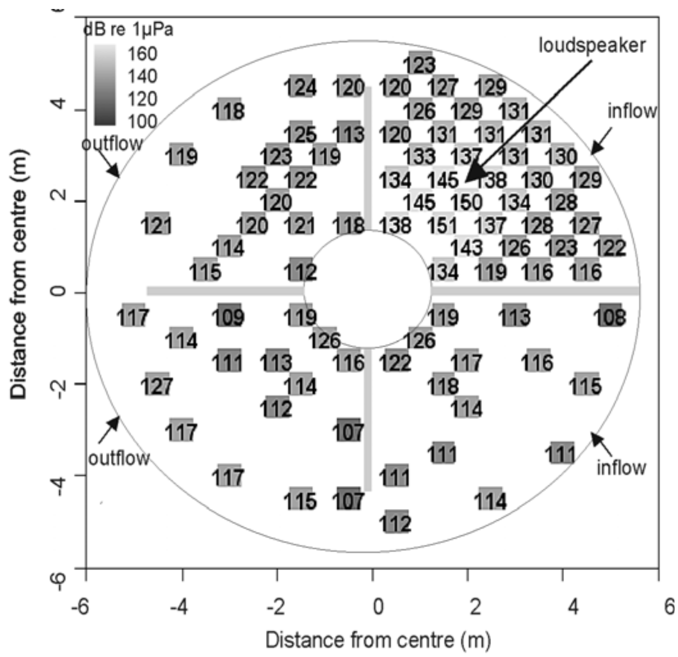

Figure 2: Sound field in the experimental tank 0.4 m above the bottom of the tank during sound production of 250 Hz at a sound level of 130 dB re 1µPa (measured at a reference hydrophone at 0.72 m distance from the sound source). The sound was produced in quarter 1 (above right). In the vicinity of the loudspeaker sound pressure exceeded the reference sound level. With distance from the loudspeaker the sound decreased rapidly. In the other quarters the sound levels were much lower, sound levels being lowest in quarters 3 and 4 (bottom left and right). Close to the outflow in quarter 3 (bottom left) the sound level increased by more than ten decibel.

Two groups of juvenile and adult cod were exposed to 9 experiments consisting of 24 hours continuous pure tone sound production and 5 days recovery each. The number of fish, their distribution and behaviour in tank quarter 4 containing the sound source in the periods 24 hours before, during and after sound were evaluated in regular time intervals using video surveillance above the tank.

4 RESULTS

The fish showed a preference for quarter 4 (most likely caused by stronger currents at the water inflow in this quarter), and for this reason, the sound was produced in this quarter. During sound production the number of cod in quarter 4 decreased significantly in most of the experiments compared with the periods before and after sound presentation. Reactions were most pronounced at the frequencies 60 and 90 Hz with still significant reactions at the frequencies of 25 and 125 Hz. A sample is shown in Figure 3.

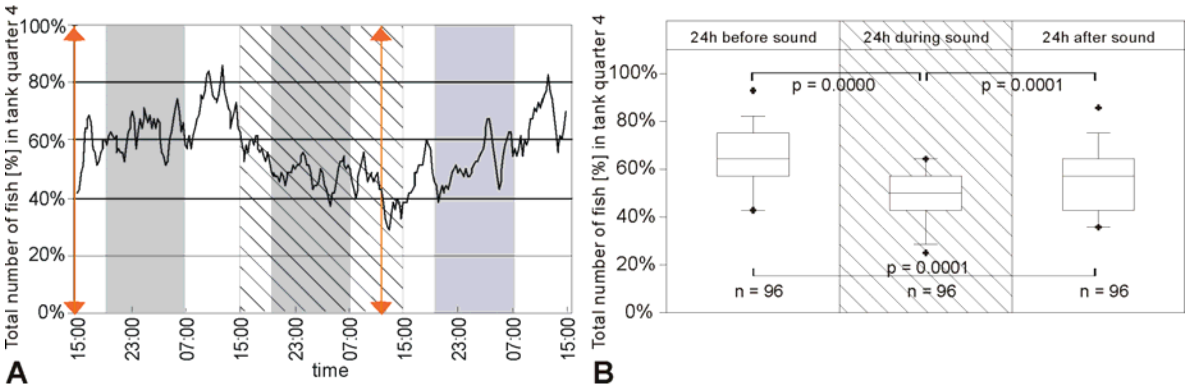

Figure 3: Number of juvenile cod present in quarter 4 before, during and after sound presentation of 125 Hz at 130 dB re 1µPa. Both figures are based on the same data set collected from a group of 14 fish. P-Values in figure B are given for significant differences between periods (Mann-Whitney U-Test with Bonferroni correction). The sound period is hatched, night periods are coloured grey, feeding times are marked with arrows. Fig. A smoothed.

But even in experiments in which the number of fish remained on about the same level during sound production the fish moved away from areas with highest sound levels. Based on an average background sound level of 105 dB re 1µPa in the tank and a signal-noise-ratio of 16 dB determined for cod [9] a reaction threshold of less than 30 dB above detection threshold was observed.

5 DISCUSSION

Spontaneously, the fish showed a preference for quarter 4 which provided the advantage to test if sound would be strong enough to scare the fish away from the preferred area. This would be loosely comparable with the situation in an offshore wind farm that is likely to attract fish as an artificial reef. The results showed significant avoidance behaviour of cod to low-frequency sound. However, the sound stimulus was not strong enough to make all fish leave their preferred quarter. This suggests that in an offshore wind farm, at least temporary distributional changes might appear but permanent avoidance of the area would not be expected if the area itself were attractive to cod.

Strong reactions appeared at frequencies between 60 and 125 Hz, which is in accordance to the most sensitive hearing range of cod between 60 and 380 Hz. In this range hearing is acute and in many cases only limited by ambient noise [3]. The reaction of cod to the frequency of 25 Hz was higher than expected, compared with the less pronounced reactions to 250 Hz despite a lower hearing threshold. Below 60 Hz particle motion is presumed to be the relevant stimulus for sound detection by cod [9] but the particle motion in the tank could not be determined in the experiments due to technical reasons. But it is to be expected that the particle motion was higher in the quarter of sound production than in other parts of the tank. At the same sound pressure level the particle motion is higher in a tank compared with the open sea [10] and therefore cod in the experiments were exposed to a higher stimulus at 25 Hz than they would have been in an offshore wind farm in the same sound pressure situation.

The sound produced by offshore wind turbines is broadband with highest sound levels emitted in a range between about 25 and 250 Hz. Higher frequencies of offshore wind turbines are masked by background sound produced by wind, waves, current and other sound sources [11]. Different frequencies from this spectrum were tested to identify those that might cause greater effects in cod. Reaction to broadband noise could differ in its intensity but this should be tested in future experiments.

The hearing thresholds in the cod family (gadoids) are generally lower than in most other hearing generalists, and therefore stronger reactions in other hearing generalists would not be expected. Further research is urgently necessary, especially on possible masking of biologically important sounds.

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