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Marine Renewable Energy
Knowledge Exchange Programme

Internship Report

Developing and testing models of fish behaviour around tidal turbines

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In partnership with Sustainable Marine Energy Ltd

and HR Wallingford Ltd.

Developing and testing models of fish behaviour around tidal turbines

Aim of the internship

The work described here has been carried out as an MRE Knowledge exchange NERC Fellowship (NE/L014335/1) *Developing and testing models of fish behaviour around tidal turbines*. The overarching aim of this project was to provide an evidence-based tool to forecast the effects of anthropogenic noise on marine fish for Environmental Impact Assessments (EIA). The project was run in collaboration with the tidal turbine developer Sustainable Marine Energy (SME), the marine modelling consultant HR Wallingford (HRW) and University of Exeter. SME has provided access to the marine operations to install the PLAT-O 1 platform, a structure for supporting two turbines off of Yarmouth, Isle of Wight, for recording the noise levels generated by these activities. HRW provided the HAMMER model to implement with the inclusion of measurements of sound levels from an MRE and fish behavioural data in response to noise exposure. Behavioural experiments on fish have been performed at the University of Exeter and supervised by Dr Steve Simpson.

Objectives are those included in the contingency plan and included: the acoustic measurements and analysis of the underwater sound levels generated during the different marine operations, including those accidental sounds coming from the vessel participating to the operations and the actual sounds from the installation process. This noise has been employed in playback experiments to collect data on the effects on behaviour of fish and use HAMMER model. SME has been unable to install the tidal turbines during the internship period and, therefore, measurements of the operational tidal device were not collected, but granted the access to the installation phase of PLATO-O1.

The study objectives were fulfilled as follows:

1) we measured and quantified underwater noise levels of installation operations of PLAT-O platform at Yarmouth, Isle of Wight;

2) we measured the reduction in sound level of installation noise with increasing range;

3) we measured sea ambient noise with no installation-noise;

4) we used noise levels of installation operations in HAMMER to predict noise levels of PLAT-O installation operations experienced at increasing range from operational site;

5) we compared the computed sound levels in HAMMER with the measured levels;

6) we used the noise produced by PLAT-O installation operations to investigate the effects of noise on European sea bass.

This report presents 1) an analysis of the Yarmouth (Cowes, Isle of Wight) underwater noise measurements before and during the PLATO-1 installation, 2) a validation exercise of the HAMMER model propagation of noise for certain frequencies 3) the results from the behavioural experiments on sea bass. The final discussion considers the biological implications of the noise produced by the PLAT-O1 installation operations.

Field work

During the period between March and August 2014 we performed a total of three acoustic surveys. On the 2nd July we surveyed the area off Yarmouth to collect ambient noise. The survey lasted one day and produced 45 recordings of 30s (three consecutive recordings were made at each location). During August 2014 we surveyed the area during the mooring of the drilling vessel (19/8) and drilling of the first anchor pile (20/8). Both these surveys lasted one day and produced 21 and 56 recordings, respectively, ranging from 30 to 90s.

The installation of the PLAT-O1 comprised:

1. to install vessel moorings
2. to load out drill rig
3. to moor up vessel
4. to deploy rig
5. to drill anchor piles

We had access to operations 3 and 5 during which we have recorded the noise emission of these activities.

Field site

The areas designated for mooring of the vessel are reported in Table I and Table II presents the screw pile anchor positions. The central position of PLAT-O1 was 50 42.57 N, 001 31 00 W. The seabed contours run approximately 065/245 degrees and the slope run approximately 155/335 degrees. The steepest gradient was the North West pile location TNW and the North East pile location TNE (Figure 1). Bottom type in the area was course, medium and fine gravel with clay nearer the surface (known from material recovered on drill feet and anchors). Clay was expected underlying this layer (based on historical borehole report and sub-bottom profile data).

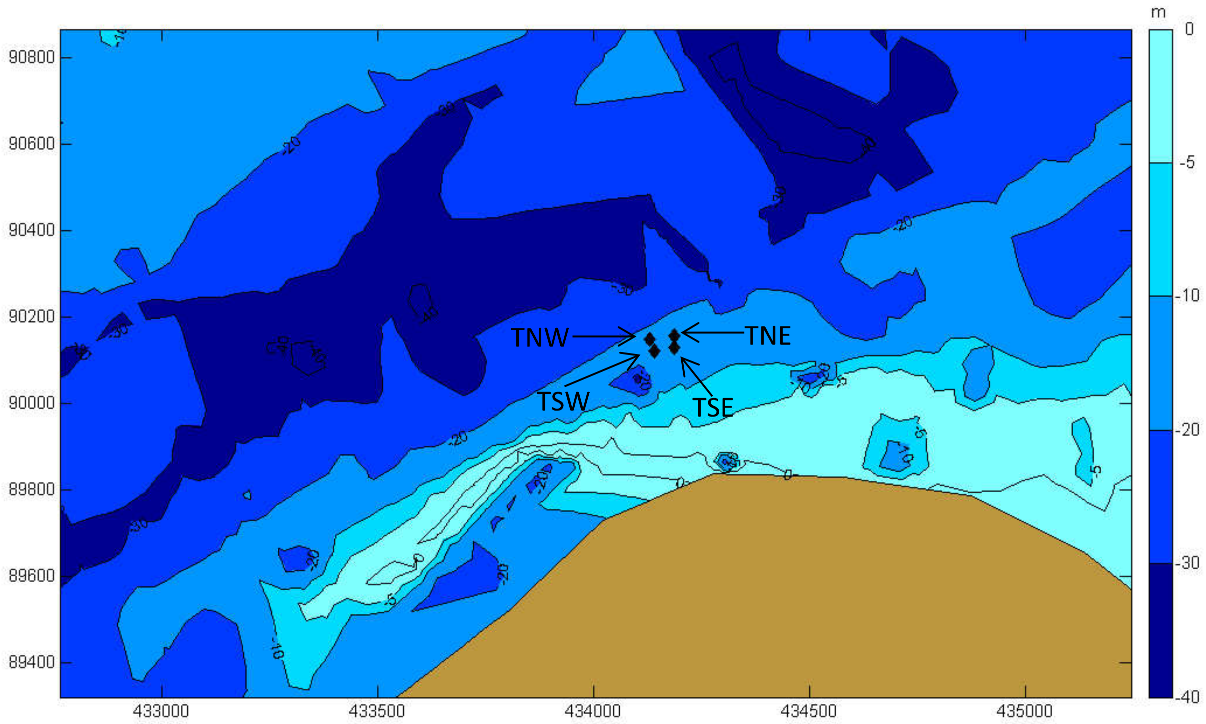

Figure 1 Map of the study area created with Mermaid v3.077 - Provided by HR Wallingford. Map reports isolines for bottom depth - Provided by HR Wallingford. The four black diamond dots represent the screw pile anchor positions as planned (see Table II).

Table I Coordinates of the mooring stations.

Designation of Vessel Moorings	Position of Vessel Moorings
Mooring 1	50 42.618’N 001 31.126’W
Mooring 2	50 42.561’N 001 31.111’W
Mooring 3	50 42.621’N 001 30.993’W
Mooring 4	50 42.584’N 001 30.984’W

Table II Screw Pile Anchor Positions (pre-lay)

			Offset from planned position	
Pile #	Positions		Distance (m)	Bearing (degrees)
TSE (1)	50 42.5893’ N	001 31.0303’ W	0.86	24
TNE (2)	50 42.6041’ N	001 31.0307’ W	2.5	16
TSW (3)	50 42.5832’ N	001 31.0700’ W	0.47	216
TNW (4)	50 42.5992’ N	001 31.0795’ W	0.71	54

Methods

Acoustic recordings

Underwater sounds were recorded from a RIB using a C55 Cetacean Research Technology hydrophone (Transducer Sensitivity + Preamplifier Gain – Effective Sensitivity: -165dB, re 1V/µPa) connected to a Fostex FR-2LE compact audio recorder (Recording/Reproduction Frequency 20 Hz - 20 kHz ±2dB; FS 44.1/48kHz), which recorded on a Type II CompactFlash™ card; to reduce the flow noise over the device, the RIB was allowed to drift during the measurements. The hydrophone was deployed into the water from the side of the vessel and it was mounted on an anti-heave buoy, at 5 m below the surface. To reduce additional noise from the RIB (movements, voices) the hydrophone was allowed to drift at least 10 m away from the vessel before measurements were taken. Recordings were made with the following format: 44.1 kHz/ 16 bit, BWF file mode.

For the measurements used in this study, transects radiating outwards from the source, at ranges increasing geometrically were planned. The RIB was used to move from location to location along transect lines. Each measurement location was identified by means of the GPS. At each location, the RIB was manoeuvred into position, the engine stopped and all electrical equipment turned off. The GPS information was recorded again at the end of the acoustic measurements.

Vessel specifications and activities

Willchallenge (Figure 2) was a multicat type vessel, length O.A. 20m, beam O.A. 7m, 2 engines (Total Power 720HP/530Kw @ 2000rpm). The Willchallenge was used as vessel to install its own moorings and to act as the platform to deploy the drill rig. The vessel was equipped of a USBL scout-vessel based underwater positioning system.

The rig was lifted over the side and lowered from the bow slowly into the sea bed. Orientation of the rig was maintained with tag lines. The drill rig has the following approximate specifications: length 3.40m, breadth 3.15m, height 1.66m. Drilling operation of the first pile lasted approximately 20 minutes.

Figure 2 Willchallenge deploying the drill rig on the 20th August 2014.

Results

Ambient noise

Samples of spectral levels of ambient noise recorded in July are shown in Figure 3. Each plot represents the median values of 30s power spectra (dB re 1µPa^2 rms /Hz; FFT, Hann, FFT length 1024, 50% overlap) computed in the frequency range 1Hz-20KHz of three recordings made at the same location. Since the handle GPS was not available at the time of the recordings, the RIB's fishing finder was used and coordinates noted on the logbook, in addition to information on weather, sea state and number of vessels surrounding the RIB (within 200-300m, Table III). Sea conditions throughout the recordings were calm with moderate wind (between 11 and 17 Km/h), up to 90% percent cloud but not rain, and sea state was estimated between 2 and 3.

Ambient noise ranged between 110 and 150 dB re 1µPa^2 rms /Hz (30s averages), with the spectra energy being concentrated in the frequency range 100 – 0.1Hz. The high spectral levels recorded at this frequency range are likely due to the heavy maritime traffic characterising the study area. In coastal areas vessel traffic noise dominates the sea ambient noise below 1 kHz (Richardson and Würsig, 1997) and the relationship between vessel movements and ambient noise levels is well known in literature (Merchant et al., 2012). The high amplitudes found in the study area are in accord with other measurements of background noise levels taken at sites of wave and tidal stream energy (reviewed in Robinson and Lepper, 2013) and at nearby busy areas in UK (Nedwell and Edwards, 2004; Table 4.2 and 4.5 in the Report).

At the time of the measurements (July afternoon, 15:00-17:00), the area was affected by motor boats of small and medium size (25-100 HP) returning to the nearby ports of Yarmouth and Cowes. Some of the recordings included also a car and passenger ferry to Lymington from Yarmouth and a helicopter surrounded the area during the entire survey. Several medium size sailing boats using motors were also observed during the survey. The only recording that did not include any boat within 200m or other anthropogenic noise (bkg, Figure 3) had spectrum energy ranging 109-140 dB re 1µPa^2/Hz rms (30s averages) and it is likely to be very close to the true background level of the area at the time of the measurements.

Analysis of the spectral levels in the region above 2 KHz also showed higher acoustic energy of background noise, which is likely due to sediment transport generated by the high speed of tidal flow in the area and consequently collisions between moving sediment grains and between moving grains and the sea bed. Seabed surveys performed by SME reported a seabed of course, medium and fine gravel with clay nearer the surface, which can produce noise at frequency close to 2KHz and above (Thorne, 1986). The raise in levels is particularly visible in the spectrum line labelled as centre in Figure 3, where frequencies between 2 and 8 KHz have higher levels. At the time of the measurements, the tide was high (3.1m at 14:55 h; c.a. 2.5 at 17:00) and the tide speed estimated based on the RIB's drifting speed was 0.8Kn at the PLAT-O1 central location. Similar results have been reached by other authors describing background noise in areas of high energy (reviewed in Robinson and Lepper, 2013; Merchant et al., 2014), however it is important to note the our recordings were highly affected by the presence of nearby vessels whose positioning system, about which we were unware of during the entire survey, could possibly have contributed to the background levels at high frequencies. The limited time window available for this survey did not allow identifying the temporal variation in noise level to explain the relationship between tidal flow and noise levels in the study area. It would be worth to do this in future surveys to better characterise the background noise levels.

Finally, the low frequency component (<30Hz) identified in all recordings was likely caused by turbulence around the hydrophone creating flow noise.

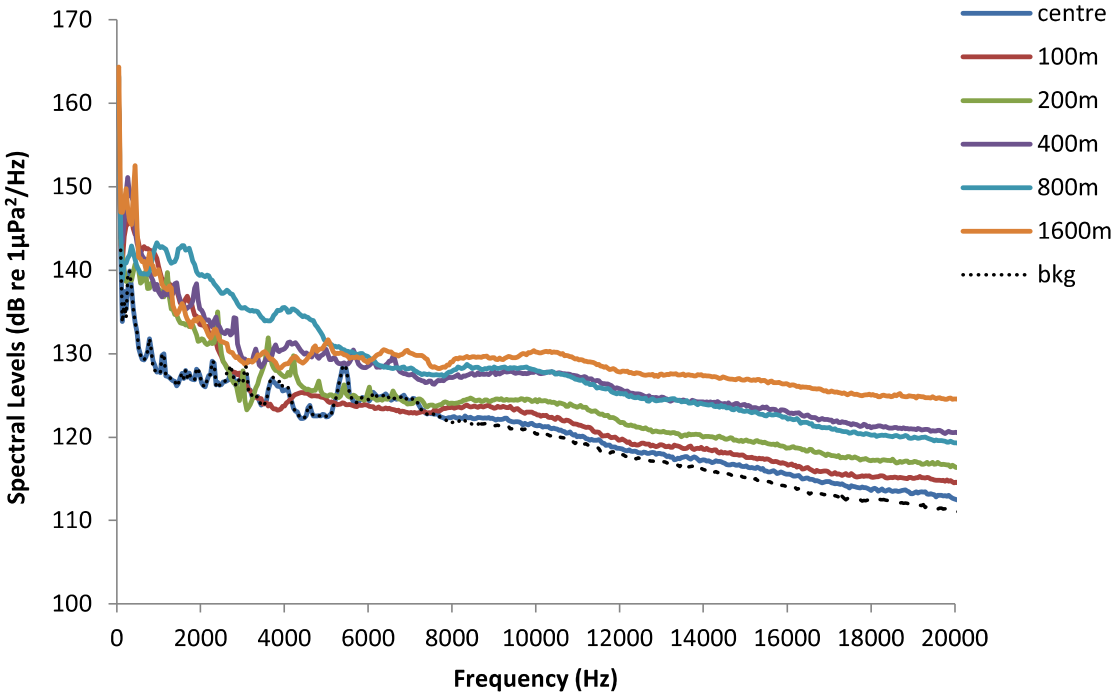

Figure 3 Median spectral levels (dB re 1µPa^2 rms/Hz; 30 s averages) in the full frequency range (1Hz-20KHz) of sea noise, with no Willchallenge vessel nor drilling noise, recorded at distances North from the PLAT-O1 central location – 02/07/2014. Centre is the central location of PLAT-O1. Spectrum line labelled bkg is from one 30s recording (1Hz-20KHz) made at PLAT-O central location where no vessels were noted within 200-300m. Fast Fourier transformation FFT, Hann, FFT length 1024, 50% overlap.

Table III Details of the recordings – 2/7/2014. Recording level was set to be the same during the whole survey.

ID location	File name	Hydrophone depth (m)	Wind speed	Cloud cover	sea state	precipitation	Postion	vessels/boats present
centre	B14h54m14s02jul2014	5	approx. 6knots	80%	2	none	N50˚ 42.57', W001˚ 31. 000'	3
centre	14:54:47	5						
centre	B14h55m20s02jul2014	5					N50°42.601'/W001°31.062'	
100	B15h05m00s02jul2014	5					N50°42.679'/W001°31.205'	4
100	B15h05m32s02jul2014	5						
100	B15h06m06s02jul2014	5					N50°42.668'/W001°31.275'	
200	15:11:16	5					N50°42.769'/W001°31.037'	3
200	B15h11m59s02jul2014	5						
200	15:12:47	5					N50°42.760'/W001°31.101'	
400	15:17:22	5					N50°42.815'/W001°31.077'	11
400	B15h17m57s02jul2014	5						
400	15:18:33	5					N50°42.807'/W001°31.168'	
800	15:23:56	5					N50°42.931'/W001°31.036'	7
800	B15h24m31s02jul2014	5						
800	15:25:06	5					N50°42.916'/W001°31.164'	
1600	15:35:35	5		90%	3	none	N50°43.229'/W001°30.997'	19
1600	B15h36m12s02jul2014	5						
1600	15:36:49	5					N50°43.186'/W001°31.123'	

Anchoring operations

Figure 4 refers to the background noise recorded at distances East from the Willchallenge vessel. During the measurements the mooring vessel was preparing for anchoring and it was already anchored to two of the four anchors. Ambient noise amplitudes compared with the results of the 2nd July were on average 3-5 dB higher in the frequency range 100-0.1 Hz and this was mainly due to the presence of Willchallenge vessel. However, in general spectral levels of background noise were lower during these measurements (broadband ambient noise ranged between 102 and 140 dB re 1µPa^2 rms /Hz; 30s averages) and this could be due to the relatively fewer vessels noted during the survey and the calmer weather experienced (wind speed was 9-18 km/h), compared to the 2nd July. Again, the spectral analysis revealed an increase in levels at high frequencies (2-8 KHz), which was due to transport of coarse and fine sediments of the sea bed. The increase in background noise level was more pronounced in these recordings compared to those of the 2nd July, potentially because the measurements were made during flood tide when the water level was higher and the tide speed reached 1.3kn (according to SME – Methods Statement).

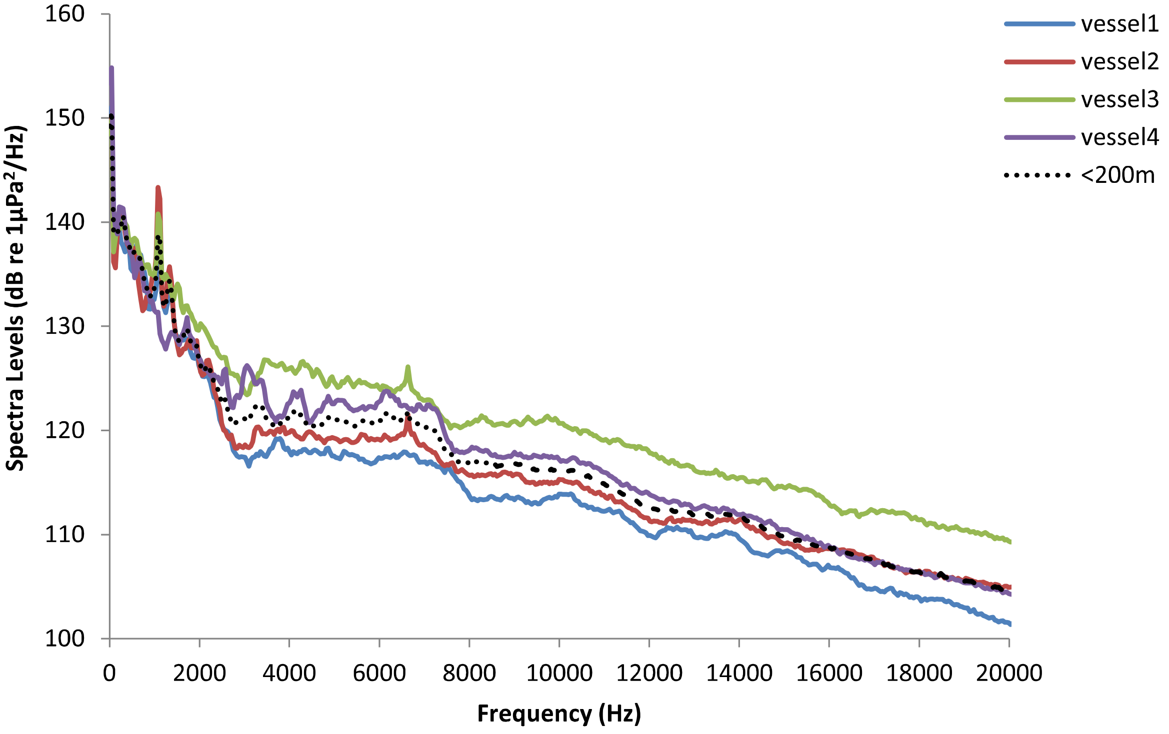

Figure 4 Spectral levels (dB re 1µPa^2 rms/Hz; 30 s averages) of ambient sea noise and mooring vessel recorded at distances <200m East from the mooring vessel – 19/08/2014. Individual spectra lines (colour lines; 30s averages) indicate each recording. The dotted spectrum line (30s average) is the median spectrum level of the four recordings. Willchallenge vessel noise contribution to background noise is visible at frequencies between 100-0.1Hz. Sounds at frequency between 2-8KHz are due to sediment transport. Fast Fourier transformation FFT, Hann, FFT length 1024, 50% overlap.

Figure 5 represents the background noise recorded at distances East from the third anchor (point TNE in Table II) during the anchoring operations of Willchallenge. Measurements at 114 and 138m included anchoring operations; the spectrum was computed from 8s recordings. Compared with the amplitudes recorded at the same location when no anchoring was taking place (vessel noise, Figure 5), ambient sea noise levels are similar in the low frequencies of the spectrum, representing the noise from the Willchallenge vessel (100-0.1 Hz), but increased at frequency up to 20 KHz, increase likely due to the anchoring operation. The broadband nature of the anchoring noise is presented in the spectrograms (15s samples) in Figure 6 and Figure 7.

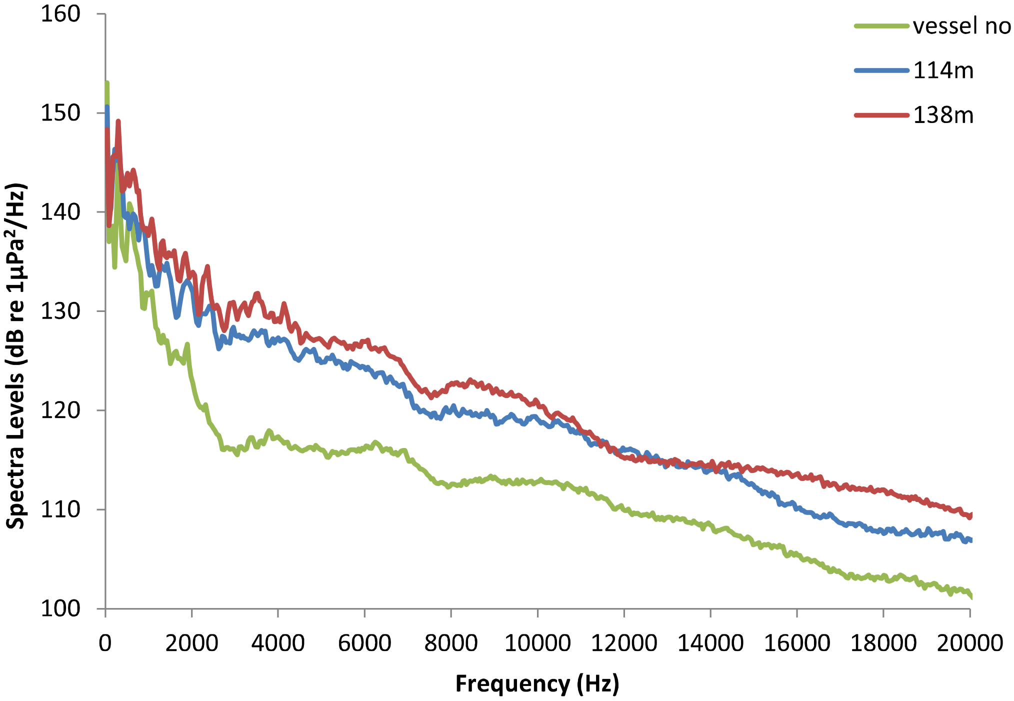

Figure 5 Broadband spectral levels of ambient sound with mooring vessel (8s averages) during anchoring operations (anchor 3) – 19/08/2014. Distances are from the anchor located at TNE point (Table II). Spectrum line labelled vessel noise is from one recording of the background noise with vessel only, taken just before the anchor release at 114m East from TNE point. Fast Fourier transformation FFT, Hann, FFT length 1024, 50% overlap.

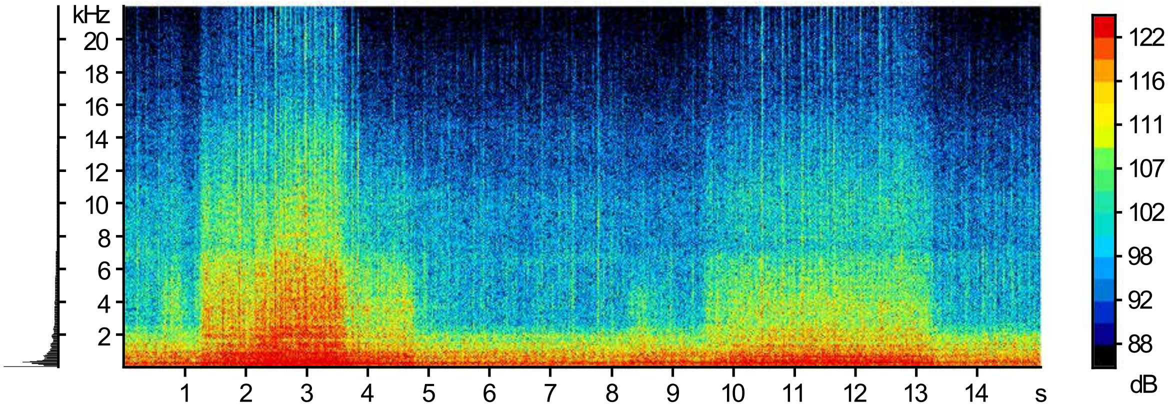

Figure 6 Spectrogram represents 15 s of the measurement taken during the anchoring operation and includes two steps of the anchor 3 lowering underwater. This recording was made at 114 m East from the anchor at location TNE at 15:00 hrs. Fast Fourier transformation FFT, Hann, FFT length 1024, 50% overlap.

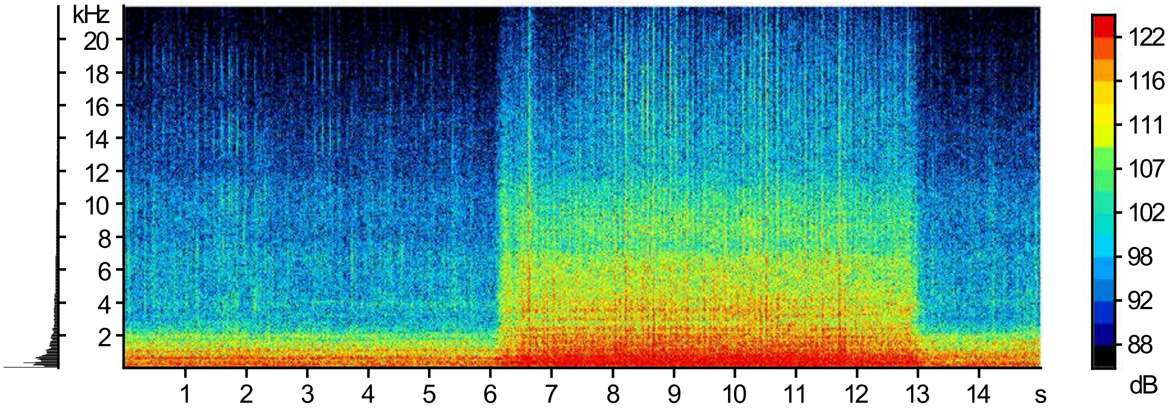

Figure 7 Spectrogram of 15s of the measurement taken during the anchoring operation including the anchor lowering underwater. This recording was made at 138 m East from the anchor at location TNE at 15:02 hrs. Fast Fourier transformation FFT, Hann, FFT length 1024, 50% overlap.

Installation noise

On day 20/8/2014, SME granted access to drilling operations of the first screw pile that would secure the PLAT-O1 underwater. The measurements were made between 17:00 and 17:25 h, over as closer distance range as possible within the constraints of operation. Spectral levels (dB re 1µPa^2 rms /Hz; 10s averages) of noise recorded during drilling operation at different distances are presented in Figure 8. The choice to analyse 10s of the total recordings was made to be sure to include the highest levels of noise produced during the drilling operation since the RIB was drifting away from the drilling vessel at relatively high speed (2.5 Kn), which we assumed it reflected the flow speed underwater. The Appendix at the end of this report includes all level statistics and 1/3 octave bands of drilling recordings.

Drilling operation noise evolved between 111 to 144 dB re1µPa^{2}rms/Hz at close distances (46, 56m). At greater distances (153, 174m) drilling operation noise ranged between 112 and 138 and between

104 and 139 dB re1µPa^{2}rms/Hz at 331 and 408m. The levels of sound in the band from 100Hz up to 1kHz was elevated compared to no drilling activity by 3-10 dB, depending on the recordings. However, it must be noted that also during the drilling operations other anthropogenic sounds have been recorded and as such, their noise have affected our recordings. Spectrum line 174m for example contained noise from a helicopter that contributed to the recorded noise raising the levels in the high frequency spectrum up to 7 KHz. The spectrum line computed for the 10s recording made at 15m was taken from the back of Willchallenge vessel and as expected it was found to have the highest levels at frequencies 100-0.2 Hz that rose again at frequencies 3-8 KHz. There were also visible tonal components due to the machinery noise of the vessel.

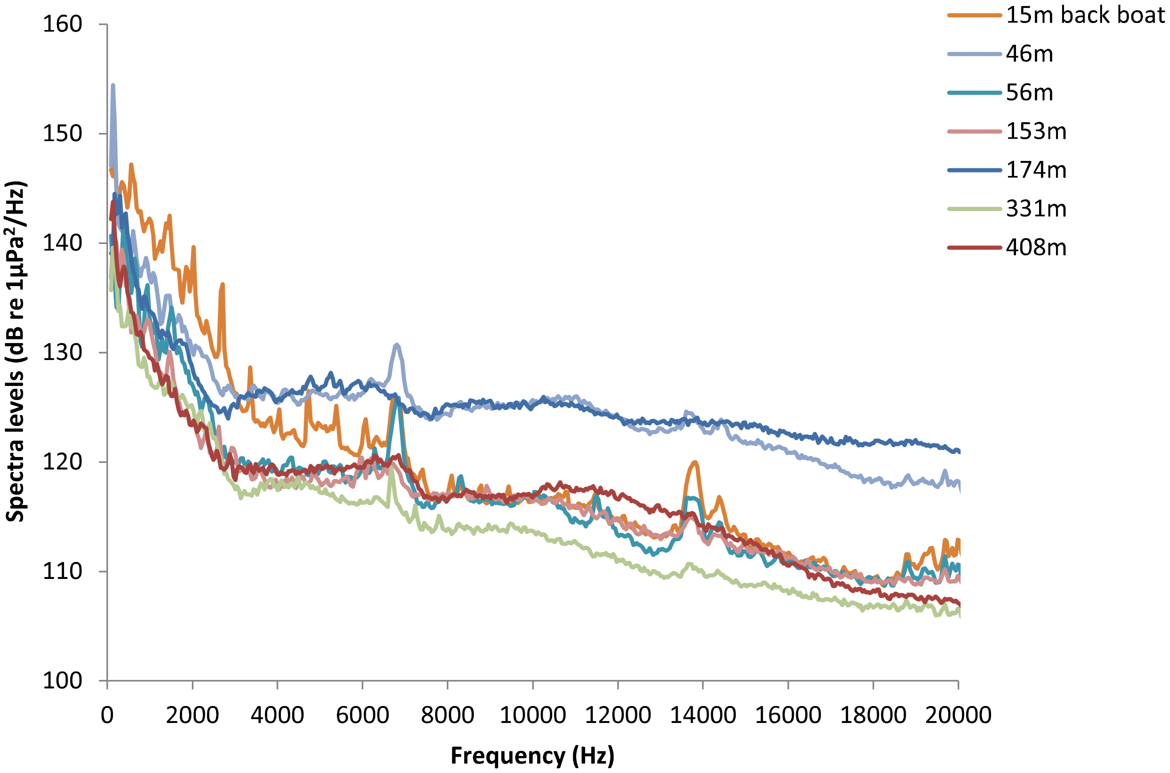

Figure 8 Broadband spectral levels of ambient sound (10s averages) during drilling operation – 20/08/2014. Distances are from the PLAT-O1 central location. Fast Fourier transformation FFT, Hann, FFT length 1024, 50% overlap.

At frequencies of 6710 Hz and 16700 Hz the spectra computed for the recordings closer to the drilling location presented a sharp rise in level due to the underwater positioning system in use. These sounds could be distinctively heard in the recordings and visibly recognised in the sound spectrogram (an example is shown in Figure 9) up to a distance from the Willchallenge of 331m.

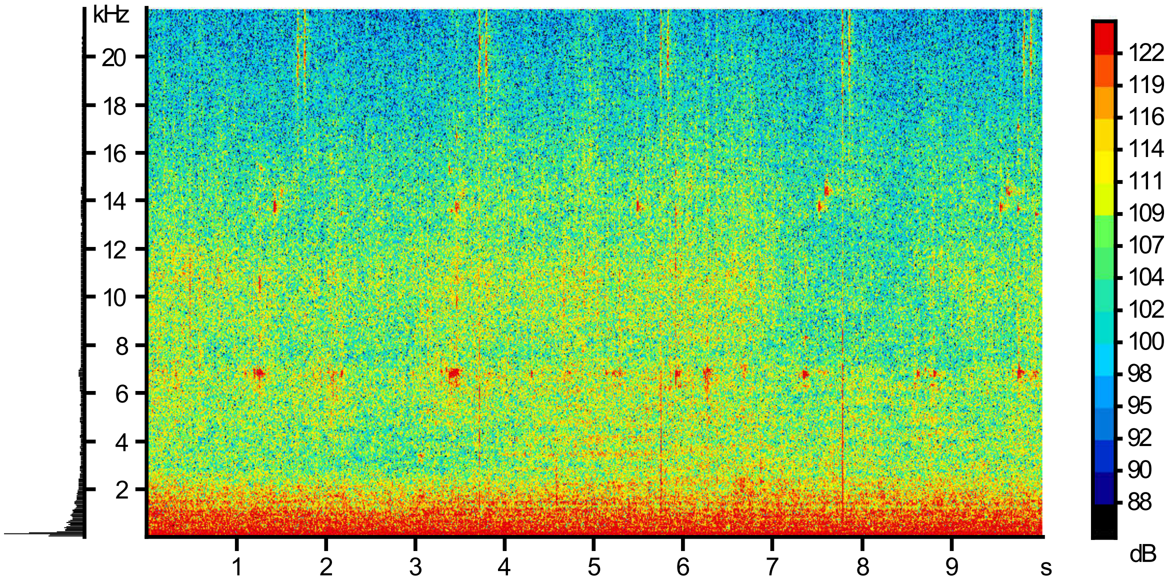

Figure 9 Spectrogram of 10s of the recording taken at a distance of 46m from the Willchallenge during drilling activity. The underwater positioning system is visible as high energy dots at frequency 6710 Hz and 16700 Hz. Fast Fourier transformation FFT, Hann, FFT length 1024, 50% overlap.

The measurements made during the drilling operation at Yarmouth were in accord with others that revealed an increase in the sound levels between 100 Hz and 600 Hz (Broudic et al., 2014; Nedwell and Brooker, 2008). However, the spectral analysis of the recordings has not allowed us to identify the signature of the drilling noise as the acoustic coupling of Willchallenge vessel noise and high anthropogenic noise (local vessels noise) in the study area have masked most of the spectra at frequencies were it is expected to find the drilling noise. Moreover, the relatively small size of the drill rig used and substrate found in the area appeared to have damped the noise from the drilling operation at ranges away from the central location, making the entire operation very quiet. A more fine resolution of the spectra levels (1 KHz; FFT, Hann, FFT length 3267, 50% overlap) revealed an increase in levels at 100-600 Hz, which could indicate that the energy of the noise generated by the installation of the pile at Yarmouth was concentrated at that frequency range.

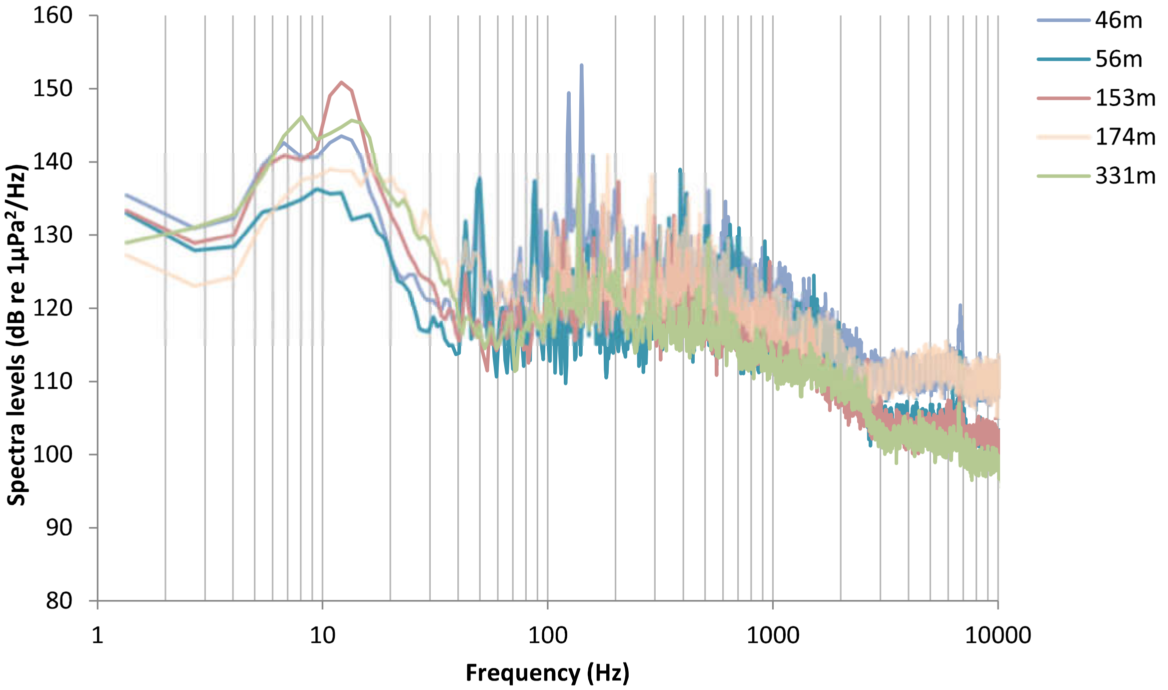

Figure 10 Spectral levels of ambient sound (10s averages) during installation operation – 20/08/2014. Distances are from the PLAT-O1 central location. The spectral levels between 100 and 600 Hz are elevated over the other and could represent the range where drilling noise has its main energy. Fast Fourier transformation FFT, Hann, FFT length 3267, 50% overlap.

Conclusion

This study has been carried out with the data collected during three days between July and August 2014 and so the results presented here are a snapshot of the ambient noise at the time of the surveys. The study area presented high level of ambient noise, which could be expected for a coastal high energy shallow water site. Sounds at frequencies below 1 kHz are most likely attributable to anthropogenic noise (local and distant vessels, machinery noise), whereas re-deposition of sediments on sea bed due to water flow made a significant contribution to the ambient sound field at frequencies above 2 kHz.

Noise from installation of the first pile of PLAT-O1 comprised noise from Willchallenge and drilling. During drilling activity noise was 3 dB to 10 dB higher than the background noise of the area and it was more intensive between 100 Hz and 1 kHz, spectrum range that was dominated by the vessel noise. It was suggested that frequencies between 100 and 600 Hz included the main energy of the drilling noise. Drilling noise level appeared to decrease by 5dB at distance of 100m from the PLAT-O1 central location and reach the ambient noise levels at 300m. Considering the high background noise found in the area and the low levels of drilling noise attenuating fast, we can suggest that noise emitted during the installation of the PLAT-O pile in Yarmouth has potentially limited impact on the surrounding marine environment. Levels recorded during this study are comparable with noise radiated by small vessels and are considerably lower than the levels of noise generated by piling, another marine techniques used to fix piles for offshore and coastal development. A major contribution to the noise during construction was caused by the presence of Willchallenge and machinery associated with the activity. Although these noise sources are not expected to cause injury on animals, behavioural effects are documented in marine animals exposed to boat noise (Codarin et al., 2010; Picciulin et al., 2010; Vasconcelos et al., 2007) and could result from exposure to higher levels added by the presence of Willchallenge. Although the short time required by SME to fix the pile underwater does not represent a concern upon the chronic exposure, in this study we were able to measure levels of background noise only during the installation of one pile out of four, which lasted 20 minutes. The installation of four piles or a commercial array of turbines each supported by four piles could bring to a longer rise of ambient noise, whose effects on animals might become a concern.

ANALYSIS OF THE SOUND PROPAGATION – HAMMER.

Acoustic monitoring of an area of interest (e.g. MRE development area) must consider the sound propagation in the ocean, ideally computed from *in-situ* measurements. However, considering that sound travels over great distances, it may be impracticable to cover the whole area of interest and measurements may result to be insufficient. The use of numerical modelling can overcome this difficulty and provide information on the propagation of sound in water.

In this study we used HAMMER (Hydro-Acoustic Model for Mitigation and Ecological Response), an underwater noise propagation model which predicts noise levels at distance from a point source. The underwater noise model is setup using the physical information from the bathymetric data and hydrodynamic model with additional data relating to the specific noise source, e.g. drilling, in this study. The model predicts the propagation of noise from the source point in a 2D vertical slice, which determines the noise levels throughout the water column in a line out from the source, covering a full 360 degrees. This allows sound maps of underwater radiated noise to be created, so that the noise levels can be understood and interpreted for EIA. The model is based on the parabolic equation method (Collins, 1993). HAMMER also incorporates an ecological response model to investigate the impact of underwater noise on species behaviour. Individuals are represented as a particle and the model predicts movement patterns, given initial input parameters of max/min swimming speed, initial direction, directness, source level intensity and frequency (Hz).

We were not able to run the ecological model with HAMMER because of the lack of responses to installation noise found in sea bass, the target species for this project. Therefore, only analysis of the sound propagation of drilling noise was performed with HAMMER.

For the analysis of the sound propagation, HAMMER computes transmission loss for discrete frequencies. We chose to run HAMMER at 125, 250 and 500 Hz. HAMMER requires a hydrological model of the location and HRWallingfrod provided one for the Solent area. Also, HAMMER requires info of the source position, depth, sound velocity, attenuation sediment layer (dB/lambda) and source level specific for each of the frequency analysed. For the source level, this was computed for each frequency by using the formula:

$$SL = SPL - TL$$

The SPL were computed in 1/3 octave using Avisoft SAS Lab Pro vs 5.2.08 (Avisoft Bioacoustics, Berlin, Germany) and the TLs for each frequency were computed using the formula $15*\log_{10}(r)$, were r was the range. The chosen ranges were: 46, 56, 153, 331 metres. Table IV reports the additional parameters used in the modelling exercise.

Table IV Density profiles and physical parameters used in HAMMER.

source depth (m)	10
receiver depth (m)	5
location of noise source	434146, 90137
sound speed (m/s)	1500
sound speed 1st sediment layer (m/s)	1600
density in water (Kg.m^3)	1600
density in the lower sponge sediment layer (Kg.m^3)	1900
attenuation sediment layer (dB / λ)	0.7
attenuation sponge (dB / λ)	2

HAMMER was run with the above input parameters and sound maps of the sound propagation for each frequency are presented in Figure 11, Figure 12, and Figure 13.

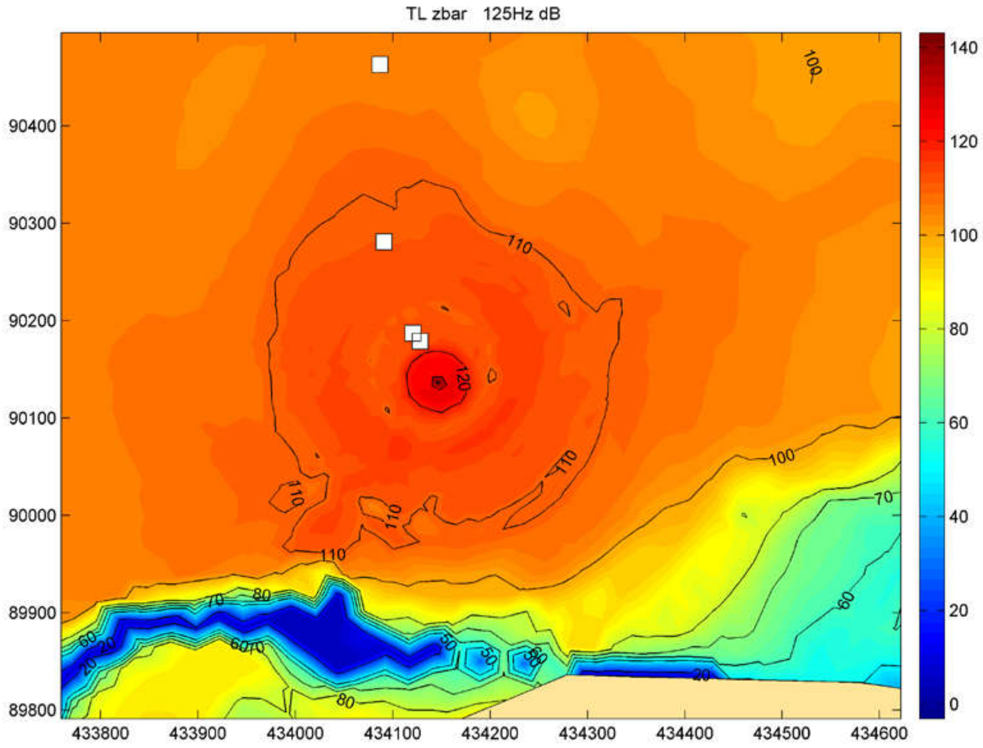

Figure 11 Sound map of the propagation of drilling noise at frequency 125 Hz. Isolines represent the noise levels computed for the study area using HAMMER. The white dots represent the locations of the measurements. Colour bar represents the noise levels for the 125 Hz.

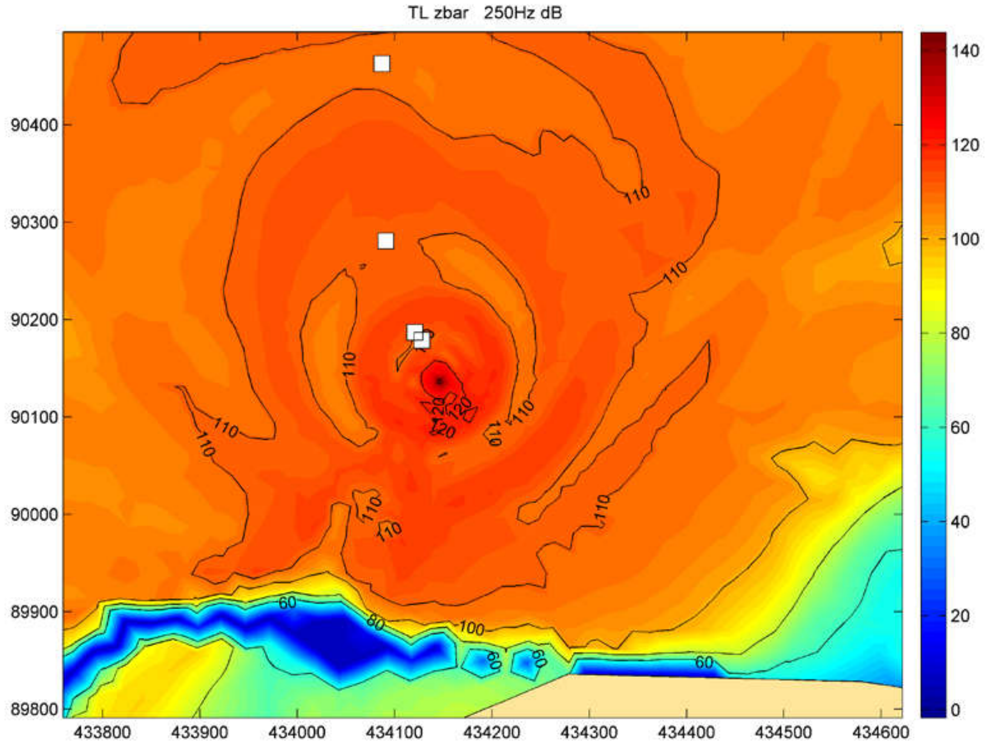

Figure 12 Sound map of the propagation of drilling noise at frequency 250 Hz. Isolines represent the noise level computed for the study area using HAMMER. The white dots represent the locations of the measurements. Colour bar represents the noise levels for the 250 Hz.

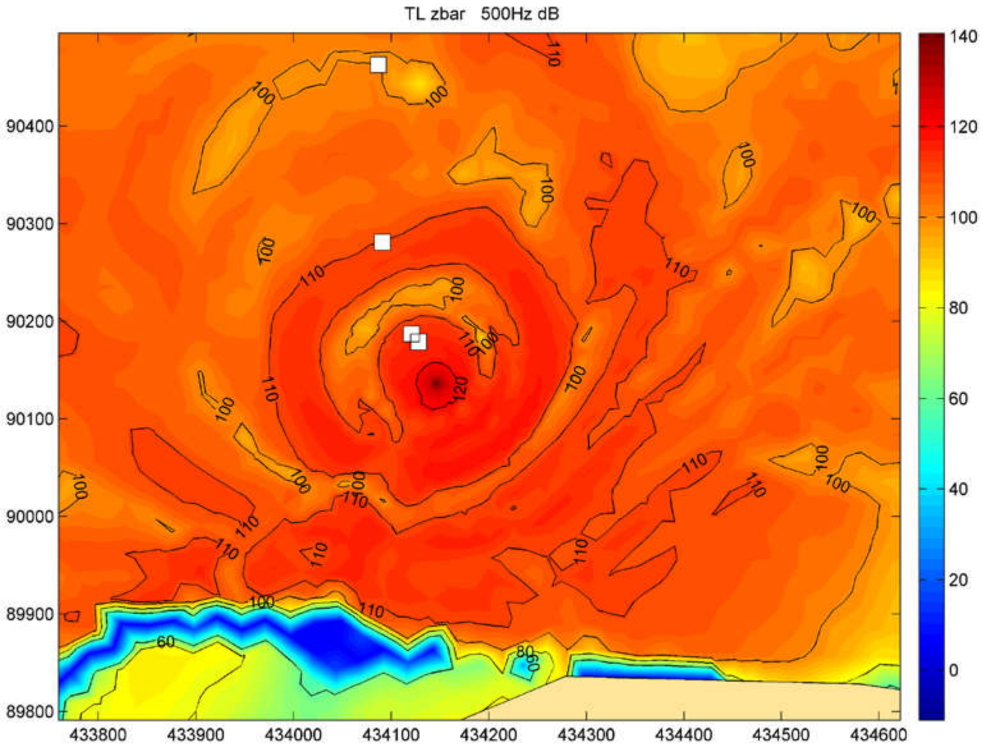

Figure 13 Sound map of the propagation of drilling noise at frequency 500 Hz. Isolines represent the noise levels computed for the study area using HAMMER. The white dots represent the locations of the measurements. Colour bar represents the noise levels for the 500 Hz.

It was not possible to do any sensitivity analysis of the modelling done with HAMMER because we did not have replicates of the drilling measurements at each range and, therefore, we could not computed any statistical difference. However, comparison of the computed levels for each frequency with the available measured levels showed a good agreement. These data are showed in Table V.

Table V computed and measured levels.

125Hz				250Hz				500Hz			
measured				measured				measured			
46m	56m	153m	331m	46m	56m	153m	331m	46m	56m	153m	331m
138.65	122.75	126.56	124.76	131.61	124.42	127.55	123.72	130.74	133.11	127.45	124.23
computed				computed				computed			
46m	56m	153m	331m	46m	56m	153m	331m	46m	56m	153m	331m
112.03	111.70	111.12	105.09	107.80	111.82	110.79	108.42	115.39	113.81	110.15	100.14

Comparing the background levels to the predicted levels during installation operations showed that drilling noise levels should reach background noise levels at range of between 300 m and above, which is in agreement with what it was found from the empirical measurements.

Effects of playback noise from installation of PLAT-O1 on movement and anti-predator behaviour of European seabass, *Dicentrarchus labrax*

RATIONALE – European sea bass, *Dicentrarchus labrax***,** is a commercially important species in the UK in both aquaculture and for capture fisheries. They are migratory fish and move between feeding and breeding grounds between the English Channel and the southern North Sea and along the west coast and into Cornish waters (Pawson, 1995). Bass are generally regarded as a schooling fish which perform migrations together. Older larger bass can often be solitary (Frimodt, 1995).

Sensitivity to low frequency sounds: a study of the saccular hair cells from *D. labrax* revealed that this fish has an inner ear configuration similar to hearing generalist fish (Lovell et al., 2005). Sea bass have their best hearing sensitivity at low frequencies (100-0.1 Hz; Lovell, 2003, Figure 14). Sea bass's 50% reaction threshold occurred for pure tone signals of 0.1–0.7 kHz when the levels were 0-30dB above hearing threshold (Kastelein et al., 2008).

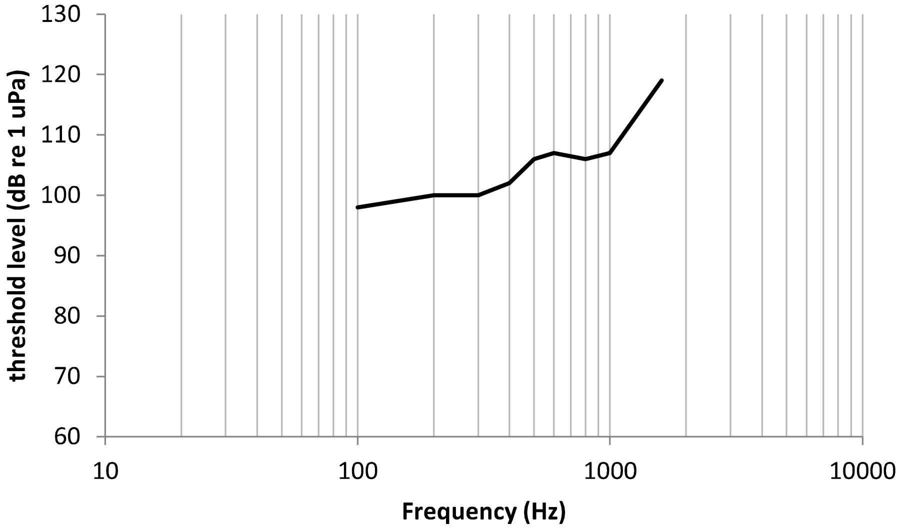

Figure 14 Auditory brainstem response (ABR) audiogram of European sea bass. Redrawn from Lovell, 2003.

Movement in response to sounds: Buscanio et al. (2009) found significant increase in motility (total movement) in sea bass exposed to a 0.1–1 kHz linear sweep (150 dB rms re 1uPa). Neo et al. (2014) found that groups of European sea bass increased swimming speed at the onset of playback sounds that differed in the temporal structure (frequency, amplitude and duration were the same between sounds). The SPL of the consistent amplitude treatments was 165 dB re 1 µPa and the SPL of fluctuating amplitude treatments changed gradually every minute between random levels ranging from 134 to 172 dB re 1 µPa.

Anti-predator behaviour: why anti-predator behaviour? Studying anti-predator behaviour allows investigating the link to individual fitness. If fish reduce the likelihood of escaping to a predator, its survival might be affected. Chan et al., 2010 found that crabs hid more slowly in response to a silent visual stimulus when simultaneously broadcasting of a white noise (82 dB SPL) was introduced, compared to silent conditions. Eels were less likely and slower to startle to a predator when exposed to playback of additional noise (148 dB RMS re 1 µPa; Simpson et al., 2014).

AIMS – In this study, we played back noise recorded during the installation of the PLAT-O1's first screw pile to investigate whether it had an effect on movement and anti-predator behaviour of European sea bass, *Dicentrarchus labrax*. Experiments were performed in tanks at the University of Exeter.

RESEARCH QUESTIONS:

1. Does noise from the installation of PLAT-O affect movement of sea bass?
2. Does noise disrupt anti-predator behaviour?

HYPOTHESIS:

1. Fish exposed to installation noise will increase their movement behaviour.
2. Exposure to installation noise might make individuals less likely to detect the attack, increasing the time they take to startle.

Materials and methods

Experimental set-up

Procedure included:

30 minutes acclimation (ambient noise) – 1 minute video (ambient noise) – change track – 1 minute video (ambient/installation noise) – throw the ball – 30 s video – stop noise – stop camera.

Ambient- and installation noise playback files were created using recordings from Yarmouth (Cowes, Isle of Wight). Ambient noise was that recorded during the acoustic survey in July 2014, whereas installation noise was recorded in August 2014 during the drilling operations of the first pile that will support the PLAT-O1 platform. Installation noise used in the playback experiments was that recorded at 46m from the drilling activities and included noise from the vessel, drilling and the positioning system. Individual tracks of recorded installation noise and ambient noise were split in three 15s track and looped to obtain 3 minutes and 45 minutes playback tracks, respectively. Before experiments began, noise playbacks were recorded and calibrated to verify that all recordings had uniform sound levels (136 ± 0.2 for ambient and 146 ± 0.5 for installation noise dB re 1µPa^2 rms /Hz Figure 15 and Figure 16).

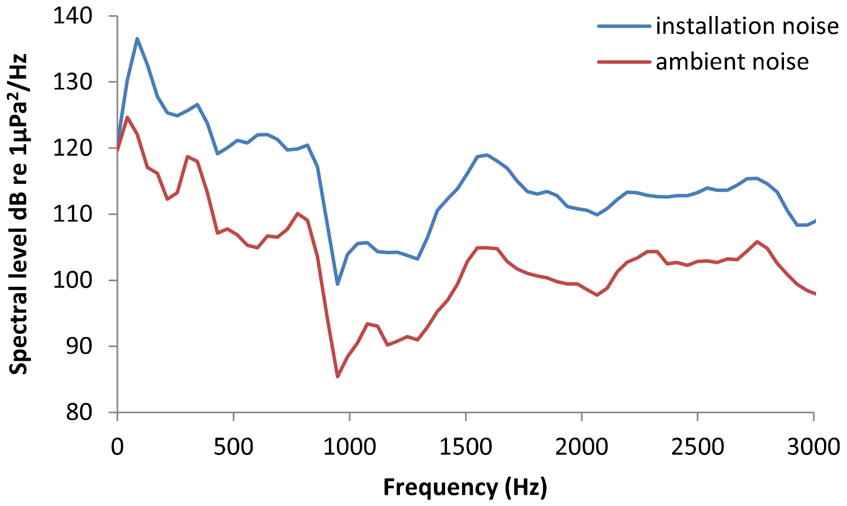

Figure 15 Sound pressure level of ambient and installation noise playbacks recorded in tank A (FFT analysis: spectrum level units, Hann evaluation window, 50% overlap, FFT size 32768).

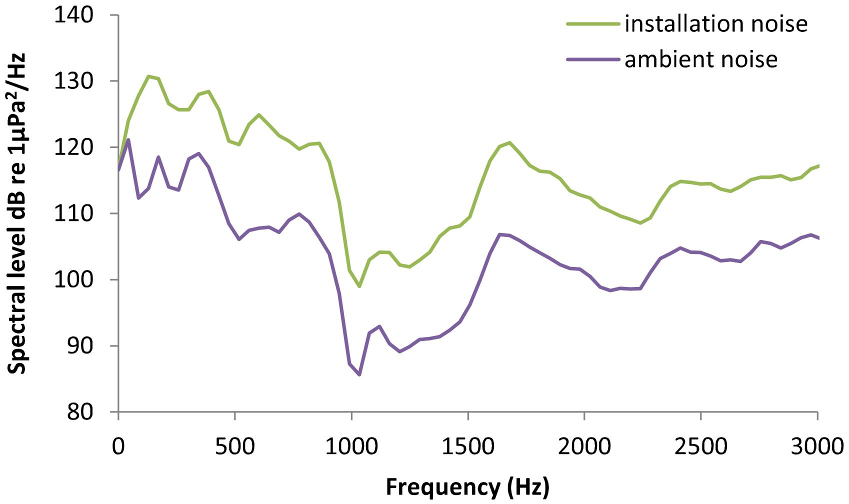

Figure 16 Sound pressure level of ambient and installation noise playbacks recorded in tank B (FFT analysis: spectrum level units, Hann evaluation window, 50% overlap, FFT size 1024).

Two tanks (53.6 x 43.9 x 44.2 cm) were used for the playback experiments. Individual fish were randomly allocated to each tank. Two GoPro cameras filmed the fish from the top of each tank. A simulated predator (a blue squash ball) was thrown from the side of the tank into the water at 30 cm circa (Figure 17). Polystyrene blocks (5 cm high) were placed underneath the tanks to stop vibrations during playback. Thick firm foam has been placed underneath the speakers to avoid additional vibrations.

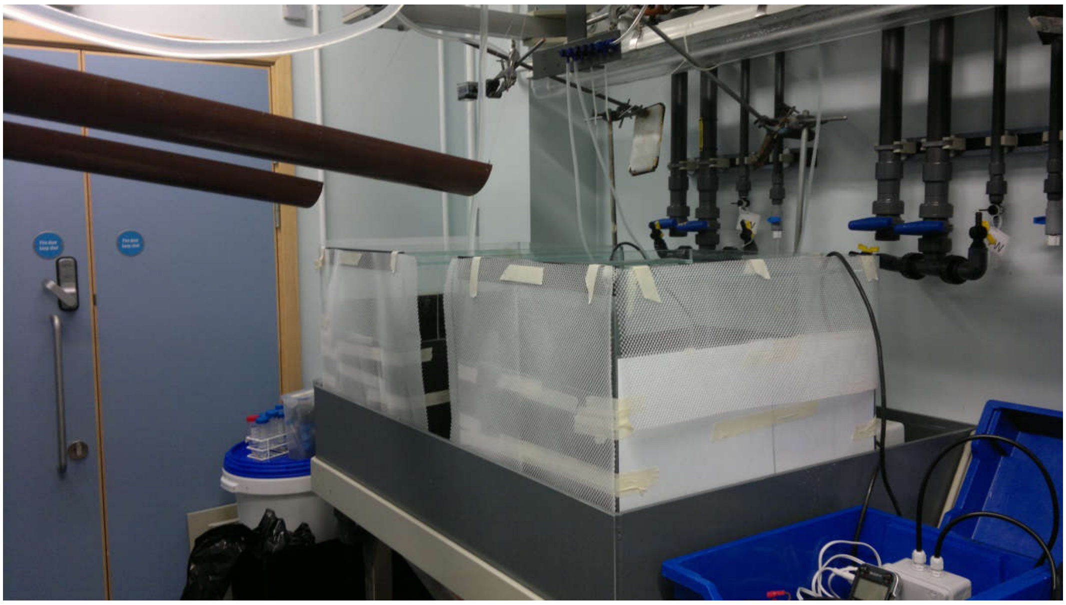

Figure 17 Set up of the experiment showing the two tanks with above a pipe line used to throw the ball (predator) in the arenas. Above the tanks are also visible the two GoPro cameras used to video the fish during exposure to noise.

Experiments used an independent samples design: 36 animals were used. 50% received ambient noise (N=18) and 50% received installation noise (N=18). All experiments involved an initial period of a control playback (ambient noise) from one of the three ambient tracks, followed by a switch to playback of either a control recording or an additional noise (installation noise). Twelve (12) unique combinations of control to control or control to installation noise playback were created, with every 3 fish receiving one of the 12 possible playback combinations. The order in which these playback combinations were presented was randomized within each testing block.

Behavioural analysis

Movements were scored by counting how many times per minute individual fish crossed the line of a grid (5x5 cm) superimposed on the bottom of the experimental tank. Anti-predator behaviour was scored by investigating whether or not the fish startled (a sudden movement at increased speed) to the simulated predator (ball) and the lag time in the response (defined as the time between the ball crossed the wall tank and the startle response in fish). The lag time was calculated by analysing the videos frame by frame and converting the number of the frames to time using a simple formula:

$$\text{Lag-time} = \frac{\text{observed frame number}}{\text{video frame per second}}$$

During the analysis the observer was blind to the treatment to remove observer effects.

Data Analysis

Statistical analyses were conducted in R (R core team 2014, version 3.1.0). For the movement experiment, generalised linear models (GLMs) were used with noise treatment (ambient, installation noise), tanks and fish as fixed factors using the MASS package for GLMs and the core stats package for GLMs using a quasipoisson distribution (data overdispersion). For the anti-predator experiment, survival analysis was used with noise treatment (ambient, installation noise), tanks and fish ID as fixed factors using the SURVIVAL package for Cox proportional hazards regression. All tests used a confidence level of 95%.

Results

Movement

Tested fish in the two tanks responded similarly to the noise treatment (quasipoisson GLM: $F_{1,33}$=0.0226, p= 0.8813). There was no significant difference in the fish movement when fish were exposed to installation noise compared to ambient noise (GLM: $F_{1,34}$= 0.6907, p= 0.4117; Figure 18).

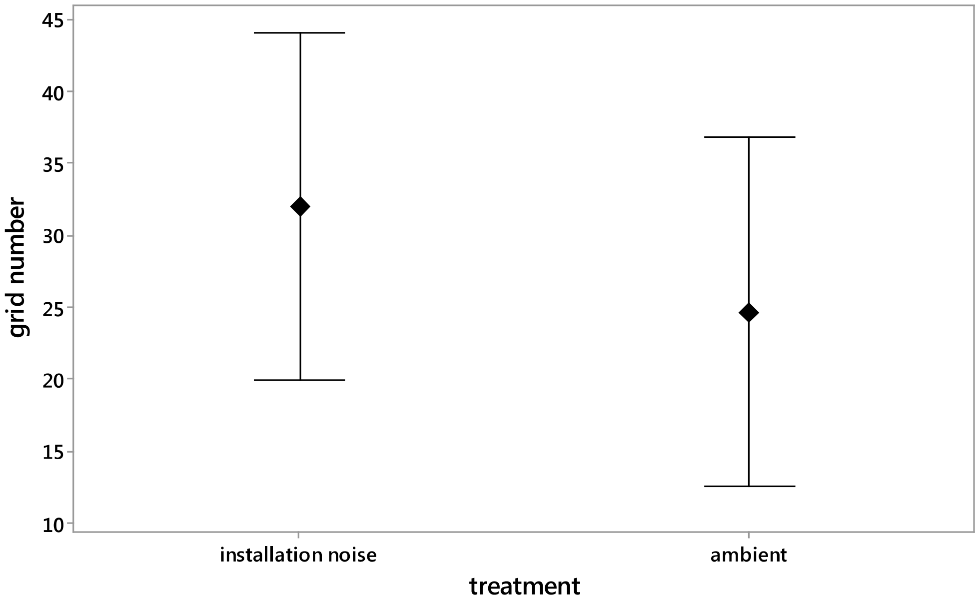

Figure 18 Fish movement (mean ± S.D.) when exposed to playback ambient noise and installation noise

AP experiments

All tested fish in both experimental tanks responded to the simulated predatory attack by freezing or running. Only four fish reacted by freezing at the occurrence of the predator compared to 32 fish that run (Figure 19). After the initial response to the predator (either flying or freezing) the fish have been found to freeze. There was no significant difference in the time taken by the fish to freeze after the initial response to the predator when exposed to ambient compared to installation noise (Cox proportional hazard regression = p = 0.708; C.I. = 0.41, 1.8; Figure 20).

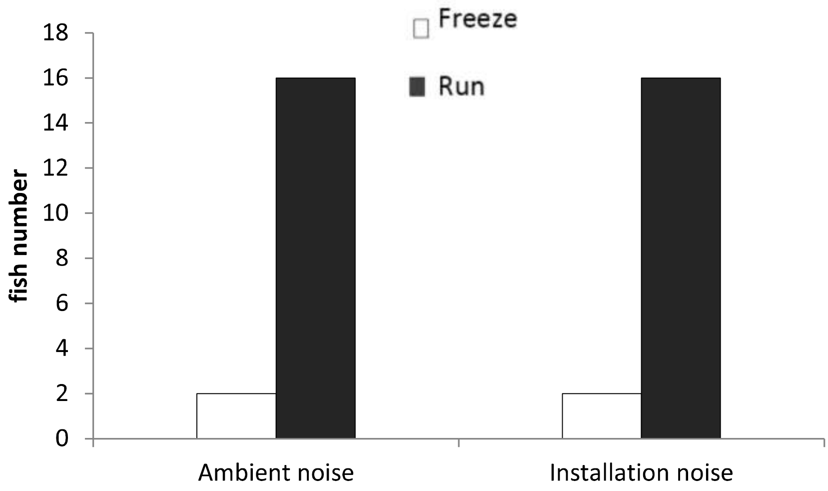

Figure 19 Startle response of *Dicentrarchus labrax* during playback of ambient noise or installation noise (n = 18 for each treatment).

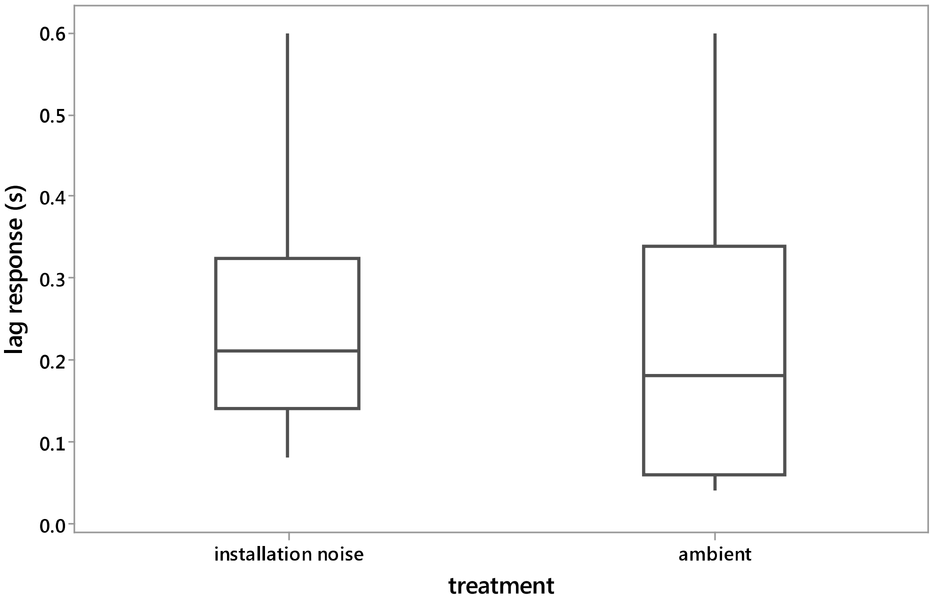

Figure 20 Time (median, IQR) taken by *Dicentrarchus labrax* to freeze after the initial response to simulated predator.

Discussion

In this study we found that European sea bass exposed to playback of noise from the installation of PLAT-O1 platform did not significantly change their movement behaviour compared to ambient noise. These findings contrast the work from Buscaino et al. (2010), who found significant increase in motility in caged sea bass exposed to low frequency sounds, but are in line with those found by Neo et al. (2014), where sea bass maintained similar swimming speed throughout the experiment, with the exception of a swimming burst at the onset of the noise. For active swimmers such as sea bass are, the lack of movement change in response to additional noise has advantages in that fish will not be affected in their routes to and from biologically important grounds (mating/ feeding). Similarly, the anti-predator behaviour appeared to be unaffected by additional noise exposure. The majority of the fish startled when presented to the predator, meaning that they did not fail to detect it during the simulated attack. This has important consequences as the startle response in fish is crucial in escaping to predator attacks and any factor that affects this ability may reduce the chance of survival (Chan, 2010). In addition, fish did not change their time to react behaviourally when exposed to the additional noise and this means that the noise produced during the installation of PLATO-1 does not induce any subtle responses and fish would successfully escape to the predator.

One possibility for the apparent lack of response to noise exposure may be that the level of the additional noise played back was moderate compared to ambient noise playback. Kastelein et al. (2008) found that 50% reaction threshold levels occurred at 0–30 dB above the hearing thresholds for the test frequencies (100-0.1 Hz). Buscaino et al. (2010) had level at 50dB above the species' hearing threshold and found increased mobility. In our study the level of additional noise within the frequencies 100-0.1 Hz was 10-20 dB above the species' hearing threshold at low frequency (<100Hz), which reflected the difference in levels recorded during the measurements in the field.

Although care should be taken not to generalize these findings from a laboratory study, our data suggest that the moderate noise increase created during the installation activity of PLAT-O1 do not have direct or subtle negative impacts on behaviour of sea bass. Nevertheless, further studies on wild sea bass are needed to draw conclusions about the consequences of the noise from this kind of installation procedure and these studies should include also an assessment of the physiological responses to the noise (e.g. respiration rate and stress). Our data suggested that this kind of installation might be less detrimental on fish behaviour than other more frequently used activities in sea, such as piling, which add high levels of noise in the water (205 dB re 1 µPa; Bailey et al., 2010). It is also important to consider that measurements of the PLAT-O1 noise were only conducted for sound pressure level and not for particle motion, to which sea bass may be more sensitive.

The fact that noise from the installation of the PLAT-O1 platform did not change the behavioural response to the predator in sea bass poses a great deal of interest on the procedure used by SME and the activity (drilling) performed. Pile driving, for example, has the potential to induce a reduction in startle responses in sea bass (Everley et al., 2015). As documented in this study, drilling may reduce the extent of behavioural impact for fish to a much smaller area due to the lower sound levels produced that mitigate the detrimental effects on local fish.

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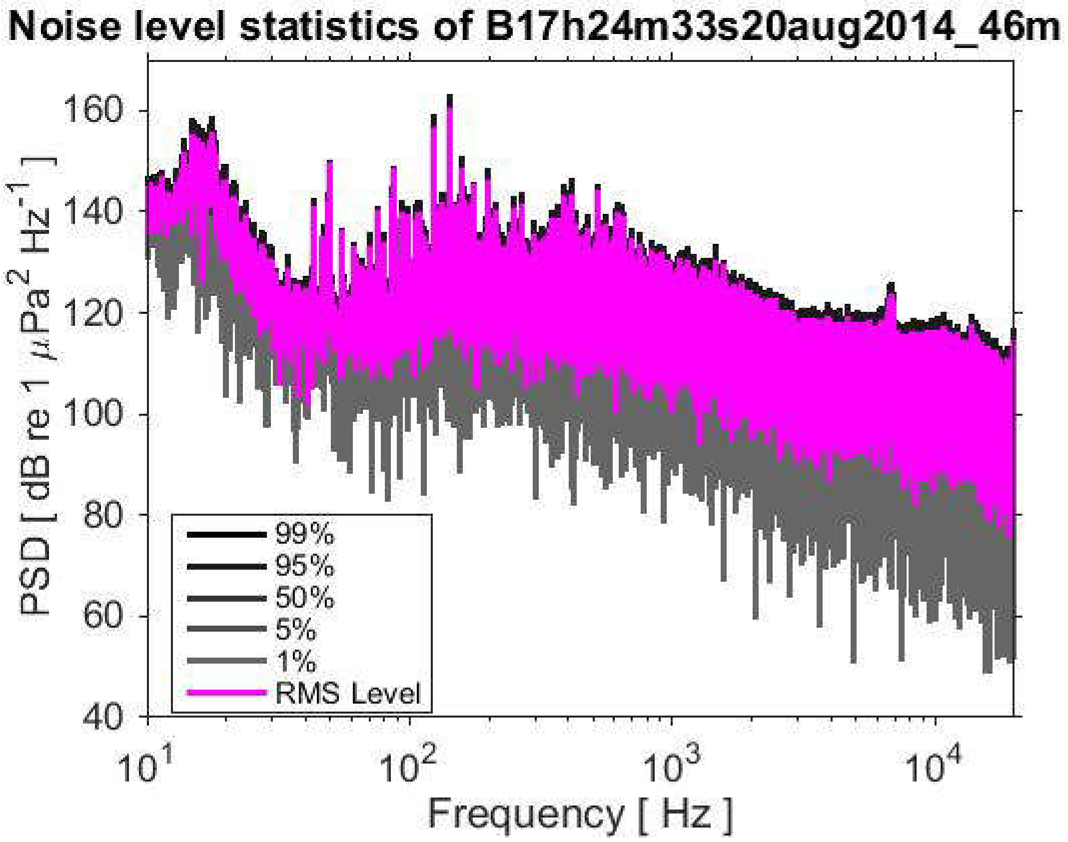
Appendix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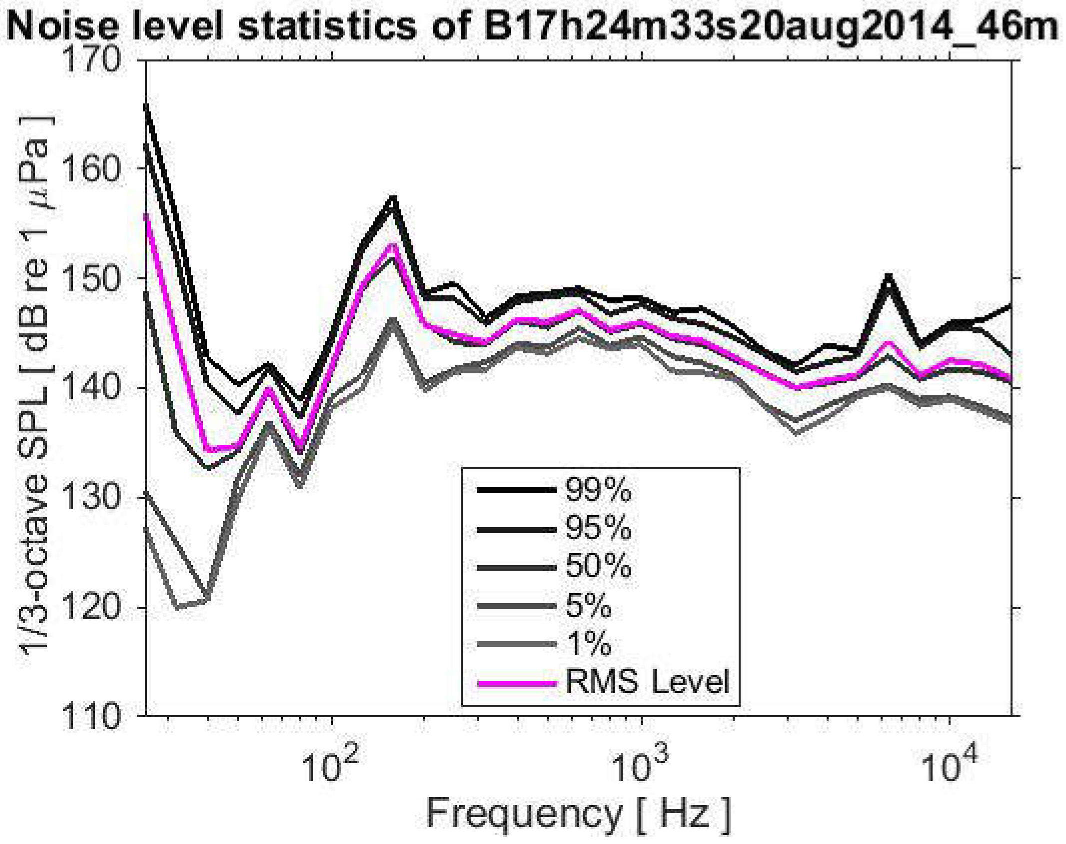
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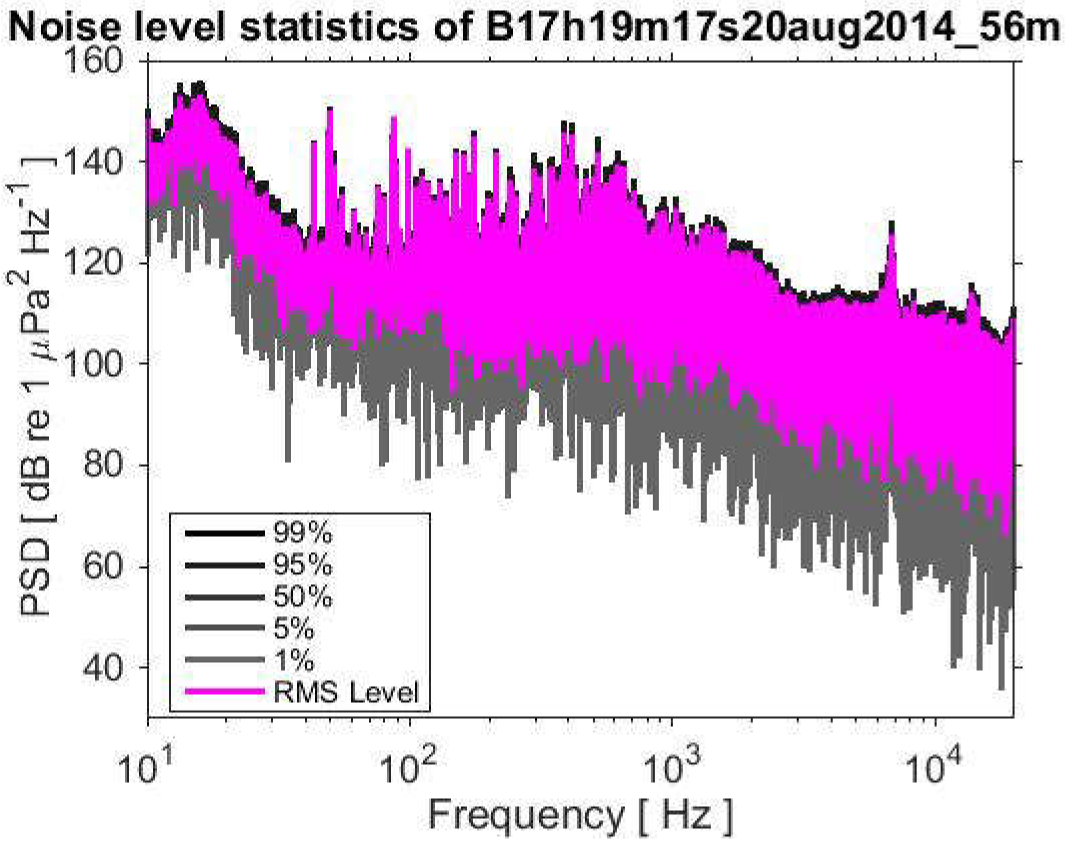
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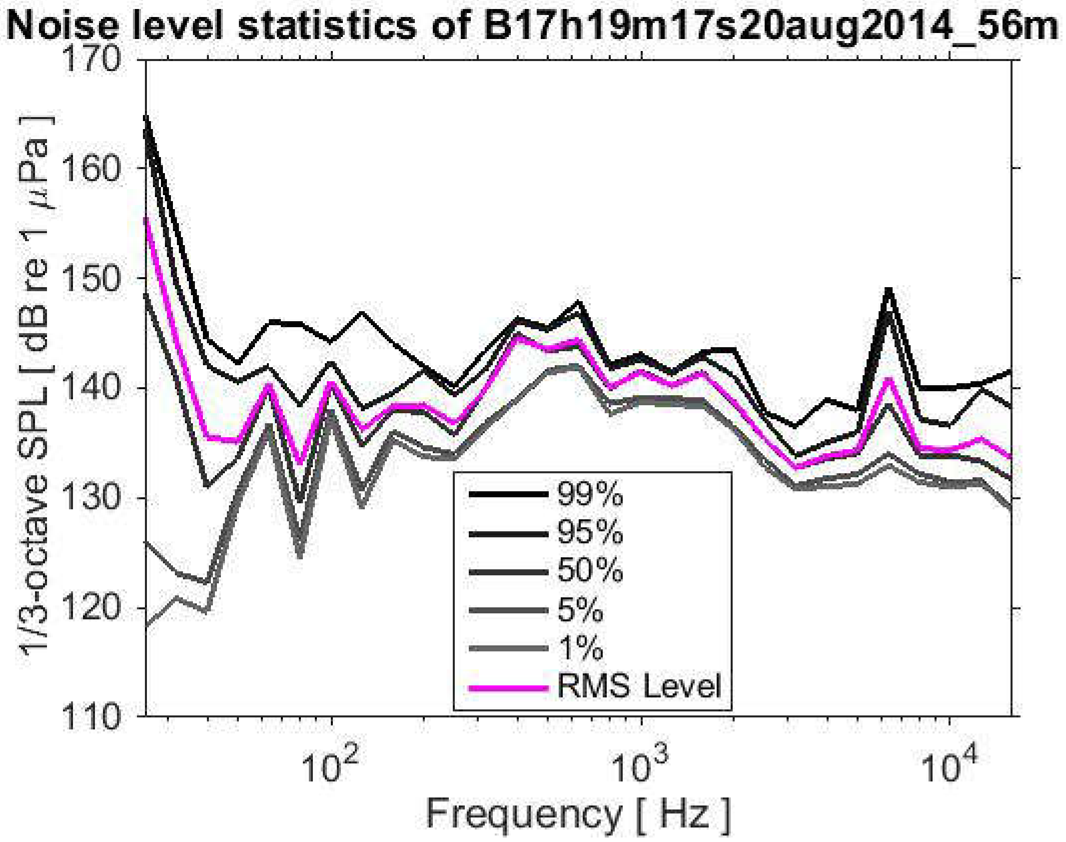
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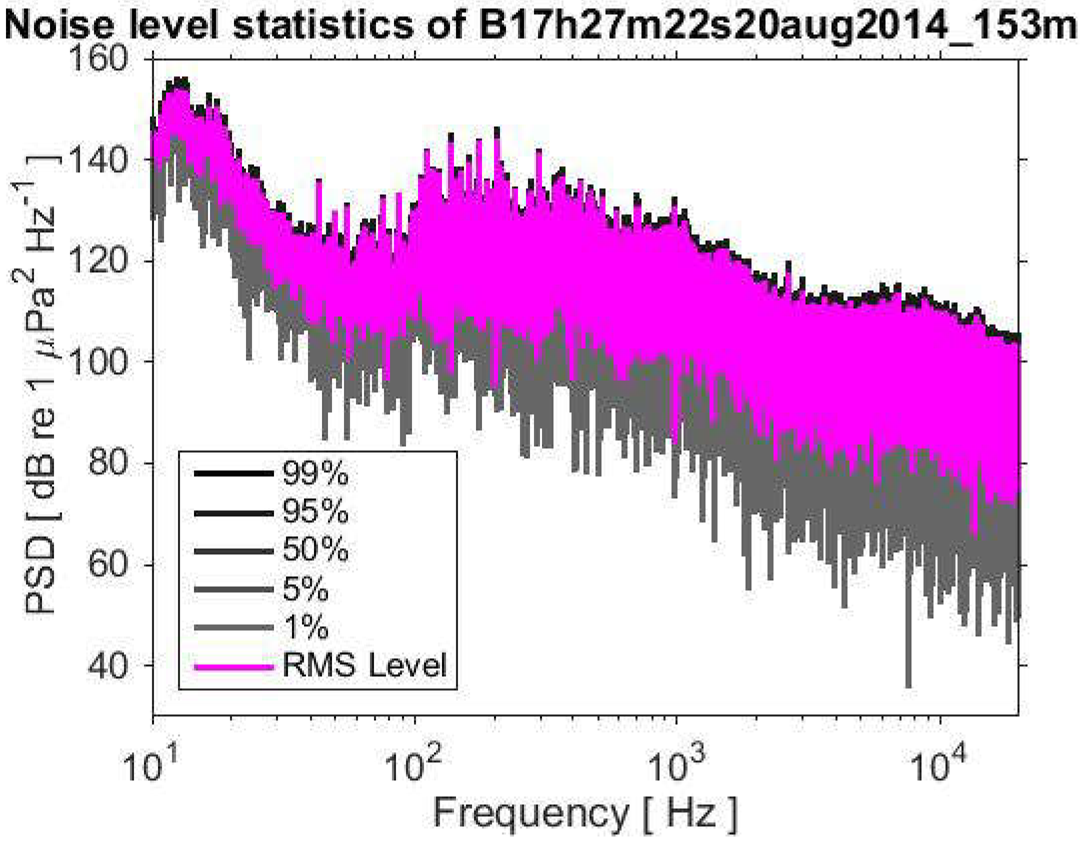
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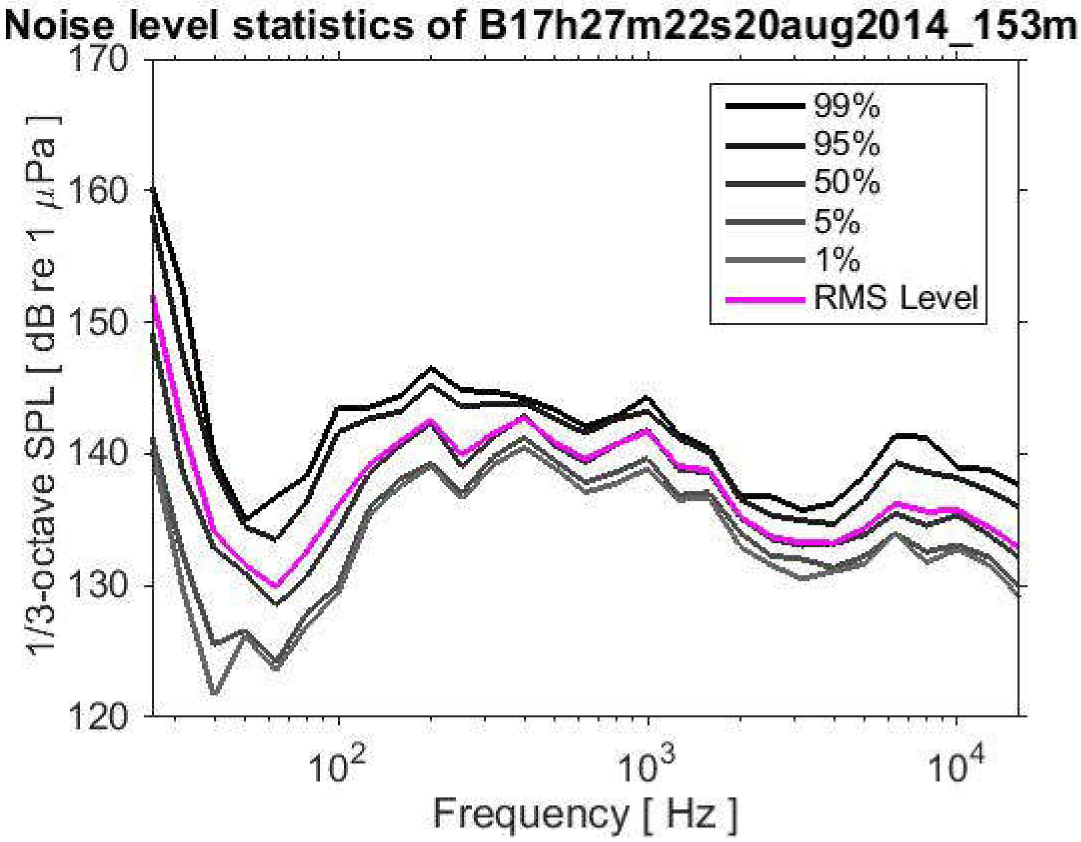
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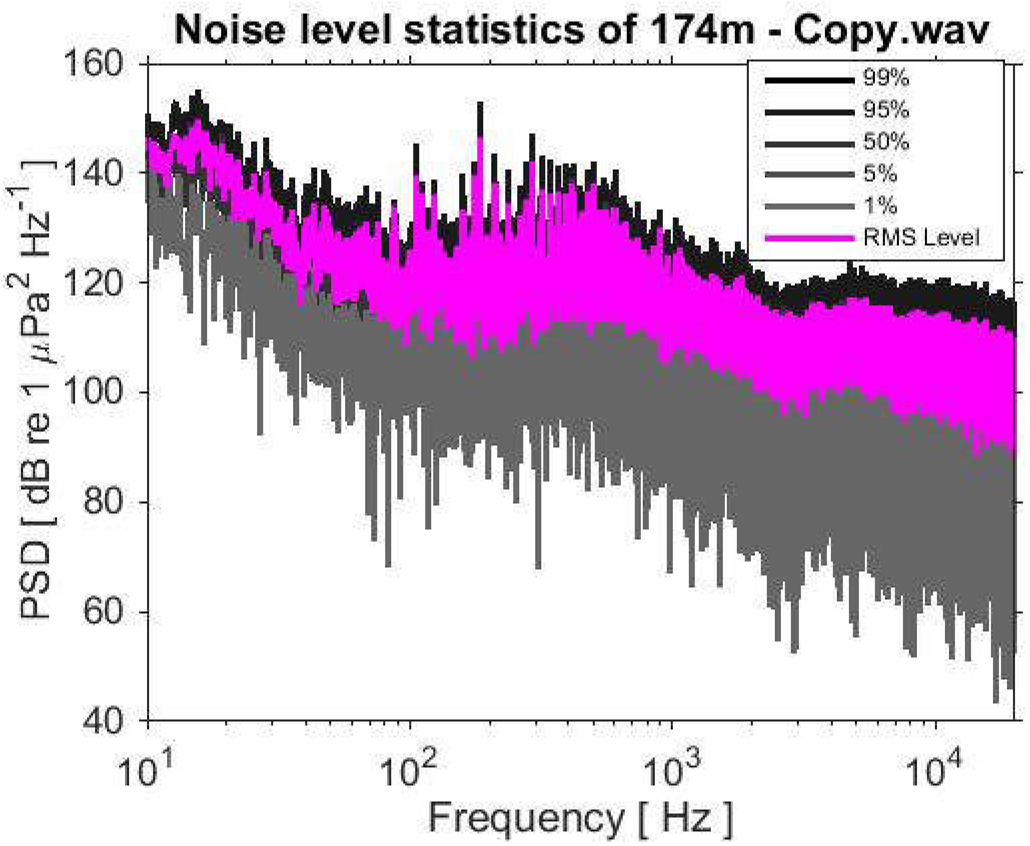
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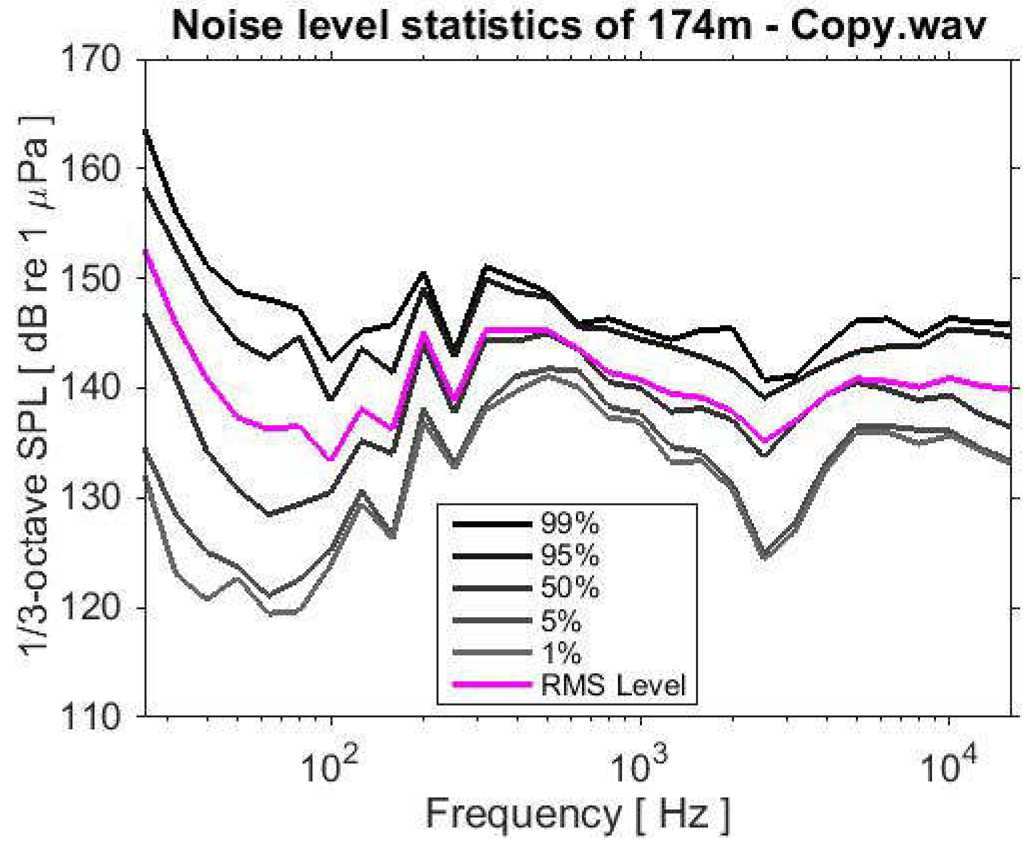
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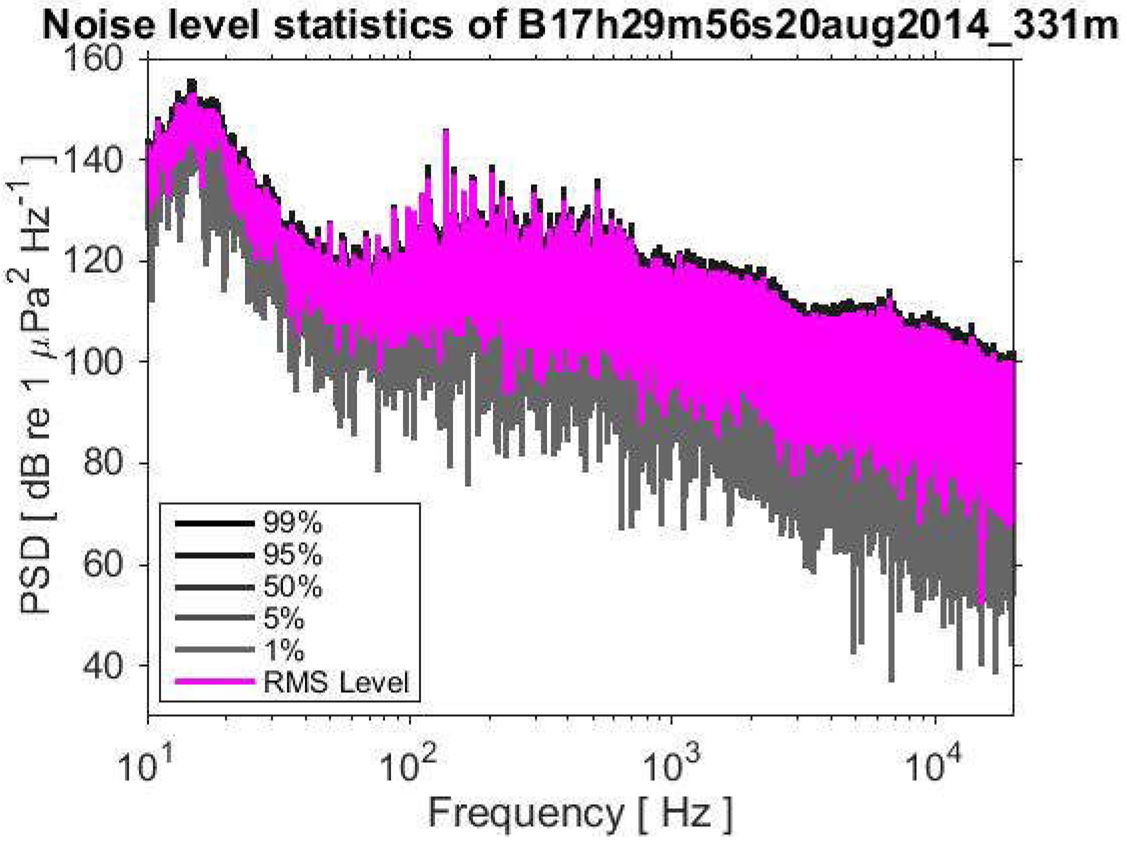
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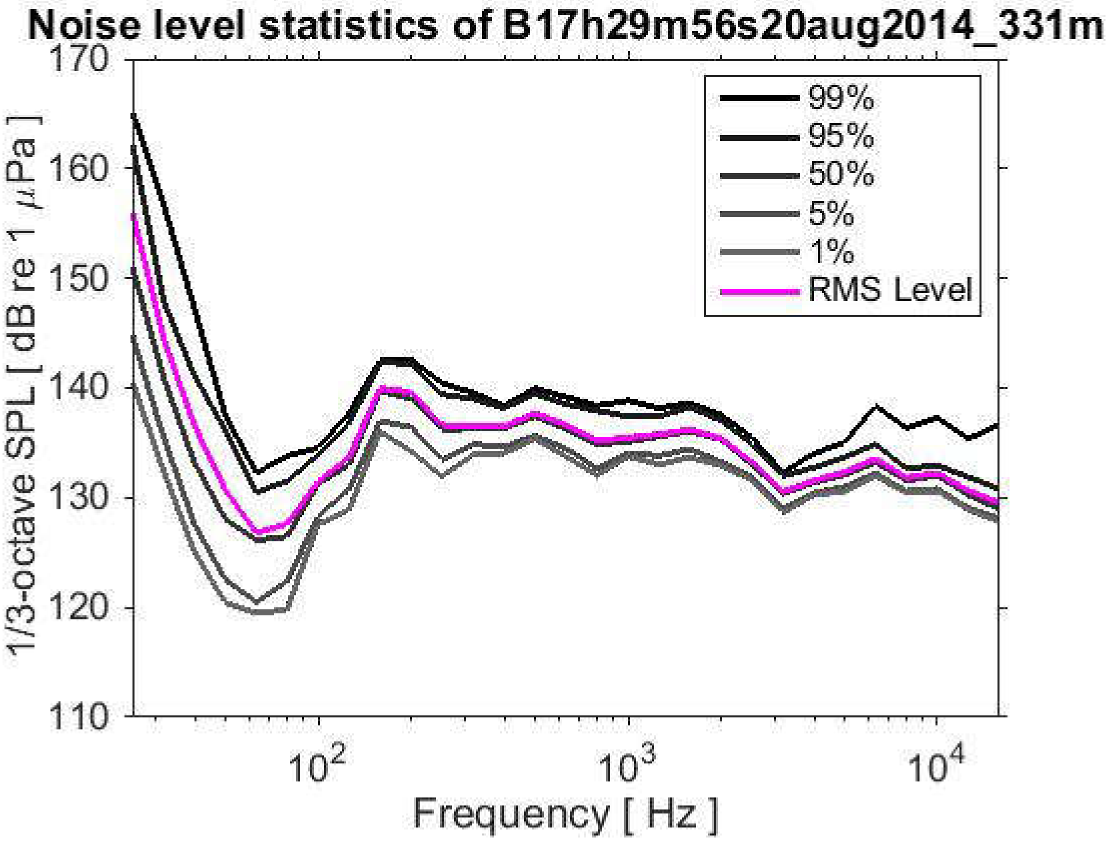
Frequency [Hz]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Frequency [Hz]