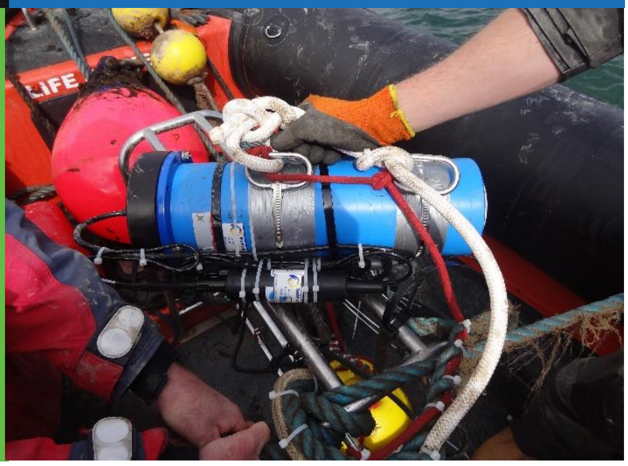
Appendix A9.3 Underwater Noise Assessment and Modelling

Irish water – Greater Dublin Drainage – Hydrophone and Noise Study Report 2017

Irish water - GDD

Submitted to GDD by TechWorks Marine Ltd.

Project Ref: TWM/IWGDDHN/2017



Document History

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This document has been prepared by:

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Contents

Figures

Tables

Abbreviations

EPA – Environment Protection Agency

EQO – Environment Quality Objective

IW – Irish Water

IWDG – Irish Whale and Dolphin Group

LAB – Laboratori d'Aplicacions Bioacústiques

SAM – Static acoustic monitor

TWM – TechWorks Marine

WMO – World Meteorology Organisation

WwTP – Waste water treatment plant

Introduction

Background

In 2013, Irish Water (IW) were commissioning Engineering Consultants to undertake the outline design and to secure planning permission for a Regional Wastewater Treatment Plant (WwTP) to serve the Greater Dublin Area. The scope of work included the production of a statutory EIS and management of the full planning process. IW's appointed Engineering Consultants, Jacobs/Tobin, undertook the role of EIA Managing Consultant and were supported by specialist sub-contractors for the various technical and environmental disciplines. RPS were appointed to the role of Project Ecologist.

The preferred solution for the project was announced in June 2013 to comprise, a WwTP located at a site in the townland of Clonshagh, Fingal, its associated marine outfall discharging 6km out to sea from Baldoyle Bay and approximately 1km north-east of Ireland's Eye, and an orbital sewer and outfall pipeline approximately 26km in length, including two pumping stations, linking the proposed Regional WwTP to the existing regional sewer network and marine outfall.

TechWorks Marine Ltd. (TWM) were contracted by Jacobs Engineering Ireland Ltd. to analyse the underwater noise impact in the context of the construction of an outfall pipeline offshore. The placement of the GDD monitoring buoys were dictated by the proposed pathway of the pipeline route. The buoys were deployed at the locations detailed in Table 1 below:

Table 1 – GPS locations of the TWM monitoring buoys

Site	Latitude	Longitude	SAM's	IcListen HF Hydrophone	Turbidity monitoring
GDD1	53°24.973' N	006°04.980' W	✓	N/A	N/A
GDD2	53°25.044' N	006°04.143' W	✓	N/A	N/A
GDD3	53°24.899' N	006°02.997' W	✓	✓	✓

These locations are further displayed in Figure 1 overleaf.

Data collected from the IcListen High Frequency Hydrophone at site GDD3 was assessed by the TechWorks Marine subcontractors, Laboratori d'Aplicacions Bioacústiques (LAB) and then utilised for modelling of the underwater noise footprint of the project by Quiet-Oceans.

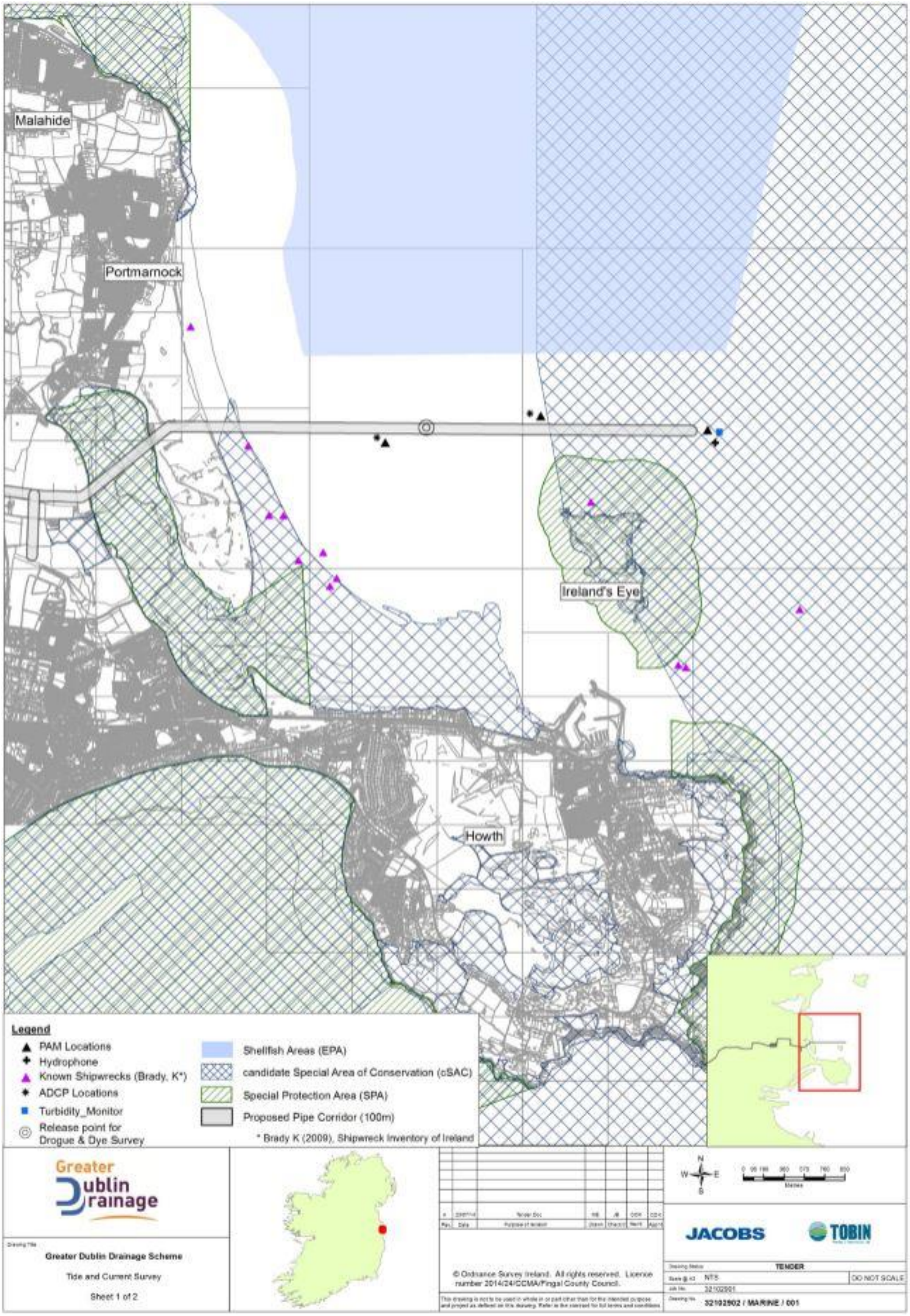


Figure 1 The location of the TWM monitoring buoys

Regional context

The dominant influence on Ireland's climate is the Atlantic Ocean. Consequently, Ireland does not suffer from the extremes of temperature experienced by many other countries at similar latitude. The warm North Atlantic Drift has a marked influence on sea temperatures. This maritime influence is strongest near the Atlantic coasts and decreases with distance inland. The hills and mountains, many of which are near the coasts, provide shelter from strong winds and from the direct oceanic influence. Winters tend to be cool and windy, while summers, when the depression track is further north and depressions less deep, are mostly mild and less windy.

The World Meteorological Organization (WMO) recommends that climate averages are computed over a 30 year period of consecutive records. The period of 30 years is considered long enough to smooth out year to year variations. Henceforth Met Éireann utilised data gathered between 1981 and 2010 as the baseline period reference for day-to-day weather and climate comparisons. A summary of Met Éireann’s data for the closest long term location to the buoys location (Dublin airport) is detailed in Table 2 below:

Table 2 A summary of Met Éireann’s meteorological average data for Dublin Airport 1981–2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly
Mean daily maximum temperature [°C]	8.1	8.3	10.2	12.1	14.8	17.6	19.5	19.2	17.0	13.6	10.3	8.3	13.3
Mean daily minimum temperature [°C]	2.4	2.3	3.4	4.6	6.9	9.6	11.7	11.5	9.8	7.3	4.5	2.8	6.4
Mean temperature [°C]	5.3	5.3	6.8	8.3	10.9	13.6	15.6	15.3	13.4	10.5	7.4	5.6	9.8
Mean relative humidity [% at 09:00 UTC]	87.0	86.4	84.0	79.5	76.9	76.7	78.5	81.0	83.4	85.5	88.5	88.0	83.0
Mean daily sunshine (hours)	1.9	2.7	3.5	5.3	6.2	5.8	5.3	5.1	4.3	3.3	2.4	1.7	3.9
Mean monthly total rainfall (mm)	62.6	48.8	52.7	54.1	59.5	66.7	56.2	73.3	59.5	79.0	72.9	72.7	758.0
Mean monthly wind speed (knots)	12.5	12.0	11.6	9.9	9.2	8.6	8.7	8.7	9.2	10.4	11.0	11.3	10.3

The Irish Sea is a region of high tidal energy (Simpson and Hunter, 1974), with a strong correlation between turbidity and tidal stirring (Mitchelson, 1984; Weeks et al., 1993; Bowers et al., 1998).

The bathing water quality of the Irish Sea has greatly improved since 1999 as a result of the construction of an advanced wastewater treatment plant in Ringsend. Prior to this, wastewater from Dublin was pumped to the Ringsend Treatment Works where it received primary treatment only before being discharged into the bay and wastewater from the north of the city was discharged, untreated, into the sea at Howth.

The Environmental Protection Agency (EPA) produces an annual report which presents key findings and results yearly on the quality of Ireland's bathing waters. The EPA Bathing Water Report for 2015 shows that the water quality at Portmarnock (Velvet strand beach) and Donabate (Balcarrick beach) has remained excellent and was fully compliant with the mandatory and guide values of the EU bathing water quality requirements.

Legislation, Standards and Guidelines

This section provides a description of legislation, standards and guidelines relevant to the project. It summarizes and examines provisions of European Directives, associated Irish national regulations and relevant international guidelines and standards.

Bathing Water Directive (76/160/EEC)

The Bathing Water Directive has been given effect in Irish law by the European Communities (Quality of Bathing Water) (Revocation) Regulations, 1992. It is the primary legislation governing the quality of bathing waters. The purpose of the Directive is to ensure that the quality of bathing water is maintained and, where necessary, improved so that it complies with specified standards designed to protect public health and the environment. This directive is based on the “Environmental Quality Objective” (EQO) approach, in which standards are laid down for various types of water in which contaminants may be found, and the concentrations of which are limited.

Dangerous Substances Directive (76/464/EEC)

The Dangerous Substances Directive on pollution caused by certain dangerous substances discharged into the aquatic environment of the Community was one of the first water related Directives to be adopted. It has objective of regulating potential aquatic pollution by thousands of chemicals. The Directive covers discharges to inland surface waters, territorial waters, inland coastal waters.

Water Framework Directive

Most of these individual Directives give way to the Water Framework Directive (200/60/EC), which addresses inland surface waters, estuarine, and coastal waters and groundwater. The Water Framework Directive was adopted into Irish Law in December 2003 and provides a comprehensive framework for water quality management across the EU. It requires that we take a holistic view of water and how it sustains life. The fundamental objective of the Water Framework Directive aims at maintaining ‘high status’ of waters where it exists, preventing the deterioration in the existing status of waters and achieving at least "good status" in relation to all waters by 2015.

Material and Methods

Buoy installation

For the accurate collection of both TechWorks Marine's turbidity data and the IcListen HF Hydrophone data a robust and stationary site was required. To this end the surface buoys used for the project were Mobilis DB350's. The buoy consists of a hull that comes in two parts that are bolted onto the ballast frame. A daymark is then mounted on top of the hull. All of the buoy also had a radar reflector, St. Andrews cross and navigation light mounted on the top of the daymark.

Ballast and anodes were attached to the ballast frame of the buoy, as per the manufacturer's specification. Shackles were also attached to the ballast frame to which the moorings were fixed. The buoy was moored using anchor chain clumps of 500kg.

Additionally, the Irish Whale and Dolphin Group (IWDG) C-PODS were deployed on this mooring. Both the C-pod and IcListen Hydrophone were secured to the line with several lengths of rope, jubilee clips and cable ties. The layout of these moorings is displayed in Figure 2 below.

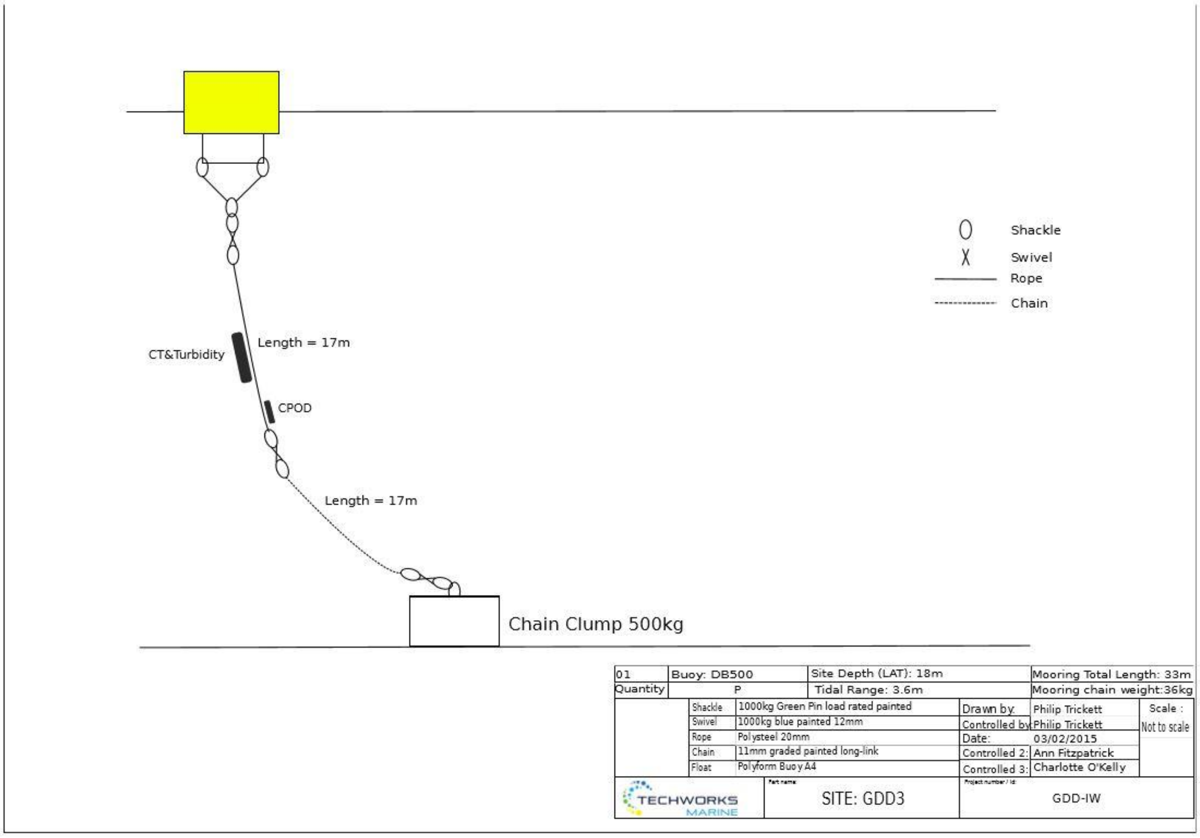


Figure 2 The mooring configuration of the buoys (The mooring lengths will differ between sites with the different depths).

Buoy sensors and data collection

Buoy GDD3 was utilised to collect Hydrophone data from the fixed mooring over the month of August 2015. The specification documents for the IcListen Hydrophone can be viewed in Appendix B. The Hydrophone was mounted approximately mid water column (~10m) below the surface. Once the hydrophone was deployed, data was collected from the sensor continuously for the month. All data is recorded internally for retrieval after the unit is recovered.

The icListen Smart Hydrophone is the industry's most sensitive broadband digital hydrophone. It's a compact, all-in-one instrument capable of processing data while collecting in real-time. The Hydrophone was calibrated to manufacturer specifications and thoroughly tested before and after the overall operation. The calibration certificate can be found in Appendix C.

Once the Hydrophone was retrieved the data was downloaded and provided to industry experts at LAB. The team at LAB then utilised this data to produce a report on the noises recorded and to produce a noise model of the area. These reports are shown in the following section overleaf:

Analysis of Dublin Recordings August 2015

Date	2017-03-31
Report version	2.0
Authors	
LAB-UPC	Mike van der Schaar Michel André
TechWorks	

Contents

Summary

Sound levels

The Marine Strategy Framework Directive descriptors that should be reported for the recording period are 107 dB and 103 dB re 1 μPa^2 for 63 Hz and 125 Hz respectively. These levels were computed leaving out the 1% highest pressure values to reduce the influence of outlier events (e.g. something knocking against the hydrophone).

The measured levels during August appear to have little variation. While nearby ships were of course registered, the overall anthropogenic contribution seems to be small. The recording location probably did not pick up traffic from shipping lanes in the Irish Sea. The data analysis indicates that dominant influences on the measured levels were wind speeds and perhaps water currents. Both may have produced typical sounds of moving cables. The results are probably not representative for the Dublin bay area and should only be compared to measurements at the same location, taking into account at least the wind speeds (i.e. comparison of levels should then only be made when recorded under similar conditions).

Cetacean Presence

No cetaceans were detected; the contribution of biological sources appears to be minimal in these recordings.

Recording Equipment

A single recorder was deployed on a buoy near Ireland's Eye at 53°24.901'N 006°2.978'W. It was operating continuously from July 30 to September 1. In order to discard noise from the deployment and recovery operations only data from August is considered in this report. The recording duty cycle was configured with 15 minutes on and 50 minutes off. The hydrophone sensitivity taken from the stored wav files was -168 dB re 1 V/ µPa. The data was sampled at 16 kHz in 24 bits; the quantization was between +-3V. No gain was used. The bathymetry of the area is shown in Figure 1. Although at the edge of a shallow 30 m trench, a large part of the zone around the recording location had depths less than 20m, affecting the propagation of the sound.

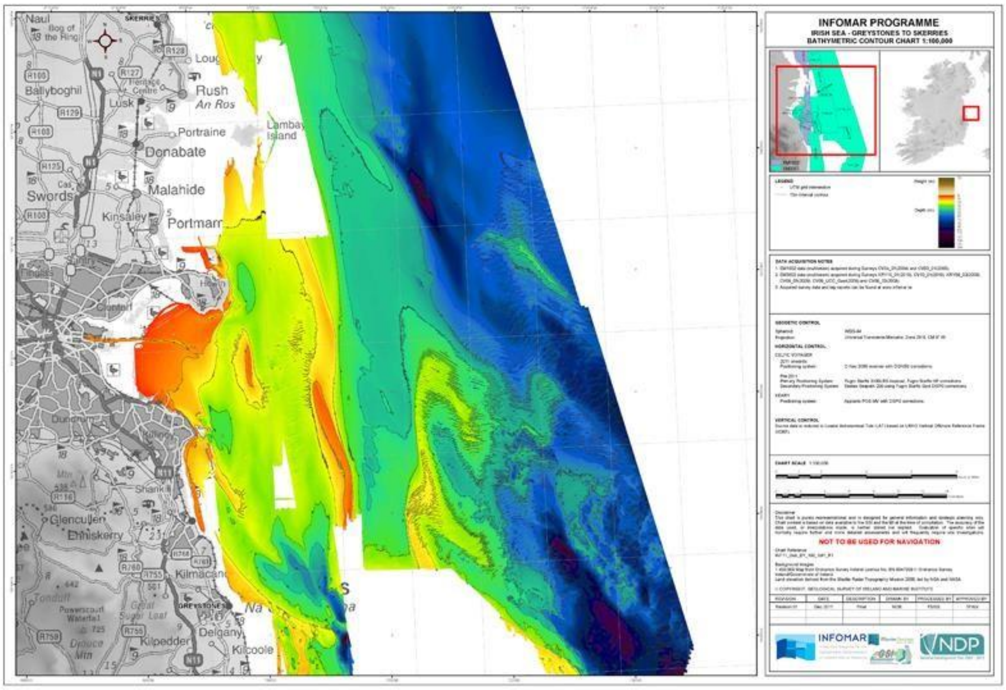


Figure 1 Irish Sea deployment location with bathymetry (INFOMAR).

Data Analysis Configuration

The configuration of the analysis was focussed on third octave band sound pressure levels. For general interest default impulse and short tonal detectors were included in the processing. Data was processed in segments of 16.384 seconds. Third octave band sound pressure level measurements were taken over 10 second snapshots.

Performed measurements on each segment:

- Broadband sound pressure and peak levels over the segment.
- Third octave band sound measurements starting at the band centred on 25 Hz up to the band centred on 5040 Hz.
- One impulsive signal detector operating between 500 – 5000 Hz.
- One short tonal detector operating between 1000 – 6000 Hz.
- Spectrograms were created to show frequency content up to 4000 Hz. The hydrophone's anti-aliasing filter starts rolling off around 6500 Hz. This frequency range was selected to focus on low frequency noise sources, while possibly showing dolphin whistles when present.
- A compressed audio stream was created for the user interface playback feature.

All analysis results are made available from the public website on http://dublin.listentothedeep.com/acoustics/.

Impulse Detections

The impulse detector was being triggered almost continuously throughout the deployment (Figure 2). There were very few moments where none were detected. It seems that these events were mostly triggered by self-noise of the mooring system. Two examples of impulse detections are given in Figure 3 and Figure 4. These noises may be due to wind or currents. It does not seem that there was a high contribution of shrimp, bivalves or other animals, which signals could also be expected to be picked up by this detector.

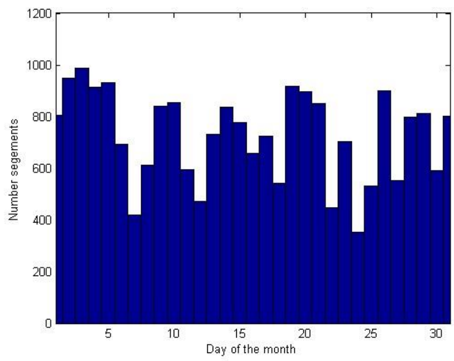


Figure 2 Segments with high impulse detector outputs during August.

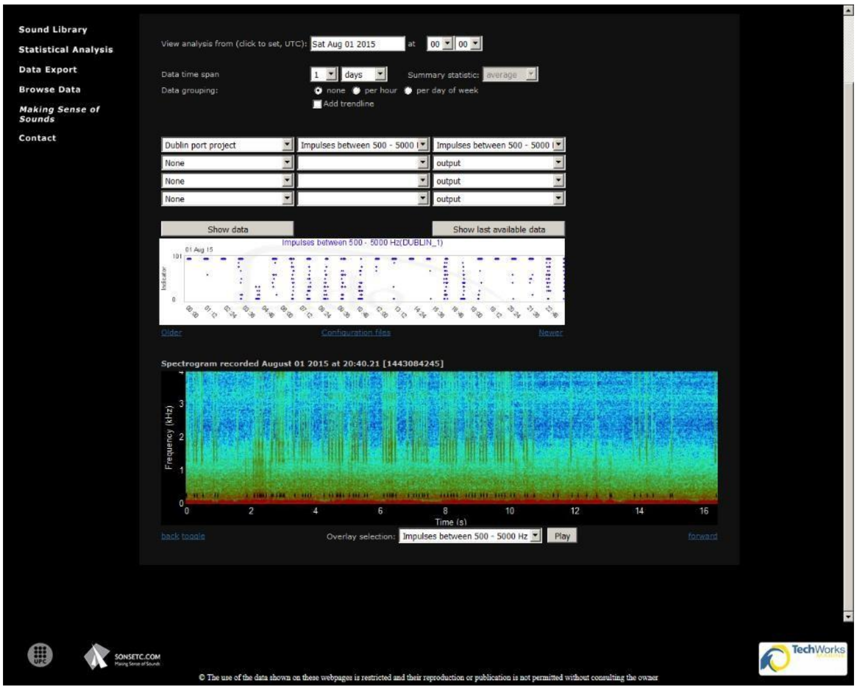


Figure 3 Example of likely self-noise detected on August 1 (Click to listen).

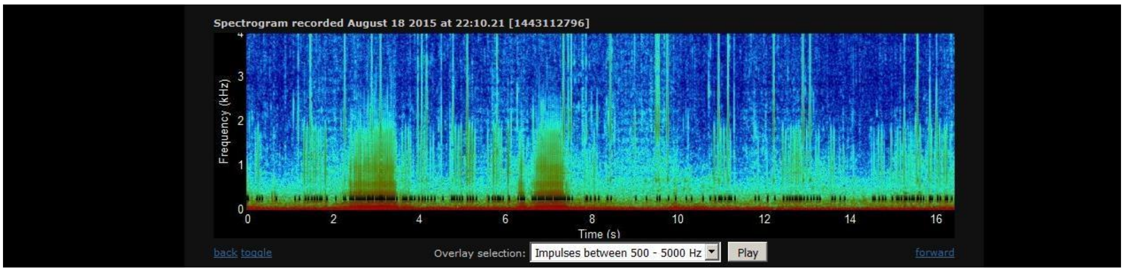


Figure 4 Self noise recorded on August 18 ([Click to listen]).

Short Tonal Detections

The short tonal detector was not providing high outputs during most of the deployment time (Figure 5). It was thought that it might be able to pick up some dolphins, but manual inspection of a few recording intervals where it was triggering did not show any signal of interest. Further data inspection did not reveal any cetacean signal and therefore no attempt was made to fine tune the detector output to a specific type of acoustic event. High outputs, such as around August 12, were mostly due to shipping activity near the buoy. One example of the detections is given in Figure 6.

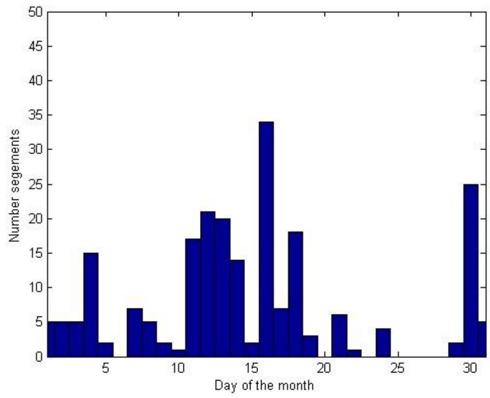


Figure 5 Segments with high short tonal detector output during August.

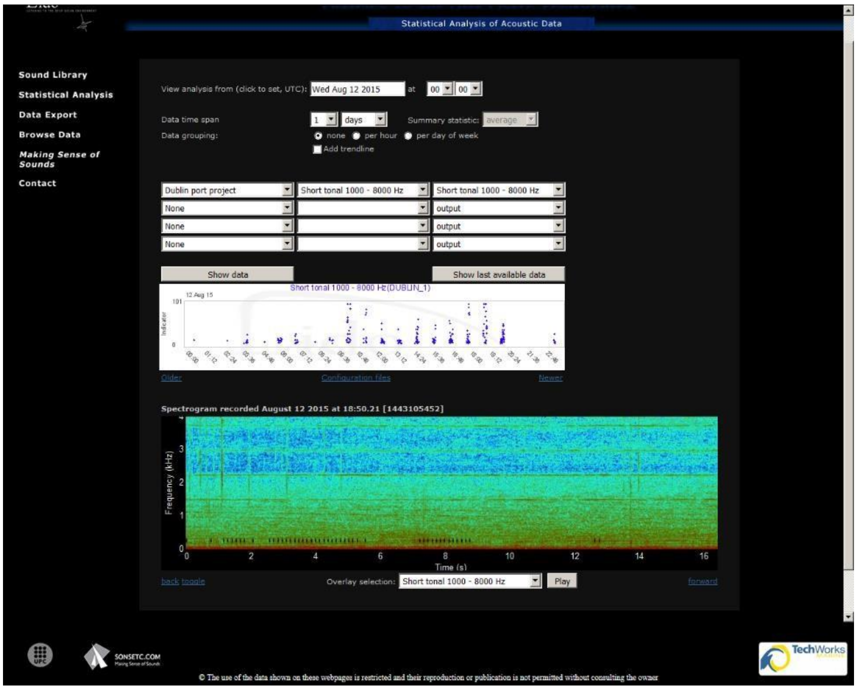


Figure 6 Short tonal acoustic events detected on August 12 from an anthropogenic source. ([Click to listen])

Distribution of noise levels

Although only a single month of data was recorded it would be interesting to see if during that month noise levels were especially high during particular hours of the day or a particular day of the week. Since the contribution of sound coming from biological sources appeared to be very small and the influence of weather (wind or rain) is not expected to strictly follow this kind of pattern, a trend here could be attributed to anthropogenic sources. For each third octave band that was measured a box plot was created to visualize this data partitioning (shown at the end of this section; these plots are not yet available through the automated report generation on the website).

The images showing the day of the week pattern are remarkably flat over all frequency bands, with very little variation in median levels. Considering the proximity to a harbour it could be expected to have more activity during the week than in the weekend due to commercial shipping, but there do not seem to be days where the activity is higher than normal.

The hour of the day partitioning shows some more interesting patterns. At low frequencies the median level remains fairly equal over all hours, but at higher frequencies there is some variation with highest levels received at mid-day and in the afternoon. The pattern with four peaks at for example 125 Hz may be related to the tidal water currents. These currents could cause some of the sounds detected by the impulse detector, increasing the proportion of selfnoise at some of the measured frequencies.

The overall flatness of low frequency noise levels is an indication that the selected location is far from shipping and fishing activities while at the same time the shallow water depths prevent long range propagation of the frequencies that are most prominently produced by human activities. The optimal frequency (from a propagation perspective) in these conditions may be well over 1 kHz, where the noise levels do show some variation. The Irish Sea does see a lot of shipping activity, especially near Dublin (Figure 7) which was not clearly registered by the recorder. As such, the recording location may not be representative for sound levels in other parts of the Irish Sea.

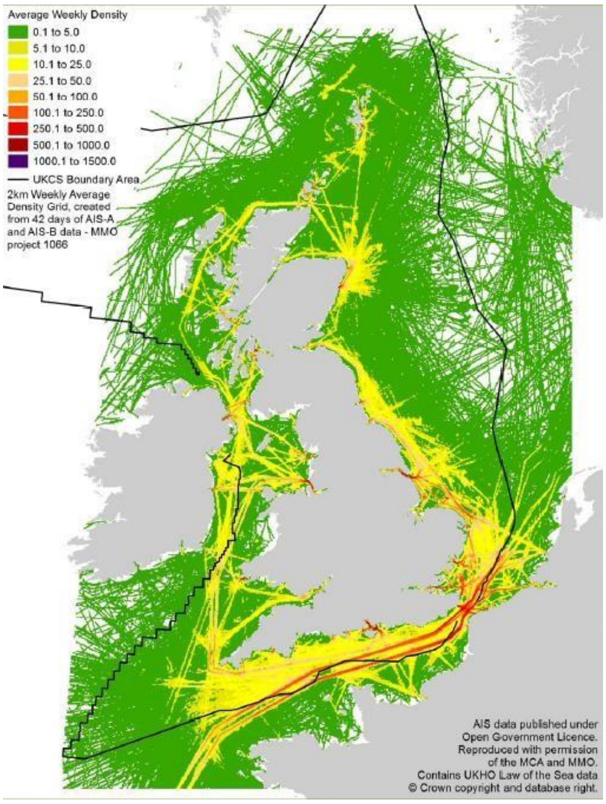
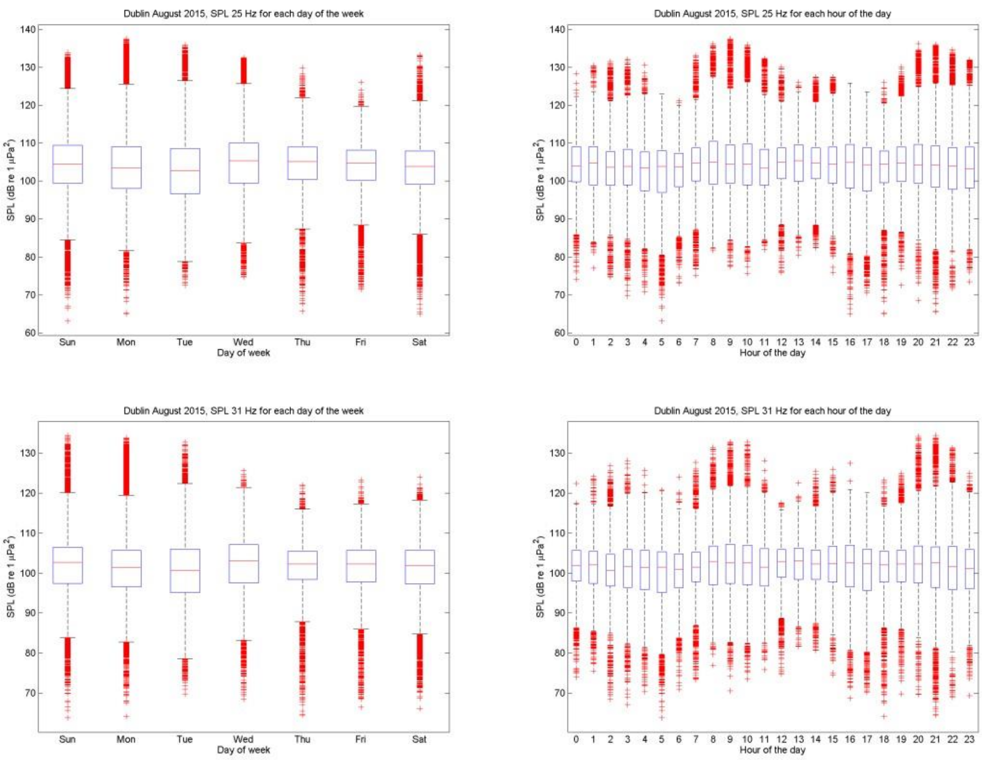
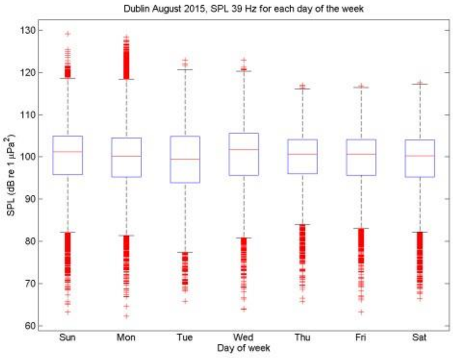
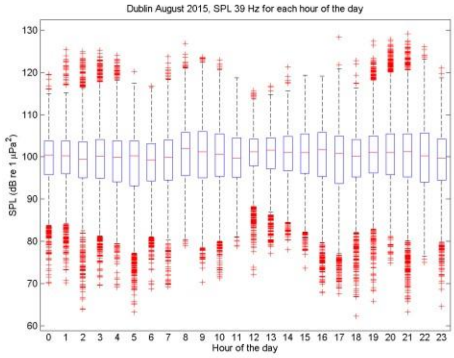
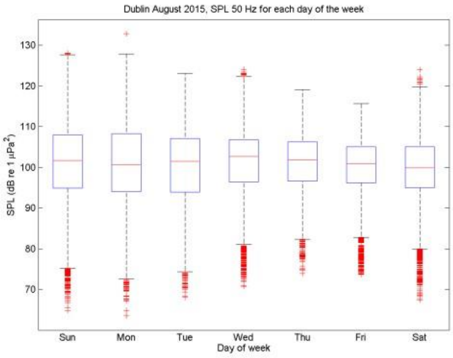


Figure 7 Shipping activity based on AIS data around the UK (Marine Management Organisation 2014).




Dublin August 2015, SPL 39 Hz for each day of the week
SPL (dB re 1 µPa²)
Sun Mon Tue Wed Thu Fri Sat
Day of week


Dublin August 2015, SPL 39 Hz for each hour of the day
SPL (dB re 1 µPa²)
Hour of the day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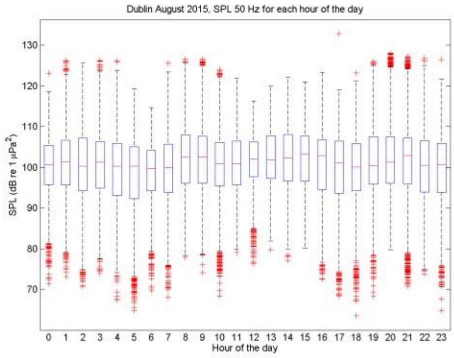
SPL (dB re 1 µPa²)
Sun Mon Tue Wed Thu Fri Sat
Day of week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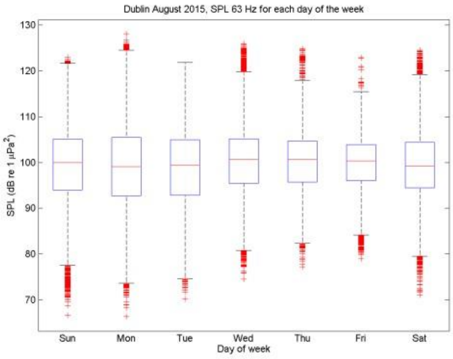
SPL (dB re 1 µPa²)
Hour of the day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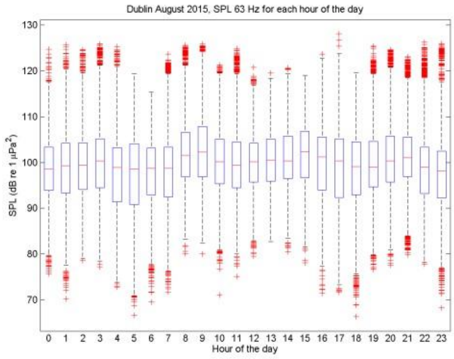
SPL (dB re 1 µPa²)
Sun Mon Tue Wed Thu Fri Sat
Day of week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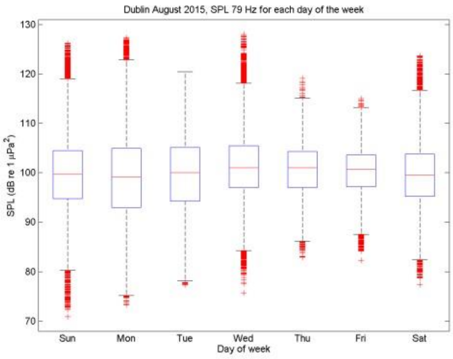
SPL (dB re 1 µPa²)
Hour of the day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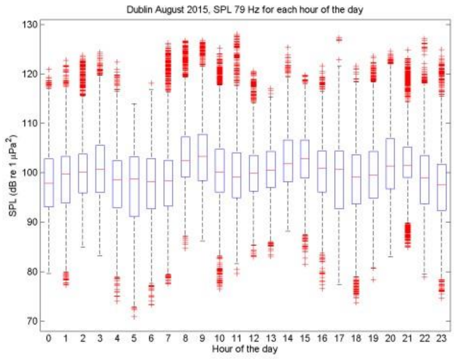
SPL (dB re 1 µPa²)
Sun Mon Tue Wed Thu Fri Sat
Day of week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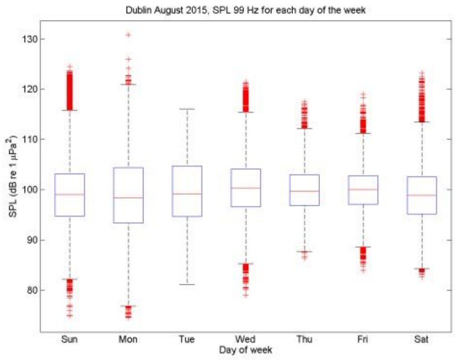
SPL (dB re 1 µPa²)
Hour of the day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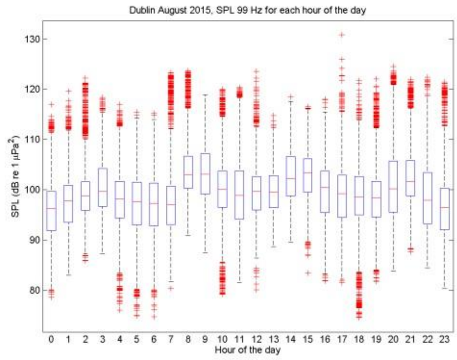
SPL (dB re 1 μPa²)
Sun Mon Tue Wed Thu Fri Sat
Day of week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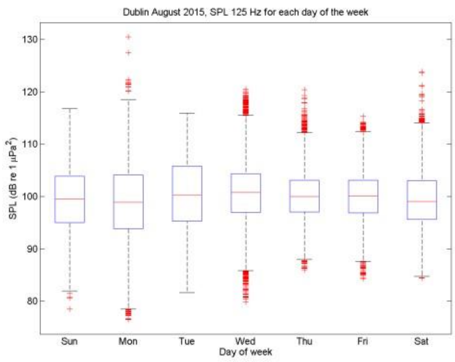
SPL (dB re 1 μPa²)
Hour of the day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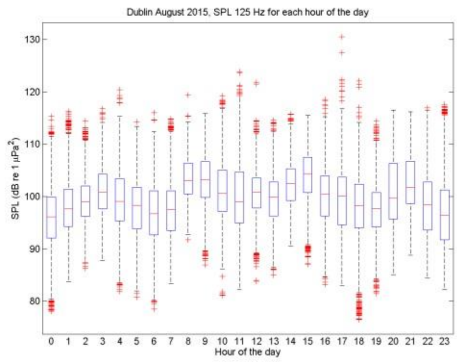
Day of week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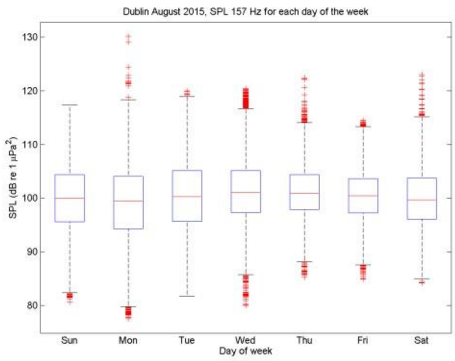
Hour of the day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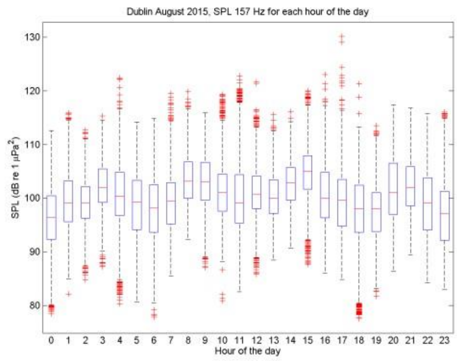
SPL (dB re 1 μPa²)
Sun Mon Tue Wed Thu Fri Sat
Day of week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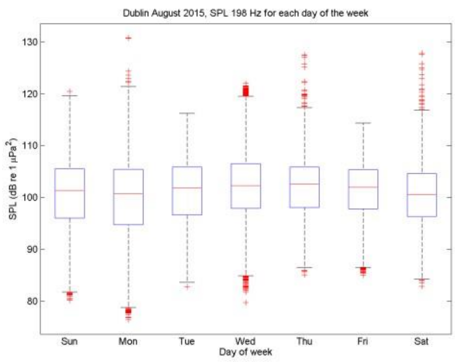
SPL (dB re 1 μPa²)
Hour of the day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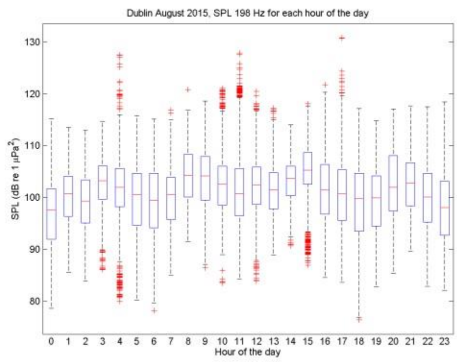
Day of week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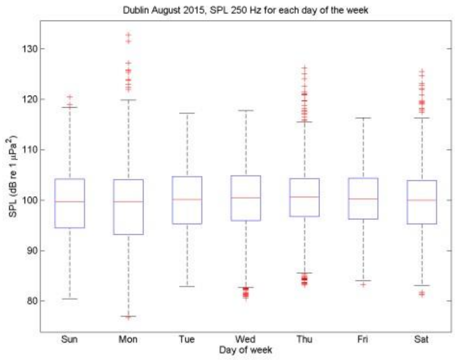
Hour of the day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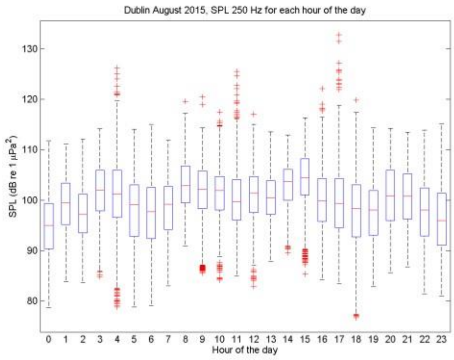
Sun Mon Tue Wed Thu Fri Sat
Day of week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SPL (dB re 1 μPa²)
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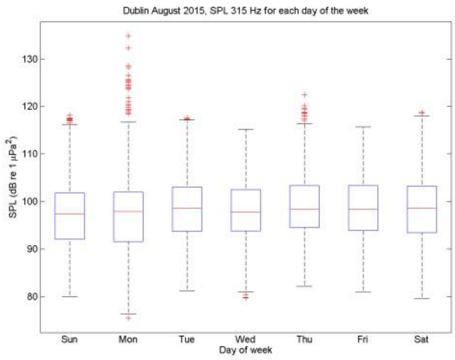
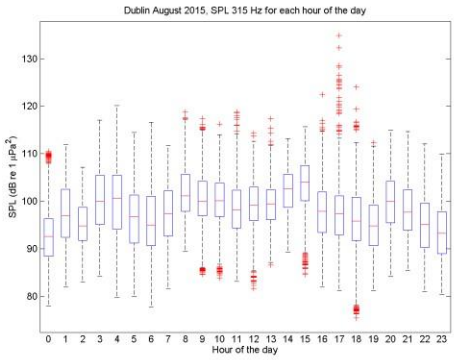
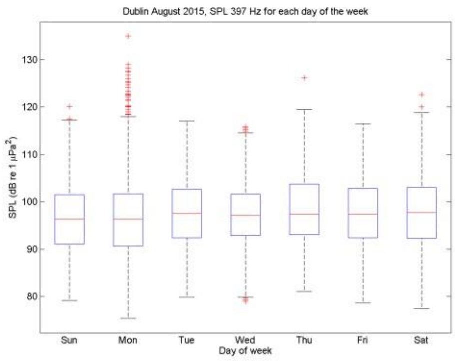
Hour of the day


Dublin August 2015, SPL 315 Hz for each day of the week
SPL (dB re 1 μPa²)
Sun Mon Tue Wed Thu Fri Sat
Day of week


Dublin August 2015, SPL 315 Hz for each hour of the day
SPL (dB re 1 μPa²)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour of the day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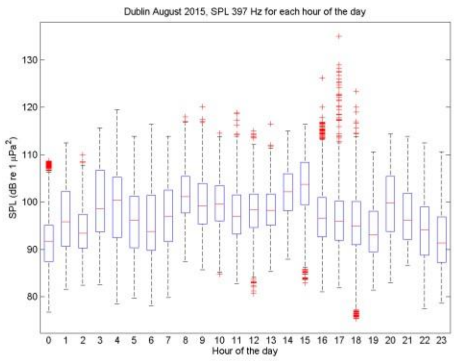
SPL (dB re 1 μPa²)
Sun Mon Tue Wed Thu Fri Sat
Day of week


Dublin August 2015, SPL 397 Hz for each hour of the day
SPL (dB re 1 μPa²)
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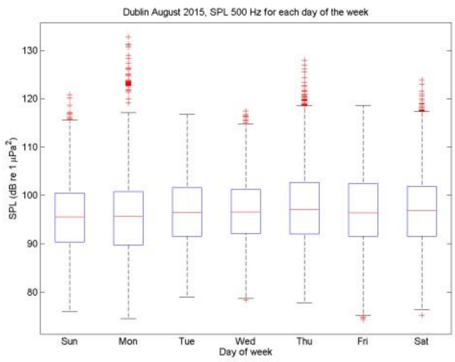
Hour of the day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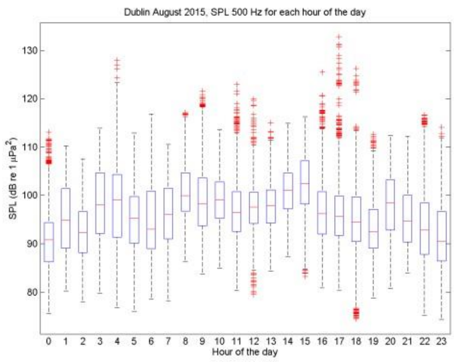
SPL (dB re 1 μPa²)
Sun Mon Tue Wed Thu Fri Sat
Day of week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SPL (dB re 1 μPa²)
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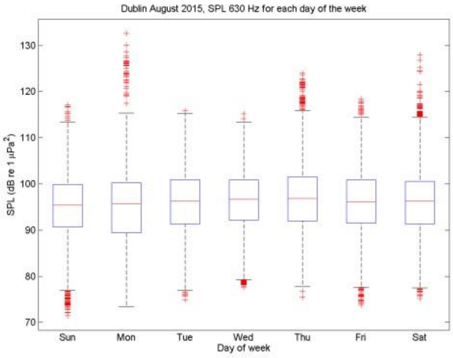
Hour of the day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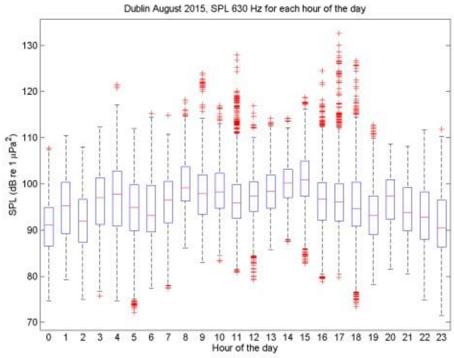
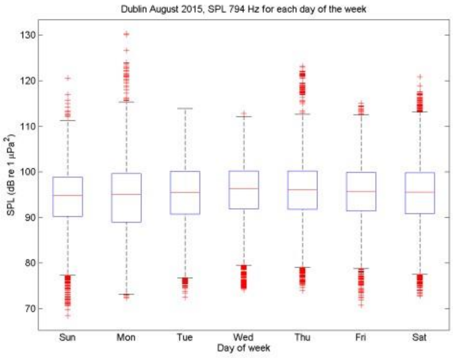
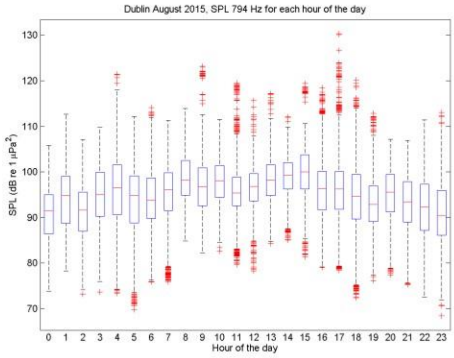
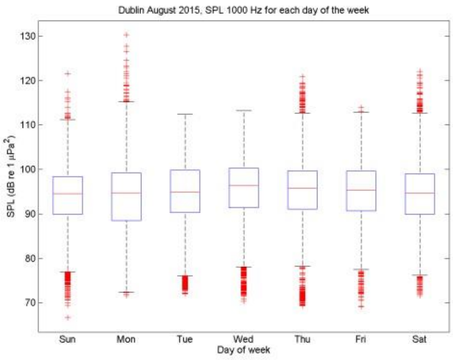
SPL (dB re 1 μPa²)
Sun Mon Tue Wed Thu Fri Sat
Day of week


Dublin August 2015, SPL 630 Hz for each hour of the day
SPL (dB re 1 μPa²)
Hour of the day


Dublin August 2015, SPL 794 Hz for each day of the week
SPL (dB re 1 μPa²)
Sun Mon Tue Wed Thu Fri Sat
Day of week


Dublin August 2015, SPL 794 Hz for each hour of the day
SPL (dB re 1 μPa²)
Hour of the day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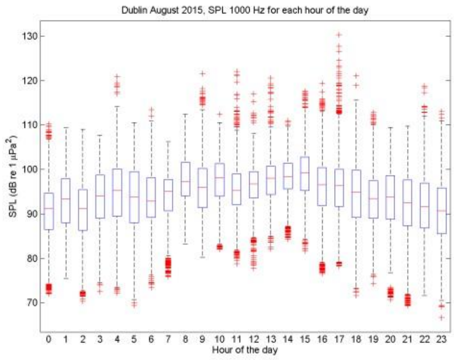
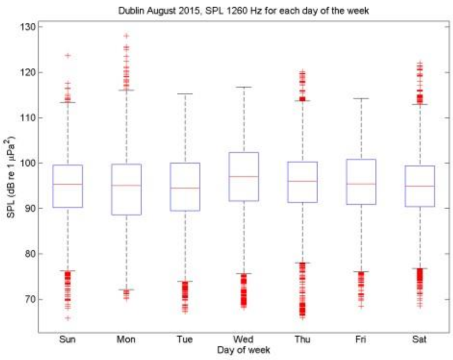
SPL (dB re 1 μPa²)
Sun Mon Tue Wed Thu Fri Sat
Day of week


Dublin August 2015, SPL 1000 Hz for each hour of the day
SPL (dB re 1 μPa²)
Hour of the day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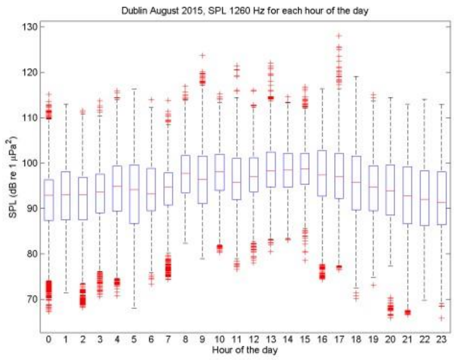
SPL (dB re 1 μPa²)
Sun Mon Tue Wed Thu Fri Sat
Day of week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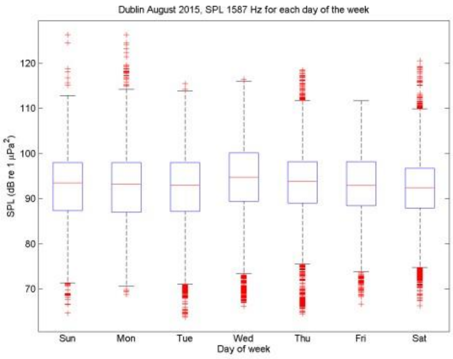
SPL (dB re 1 μPa²)
Hour of the day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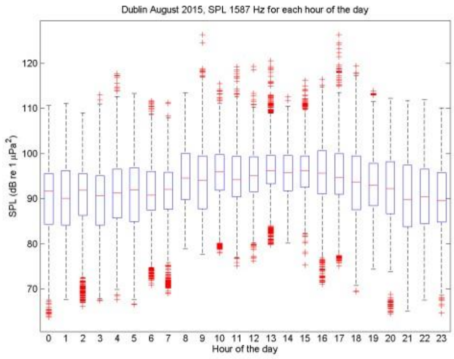
SPL (dB re 1 μPa²)
Day of week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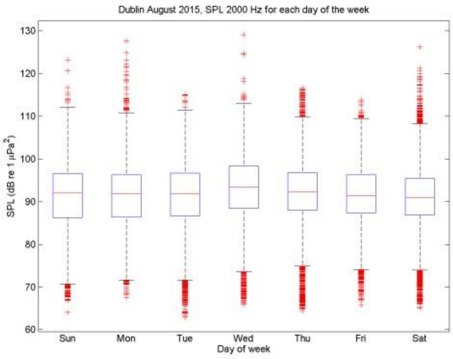
SPL (dB re 1 μPa²)
Hour of the day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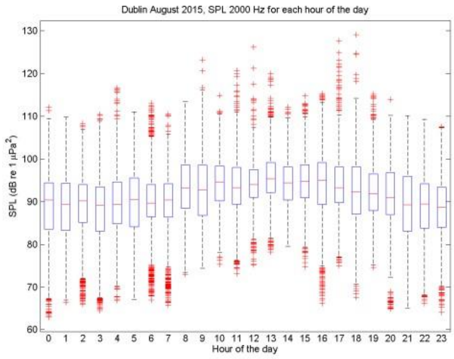
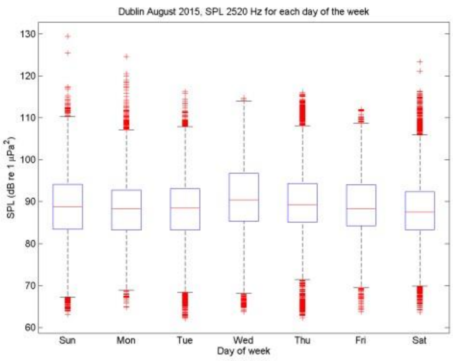
SPL (dB re 1 μPa²)
Day of week


Dublin August 2015, SPL 2000 Hz for each hour of the day
SPL (dB re 1 μPa²)
Hour of the day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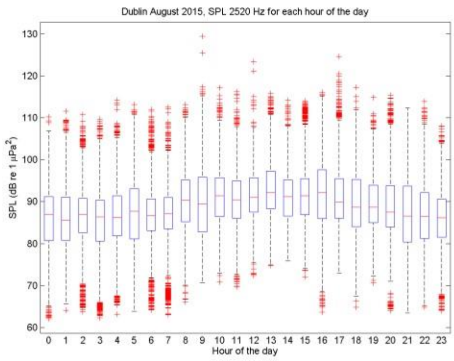
SPL (dB re 1 μPa²)
Day of week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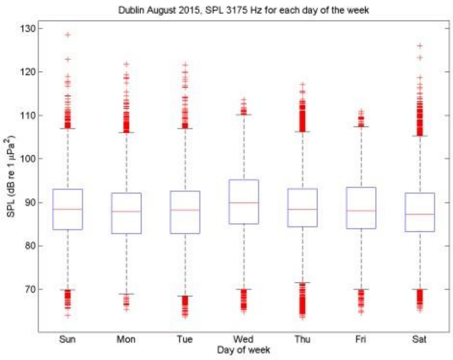
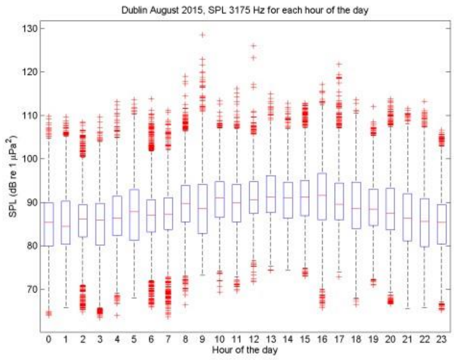
SPL (dB re 1 μPa²)
Hour of the day


Dublin August 2015, SPL 3175 Hz for each day of the week
SPL (dB re 1 μPa²)
Day of week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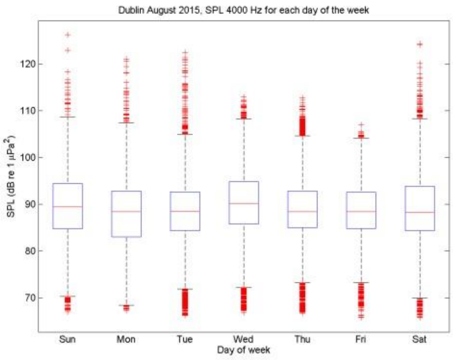
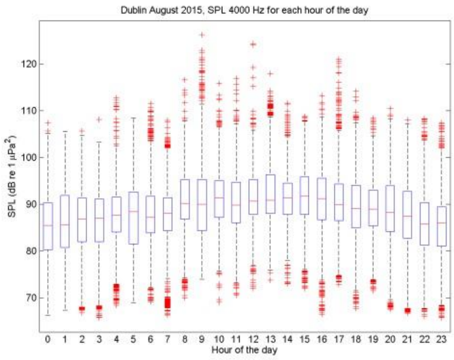
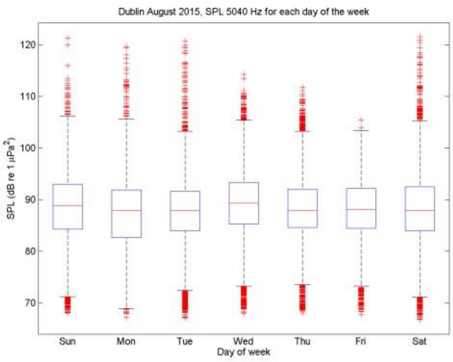
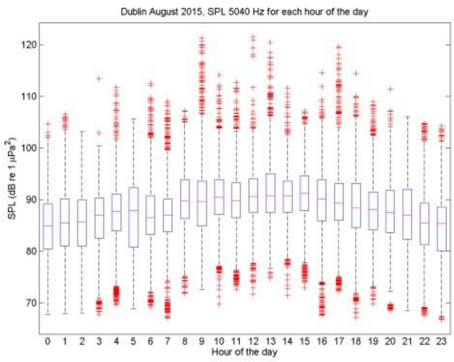
SPL (dB re 1 μPa²)
Hour of the day


Dublin August 2015, SPL 4000 Hz for each day of the week
SPL (dB re 1 μPa²)
Sun Mon Tue Wed Thu Fri Sat
Day of week


Dublin August 2015, SPL 4000 Hz for each hour of the day
SPL (dB re 1 μPa²)
Hour of the day


Dublin August 2015, SPL 5040 Hz for each day of the week
SPL (dB re 1 μPa²)
Sun Mon Tue Wed Thu Fri Sat
Day of week


Dublin August 2015, SPL 5040 Hz for each hour of the day
SPL (dB re 1 μPa²)
Hour of the day

Weather influence on noise pattern

The previous sections showed little influence from biological and anthropogenic sources on the measured data. Another dominant component could be induced by weather: either rain or wind can have a significant contribution to the received levels, especially in shallow water recordings. Rainfall data was available from the Met Eireann, but these had a daily resolution. With only 31 daily data points it would be difficult to associate measured levels during a day to rainfall. On the other hand, wind data with an hourly resolution was available from the M2 weather buoy, which is deployed approximately 40 kilometres further offshore from the recording location. Figure 8 shows in blue the wind speed (the wind gust followed a very similar pattern and was not added to the image) and in green the sound pressure level measured at 25 Hz. At a few time periods the two curves follow a very similar pattern, especially during the first week and around days 20 – 27. At other times the correlation is not present. This may be due to the fact that the recording position was much closer to land and different wind directions (coming from land or sea) will impact the measurements differently. Figure 9 shows the wind direction measured during the same time period. It appears that especially winds coming from 150 – 200 degrees influenced the measurements.

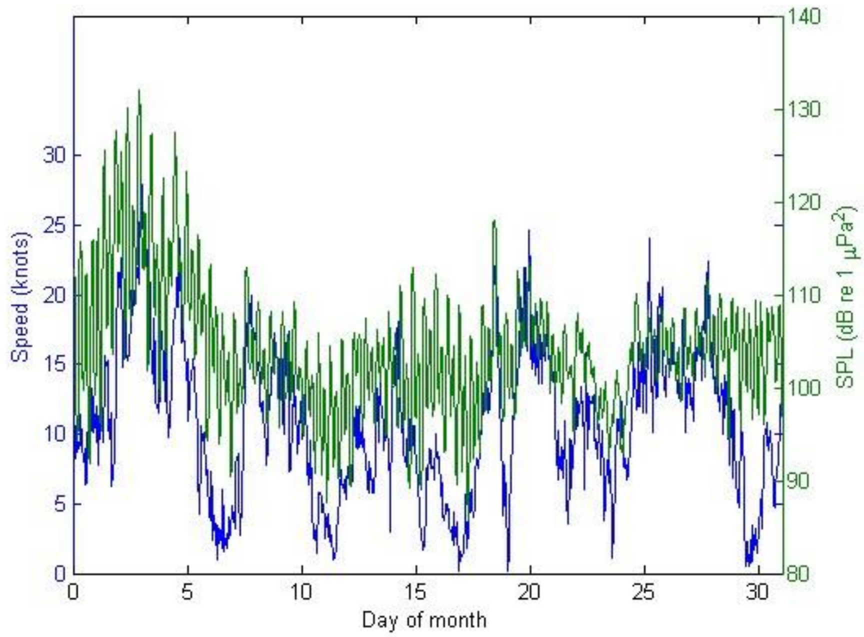


Figure 8 Wind speed (blue left) measured at the [M2 weather buoy] and sound pressure levels at 25 Hz (green, right) during August 2015.

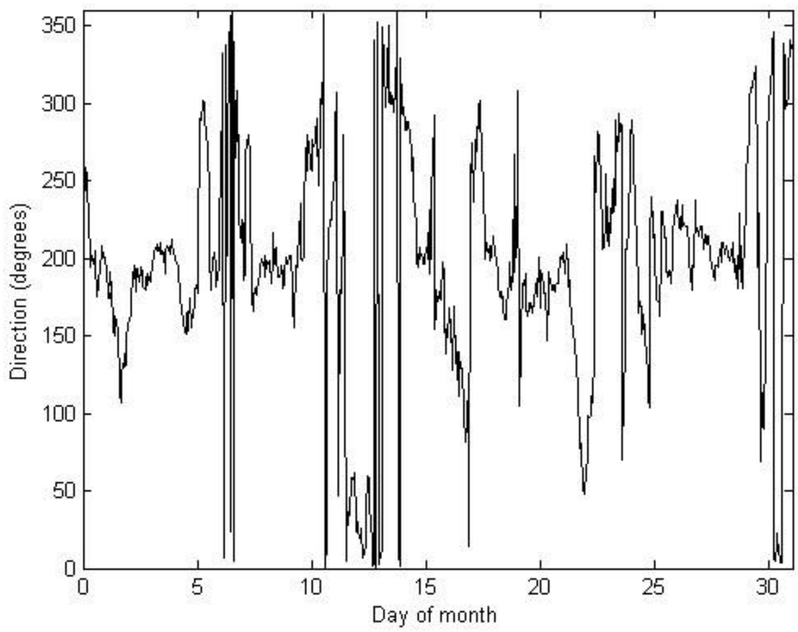


Figure 9 Wind direction at the M2 weather buoy during August 2015.

Sound Level Measurements

The following pages provide an overview of the sound level measurements in all third octave bands at the recording site. All sound level data can be viewed from the website and an automated report with these or similar graphs can be created from the export section.

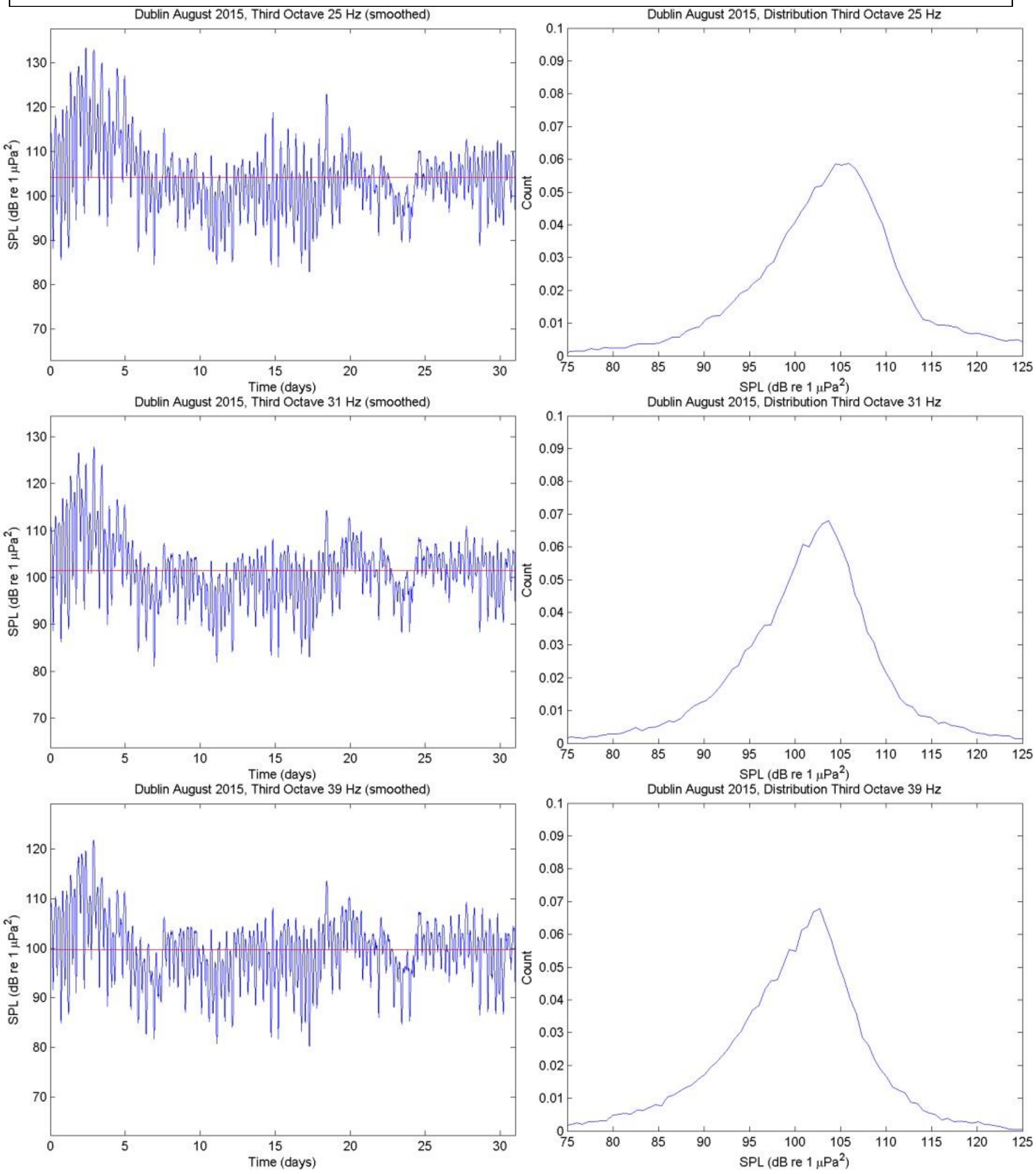
Each sound level report provides the following information:

1. A table containing values taken over the time period stated:
   a. The sound pressure level (as reported for the MSFD) removing the highest 1% of the measurement values to remove outliers caused by e.g. something bumping against the hydrophone. These kinds of outlier events will have a large influence on this type of statistic.
   b. The average over the individual snapshot SPL measurements. This value is less influenced by outliers.
   c. The median sound pressure value.
   d. The minimum and maximum sound pressure values.
2. A graph showing the snapshot SPL measurements over the reporting time period. This graph also shows the mean SPL value as computed under 1.b.
3. A graph showing the distribution of the SPL measurements. Especially this graph can serve to properly interpret the summary statistics reported in the table.

Dublin Third Octave Band Sound Measurements 25-39 Hz

Sound Pressure Level Statistics			
	25 Hz	31 Hz	39 Hz
Sound Pressure Level [MSFD D11.2]ᶧ (dB)	114	108	105
Mean Sound Pressure Level* (dB)	104	101	100
Median Sound Pressure Level (dB)	104	102	101
Maximum Sound Pressure Level (dB)	138	134	129
Minimum Sound Pressure Level (dB)	63	64	63

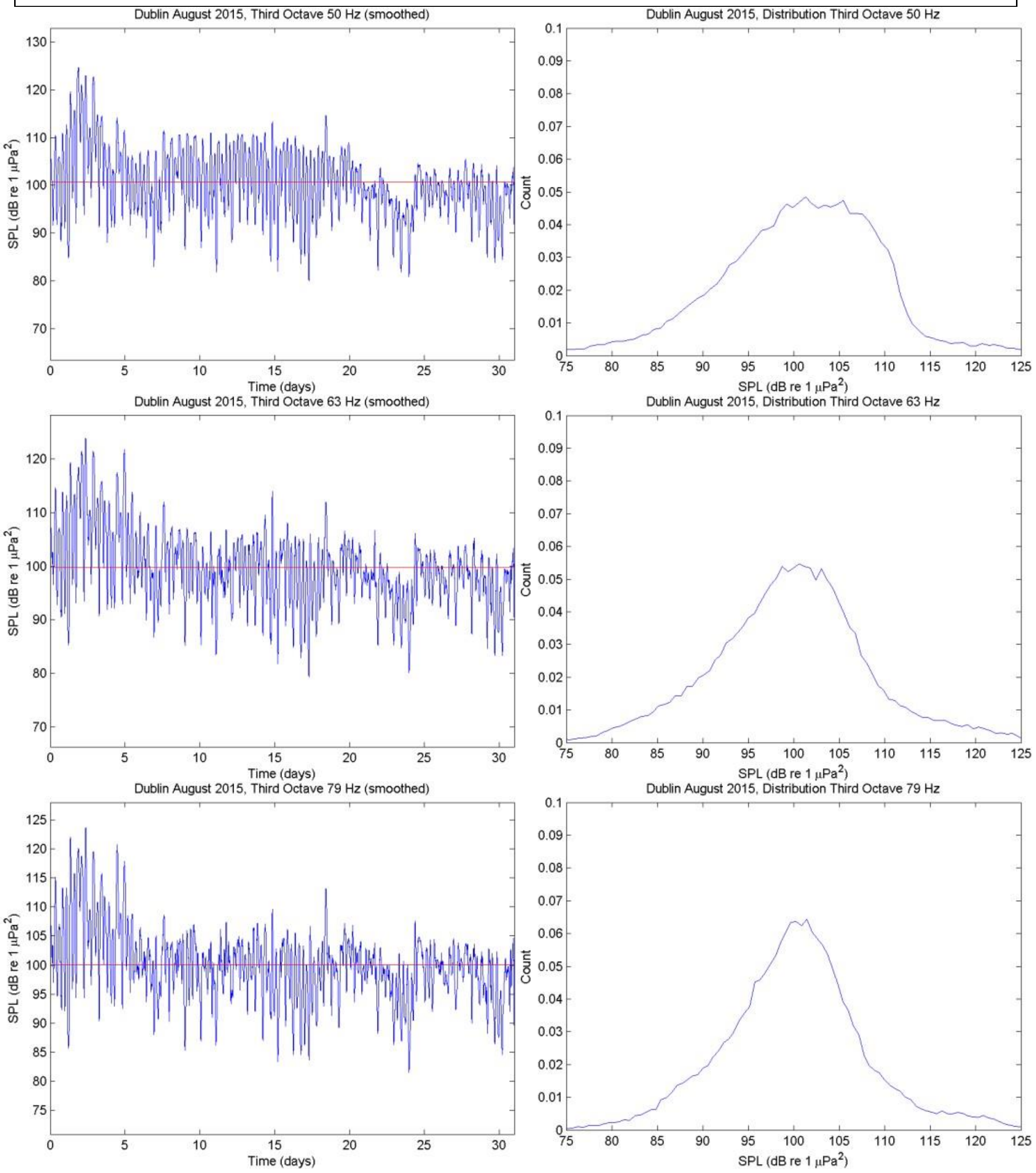
ᶧ Computed leaving out 1% of the highest snapshot sound pressure levels.
*Computed as the average over snapshot sound pressure levels.



Dublin Third Octave Band Sound Measurements 50 – 79 Hz

Sound Pressure Level Statistics			
	50 Hz	63 Hz	79 Hz
Sound Pressure Level [MSFD D11.2]ǂ (dB)	107	107	106
Mean Sound Pressure Level* (dB)	101	100	100
Median Sound Pressure Level (dB)	101	100	100
Maximum Sound Pressure Level (dB)	133	128	128
Minimum Sound Pressure Level (dB)	64	66	71

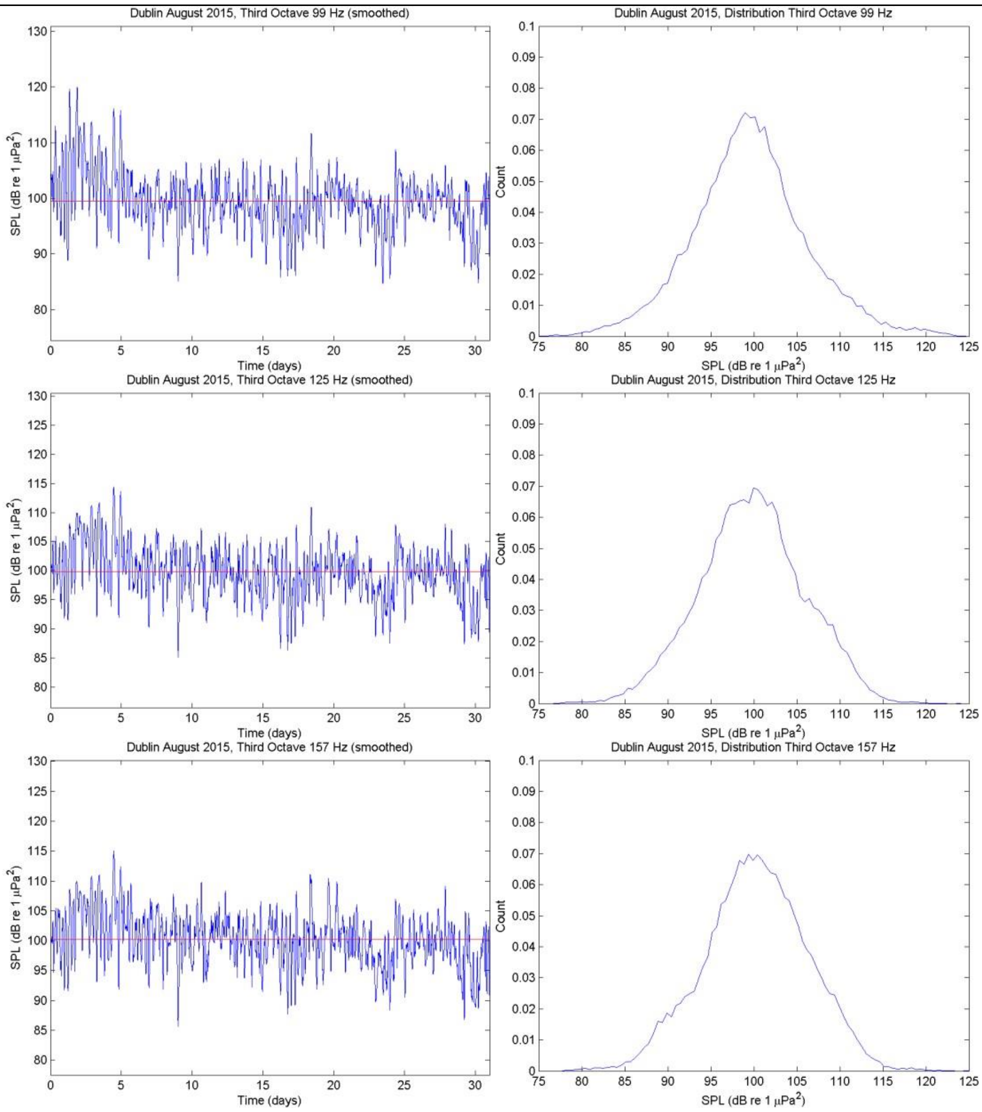
ǂ Computed leaving out 1% of the highest snapshot sound pressure levels.
*Computed as the average over snapshot sound pressure levels.



Dublin Third Octave Band Sound Measurements 99 – 157

Sound Pressure Level Statistics			
	99 Hz	125 Hz	157 Hz
Sound Pressure Level [MSFD D11.2]ᵻ (dB)	104	103	103
Mean Sound Pressure Level* (dB)	100	100	100
Median Sound Pressure Level (dB)	99	100	100
Maximum Sound Pressure Level (dB)	131	131	130
Minimum Sound Pressure Level (dB)	74	76	76

ᵻ Computed leaving out 1% of the highest snapshot sound pressure levels.
*Computed as the average over snapshot sound pressure levels.

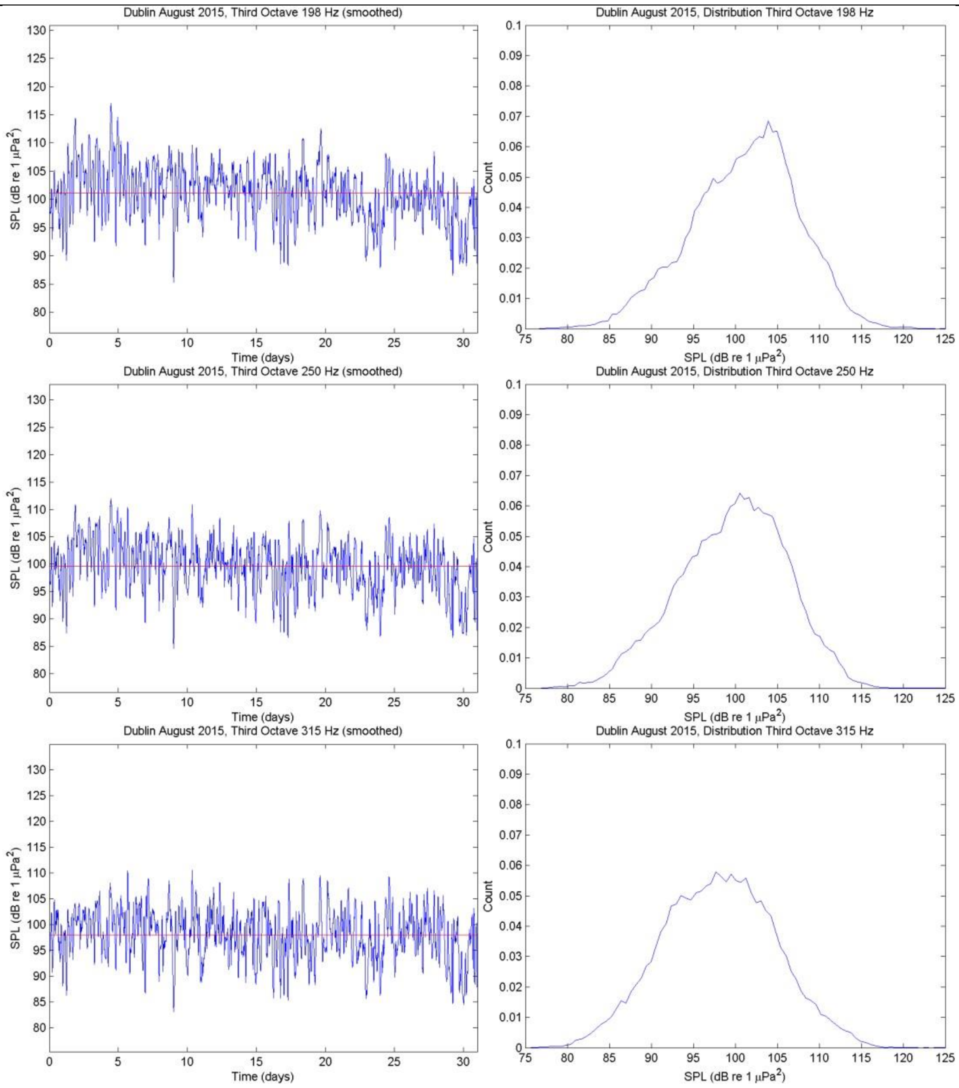


Dublin Third Octave Band Sound Measurements 198 – 315 Hz

Sound Pressure Level Statistics			
	198 Hz	250 Hz	315 Hz
Sound Pressure Level [MSFD D11.2] ⱡ (dB)	105	103	102
Mean Sound Pressure Level* (dB)	101	100	98
Median Sound Pressure Level (dB)	102	100	98
Maximum Sound Pressure Level (dB)	131	133	135
Minimum Sound Pressure Level (dB)	76	77	75

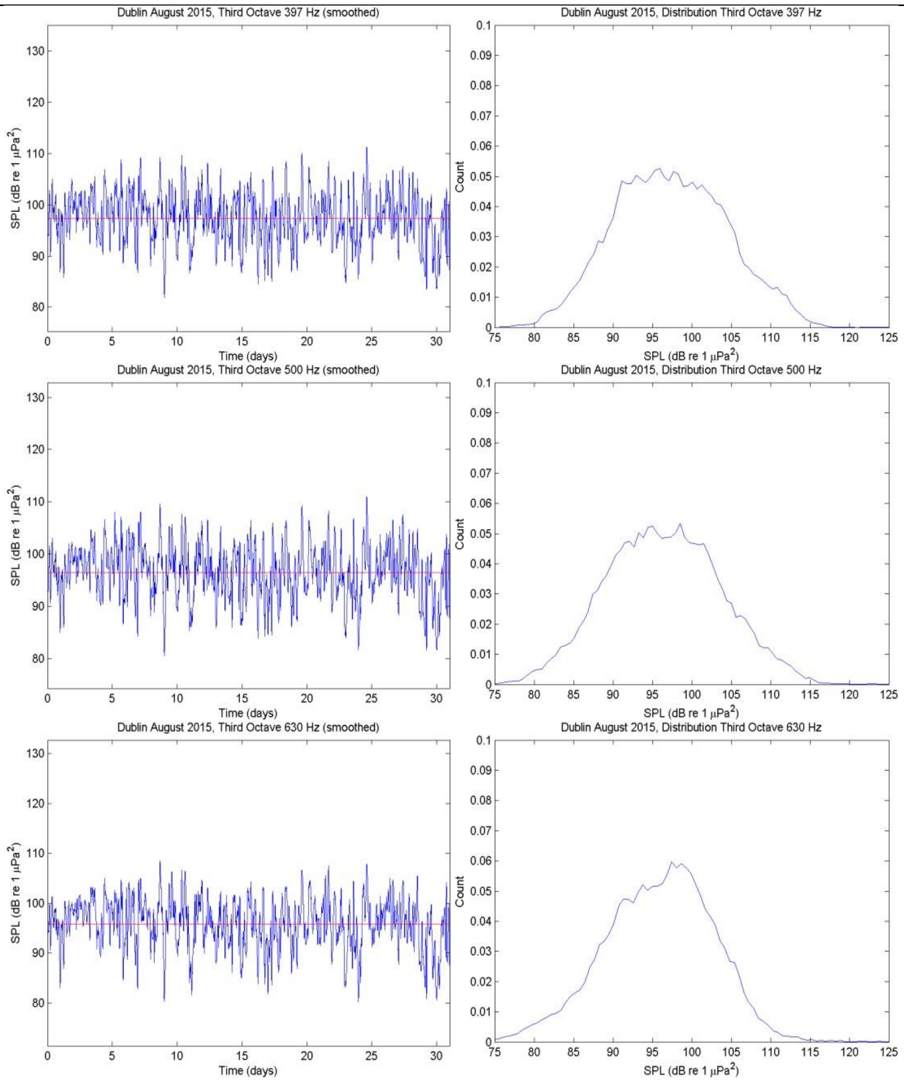
ⱡ Computed leaving out 1% of the highest snapshot sound pressure levels.

*Computed as the average over snapshot sound pressure levels.



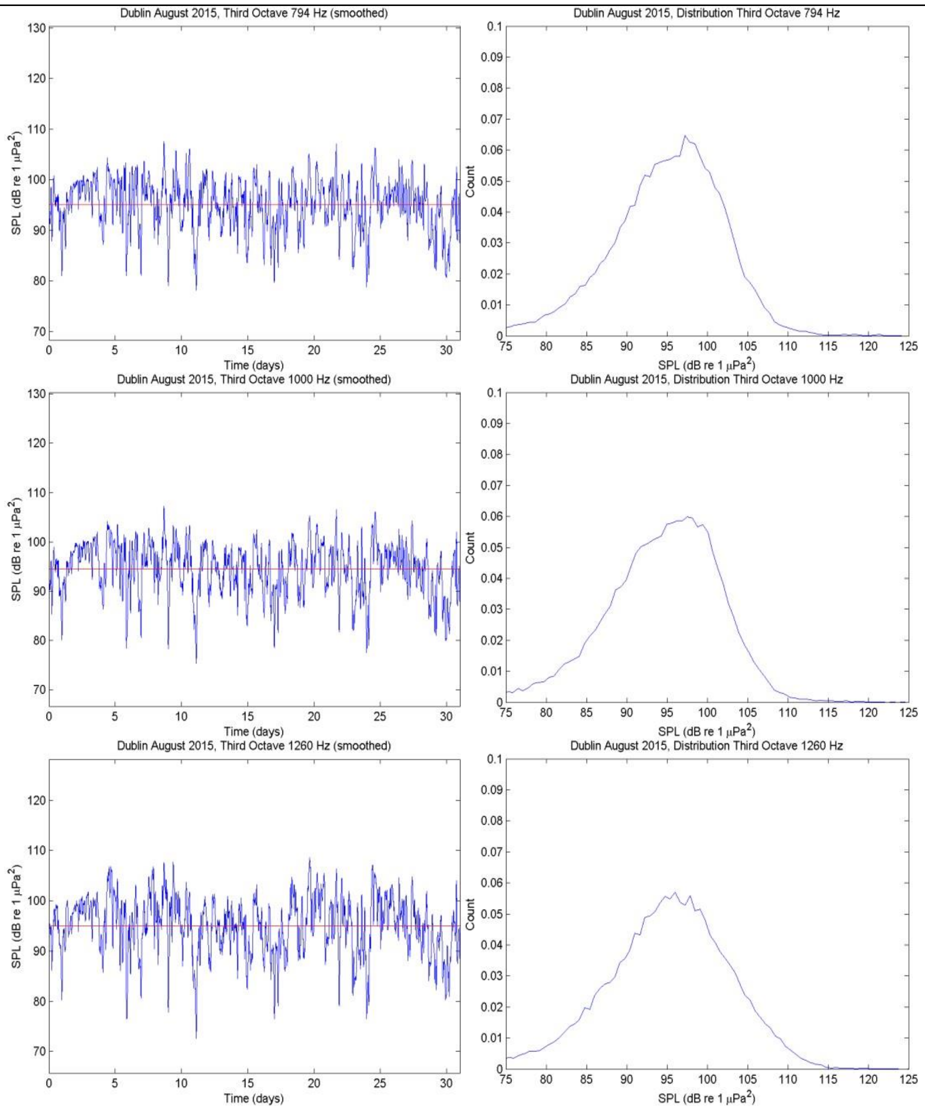
Dublin Third Octave Band Sound Measurements 397 – 630 Hz

Sound Pressure Level Statistics			
	397 Hz	500 Hz	630 Hz
Sound Pressure Level [MSFD D11.2]ǂ (dB)	102	101	100
Mean Sound Pressure Level* (dB)	97	96	96
Median Sound Pressure Level (dB)	97	96	96
Maximum Sound Pressure Level (dB)	135	74133	133
Minimum Sound Pressure Level (dB)	75	74	71
ǂ Computed leaving out 1% of the highest snapshot sound pressure levels. *Computed as the average over snapshot sound pressure levels.			



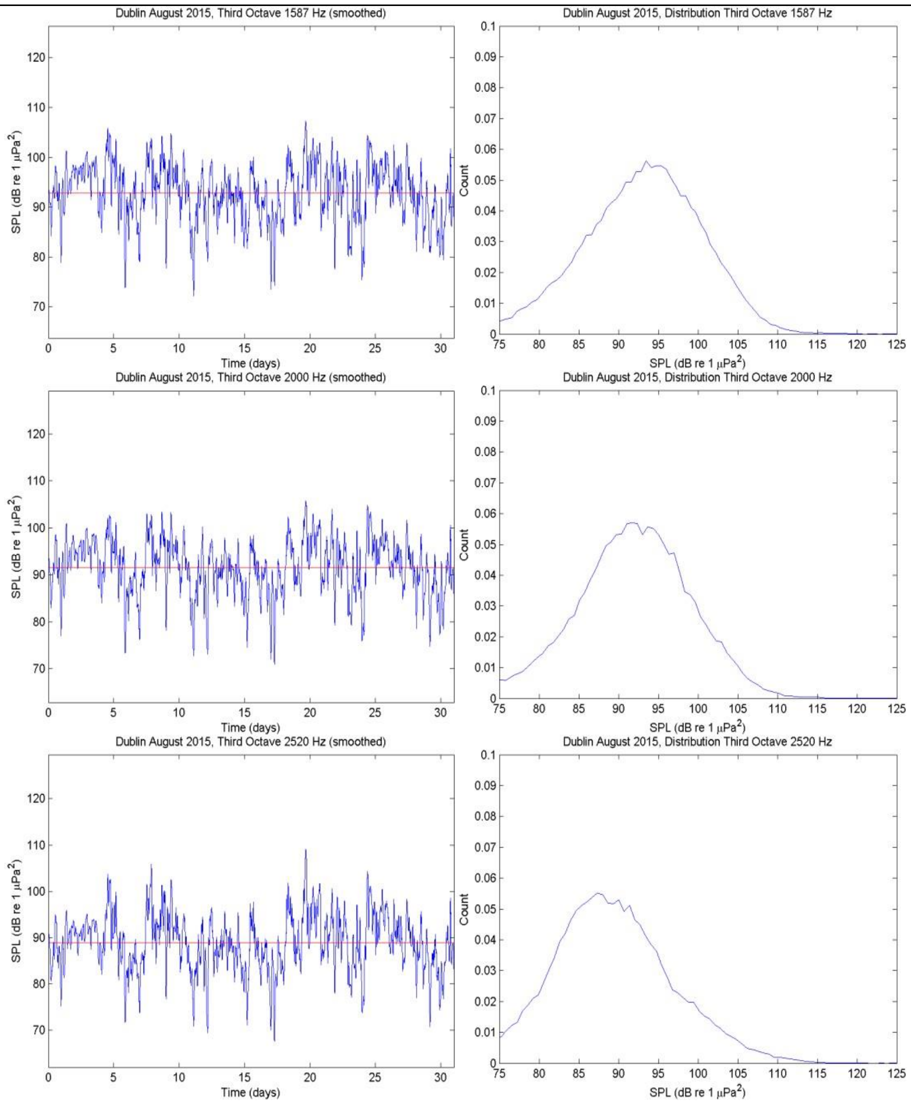
Dublin Third Octave Band Sound Measurements 794 - 1260 Hz

Sound Pressure Level Statistics			
	794 Hz	1000 Hz	1260 Hz
Sound Pressure Level [MSFD D11.2][ƚ] (dB)	99	98	100
Mean Sound Pressure Level* (dB)	95	94	95
Median Sound Pressure Level (dB)	96	95	95
Maximum Sound Pressure Level (dB)	130	130	128
Minimum Sound Pressure Level (dB)	68	67	66
[ƚ] Computed leaving out 1% of the highest snapshot sound pressure levels. *Computed as the average over snapshot sound pressure levels.			



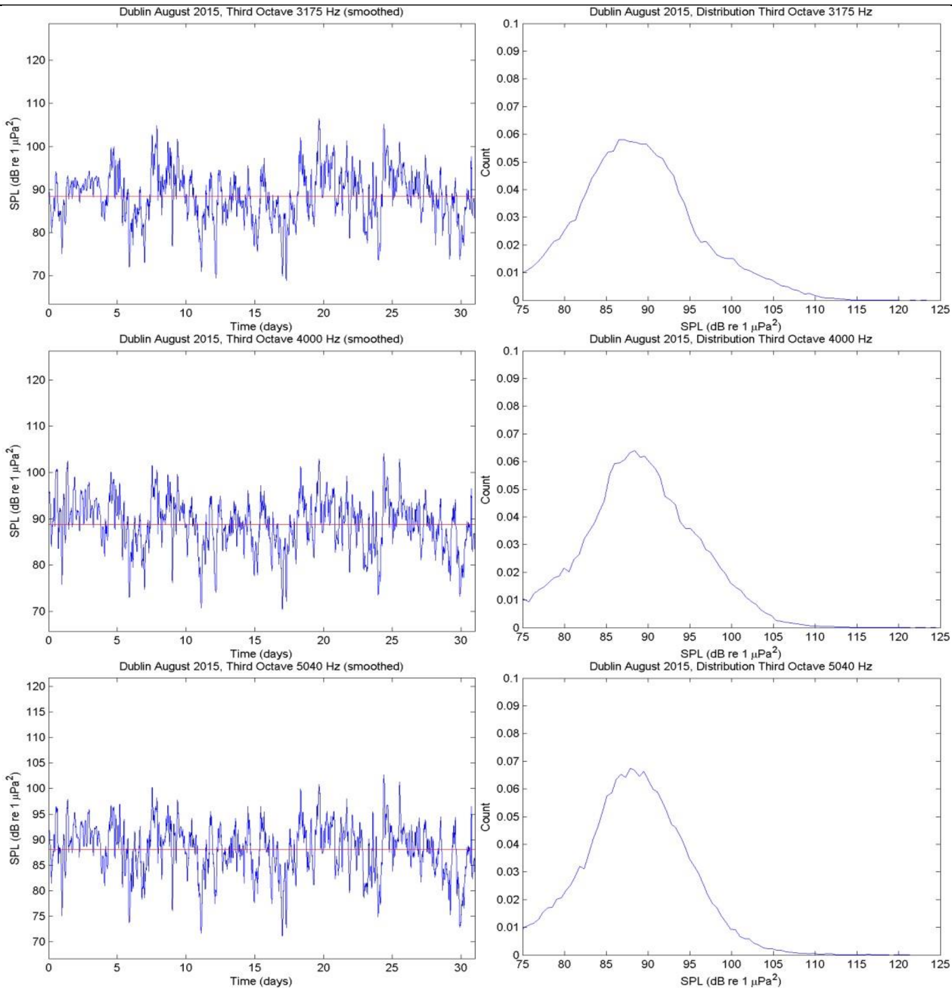
Dublin Third Octave Band Sound Measurements 1587 - 2520 Hz

Sound Pressure Level Statistics			
	1587 Hz	2000 Hz	2520 Hz
Sound Pressure Level [MSFD D11.2]ᵻ (dB)	98	96	95
Mean Sound Pressure Level* (dB)	93	92	89
Median Sound Pressure Level (dB)	93	92	89
Maximum Sound Pressure Level (dB)	126	129	130
Minimum Sound Pressure Level (dB)	64	63	62
ᵻ Computed leaving out 1% of the highest snapshot sound pressure levels. *Computed as the average over snapshot sound pressure levels.			



Dublin Third Octave Band Sound Measurements 3175 – 5040 Hz

Sound Pressure Level Statistics			
	3175 Hz	4000 Hz	5040 Hz
Sound Pressure Level [MSFD D11.2]ᵻ (dB)	94	93	92
Mean Sound Pressure Level* (dB)	88	89	88
Median Sound Pressure Level (dB)	88	89	88
Maximum Sound Pressure Level (dB)	129	126	122
Minimum Sound Pressure Level (dB)	63	66	67
ᵻ Computed leaving out 1% of the highest snapshot sound pressure levels. *Computed as the average over snapshot sound pressure levels.			



Modeling Dredging Noise Offshore Dublin

Brief Technical Report

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Référence du document	QO.20170329.01.RAP.001.02A
Donneur d'ordre	TechWorks Marine
Client	Laboratori d'Aplicacions Bioacústiques
Contract number	NA

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QO.20170329.01	RAP	001	02	A	LAB	GDD	29.03.2017	PROD	DR

Quiet oceans

Ocean Noise Forecasting Monitoring & Mitigation

Document history					
Version	Ind.	Authorship	Date	Released	Description
02	**A**	T. Folegot	26.07.2017	28.07.2017	Add piling scenario and important disclaimer
01	**A**	T. Folegot	29.03.2017	30.03.2017	Initial version

Citation

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Ocean Noise Forecasting
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Table of content

Terms and definitions

This section defines the technical terms used in the report.

1/3rd-octave frequency band

A frequency band with one third of an octave bandwidth. One octave is a doubling of frequency, whereas one third of an octave is a frequency ratio of 21/3 ≈ 1.26 between the highest and the lowest.

Bandwidth

The frequency range within which a recording system is sensitive. The frequency range (in Hertz) is obtained by subtracting the lower from the upper cut-off frequency.

Broadband level

The sound pressure level obtained over a wide frequency range with defined bandwidth.

Center frequency

The geometric mean of the lower and upper cut-off frequencies. Please note that the intensities should be averaged before converted into decibels.

Sound

The term “sound” is used to refer to the acoustic energy radiated from a vibrating object, with no particular reference for its function or potential effect. “Sounds” include both meaningful signals and “noise” (defined below), which may have either no particular impact or may have a range of adverse effects.

Noise

Noise is in direct contrast to signals, but always depending on the receiver and the context. What one receiver considers noise may be a signal to another receiver and even for the same receiver can the exact same sound be either signal or noise, depending on context.

“Noise” can be used in a more restrictive sense where adverse effects of sound are specifically described or when referring to specific technical distinctions such as “masking noise” or “ambient noise”.

Ambient noise

That part of the total noise background observed with a non-directional hydrophone, which is not due to the hydrophone and its manner of mounting (self-noise), or to some identifiable localized source of noise.

Environmental background noise not of direct interest during a measurement or observation; may be from sources near and far, distributed and discrete, but excludes sounds produced by measurement equipment, such as cable flutter.

For a specified signal, all sound in the absence of that signal except that resulting from the deployment, operation or recovery of the recording equipment and its associated platform.

Natural ambient noise

Ambient noise in the absence of any contribution from anthropogenic sources.

Continuous sound

Imprecise term meaning a sound for which the mean square sound pressure is approximately independent of averaging time.

A sound with no clear definable beginning or end with no bandwidth restrictions and a large time bandwidth product when the frequency range is broadband. Continuous sounds have finite power, but may have infinite or at least undefined energy.

Sound pressure

The difference between instantaneous total pressure and pressure that would exist in the absence of sound. Instantaneous pressure at time t. p(t) in [Pa]

Reference pressure

1 µPa in underwater acoustics. p_0 in [Pa]

Sound exposure

The integral of the square of the sound pressure over a stated time interval or event.

E in [µPa²s], $E = \int_0^T p(t)^2\,dt$, with T being the time period of the event of interest.

Sound Pressure Level

SPL in [dB re 1 µPa]

$$SPL = 10 \cdot log_{10} \frac{1/_T \int_0^T p(t)^2 dt}{p_0^2} = 10 \cdot log_{10} \left(\frac{p_{rms}}{p_0}\right)^2 = 20 \cdot log_{10} \left(\frac{p_{rms}}{p_0}\right)$$

with T = integration time.

Sound Exposure Level

SEL in [dB re 1 µPa²s]

$$SEL = 10 \cdot log_{10} \left(\frac{E}{p_0^2\, T_0}\right) = SPL + 10 log_{10}(T)$$

With reference time $T_0 = 1$ s

With T being the time period of the event of interest in seconds.

Percentile level

A percentile corresponds to the proportion of time and space for which the noise exceeds a given level. This concept is widespread even in everyday life. For example, the average income of the top 10% of income earners or the "income threshold corresponding to the 90th or to the 95th percentile", i.e. the income earned by the poorest individual among the top 10% or top 5% richest individuals. Meanwhile, the 50th percentile corresponds to the median salary. For underwater noise, the percentile, or exceedance level, is meant to describe the noise level occurring at least.

In the context of underwater noise, it is defined as the level L_N that is exceeded for N percent of the time interval considered. For example, L_1 is the level that is exceeded 1% of the time. This is accomplished by (1) ordering all measured levels in the time interval numerically in descending order and (2) and picking the value 1% of the rows below the top of this ordered list. Both steps can be done together in Matlab with the quantile or prctile function (available in the Statistics Toolbox).

The L_1 is a measure for the maximum level. It is a more robust estimate than taking just the maximum observed level, since the latter may be an outlier caused by a single event, such as rattling of the anchoring system or other types of self-noise. Accordingly, L99 and L95 are used to describe the minimum level. L_{50} is the median level.

Chapitre I. Context and objectives

I.1. Context

Techworks Marine has asked the Laboratori d'Aplicacions Bioacústiques for the assessment of the underwater noise impact in the context of the construction of an outfall pipeline offshore Dublin, Ireland. Quiet-Oceans has been asked to provide some modelling of the underwater noise footprint of the project.

I.2. Project information

The outfall pipeline consists of two elements, a tunnel section running from the Coast Road to approx. 500m off the beach, and a dredged section from this interface point to the final outfall point. The tunnel section will be constructed using a micro-tunnelling machine.

The dredged section will be constructed using Back Hoe Dredgers (BHD) and Trailer Suction Hopper Dredgers (TSHD) with the BHD working from the inshore outwards and the TSHD working from the Outfall point towards the inshore.

The dredging operation includes an excavation phase with material either side cast or placed in barrages for deposition a short distance away from the trench, and a backfilling phase where the excavated material will be replaced over the installed pipe.

I.3. Objectives

The objectives of the study requested by the Laboratori d'Aplicacions Bioacústiques is to map the noise propagation of the dredging activity at one specific position for three frequencies: 125Hz, 1kHz and 8kHz third octave as defined by the international standards [1] [2] for a single environmental condition.

Chapitre II. Introduction to Quonops©

Quiet-Oceans operates since 2010 the proprietary Quonops© ocean noise-monitoring and prediction system developed and owned by the company and protected by an international patent [1] . In a similar manner to weather forecasting systems, Quonops© produces an estimate of the spatio-temporal distribution of noise levels generated by human activities at sea, aggregating multiple sources, and assessing short-, mid- and long term source contributions to the global noise field (Figure 1). As demonstrated in a number of international projects, Quonops© caters for a broad range of maritime activities, including:

- maritime traffic [1] [5] ;
- oil exploration [6] ;
- underwater warfare exercises;
- offshore construction [7] ;
- fossil-fuel extraction;
- offshore wind-power construction and operations [8] ; underwater drilling and blasting operations.

Based on physical acoustic propagation models, Quonops© considers the reality of the area through input data and has been largely validated through in-situ measurements over the last 6 years.

The outputs from Quonops© are tailored to the requirements of existing and emerging national and international regulations regarding underwater noise, the conservation of habitats and marine ecosystems, and the protection of marine species [9] .

The production of statistical soundscapes effectively characterizes the spatio-temporal emergence of anthropogenic noise from the real environmental conditions of the area. The system also supports underwater noise impact assessments and assists in the formulation of optimized planning and focused mitigation of maritime industrial activities in terms of environmental compliance. Quonops© brings together relevant information and data into a noise prediction platform to deliver a series of services, such as:

 the geo-referenced mapping of statistical, historical or real-time human and environmental situation of the areas of interest,

- the geo-referenced mapping of noise pollution according to given ocean-meteorological and human scenarios.

Such a tool aims to support management decisions by assessing, quantifying and prioritizing direct and indirect anthropogenic pressures on marine life, according to the emerging national and international regulations on underwater noise, especially the descriptor 11 of the European Marine Strategy Framework Directive [10] .

Quonops© is able to provide:

- real-time regional survey of shipping noise and natural noise from waves;
- historical statistical regional noise maps at a daily, weekly, quarterly and/or annual resolution;
- noise maps of single or multiple customized noise sources through a large selection of maritime activities.

Figure 1 : Principle of Quonos©, Quiet-Oceans' underwater noise prediction and monitoring system.

Chapitre III. General principles of noise mapping

The noise received at a particular position in the marine environment depends on the characteristics of the sound source(s) and the propagation through the marine environment (Figure 2). Noise propagation and therefore noise levels are mainly determined by the following (Table 2):

- ✓ Bathymetry (underwater terrain);
- ✓ The nature of the seabed (sediment type);
- ✓ Oceanographic conditions such as temperature and salinity, currents, sea level;
- ✓ Weather conditions such as the wind (and consequently waves) and rainfall intensity.

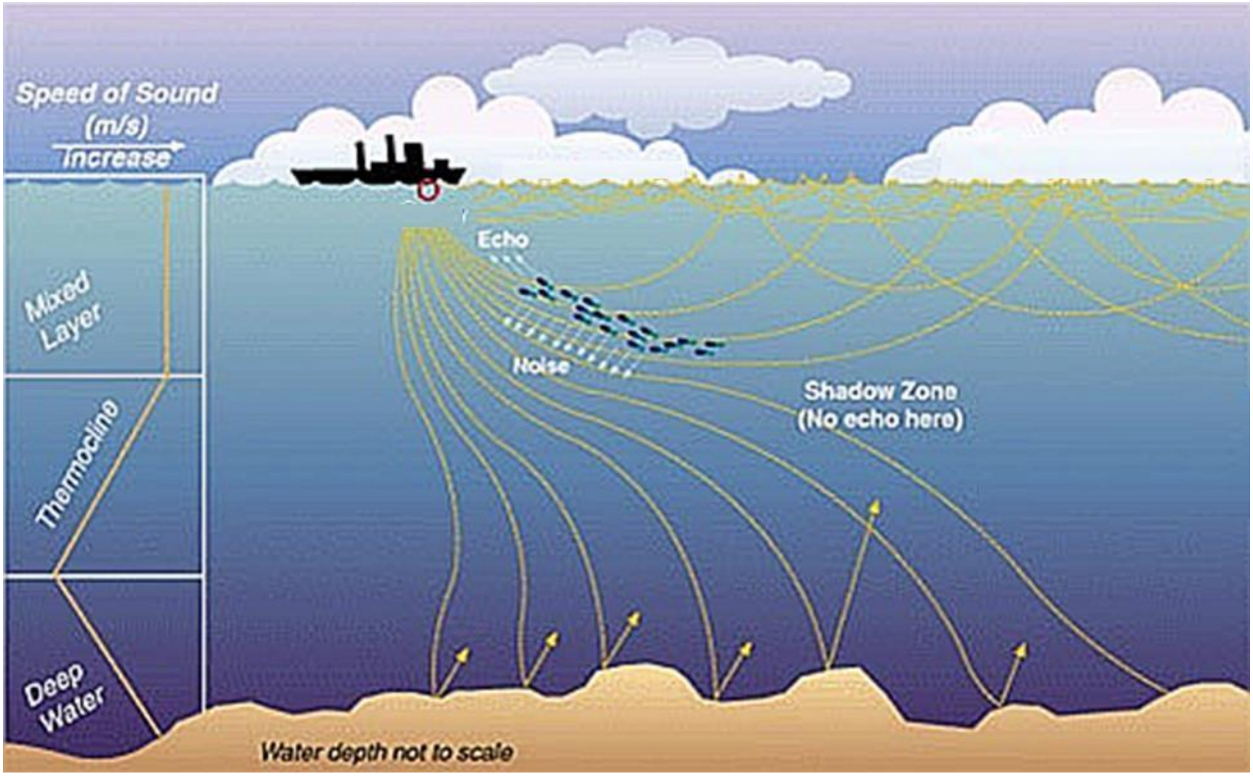


Figure 2: In the warm upper layer of the ocean, sound is refracted toward the surface. As sound waves travel deeper into colder water, they slow down and are refracted towards the seafloor, creating a shadow zone. Image courtesy of the National Academy of Sciences. Source: www.dosits.org.

III.1. Key ocean variables affecting sound propagation

Sound propagation losses increase as water depth lessens, and this is a cumulative loss effect which applies to shoaling caused by bathymetry and tidal fluctuations together. The effect is linked to the interaction of sound waves with the interfaces of the oceanic waveguide (surface and seabed). Furthermore, it should be noted that ocean waves (waves at the sea surface) tend to surge as they encounter shallower water, which increases their contribution to the ambient noise.

Propagation losses are more significant when the seabed is loose and fine-grained (i.e. silt absorbs sound waves better than gravel). However, the denser the sediment, the more reverberant it is; sound waves with significant angles of incidence on sediment are better reflected when the sediment is dense.

Wind generated ocean-surface waves propagate and absorb sound waves, an effect that increases with increasing sea-state. However, the noise generated by surging waves also increases the level of ambient noise. In other words, rough seas increase natural noise levels, but other noise sources do not carry as far as they would in calm conditions.

In shallow water, sedimentary particles are mobilized by currents and/or waves, and noise is generated when sedimentary particles collide with each other. The coarser the sediment and faster the speed of sound in the sediment, the higher the noise level.

Rainfall exerts a negligible effect on underwater sound propagation; however the sound generated by droplets falling on the sea surface does contribute to an increase in natural noise levels.

Table 1: Effect of physical properties of the ocean environment on acoustic propagation and noise generation.

	Influence noise propagation	Generate noise and contribute to ambient noise
Bathymetry	✔	✖
Bottom parameters	✔	✔
Temperature/salinity	✔	✖
Sea level	✔	✖
Currents	✖	✔
Wind/waves	✔	✔
Rain	✖	✔

✔ *indicates that the effect exists* ✖ *indicates that the effect does not exist or is marginal.*

III.2. Underwater noise modelling

Underwater modelling benefits from more than 50 years of scientific and operational development for military purposes, ranging from basic propagation modelling to more sophisticated sonar performance modelling. The military research in the field of experimental ocean acoustics has involved extensive equipment, with typically at least one ship and often an assortment of at-sea platforms equipped with sound projectors and receiving arrays. The objective of this research was to incorporate the acoustic propagation phenomena into a theoretical and numerical formalism, which gives a quantitative prediction of the sound field for arbitrary ocean environments. The progress in the field of numerical computing has largely contributed to the development of the modelling capability.

There are essentially five types of models (computer solutions to the wave equation) to describe sound propagation in the sea: spectral, normal mode, ray, and parabolic equation models, and direct finitedifference, or finite-element solutions of the full wave equation. All these models permit the ocean environment to vary with depth. Models also permit horizontal variations in the environment, i.e., slopping bottom or spatially variable oceanography [12] .

The acoustic models accurately reflect the propagation of noise in the water column in realistic oceanographic conditions by resolving the Helmholtz Equation, the State Equation:

where p is the acoustic pressure, c is the sound speed in the medium (water or sediment), t is time, t_0 the instant of emission of the signal, and r the three-dimensional position of observation and r_0 the threedimensional position of the source, assumed to be punctual.

$$\Delta p - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = \delta(t - t_0, r - r_0)$$

$$\rho c^2 = p \;\; \rho_0 \frac{\partial \vec{v}}{\partial t} + \vec{\nabla} p = 0$$

$$j2\pi f \rho_0 \vec{v} + \vec{\nabla} p = 0$$

III.2.1. Modelling bellow 2kHz

For frequencies bellow 2kHz, we have used state-of-the-art parabolic equation [13] [14] [15] [16] . Developed before World War II, and widely used in many areas of physics, parabolic equation methods are based on fast

Fourier transforms. It has become the most popular wave-theory technique for solving range dependent problems in ocean acoustics. It consists in a parabolic approximation of the Helmholtz equation into an elliptic wave equation. We have used the model developed by Collins et al. which is among the state-of-the-art parabolic equation implementation which especially solves the equation for elastic media, such as the marine environment.

III.2.2. Modelling above 2kHz

For frequencies above 2 kHz, we have used an energy distribution to Gaussian beams approach to limit calculation times. Used since the early 1960's, the ray modelling is based on a high frequency approximation. Ray methods are still used extensively in operational environment where speed is critical and where the environmental uncertainties pose more constraints on the accuracy. Quonops© use Bellhop [17] which is among the state-of-the-art ray tracing codes which handles Gaussian ray bundles to somewhat overcome the high frequency approximation.

Table 2: Validation of Quonops through in-situ acoustic measurements in a very large number of different marine environments and projects.

Project Name	Year	Area	Type of noise	Effort	Partners
ERATO	2011	Atlantic Ocean	Shipping and natural	6 hydrophones, 24 hours	French Hydrographic Office (France)
STRIVE	2011	Irish seas	Shipping and natural	1 hydrophone, 21 days	Environmental Protection Agency, Cork University (Ireland)
AQUO	2013-2015	Mediterranean Sea	Shipping and natural	1 hydrophone, 9 months	Laboratory of Bioacoustics Applications, Barcelona (Spain)
AQUO	2013-2015	North-sea	Shipping	Cross-models validation	TNO (Netherland), FOI (Sweden), Leiden university (Netherland)
MaRVEN	2013 - 2015	North-sea	Piling noise & Windfarm operation	2 hydrophones	DHI (Denmark), Royal Belgian Institute of Natural Sciences (Belgium), European Commission
NRL	2013-2014	Indian Ocean	Shipping and natural	2 hydrophones, 7 months	Biotope (La Réunion)
FEC-COU	2013	English Channel	Shipping and natural	4 hydrophones, 20 days	EMF, EDF, WPD (France)
SNA	2013	Atlantic Ocean	Shipping and natural	3 hydrophones, 20 days	EMF, EDF, WPD (France)
BENTHOSCOPE	2015	English Channel	Tidal device in operation	1 hydrophone, 1 day	Marine Energy France (France)
POSTE H	2013	Indian Ocean	Vibrodriving Shipping and natural	2 hydrophones	Biotope (La Réunion)
ETM	2014	Caribbean	Shipping and natural	1 hydrophone, 30 days	AKUO (France)
JETSKI	2014	Atlantic Ocean	Watercraft	1 hydrophone	Marine Protected Area (France)
PORTIER	2014 2016	Mediterranean Sea	Shipping and natural	2 hydrophones, 5 months	BYTP (France)
EMDT	2015-2016	English Channel	Shipping and natural	4 hydrophones, 12 months	ENGIE (France)
EMYN	2015-2016	Atlantic Ocean	Shipping and natural	4 hydrophones, 12 months	ENGIE (France)
GOEMONIER	2016	Atlantic Ocean	Fishing device	1 hydrophone	Marine Protected Area (France)

III.3. Calibration of the maps

It is essential to bear in mind that no underwater noise measurements made with hydrophones have been used to calibrate the noise maps. An active acoustic calibration measurement is strongly recommended.

Chapitre IV. Input data and assumptions

The data used to perform the modelling describes:

- the bathymetry of the area provided by EMODNet [19] and illustrated in Figure 3;
- the coast line of the area provided by [20] ;
- the sediment provided by EMODNet [19] ; The original sediment data has a spatial resolution of 1/40°. The EMODnet database classifies the sediments into 6 categories:
  - ✓ Boulders & bedrock;
  - ✓ Till/diamincton;
  - ✓ Coarse-grained sediment;
  - ✓ Mixed sediment; ✓ Muddy sand and sand; ✓ Mud and sandy mud.

  The geo-acoustic parameters used in the acoustic model as boundary conditions are reported in Table 4. Since the sediments being assumed to be fluid-elastic, the geo-acoustic parameters are limited to density (in ton per m3), compressional speed (m/s) and compressional attenuation (in dB/, being the acoustic wavelength) as illustrated in Figure 4. Shear waves propagating in solid materials are neglected.

- the sound speed derived from temperature and salinity of the sea water provided by the Copernicus Marine Environment Monitoring Service (CMEMS) which provides regular and systematic reference information on the physical state, variability and dynamics of the ocean and marine ecosystems for the global ocean and the European regional seas. The Mackenzie equation (1981) has been used to derive temperature and salinity into sound speed (Figure 5):

$$c(D,S,T) = 1448.96 + 4.591T - 5.304 \times 10^{-2}T^2 + 2.374 \times 10^{-4}T^3 + 1.340\,(S-35) + 1.630 \times 10^{-2}D + 1.675 \times 10^{-7}D^2 - 1.025 \times 10^{-2}T(S - 35) - 7.139 \times 10^{-13}TD^3$$

  In which T is the temperature in degrees Celsius, S is the salinity in parts per thousand, and D is the depth in meters. The range of validity: temperature 2 to 30 °C, salinity 25 to 40 parts per thousand, depth 0 to 8000 m.

- the sea-state or sea surface roughness provided by the Wave Watch 3 model.

The type and source of data used is summarized in Table 3. The background noise is set using the Wenz model [21] for natural noise derived from the surface roughness of the sea in the area.

Table 3 : Summary of the input data used for the modelling

Data Type	Provider	Coverage	Spatial resolution
Bathymetry	EMODNet	European seas	7.5"
Coast line	Open Street Map	World	-
Sediment	EMODNET	European seas	7.5"
Temperature	Copernicus Ocean	World	5'
Salinity	Copernicus Ocean	World	5'
Surface roughness	Wave Watch 3	World	30'

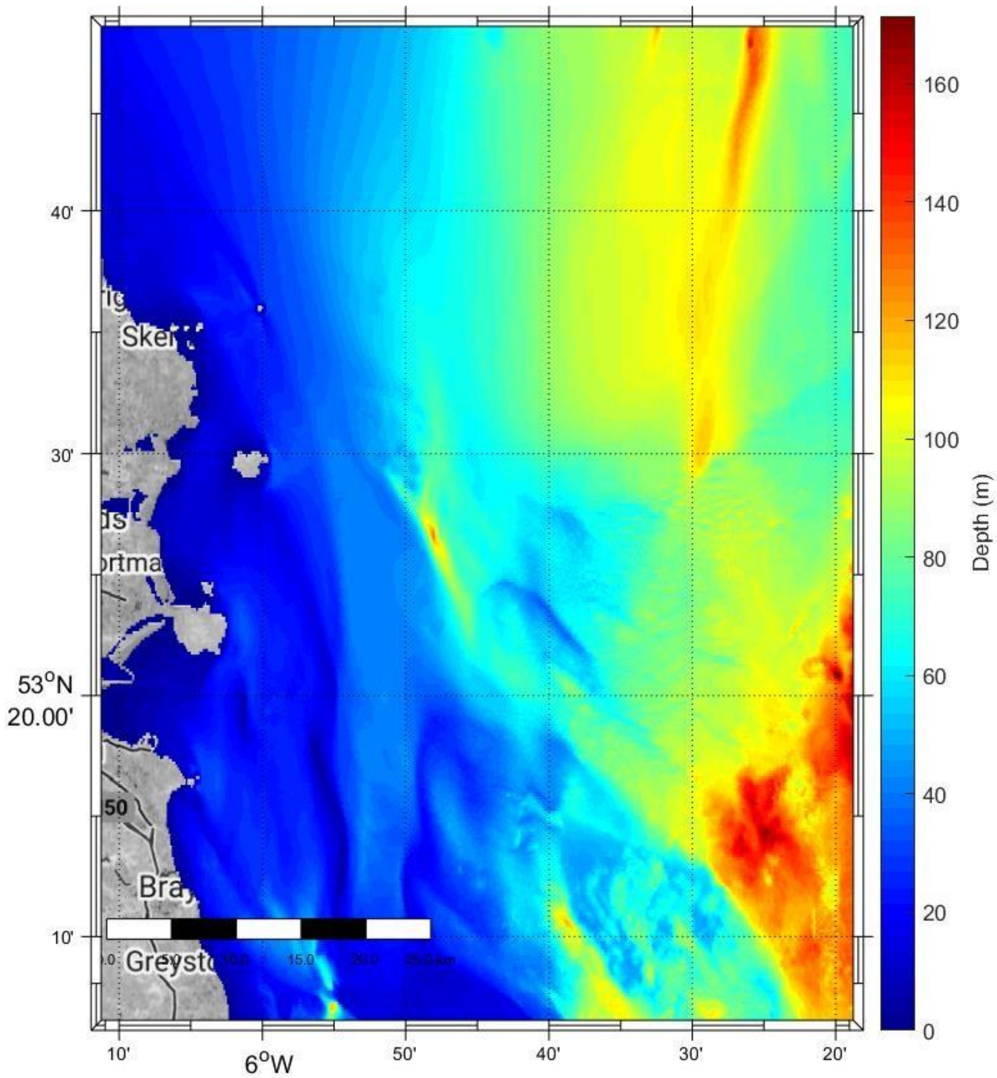


Figure 3: Bathymetric map used for modelling offshore Dublin extracted from [19]

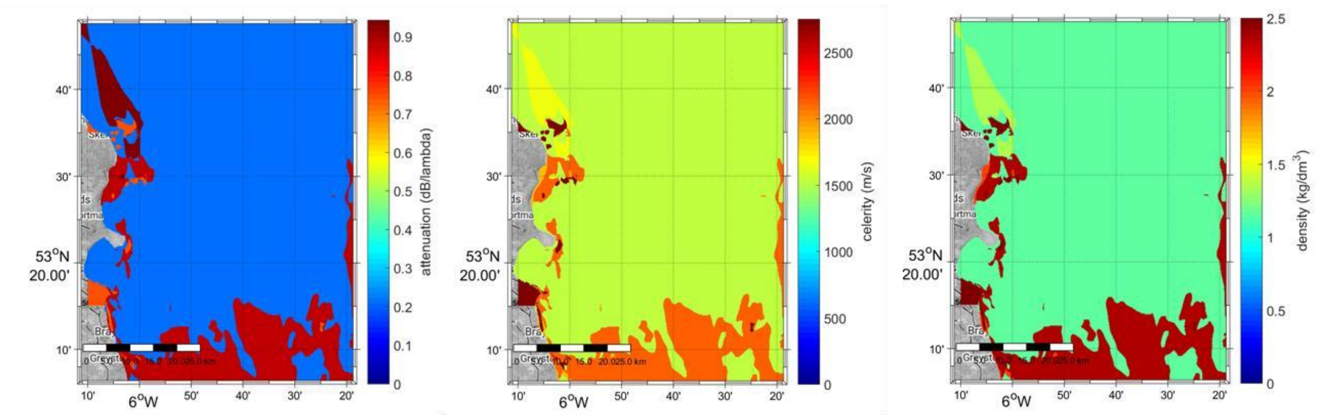


Figure 4: Distribution of values of compressional attenuation of sound (left), compressional sound speed (middle), and density (right) of the sediment provided by [19] .

Table 4: Bottom characteristics used for modelling.

Sediment Name	Density		Compressional Speed		Compressional Attenuation	
	Ton/m3		m/s		dB/lambda	
	Mean	Uncertainty	Mean	Uncertainty	Mean	Uncertainty
Boulders & bedrock	2,50	0,08	3 820	23	0,75	0,04
Till/diamincton	2,50	0,08	2 750	23	0,75	0,04
Coarse-grained sediment	2,37	0,10	2 122	315	0,88	0,07
Mixed sediment	2,03	0,26	1 855	79	0,89	0,01
Muddy sand and sand	1,53	0,22	1708	70	0,91	0,06
Mud and sandy mud	1,16	0,03	1517	32	0,37	0,41

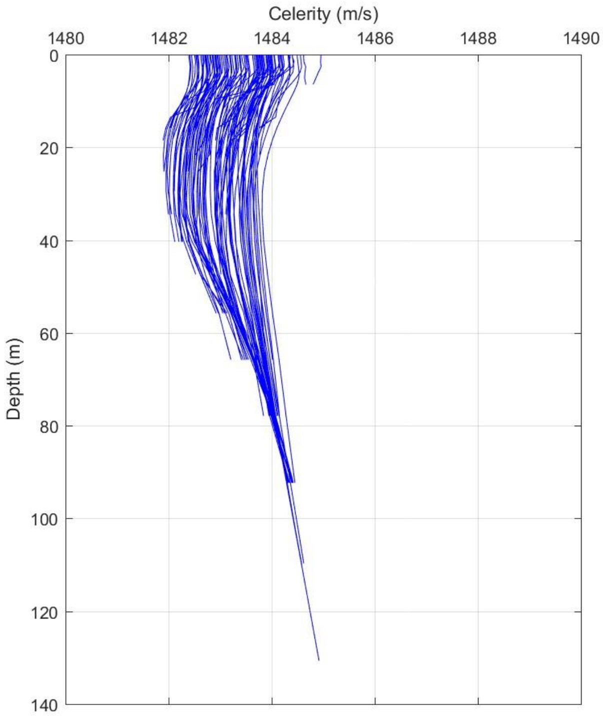


Figure 5: Sound speed profiles in the area the 17th of March 2017 provided by CMEMS.

IV.1. Noise introduced in the marine environment from dredging

We will consider as sources a Trailing Suction Hopper Dredger (TSHD) (see illustration Figure 6).

The location for modelling is at 53.4169° latitude and -6.075° longitude, offshore Dublin, which correspond to the far end of the dredging track length (about 4 km offshore). The physical geometry of the sound source is modelled as two points of generation: 50% of the generated energy is at 6m depth to describe the noise from the vessel, and 50% of the energy is located close to the bottom to describe the noise generated by the suction pipe.

The activity selected for the modelling is the flattening and removal of rocks. The wideband source level is derived from [23] and [24] and set at 178 dB ref 1µPa in the 50Hz to 89 kHz). Detailed source levels for the frequencies modelled are reported in Table 5.

Table 5 : Source levels used for modelling the dredging activities

Source level dB ref1µPa²@1m	Sound Pressure Level in the 125Hz 1/3 octave	Sound Pressure Level in the 1kHz 1/3 octave	Sound Pressure Level in the 8kHz 1/3 octave
TSHD	190.5 dB ref1µPa²@1m	188.5 dB ref1µPa²@1m	187.2

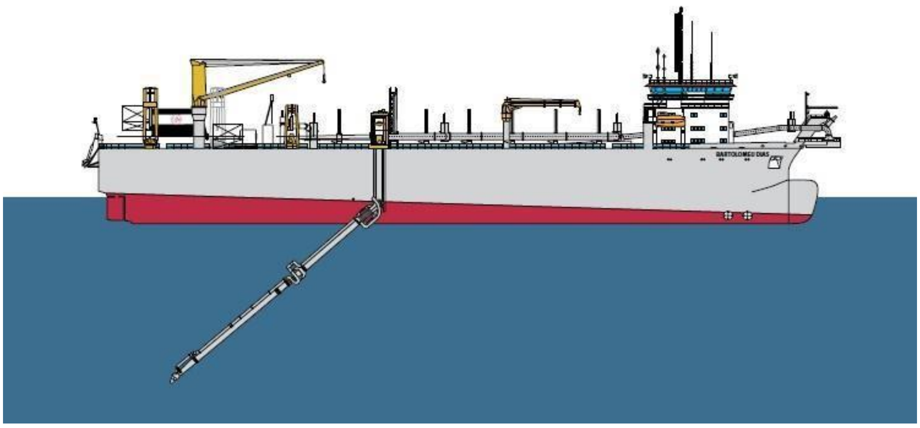


Figure 6 : Illustratio of a Trailing Suction Hopper Dredger (TSHD)) (vessel name: Bartolomeu Dias) Source : Jan De Nul

IV.2. Noise introduced in the marine environment from piling

We will consider as sources the piling of 600mm piles using an impact hammer (see illustration).

The location for modelling the piling is at 53.42466° latitude and -6.098955° longitude, offshore Dublin. During a piing phase, the sounds generated are impulsive. In order to translate the potential impacts more accurately, the scientific community (NOAA, 2016) now agrees to quantify the level as Sound Exposure Level (SEL), expressed in dB 1µPa².s). The sound exposure energy corresponds to the acoustic energy received at a point, integrated over a given frequency band and over the significant duration of the sound pulse (Ti). In this study, Ti is chosen to be 100ms, according to the literature (De Jong, et al., 2008), for example.

Earlier modeling and measurement research programs have shown that the level of sound exposure in water increases logarithmically as a function of the diameter of the pile, which makes it possible to extrapolate with confidence measurements reported in the literature. The source levels used in the modeling study are derived from measurement taken at the Q7 and OWEZ construction projects (De Jong et al., 2008), Beatrice (Talisman Energy et al., 2004) and Horns Rev II (ITAP, 2008).

The piling source is modelled using an ensemble of four punctual sources. 40% f the total energy is at the bottom end of the pile, while 60% of the energy is equally distributed along the pile. Detailed source levels for the frequencies modelled are reported in Table 6.

Table 6 : Source levels used for modelling the piling activities

Source level dB ref1µPa²@1m	Sound Pressure Level in the 125Hz 1/3 octave	Sound Pressure Level in the 1kHz 1/3 octave	Sound Pressure Level in the 8kHz 1/3 octave
600mm diameter pile driving Per stroke	186 dB ref1µPa²@1m	172 dB ref1µPa²@1m	Not modelled as requested by customer

Chapitre V. Noise maps produced

V.1. Important disclaimers

Maps have been produced at 125Hz, 1kHz and 8kHz third-octaves. Therefore, the levels obtained **cannot** be directly compared to cetaceans' nor seals' PTS or TTS thresholds, since the thresholds are valid for the total energy contained in the audibility band of the species (NOAA, 2016), which is much larger than a third-octave band. To be able to compare and estimate a risk area, modelling should be performed for the full audibility band of each species, which has not been required by the costumer. For example, the source level in the auditory band of seals for a single-stroke piling of a 600mm diameter pile is 178 dB ref1µPa²@1m, while the source level in the 1kHz third-octave band is only 172 dB ref1µPa²@1m, which makes a significant difference.

The maps are purely modelling maps using the best known description of the environment. Usually, an acoustic calibration measurement is needed to ground truth the maps and reduce uncertainties.

V.2. Summary of maps produced

For each scenario (dredging and piling), a total of 21 maps have been produced and delivered in a NetCdf Format. The noise maps correspond to:

- ✓ March 2017 environmental context;
- ✓ The full water column;
- ✓ Three third-octave bands, centred at 125 Hz, 1kHz and 8 kHz (only for dredging) as required by the costumer;
- ✓ Seven percentiles, 0^{th} (maximum), 10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th} and 100^{th} (minimum) percentiles to characterise the variability of the sound field with depth;
- ✓ Three depth ranges (Surface to -15m, 30m to the bottom, and the full water column).

V.3. Delivery

Quiet-Oceans has delivered noise ambient maps in NetCDF format version 4. Files format respect principals rules of NetCdf Climate and Forecast (CF) Metadata Conventions release 1 [22] .The NetCdf provided is described by :

- ✓ global attributes : attributes used for context, history or versioning file ;
- ✓ dimensions : scalar data that describes dimensions for the variables contained in file ; ✓ variables : vectors or matrix that describes the data.

The following sections detail the content of the delivered data.

V.3.1. File name

Files are named as follow: Dredging_DublinNorth_20170330.nc for the dredging scenario and Piling_600mm_DublinNorth_20170728.nc for the piling scenario.

V.3.2. Dimensions

The dimensions of the variables contained in the delivered Netcdf are detailed in Table 7.

Table 7: Summary of the dimensions of the variables contained in the delivered Netcdf files.

Group	Name	Value	Statut (Mandatory, Optionnal)
AcousticData	Lat	number of latitudes, configuration dependent	M
	Lon	number of longitudes, configuration dependent	M
	frequency	number of frequency	O
	percentile	number of percentiles, configuration dependent	M
	Layer	Number of immersion layers	M
	maxLayerNameLen	Max length of layer names	M

V.3.3. Variables

A variable can be associated with attributes. When CF conventions describes it, standard attributes are mentioned:

- ✓ standard_name : name for variable according to CF conventions
- ✓ long_name : description for variable according to CF conventions
- ✓ units : : units according to UD Units Unidata dictionnary
- ✓ valid_min : minimal value for data validation
- ✓ valid_max : maximal value for data validation

For geographic reference, SPL is linked to a coordinate reference system (CRS) which defines all the parameters attached to a mapping projection :

- ✓ grid_mapping_name : naming of projection as defined in conventions
  (Appendix F. Grid Mappings). In our case, latitute_longitude is equivalent to geodesic projection in which coordinates positions are latitude and longitude,

- ✓ epsg_code : EPSG code (4326) for correspondant geodesic projection with WGS84 ellipsoid
- ✓ longitude_of_prime_meridian : longitude of prime meridian in geodesic projection
- ✓ semi_major_axis : half the major axis of the ellipsoid linked to the projection
- ✓ inverse_flattening : 1/flattening of the ellipsoid linked to the projection

Table 8: Description of the variables of the Netcdf delivered.

Name	Dimensions	Datatype	Statut (Mandatory/ Optionnal)	Attributes	Description
layer	Layer	int8	M	Standard_name Layer Layer Long_name layer_bnds bounds layer_names layer_names	Immersion field.
Name	Dimensions	Datatype	Statut (Mandatory/ Optionnal)	Attributes	Description
layer_names	Layer, maxLayerName Len	char	M		Immersion identification (Ex : High, Low, Full).
layer_bnds	layer, nv	int	M	unit m positive down	Immersion bounds
frequency	frequency	int	O	Standard_name frequency long_name Central band frequency units Hz order_convention IEC 61260 : 1995"; order_octave 3.0	
percentile	percentile	int8	M	Standard_name percentile Long_name percentile comment QO definition : The value above which a given percentage of observations in a group of observations fall unit Percent	
Lon	Lon	double	M	Standard_name longitude longitude Long_name None comment unit degrees_east	

lat	Lat	double	M	Standard_name latitude latitude Long_name None comment unit degrees_north	
energy	layer, frequency percentile, lon, lat	single	O		

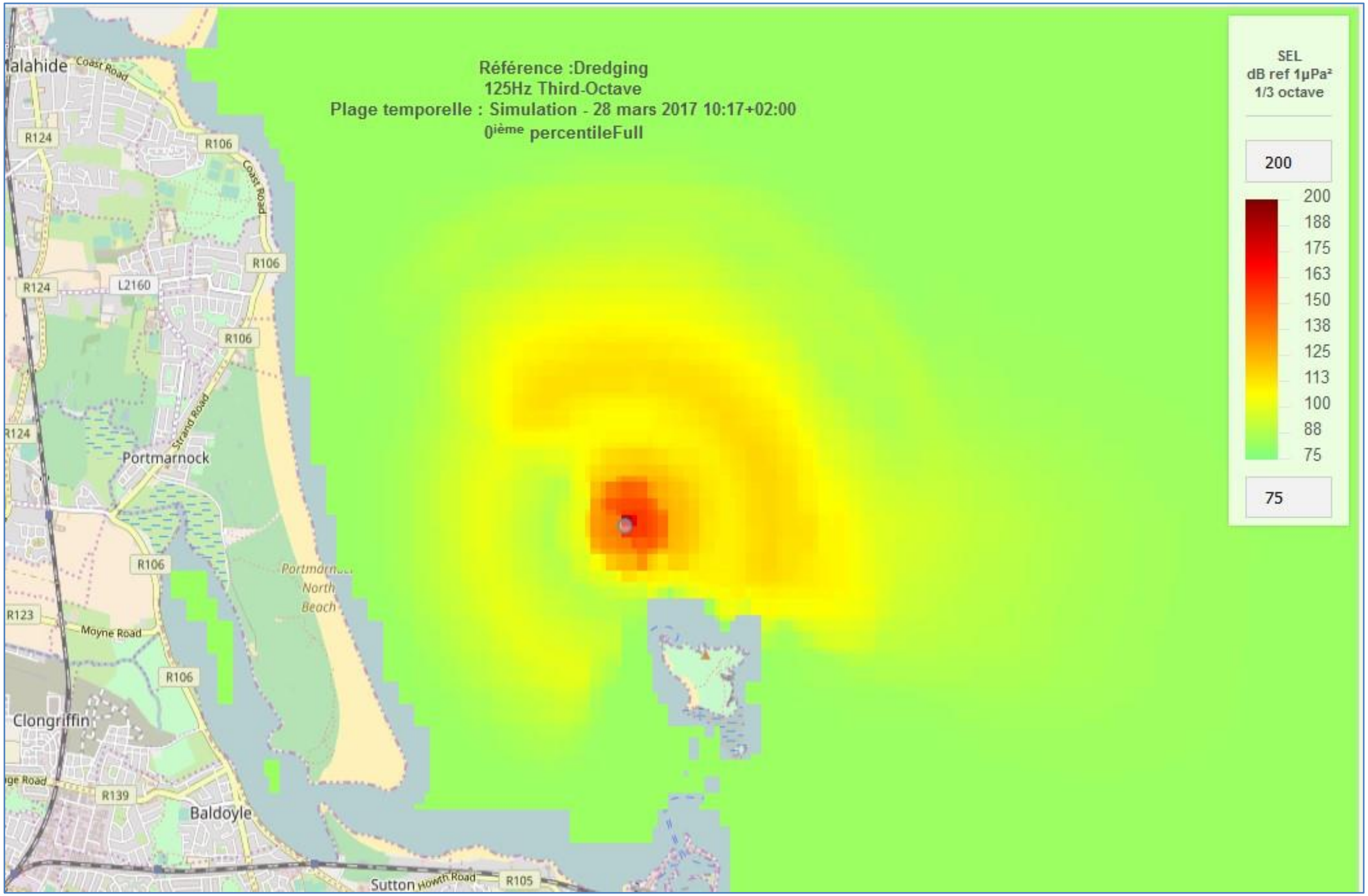
crs		Single	M	grid_mapping_name latitude_lo ngitude
				epsg_code EPSG:4326
				longitude_of_prime_meridian 0.0; // double
				semi_major_axis 6378137.0;
				// double
				inverse_flattening
				563; // double 298.257223	

V.4. Selection of noise maps

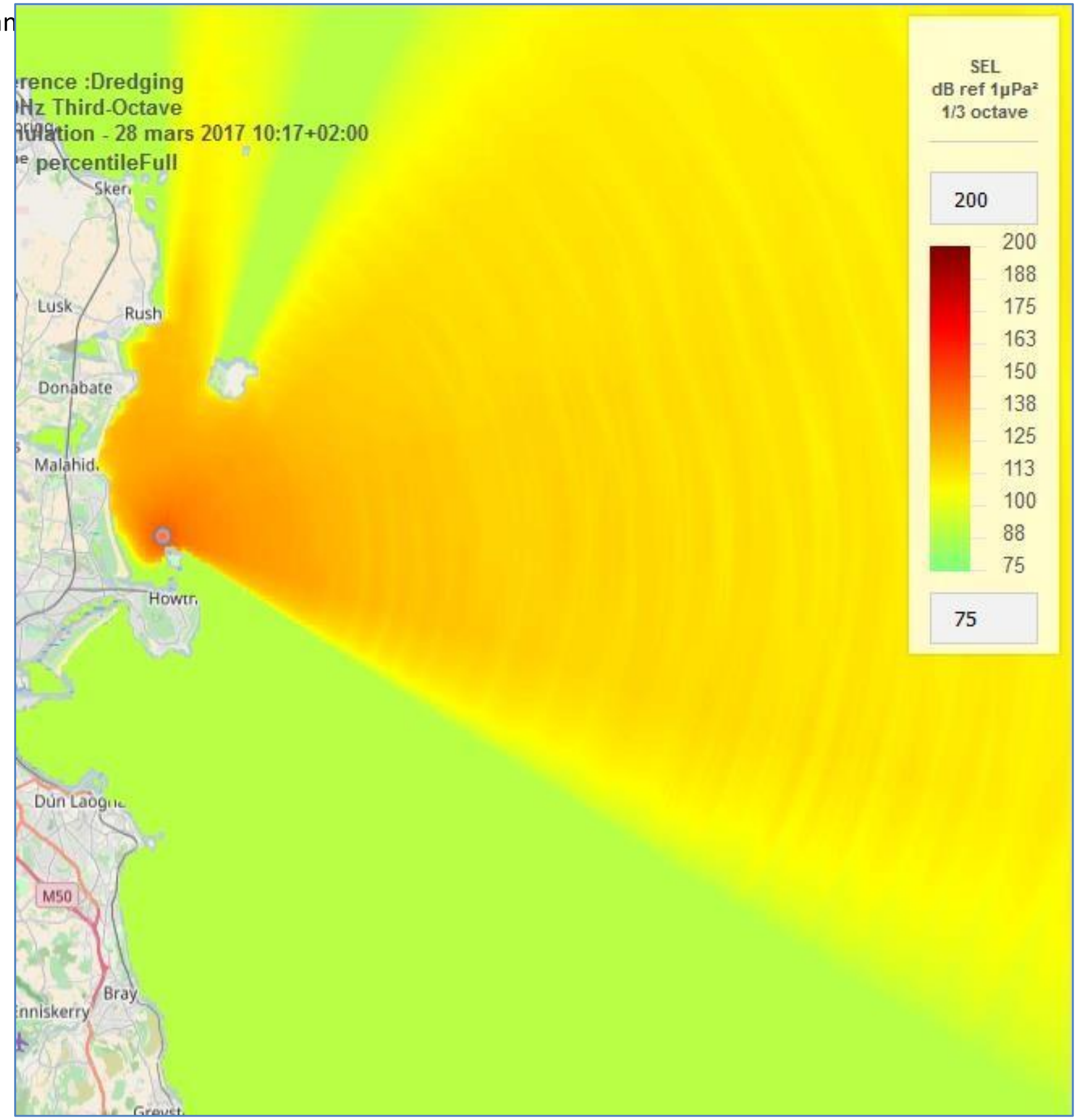
This section gives a non-exhaustive overview of the noise maps for dredging. The maps reported hereafter are the 0th percentile (maximum levels) for the full water column for the 125 Hz, 1kHz and 8 kHz third-octave bands.

V.5. Dredging noise maps

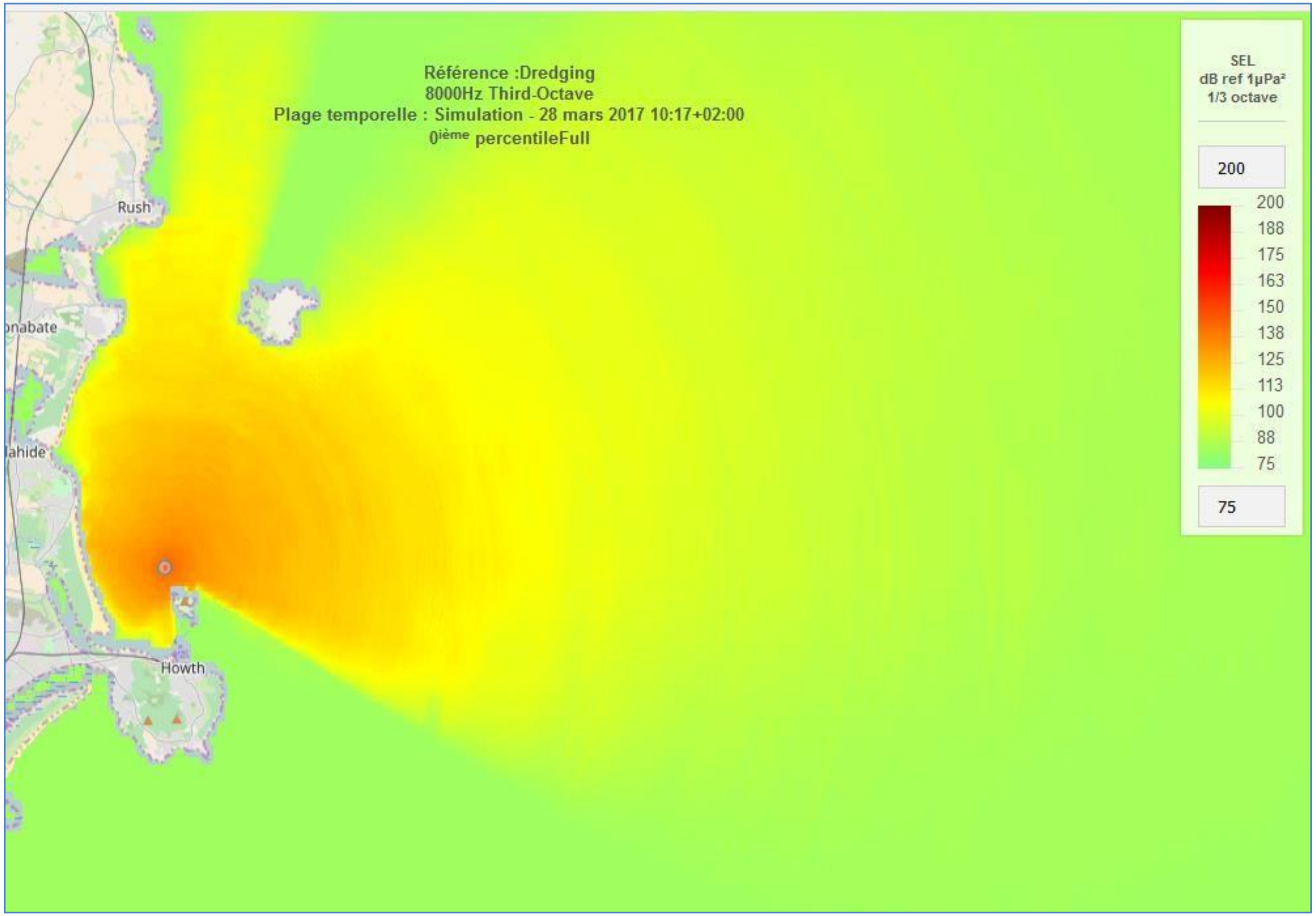
Maximum levels at 125 Hz 1/3 octave band



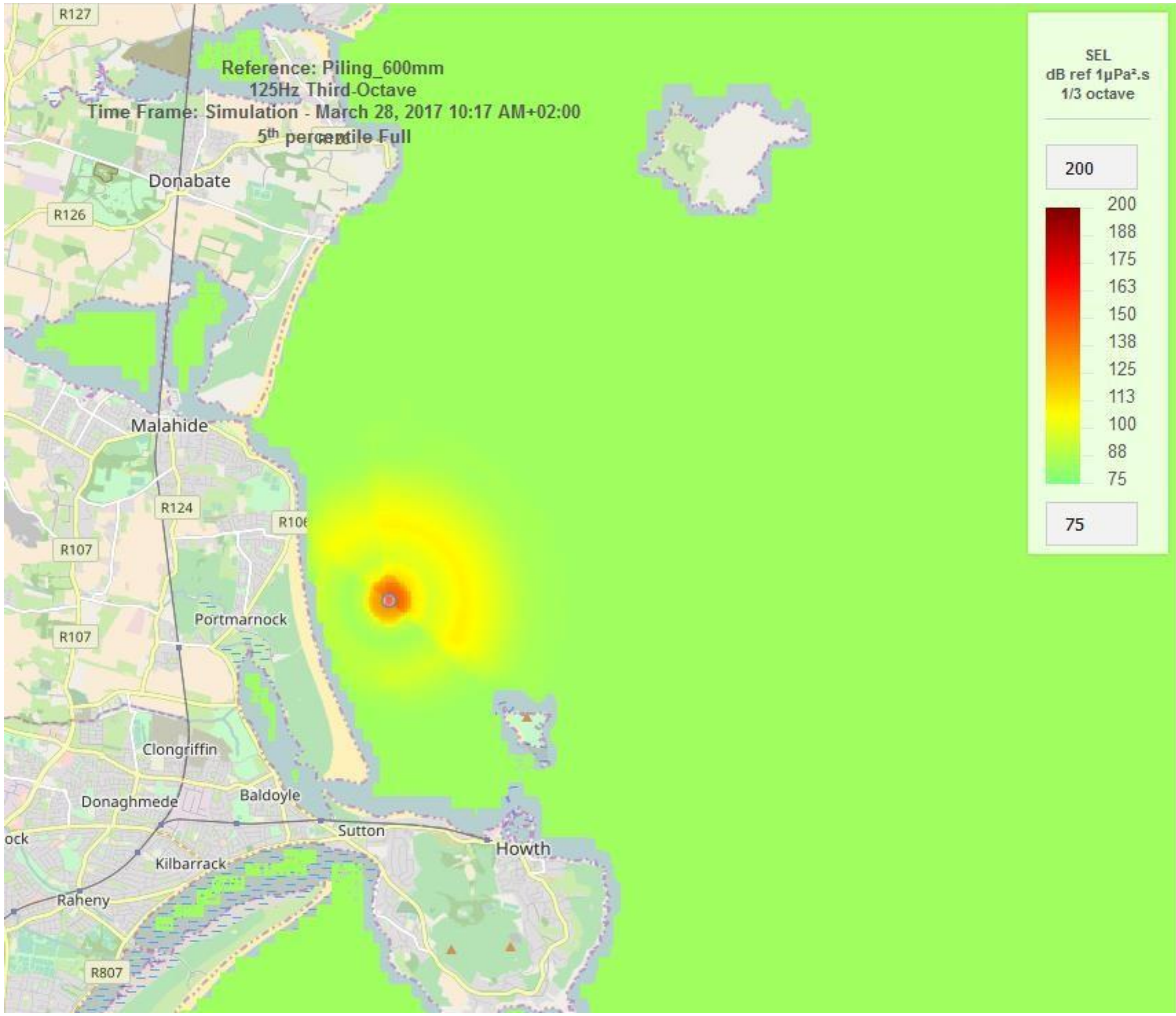
Maximum levels at 1kHz 1/3 octave ban



Maximum levels at 8kHz 1/3 octave band

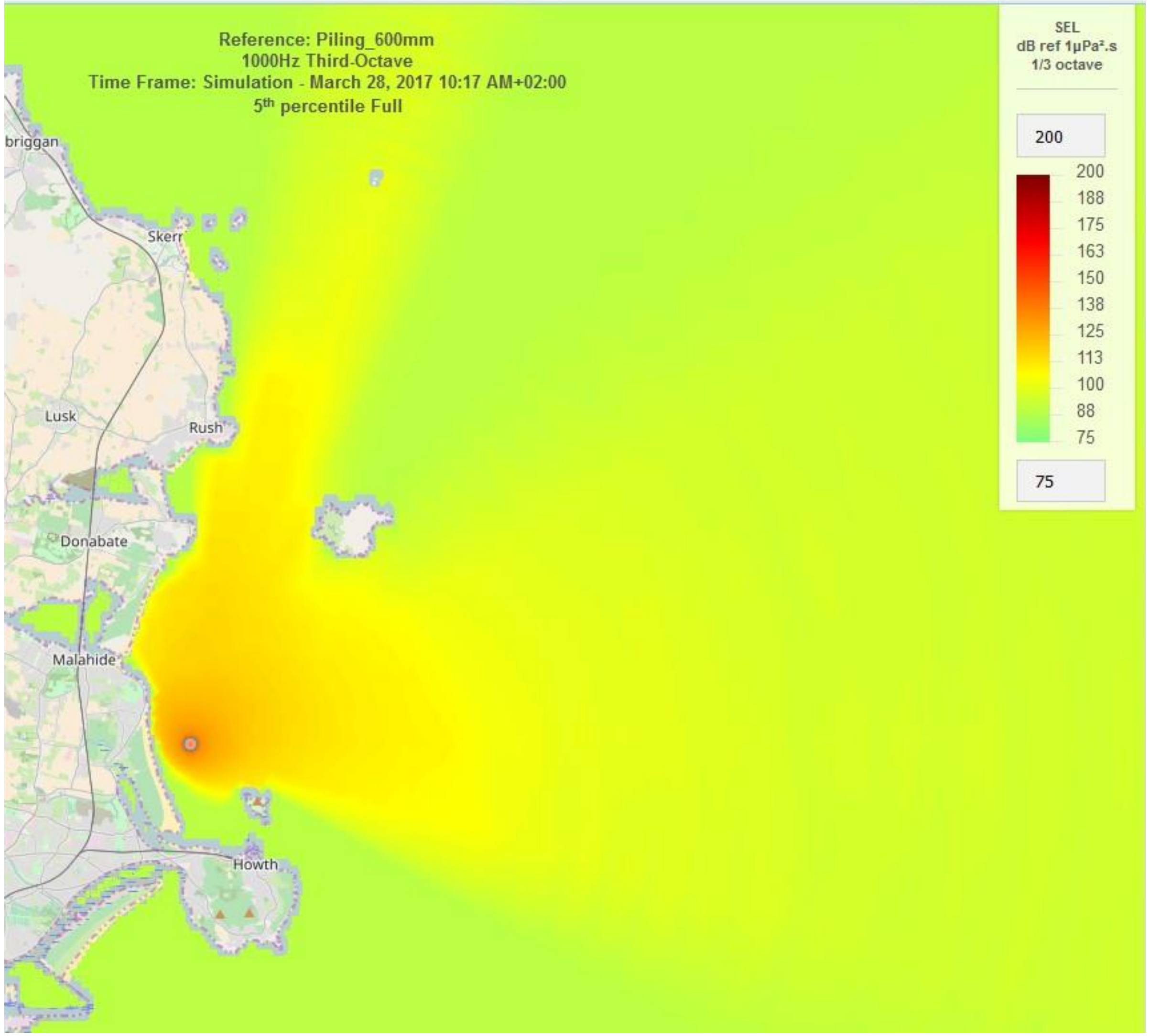


V.6. Piling noise maps



Piling 600mm diameter Maximum 1sec SEL levels at 125 Hz 1/3 octave band

Maximum 1sec SEL levels at 1kHz 1/3 octave band



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Report overview and conclusions

The following sections are the comments and conclusions drawn by TechWorks Marine in review of the reports above.

Location details

The report utilises data from The European Marine Observation and Data Network (*EMODnet*) as the source for the bathymetry. This data was utilised in the models and the sediment types were also gained from this model. The anthropogenic activity in the area was demonstrated from the overview of AIS data. However the AIS data from the specific location during the deployment period was unfortunately not available.

Equipment and methodology

A single icListen recorder was deployed on a line below a buoy near Ireland's Eye at 53°24.901'N 006°2.978'W. It was operating continuously from July 30 to September 1. The recording duty cycle was configured with 15 minutes on and 50 minutes off. The hydrophone sensitivity taken from the stored wav files was -168 dB re 1 V/ µPa. The data was sampled at 16 kHz in 24 bits; the quantization was between +-3V. No gain was used.

The data collected was then used to produce maps at 125Hz, 1kHz and 8kHz third-octaves. The Marine Strategy Framework Directive (MSFD) standardises the use of third octave bands.

Recordings and soundscape

As the description of an area as being noisy or quiet can quickly become contentious depending on the parameters being measured it is not possible to definitively categorise this area in this way from the results of the report.

However, while the data in the report only represents a month long 'snapshot' of the area the only noises picked up by the recorder were mooring noises and environmental. While further recordings and modelling would allow for modelling during different seasons, greater assessment of marine mammal presence, MSFD sound level indicators etc. the report shows the propagation characteristics of the area in the range of frequencies that were measured and can be expected from dredging.

Thought the location cannot be called "quiet". The levels were not different than what could be expected at a location like this.

The bathymetry of the location is fairly flat and shallow towards the coast and demonstrates quick absorption. Looking at the radiation of noise into the deeper water the modelling shows that low frequencies are absorbed quickly and close to the source. Higher frequencies propagate out, but with source levels close to 190 dB the received level drops below 160 dB within a kilometre.

This noise level can have an effect on marine mammals at a range of 1km. It would therefore be recommended that dredging or pile driving does not commence if marine mammals are sighted within this distance. The use of a marine mammal observer (MMO) on board is also recommended.

However, it is also worth noting that the recordings collected did not contain any cetacean vocalisations. This may be due to several factors. The depth of the recording area was quite shallow which reduced the effective detection range. Therefore, we can only specifically state that no cetaceans were present for that month inside the detection zone. Additionally, due to the range of the recording device it is also only possible to state that no cetaceans were present that were vocalising under 8 kHz within range of the recorder; though this does not mean no cetaceans were present.