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Underwater noise in ports and harbours and its effects

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ABSTRACT

It has been established that underwater noise in the deep ocean has increased significantly in the last decade, largely due to the increase in shipping. Consequently it is reasonable to expect that noise in coastal waters, ports and harbours has increased proportionately more, since these provide a concentration of ships. In addition, civil engineering projects in these areas such as the construction of quays are common. Despite the concentration of such noise-generating activities, little investigation of the typical levels of noise in the busy environments of ports and harbours, and interpretation in respect of the likely effects on marine animals has been carried out.

The authors have taken a significant set of measurements of underwater noise in ports, including the movement of vessels and during construction such as piling. These measurements have been evaluated in terms of their dB_{ht} level, or loudness, for several key species. The results indicate that the noise levels of a source are often not connected to the human perception of its noisiness; for instance, a hydrofoil vessel that is noisy in air may be quiet underwater, and a container vessel that is quiet in air may be very noisy underwater. Sound sources such as piling and seismic surveying in deep water may have the capacity to cause avoidance over large ranges. However, the rapid attenuation of noise that results in shallow water, and the relatively low source levels of the noise, mean that relatively insensitive fish such as salmon are probably little effected by the noise.

1. INTRODUCTION

The underwater noise from shipping and marine construction has the capacity to cause environmental effects on fish and marine mammals, such as causing the avoidance of an area by fish and marine mammals and the blocking of migration routes of species such as salmon.

An existing container facility in Southampton Water is being redeveloped; it forms part of the migratory route for fish including the Atlantic Salmon (*Salmo salar)* and Sea Trout (*Salmo trutta)*, that move to and from the Rivers Test, Itchen and Hamble. The marine environment within Southampton Water includes the Solent and Southampton Water Special Protection

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Area (SPA) and Ramsar site, the Solent Special Area of Conservation (SAC), along with component SSSIs.
In order to ascertain the effects of man made noise, the authors have taken a significant set of measurements of underwater noise during typical activity in this port, including the movement of vessels and construction activities.

2. BEHAVIOURAL RESPONSE INDUCED BY NOISE

A number of studies have established that changes in fish behaviour may arise following exposure to relatively low level sounds. Engås and Lokkeborg[1] observed a reduction in the catch of haddock and cod that lasted for several days after they had been exposed to seismic airgun emissions. It was suggested that the sound probably caused the fish to leave the insonified area, although there was no data to support this. Slotte *et al*.[7] found broadly similar results for blue whiting and herring. Skalski *et al*.[6] found that the catch of rockfish reduced by 52% following exposure to a single emission of an airgun at 186-191 dB re 1 µPa (mean peak level). They also observed a startle reaction in fish at levels of sound as low as 160 dB re 1 µPa, although catch rates were not subsequently affected. Wardle *et al*.[9] noted a similar startle reaction in fish. Cod, pollack and saithe were exposed to airgun emissions of varying intensities at levels above 195 dB re 1 µPa and, in each case, the fish made an involuntary reaction in the form of a "C start" reflex.
A comprehensive study of the effects of underwater sound on fish and other marine animals was undertaken by Turnpenny *et al*.[8] The study considered levels of sound from seismic sources and pure tone sources that might give rise to fatalities, less serious injuries, deafness and changes in behaviour. Reaction thresholds for the trout and whiting were found to be around 170 dB re 1 µPa, although in the bass there was a significant avoidance to the sound at levels above 130 dB re 1 µPa.
Data on fish avoidance to underwater sound is also available from the use of fish deflection systems, developed to reduce fish kill at power station water inlets.[3] For fish species sensitive to underwater sound such as the herring (*Clupea harengus)* and the sprat (*Sprattus sprattus)* average intake rates decreased by 94.7% and 87.9% respectively[3]. The same data for insensitive species indicated that the efficiency for the flounder (*Platichthys flesus)* was 37%, and for the sole (*Solea solea)* 47%.
This data indicates that when considering the behavioural avoidance response of fish species to activities such as construction, it is the perceived level of loudness and vibration of the sound by the species that is important. Consequently, many researchers have advocated the use of frequency weighting scales to determine the level of the sound in comparison with the auditory response of the aquatic or marine animal. Madsen *et al.*[2], for example, recommend that "*as the impact of sounds impinging on the auditory system is frequency-dependent, noise levels should (as for humans) ideally be weighted with the frequency response of the auditory system of the animal in question*".

A study by Nedwell *et al* 2007[4] assessed the data from Maes *et al*,[3] and related other published data on the impact of underwater sound upon marine species to the level above hearing threshold or dB_{ht} (*Species).* Analogously with the dB(A) scale used for humans, this technique compares the measured underwater noise with the hearing threshold of a fish or marine mammal species, and provides a dB value that represents the perceived level, or "loudness" to the species included in the brackets. The formal method of calculating the dB_{ht}, and audiograms available is beyond the scope of this paper but is indicated in Nedwell *et al* 2007.[4]

Based on a large body of measurements of fish avoidance of noise the following assessment criteria have been proposed by Nedwell for assessing the potential impact of the construction noise and vibration[4]:

- 90 dB_{ht} (*Species*) and above – strong avoidance reaction by most individuals.
- 0 – 50 dB_{ht} (*Species*) – low likelihood of disturbance.

In human perception terms 0 dB_{ht},(i.e. 0 dB(A)) represents the threshold of hearing. A noisy office might have a level of 60 dB(A), and a hifi system in a small room at full power 90-100 dB(A)

3. BACKGROUND NOISE MEASUREMENTS

A series of over 2,500 individual measurements of background underwater noise were taken in Southampton Water over the frequency range from 1 Hz to 120 kHz using a Bruel & Kjaer Type 8106 hydrophone deployed from an anti-heave buoy, conditioned by a Subacoustech hydrophone power supply / amplifier, which could pre-emphasise the signals to increase the effective dynamic range of the system.

Underwater noise recordings were undertaken at five sites throughout Southampton Water, from the Container Terminal site at the western end of the Southampton Water channel, to Calshot Bay at the entrance to Southampton Water. The measurements are tabulated in table 1; it may be seen that the coastal underwater noise level is relatively high compared with open ocean noise. Some typical spectra are presented in figure 2.

The broadband (1 Hz to 120 kHz) Sound Pressure Levels were higher than those in the open sea, varying from 101 to 141 dB re. 1 µPa, with mean levels of typically 120 to 130 dB re. 1 µPa. However, the perceived levels for the salmon varied from 0 to 38 dB_{ht}(*Salmo salar)* which is considerably below the levels likely to have a disturbance effect on the species, corresponding roughly in human terms to the level of noise in a quiet office. It was concluded that no adverse impact of the background noise on salmon would be likely.

Table 1: Summary of measurements of background underwater noise at five sites in Southampton Water (n = number of individual time histories).

	Sound Pressure Level (dB re. 1 µPa)			**RMS dB_{ht}(*Salmo salar*)**		
4th April 2008	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**
Bury Swinging Ground [n=95]	128	127	128	28	27	27
Upper Swinging Ground [n=155]	123	118	119	20	17	18
Dock Head [n= 65]	118	111	113	6	2	4
Netley Abbey [n=95]	124	116	120	5	0	2
Hook Buoy [n=90]	139	135	137	37	32	34
2nd May 2008						
Bury Swinging Ground [n = 115]	132	131	131	28	25	26
Upper Swinging Ground [n = 140]	123	119	120	18	11	14
Dock Head [n = 303]	130	111	121	32	7	15
Netley Abbey [n = 300]	122	101	109	12	0	0
Hook Buoy [n = 175]	126	114	119	26	9	18

7th May 2008						
Bury Swinging Ground [n = 179]	130	125	126	28	21	23
Upper Swinging Ground [n = 235]	127	115	120	20	10	15
Dock Head [n = 140]	141	134	138	38	30	34
Netley Abbey [n = 150]	123	116	118	22	10	15
Hook Buoy [n = 280]	128	113	120	28	8	15

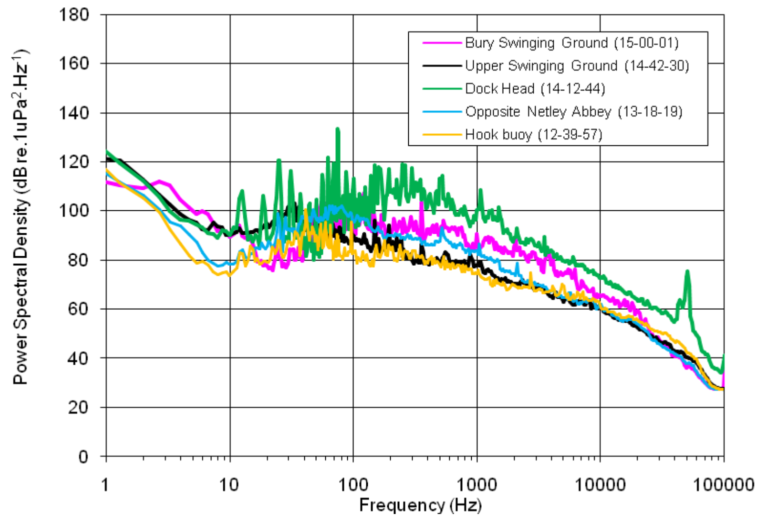

Figure 2: Comparison of spectral levels of underwater noise at five measurement positions in Southampton Water on the 7th May 2008.

4. LONG TERM MONITORING OF UNDERWATER NOISE AT A FIXED POINT

The preceding results indicate the levels of "snapshots" of underwater noise at various positions, but it is interesting to investigate the temporal variation in noise at a given point. Figure 3 illustrates the underwater noise over a typical operational working day at the container port, adjacent to a berth. The corresponding activity is indicated in Table 2. It may be seen that the level of noise reflects the level of activity in the port, and increases during the working day. However, the perceived levels for the salmon varied from 5 to 31 dB_{ht}(*Salmo salar*) and were thus, at the point at which the measurement was made, insufficient to cause an adverse behavioural effect.

Table 2: Table of shipping movements and events in the berth 201 / 202 region during 10th June 2008.

Event	Time	Activity
	06:15	Start of monitoring. Little harbour activity.
1	06:26	Vessel 'Queen Victoria' approaching through shipping channel and mooring at berth 106.
2	07:04	'Queen Victoria' stationary, support vessels in attendance.
3	07:25	'Queen Victoria' at berth 106. Lorry reversing along quay wall 201 / 202.
4	09:17	Engines started on service barge at berth 106.
5	10:22 – 10:35	Container vessel 'Margareta B' leaves Berth 205E, moves through Upper Swinging Ground and leaves Western Docks area.
6	11:33	Fork lift truck passing along dock wall, passed measurement position.
7	12:08	Medium sized motor boat passes through Upper Swinging Ground.

8	12:51 – 12:57	Cargo vessel 'Humber Star' enters Upper Swinging Ground from Bury Swinging Ground, moves past measurement position and leaves Western Docks area.
9	13:09 – 13:18	Gosport ferry moving through Upper Swinging Ground.
10	14:00 – 14:42	Various small vessel movements in Upper Swinging Ground area.
11	16:06 – 16:17	Tug boat 'Apex' manoeuvring near Ro-Ro terminal and moving out of area.
12	16:35 – 17:07	Large container vessel 'Wan Hai 605' approaching from shipping channel (Town Quay area) entering Upper Swinging Ground aided by two tugs. Vessel turns in Upper Swinging Ground and manoeuvres into Berth 204.
13	17:06 – 17:34	Vessel 'Queen Victoria' leaves Berth 106, enters Upper Swinging Ground, turns and exits Western Docks area.
14	17:37 – 17:45	Two tugs 'Bentley Felixtowe' and 'Svitzer Sussex' moving through Upper Swinging Ground and moving out of Western Docks area.

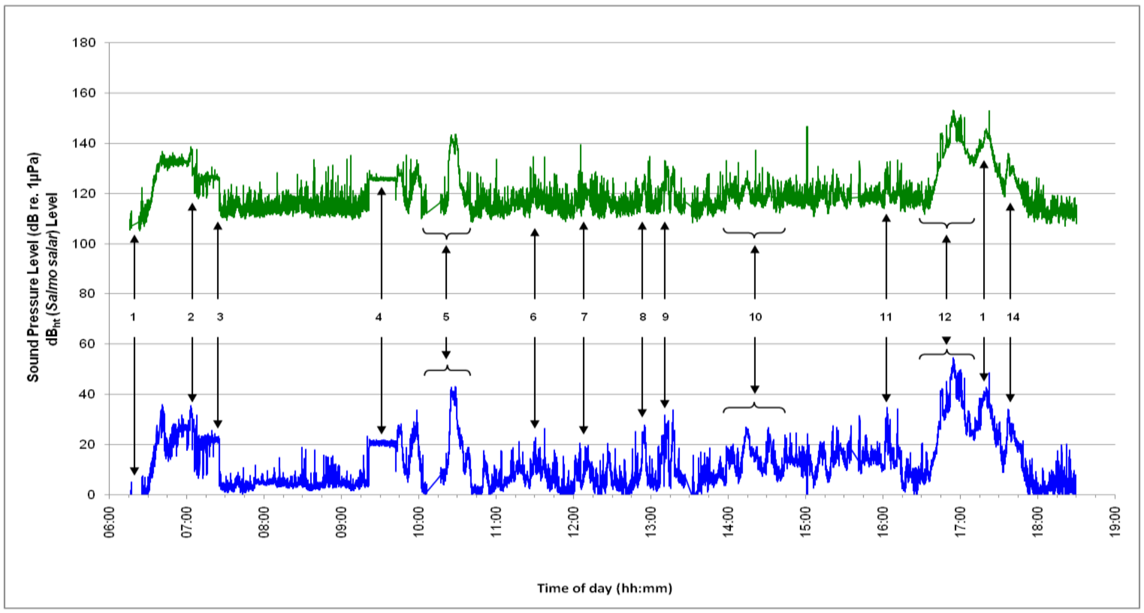

Figure 3: Results of monitoring of underwater noise at berths 201 / 202, Southampton Container Terminal, on the 10th June 2008.

5. SHIPPING NOISE

Measurements of underwater noise from shipping in Southampton Water were undertaken during a period from March to May 2008. In confined waters ships maneuver at low speed, and hence their noise may be lower. The distance between the recording position and the vessel was determined by GPS.

Figure 4 presents a summary of the one second, Sound Pressure Levels of underwater noise with range for the vessel CMA CGM Verlaine, which is 300 m long with a draft of 14.5 m and a deadweight tonnage of 77900 tons. Weather conditions were clear and calm with minimal wind speeds. At 220 m range the broadband Sound Pressure Level (1 Hz to 120 kHz) was approximately 140 dB re 1µPa, decreasing to 120 dB re 1µPa, at a range of 2 km, corresponding to an estimated Source Level at low speed of 171 dB re 1µPa @ 1 m, Transmission Loss of 12 log r, and an absorption coefficient of 0.004 $dB.m^{-1}$.

The same measurements in Figure 5 indicate that at a range of 220 m the noise is at a level of 37 dB_{ht} (*Salmo salar*), or below the level of noise at which a behavioural disturbance of salmon would be considered likely. The perceived sound level decreases with range, until at approximately 2 km, the ship noise is at a background sea noise level of 18 to 20 dB_{ht} (*Salmo salar*), and does not decrease further as the vessel moves from 2 to 3.3 km. The Source Level for the salmon is 64 dB_{ht} (*Salmo salar*) @ 1 m, with an underwater sound Transmission Loss of 11 log r, and an absorption coefficient of 0.0036 dB.m^{-1}. Thus, even at close ranges to the vessel, it is very unlikely that any adverse behavioural effect of noise would occur.

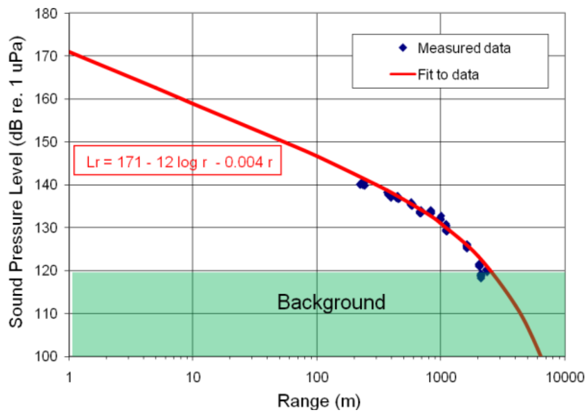

Figure 4: Summary of one second, Sound Pressure Levels of underwater noise with range for the vessel 'CMA CGM Verlaine' measured during exit from Southampton Docks on the 15th April 2008.

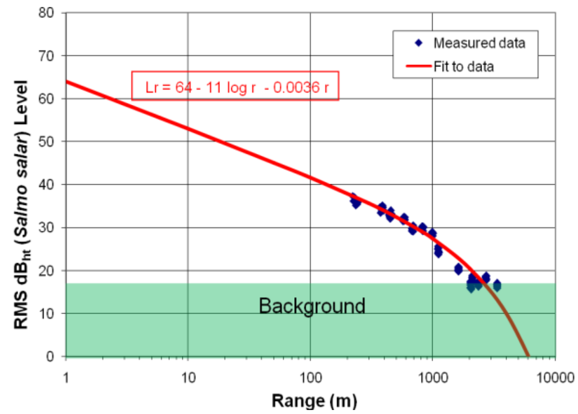

Figure 5: Variation of dB_{ht}(*Salmo salar*) underwater noise level with range from the vessel 'CMA CGM Verlaine' measured during exit from Southampton Docks on the 15th April 2008.

Table 3 provides a summary of the measurements of underwater noise for other typical vessel traffic moving through Southampton Water. The larger container vessels were all moving at considerably slower speed than similar vessels in the open seas. The levels are all similarly low and it is concluded that noise from shipping activities should not adversely affect salmon behaviour. It is also interesting to note that while the jet ferry was perhaps somewhat noisier than the other vessels in air, it was actually the quietest vessel measured underwater.

Table 3: Summary of broadband (1 Hz to 120 kHz), dB_{ht}(*Salmo salar*) Source Levels and levels of underwater noise from shipping noise in Southampton Water, March to May 2008.

Vessel	**Vessel Type**	Source Broadband Sound Pressure Level (dB re. 1µPa @ 1 m)	Source level dB_{ht} (*Salmo salar*) @ 1 m.	50 dB_{ht} (*Salmo salar*) range.
CMA CGM Verlaine	14.5 m draft container vessel	171	64	18 m
Kyoto Express Approaching	12.6 m draft container vessel	169	67	18 m
Kyoto Express Moving away	12.6 m draft container vessel	174	76	70 m
Vega Stockholm	6.6 m draft container vessel	186	93	200 m
Red Jet Ferry Run 1	Jet hydrofoil ferry @ > 10 knots.	154	56	3 m
Red Jet Ferry Run 2	Jet hydrofoil ferry @ > 10 knots.	155	43	-

6. CHARACTERISTICS OF UNDERWATER NOISE FROM IMPACT PILING OPERATIONS

Impact piling has received much attention as a cause of high levels of underwater noise. Figure 6 presents an underwater noise time history recorded at a range of 225 m from sheet piling operations on the banks of the Southampton Water. The underlying low frequency variation in pressure is due to wave motion causing hydrostatic pressure changes. The individual pile strikes are clearly characterised by the sharp peaks in pressure level. At this range the piling noise reached a maximum peak to peak level of 106 Pa or 161 dB re 1 µPa. The RMS sound level here was measured at 145 dB re. 1 µPa. The perceived peak to peak levels for salmon was approximately between 56 and 57 dB_{ht}, and hence it is very unlikely that any behavioural effect would have occurred at this distance.

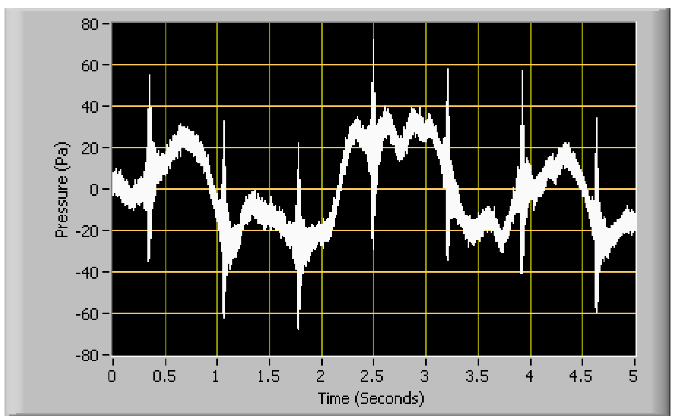

Figure 6: An underwater noise time history at a range of 225 m from sheet piling operations on the bands of Southampton Water.

7. UNDERWATER NOISE FROM CONCRETE BREAKING ON A QUAY

Figure 7 presents a serendipitous measurement of the underwater noise time history at a distance of approximately 400 m from a large machine mounted 'rock pecker' on a dockside at the River Tees. The rock pecker was operated on land approximately 50 m from the shore; the measurements were taken in the centre of the water channel at a further distance of 300 to 400 m. The rock pecker operated for the initial 2.5 seconds of the sound file. The remainder of the recording indicates the background underwater noise in the region.

There is a rapid increase in pressure each time that the rock pecker strikes the concrete dockside. The peak to peak noise is 100 Pa (160 dB re. 1µPa). Figure 8 presents unweighted and dB_{ht}(*Salmo salar*) level *versus* time; it is interesting to note that the levels are below 50 dB_{ht}(*Salmo salar*) and thus there would be little likelihood of salmon behaviour being affected. There is, indeed, little increase in noise caused by the breaking, probably because the noise is largely high-frequency and hence above the hearing range of salmon.

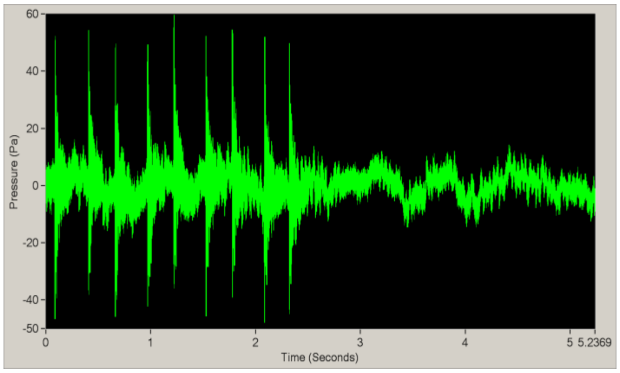

Figure 7: An underwater time history during rock pecker construction operations at a range of approximately 400 m.

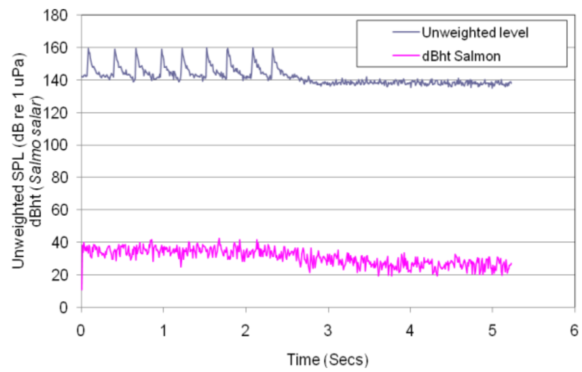

Figure 8: Variation of Sound Pressure Level and dB_{ht}(*Salmo salar*) during rock pecker construction operations at a range of approximately 400 m.

8. SUCTION DREDGING

A trailing suction hopper dredger is typically used for channel dredging and harbour maintenance and is a self propelled ship that is equipped with trailing pipes that suck up seawater and seabed sediment into a large hopper contained within the hull of the vessel. The suction pipe terminates in a drag head that moves over the seabed removing layers in long runs.

Measurements were made of a trailing suction dredger undertaking channel dredging operations at a range of 200 m. The dominant noise was from sediments rising up through the suction pipe, characterised by a relatively high frequency broadband hiss. Lower frequency noise arose from the dredging vessel machinery.

The underwater noise time history of Figure 9 indicates that at a range of 200 m, the RMS sound pressure varied from 3 to 16 Pa, that is, from 130 to 144 dB re. 1 µPa. If spherical spreading of underwater sound is assumed, this would indicate a broadband source level noise for the suction dredging operation of 190 dB re. 1 µPa @ 1 m. For comparison, Richardson *et al.*[5], quotes a broadband source level of 185 dB re. 1 µPa @ 1 m, for this type of operation.

Figure 10 presents the spectral level of the underwater noise. At 200 m the spectral levels from 40 Hz to 400 Hz exceed 100 dB re. $1\mu Pa^2.Hz^{-1}$, and are above 80 dB re. $1\mu Pa^2.Hz^{-1}$ over the broad frequency range from 25 Hz to 6 kHz. At 25 kHz this is some 30 dB above background sea noise, and approximately 50 dB at 100 Hz.

The underwater noise at a range of 200 m varied from 25 to 35 dB_{ht} (*Salmo salar*). Assuming spherical spreading of the underwater noise, this would indicate a source level for the suction dredging operation of approximately 80 dB_{ht} (*Salmo salar*), and a 50 dB_{ht} (*Salmo salar*) loudness zone extending to a range of 50 m. It is therefore concluded that there is a low likelihood of the underwater noise from the trailer suction dredging operations causing any disturbance to salmon.

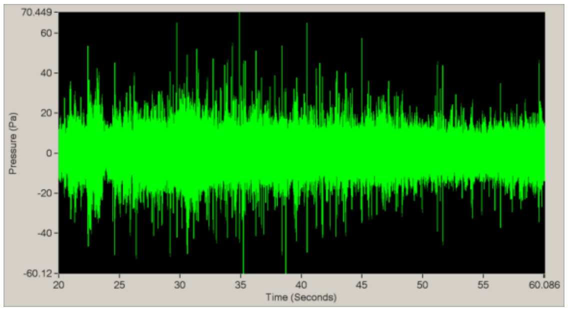

Figure 9: An underwater noise time history at a range of 200 m from trailing suction dredging operations, Lerwick.

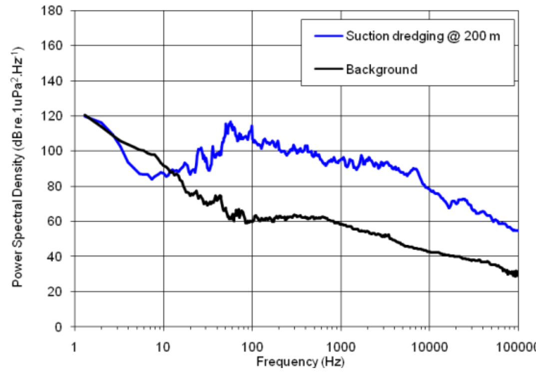

Figure 10: Spectral levels of underwater noise at a range of 200 m from trailing suction dredging operation, Lerwick.

9. SUMMARY AND CONCLUSIONS

The level of man made noise underwater in ports and harbours has significantly increased in recent years, and the mean levels measured by the authors of typically 120 to 130 dB re. 1 µPa are above those typical of deep water. However, the perceived levels for the salmon varied from 0 to 38 dB_{ht}(*Salmo salar)* which is considerably below the levels likely to have a disturbance effect. The level of noise during a working day reflected the level of activity in the port and movement of various vessels.

Measurements were made for vessels, impact piling, concrete breaking and dredging, but none of these generated noise at the distances measured that was thought likely to cause behavioural avoidance in salmon. Extrapolation of the measured data using a typical Transmission Loss equation has indicated that at closer ranges some sources of noise associated with ports and harbours may cause a mild behavioural avoidance response in salmon but that this is, in general unlikely.

It should be noted that the salmon are relatively insensitive to sound when compared with other fish and marine mammals, and hence it is possible that other species might react to these noise levels more adversely.

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