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Baseline Underwater Noise Measurements for the Humber Gateway Offshore Windfarm

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Baseline Underwater Noise Measurements for the Humber Gateway Offshore Windfarm

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ABSTRACT

This report describes work undertaken by the National Physical Laboratory and Loughborough University to undertake baseline underwater acoustic noise measurements for the Humber Gateway offshore windfarm. For the work, the background noise was sampled both spatially and temporally by measuring at selected locations through the site of the proposed windfarm. Measurements were also made at a location close to Donna Nook, 15 km away from the proposed windfarm site. Long term audio recordings using the a recording buoy were made at one position for a total of 16 hours starting from 17:30 21st February and finishing at 09:45 on the 22nd February.

The results presented in this report show the characterisation of the noise in terms of spectral level as a function of frequency, including levels at ultrasonic frequencies (up to a maximum of 200 kHz). The data show that the underwater background noise is quite high in the locality, by comparison with deep ocean noise. It is also slightly higher than the mean levels reported for other sites around the UK coastal waters. The general levels at Donna Nook were not significantly different to those found at the windfarm site. At the Donna Nook site, as the coast is approached the levels will be dominated by noise generated in the surf zone (only partially sampled here).

The higher levels are almost certainly due to the high ship traffic present during the measurements. Since this traffic is present almost continuously in the Humber estuary area, it is likely that it is characteristic of the area. The long term monitoring showed no reduction in overnight levels (the port is busy 24 hours a day). It would be reasonable to assume that the levels presented here are typical for the area. However, caution should be shown when extrapolating this data to other weather conditions.

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Approved on behalf of the Managing Director, NPL
by Martyn Sene, Director, Quality of Life Division

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1. EXECUTIVE SUMMARY

This report describes the baseline measurement of underwater acoustic noise at the site of the proposed Humber Gateway windfarm (see Figure 1.1)).

For the work, the background noise was sampled both spatially and temporally by measuring at selected locations through the site of the proposed windfarm. Measurements were also made at a location close to Donna Nook, 15 km away from the proposed windfarm site and the site of a colony of grey seals (Atlantic seals). Long term audio recordings using the a recording buoy were made at one position for a total of 16 hours starting from 17:30 21st February and finishing at 09:45 on the 22nd February. The buoy was recovered earlier than planned due to deteriorating weather conditions. A second buoy (intended to be used at Donna Nook) was lost due to inclement weather (approaching gale force winds on February 22nd) and it was not possible to retrieve any data from this.

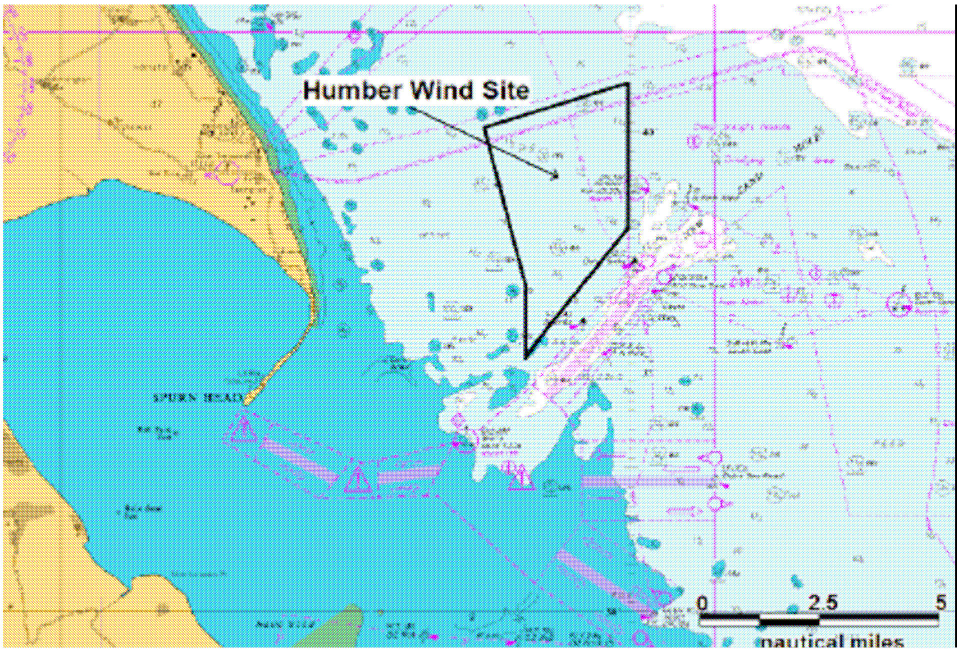


Figure 1.1 Site footprint for Humber Gateway windfarm

The results show the characterisation of the noise in terms of spectral level as a function of frequency, including levels at ultrasonic frequencies (up to a maximum of 200 kHz). The data show that the underwater background noise is quite high in the locality, by comparison with deep ocean noise. It is also slightly higher than some of the mean levels reported for other sites around the UK coastal waters. Figure 1.2(a) shows a typical noise level curve for a location in the windfarm site.

The higher levels are almost certainly due to the high ship traffic present during the measurements. Since this traffic is present almost continuously in the Humber estuary area, it is likely that it is characteristic of the area. Long term monitoring showed no reduction in overnight levels. Also shown in Figure 1.2(b) are individual frequency component levels for a 11 hour overnight sequence on the long term monitoring buoy.

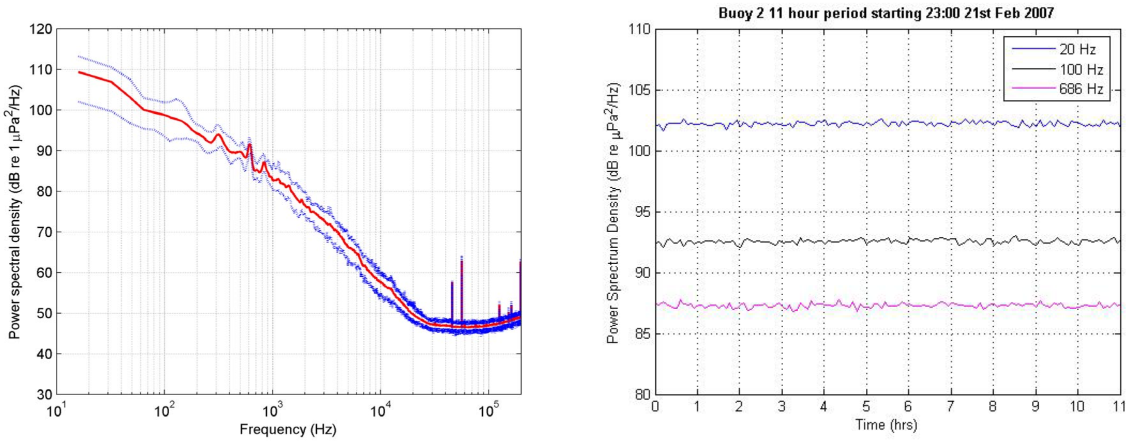


Figure 1.2 Typical noise plot (a) measured at the windfarm site (left); and (b) individual frequency component levels for a 11 hour sequence on the long term monitoring buoy (right).

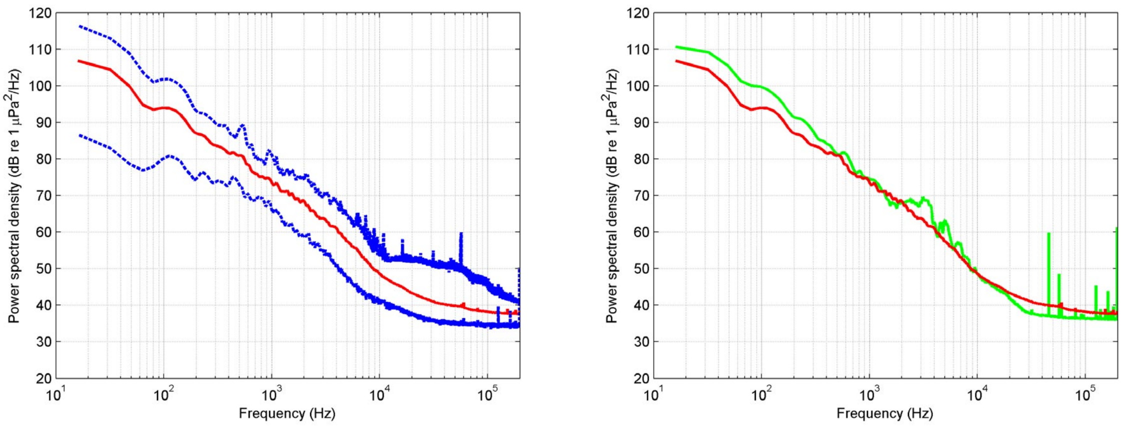


Figure 1.3 Plots showing: (left) mean ambient noise plot for the locations within the windfarm site (red curve) showing maximum and minimum range of values (in blue); and (right) comparison of the mean levels observed (red curve) in with measured levels at Donna Nook (green) .

It would be reasonable to assume that the levels presented here are typical for the area and that the results provide a reasonable baseline for background noise. Figure 1.3(a) shows the mean noise level versus frequency and the overall maximum and minimum noise levels encountered. However, some caution should be shown when extrapolating this data to other weather conditions. The sea conditions were lively and worsening over the measurement duration and reduced levels may be observed in very calm conditions. Similarly, rough conditions will increase the overall levels.

The general levels at Donna Nook were not significantly different to those found at the windfarm site (see Figure 1.3(b)). Figure 1.4 shows the typical levels of deep water ambient noise for comparison.

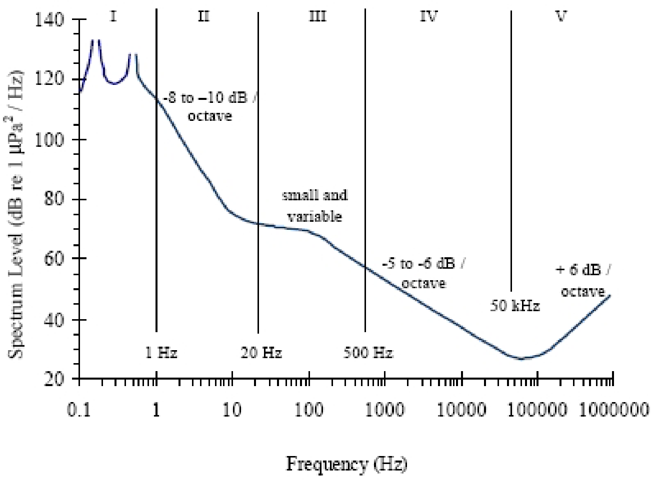


Figure 1.4 A summary of deep water ambient noise levels. The dominant source in the regions shown are: I and II – turbulence, hydrostatic sources (e.g. tides) and seismic tremors; III - distant shipping; IV – local sea surface noise; V – thermal noise. Plot adapted from Urick, 1983.

2. BACKGROUND NOISE IN THE OCEAN

2.1. BACKGROUND OR AMBIENT NOISE

The background or ambient noise in the ocean is regarded as sound perceived by a sensor (such as a hydrophone) which is due to a range of noise sources and is not due to the sensor itself (or the manner in which it is mounted). The noise originating from the sensor or its mounting is usually termed self-noise. Many sources contribute to the ambient noise, both natural and anthropogenic. These sounds combine to produce a background noise within which all acoustic receivers must detect the signals which are the subject of specific measurements.

It should be noted that although the ambient noise is sometimes defined as the residual noise left after all identifiable sources have been removed, for the purposes of this report all contributions of noise have been included in the measured background noise. This includes noise sources such as local shipping. This is valid since all the noise present, from whatever source, will potentially impact upon marine life.

2.2. TYPES OF AMBIENT NOISE

Ambient noise may consist of broadband continuous noise, tonal components, and impulsive noise. Each of these is best characterised in different units. Continuous broadband noise of an essentially random nature must be characterised using the bandwidth over which the noise is measured in addition to the amplitude or level. Typically this is done using as a power spectral density which represents the power in a 1 Hz bandwidth. The S.I. units of this quantity are Pa^2/Hz, but for underwater sound it is more commonly presented as a spectral level in decibels as dB re 1 $\mu Pa^2/Hz$. This is how the majority of the data in this report is presented.

Impulsive noise is transient in nature (of finite time duration) and is generally of wide bandwidth and short duration. It is best characterised by stating the repetition rate, the peak pressure amplitude and/or the pulse energy.

Tonal components are narrowband signals and are usually characterised by stating the frequency and the pressure amplitude (usually expressed as dB re 1μPa).

2.3. TYPICAL VALUES OF AMBIENT NOISE

Ambient noise in the ocean spans a large frequency range from below 1 Hz, to well over 100 kHz. Above 100 kHz, the ambient noise is dominated by thermal noise levels.

In deep water, the contributions from various sources have been extensively studied and the levels of ambient noise are relatively well defined. The classic text by Urick [Urick 1983] summarises deep water ambient noise in a curve similar to that of Figure 2.1.

Wenz [Wenz 1962] summarised ocean noise levels and these are known as Knudsen spectra from the pioneering work carried by Knudsen to measure the levels of ambient noise

[Knudsen et al. 1948]. The ambient noise spectrum will normally be made up from a number of contributing sources and is illustrated in Figure 2.2. This figure has been adapted from the presentation of the ambient noise spectra by Richardson [Richardson. 1995]. At the lower frequencies shipping noise will dominate, while at the higher frequencies noise from waves and precipitation will dominate. The frequency at which the change occurs is a complex function of local bathymetry, propagation conditions, shipping levels and weather.

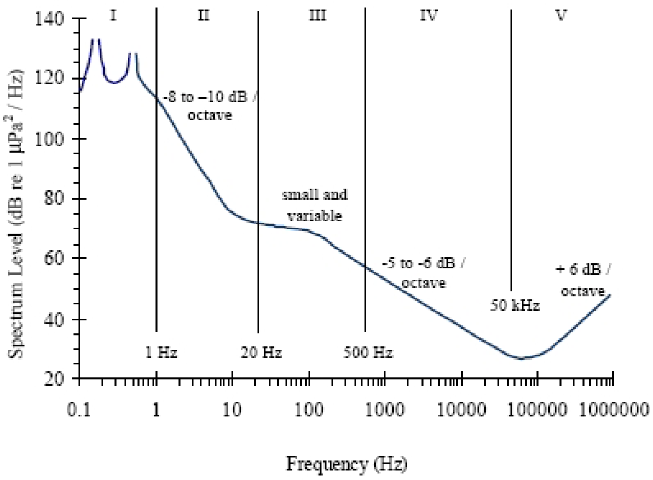


Figure 2.1 A summary of deep water ambient noise levels. The dominant source in the regions shown are: I and II – turbulence, hydrostatic sources (e.g. tides) and seismic tremors; III - distant shipping; IV – local sea surface noise; V – thermal noise. Plot adapted from Urick, 1983.

The region of interest to this report is shallow coastal water in the North Sea. Shallow water will not support acoustic propagation once the wavelength is long compared with the water depth (effectively acting like a high-pass filter). This means that in shallow water, low frequency noise from *distant* sources will not be detected at the receiver. Therefore, any low frequency noise present will have originated from local sources rather than have propagated from the great distances found in the deep ocean.

At high frequencies (tens of kilohertz), increasing absorption of sound by sea-water also prevents sound propagating over great distances. Therefore, the high frequency ambient noise is once again dominated by local sound sources. Values for absorption are typically around 1 dB/km at 10 kHz, rising to around 30 dB/km at 100 kHz [Fisher *et al* 1977, Francois *et al* 1982, Ainslie *et al* 1998]. Above 100 kHz, only very local sources contribute to ambient noise and above this frequency thermal noise takes over as the dominant source of underwater noise.

There are relatively few recent publications listing measured levels of ambient noise in UK coastal waters. There are several reports published by DTI under the auspices of the Strategic Environmental Assessment (SEA) which describe the ambient noise in UK waters. Underwater noise is only dealt with in a significant way in SEA6 and SEA7 [Harland and Richards 2006, Harland *et al* 2005] and unfortunately the reports do not cover the North Sea (they instead cover the Irish Sea and the Western Approaches to the UK). Despite the fact that they do not provide any measured absolute data for ambient noise, the reports provide an excellent review of the noise sources and noise generation mechanisms in UK waters, and many of the noise generation mechanisms apply equally to the area which is the subject of this report.

There have been a number of other measurements made of baseline underwater ambient noise at sites of other off-shore windfarms in UK waters. However, many of these were made for commercial clients and the data are not published in the open literature. One study which *is* published is that of Nedwell [Nedwell 2004] which was undertaken for COWRIE. Measured ambient noise data are given in this report for the North Hoyle and Scroby windfarm sites.

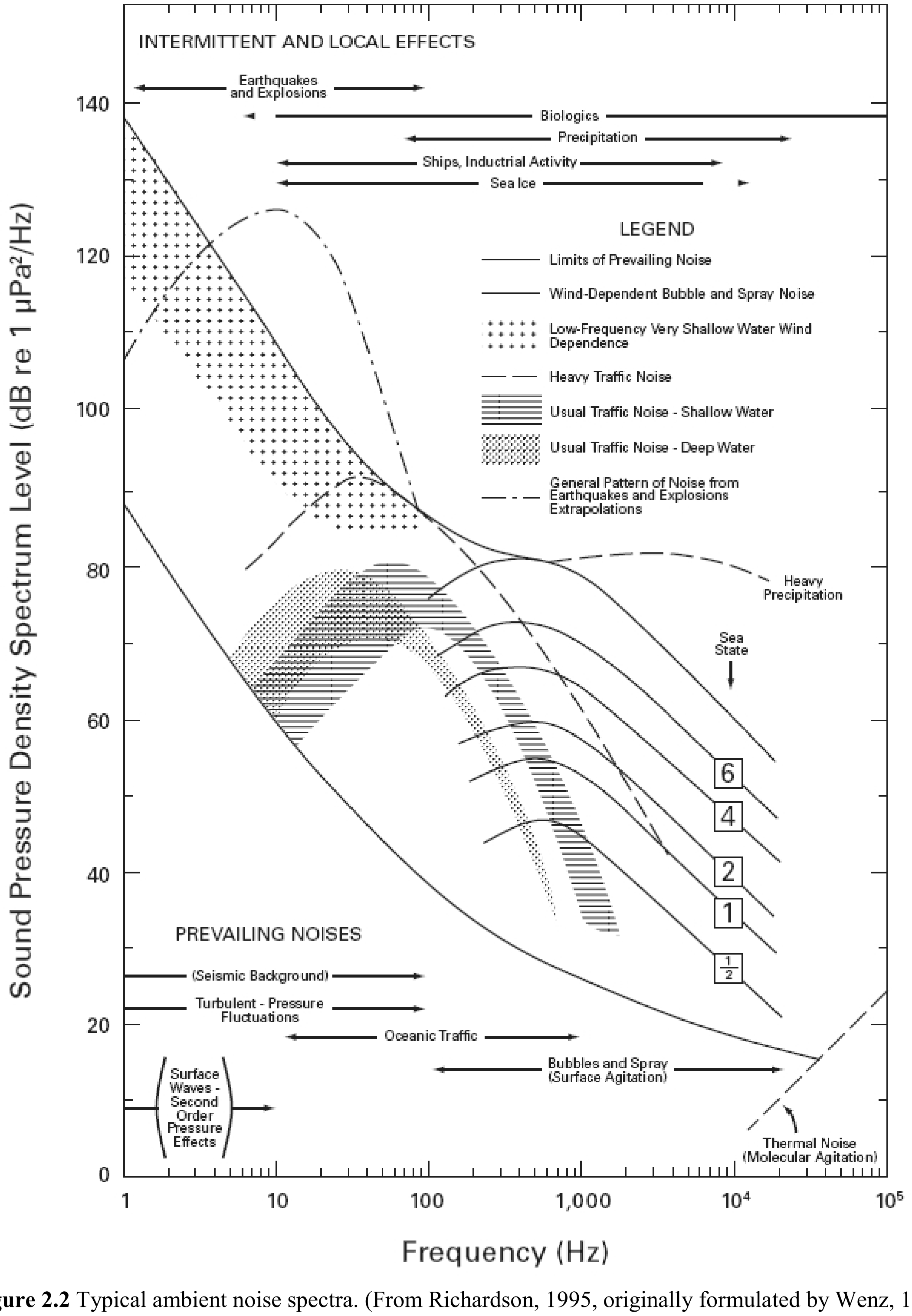


Figure 2.2 Typical ambient noise spectra. (From Richardson, 1995, originally formulated by Wenz, 1962)

2.4. SOURCES OF AMBIENT NOISE

2.4.1 Natural sources of ambient noise

Wind on the sea surface

The dominant mechanism for the generation of noise by wind at the sea surface is breaking waves, although this mechanism is still not fully understood. The noise spectra results from the incoherent sum of the noise from individual resonant bubbles, and at higher sea states, with larger breaking waves, large amounts of air are entrained and bubble oscillations may be coupled, leading to collective oscillation of bubbles in a plume [Medwin 1989, Prosperetti 1989]. The dependence on wind speed holds even below the speeds that produce breaking waves and this may be due to noise from flow noise as the wind passes over the sea surface and/or by bubbles induced from turbulence produced at the sea surface by the wind.

Rain

Rain or hail can cause significant elevation of ambient noise levels in the 1 kHz to 100 kHz region. The noise is generated by impact noise as the rain/hail impacts the surface of the water, oscillation of the bubble entrained by the raindrop, and large raindrops can cause a more complex multiple bubble and multiple impact noise [Medwin 1992]. At low wind speeds bubble oscillation is the dominant noise source in UK waters while impact noise dominates at higher wind speeds [Harland and Richards 2006, Harland *et al* 2005].

Surf noise

Surf noise can make a significant contribution to the ambient noise field in the nearshore region. The level of noise from this source depends on several factors: the beach profile and beach sediment type; the nature of the breaking waves in the surf zone; the degree to which bubbles are entrained by the breaking waves (causing oscillations of either free bubbles or bubble clouds); the degree to which sediment is disturbed and agitated; the presence of splashing, pounding and wave impact noise [Jones and richards 2001].

Sediment transport noise

Under some circumstances it is possible for the sediment on the seabed surface to become highly mobile. This occurs when the water is shallow (<10 metres), there is a current running and there is significant wave height to disturb the seabed causing the sediment to collide with itself and obstacles on the seabed and generate high frequency noise (mostly above 10 kHz with peak frequencies at a few tens of kHz). For shallow tidal water, reports have been made of increases in levels of up to 40 dB in the range 15 kHz to 20 kHz during easterly gales and flood tides [Thorne 1985, Thorne 1993].

Biological noise

Marine life can make a major contribution to ambient noise levels. The most vocal of marine species are the cetaceans and species to be found in UK waters can produce sounds over the range 2 kHz to 200 kHz. Cetacean sounds are either tonal whistles in the range 2-25 kHz, or wideband echolocation clicks with maximum energy in the 40 kHz to 140 kHz region. Source levels for the tonals sounds are up to 180 dB re 1 μPa·m while echolocation clicks range from a source level of 170 dB re 1 μPa·m for the harbour porpoise (*Phocoena phocoena*) up to 226 dB re 1 μPa·m for the bottlenose dolphin (*Tursiops truncatus*). Many fish can produce sound, particularly as part of the mating process. Although the UK does not have the highly vocal species to be found in tropical seas, many UK fish species can produce some sound [Richardson, 1995].

Thermal noise
In the absence of all other sources of ambient and self noise, the underlying noise level is determined by thermal agitation of the molecules. This noise rises proportionally with frequency and for real systems is only important above 100 kHz. Ambient noise generally falls with increasing frequency until thermal noise dominates when the slope changes to a 6 dB/octave rise with increasing frequency [Urick, 1983].

2.4.2 Anthropogenic sources of ambient noise

Commercial shipping
The Humber Estuary area contains a considerable amount of shipping. This mostly consists of traffic to and from the major port of Hull, but the general area is very busy with commercial shipping. The shipping includes passenger and car ferries, tankers (for example for Liquid Petroleum Gas), large car transporter ships, survey vessels, support vessels, fishing boats, and bulk cargo carriers (with loose cargo). Shipping noise is a major contribution to ambient noise in shallow water areas close to shipping lanes and in deeper waters, and this is undoubtedly the case for the work reported here. Shipping noise is most evident in the 50 Hz to 500 Hz frequency range, but can extend up to 20 kHz. In the vicinity of ships under way, the noise spectrum may be separated into a number of regions: at frequencies below 1 kHz there is a continuous wideband spectrum of noise with a number of tonals originating from rotating machinery superimposed; above 1 kHz, machinery noise diminishes and water displacement noise becomes dominant. Strong tonals can be generated by a “singing” propeller, a faulty gearbox or by electrical generation machinery. Different ship types have different contributions from the different noise sources: for example, for a fast ferry the major noise sources are usually from displaced water in the 5 kHz to 20 kHz [Harland and Richards 2006, Harland *et al* 2005]. In addition to commercial shipping, leisure craft are a source of noise. Leisure craft routes are generally separated from the commercial shipping routes and are usually closer inshore.

Dredging and aggregate extraction
The dredging of deep deposits of gravel is inherently a noisy operation. The resulting noise is a mixture of mechanical noise from operation of the dredge and a noise similar to sediment transport noise resulting from the disturbance of the gravel. Little information is available on this noise source, but it is likely to vary with sediment type and water depth. [Harland *et al* 2005, Greene 1987].

Industrial noise
Offshore industrial noise includes the noise generated by the operation of offshore oil and gas rigs and offshore construction noise. Oil and gas rigs generate noise by conduction of the noise from machinery on the platform into the water column, and from pipelines supplying oil or gas. This is likely to comprise low frequency tonal noise from the rotating machinery (<1 kHz) and a wideband noise level made up of many individual contributions from all the noises sources on a typical rig. There is a lack of published data on these sources of noise. Industrial activity onshore adjacent to the coastline can produce underwater noise by coupling through the substrate. Noise levels are only significant if the noise is intense (e.g. quarry

blasting), or if there are a number of noise sources, e.g. gas terminals and refineries such as those present in the Humber area. The coupling through the substrate will generally only occur at very low frequencies (<100 Hz). Again there is a lack of published data of such noise sources [Harland *et al* 2005].

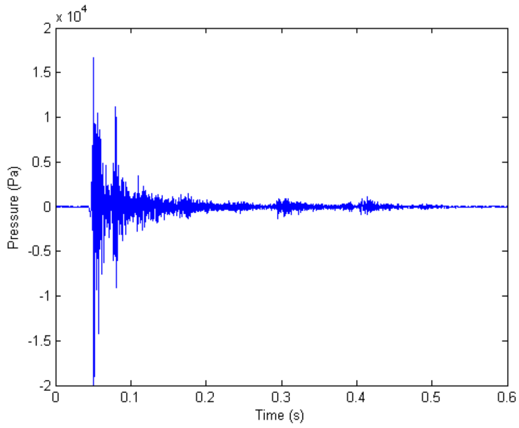
Sonar and geophysical surveying
Sonar is widely used by leisure, fishing and commercial vessels, and by the military. By far the most common type of sonar in this area is the echosounder. Most vessels from small leisure craft up to the largest commercial ships have at least one echosounder. These work at frequencies from 25 kHz to 300 kHz, with source levels up to 220 dB re 1 μPa·m. These sonars generally direct acoustic energy downwards into the seabed but there is significant energy travelling horizontally either from the sidelobes of the transducer or by multipaths and scatter off the seabed. The higher frequencies are attenuated quickly by absorption, but the contribution to ambient noise is significant due to the high numbers of such units. Acoustic modems are used to carry data from seabed installations to the surface and typically work in the range 2 kHz to 20 kHz, and are typically in use around the oil and gas fields and also in use by scientific equipment deployed elsewhere in the area. Military sonars use high power transmitters to generate tonal signals in the range 1 kHz to 10 kHz and with pulse lengths between 0.1 s and 4 s, depending on mode of operation. When operating they can be heard up to 10 miles away, depending on the propagation conditions, even in the shallow waters. However, it is not believed that military sonars are commonly encountered in this area. Seismic air guns are used to generate very high level impulses of low frequency sound directed downwards into the seabed for geological survey work. Source levels may be as high as 250 dB re 1 μPa·m with centre frequencies between 50 Hz and 100 Hz. The North Sea has already been heavily surveyed in the past, but because of the low frequencies and very high powers in use they can be heard over large areas and, with a high repetition rate, they can make a very significant addition to ambient noise levels over a wide area [Harland *et al* 2005, Harland and Jones 2006].

Aircraft noise
Aircraft noise can couple through the sea surface when an aircraft flies low over the sea surface [Urick 1972]. This can happen when fixed wing aircraft approach a runway located on the coast or make low level fly pasts, or when a helicopter operates low over the sea. Aircraft approaching Humberside airport are unlikely to contribute significantly. However, helicopters may sometimes operate within the area to service offshore installations. Of perhaps the most significance for this study is the military range just south of Donna Nook. Although live ordnance is not used at the range, jet aircraft make repeated low level passes over the area. This is highly likely to make a contribution to the ambient noise for the duration of the passage of the jet.

Fishing activity
Commercial fishing can make a contribution to ambient noise by vessel noise, fish finding sonar, and trawl noise. The sound of chains and rollers being dragged across the seabed can sometimes be heard for several miles from the activity [Harland *et al* 2005, Harland and Jones 2006].

Marine piling
Marine piling is undertaken for a variety of offshore construction applications. Examples of its use may be seen in the construction of bridges, offshore windfarms, and oil and gas

facilities. Piling is a low frequency source of impulsive noise. There have been a number measurements of marine piling noise reported [Nedwell 2004, Rodkin 2004, McHugh 2005], but relatively little which is in peer-reviewed journals [Blackwell 2004, Madsen 2006]. Most studies report measurements of the sound pressure level as a function of source-receiver separations in order to determine the source level, a range of separations being required to adequately determine the transmission loss in the shallow water environment. The source level depends upon a number of factors such as hammer energy, pile size and sea-bed type. The values of source level reported vary widely, ranging from 180 dB re 1 μPa·m to 250 dB re 1 μPa·m depending on the above factors, with much of the energy concentrated in the 100 Hz to 2 kHz range. Figure 2.3 shows an acoustic pulse recorded within a few hundred metres of a marine piling site. Also shown is the spectrum of the pulse showing the frequency content up to a maximum of 5 kHz. Figure 2.4 shows a spectrogram of two successive pulses showing the time history of the pulse frequency content. As can be seen, although the greatest concentration of energy is at low frequencies, there is some energy content at frequencies greater than 10 kHz (although at much reduced amplitude).



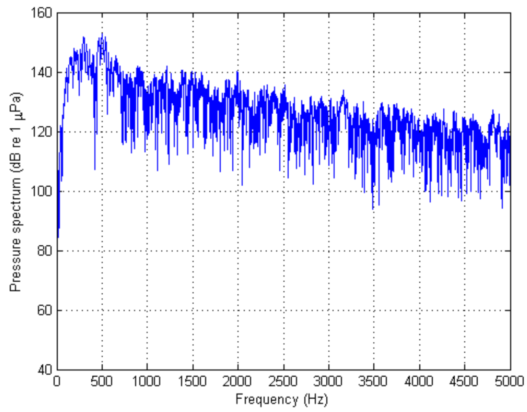


Figure 2.3 Example of a time waveform of an acoustic pulse from marine piling (left) and the spectrum showing the frequency content (right).

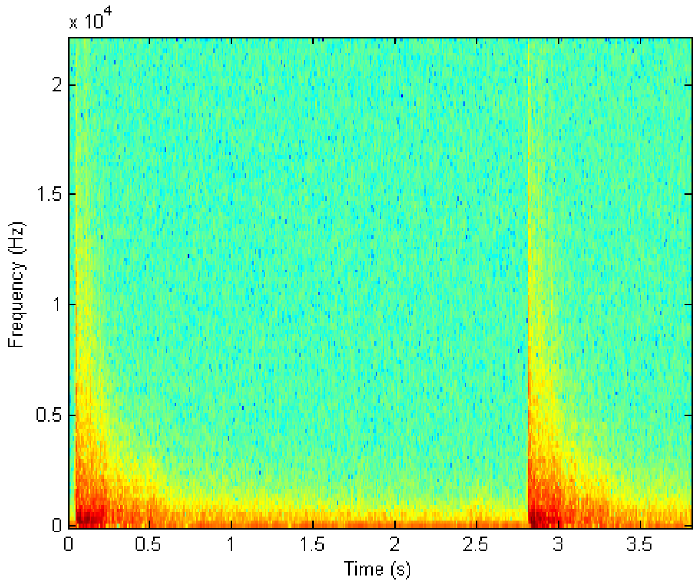


Figure 2.4 Spectrogram of two acoustic pulses generated by marine piling showing the time history of the pulse frequency content with arbitrary colormap amplitude scaling (high amplitude is red, low amplitude is blue). Although the greatest concentration of energy is at low frequencies, there is some energy content at frequencies greater than 10 kHz (although at much reduced amplitude).

3. MEASUREMENT METHODOLOGY

3.1. OVERALL METHODOLOGY

For the underwater acoustic noise assessment, the following overall methodology was adopted:

- Measurement of the spatial variation in the background underwater acoustic noise by recording short samples of the noise at selected locations;

- Measurement of the temporal variation in the background underwater acoustic noise by making a longer duration recording of the noise at a specific location within the area around the windfarm site.

Spatial variation of ambient noise

For the measurement of the spatial variation of background acoustic noise, measurements were made at selected locations along intersecting paths through the site of the proposed windfarm, with hydrophone deployed from a small vessel. In addition, measurement of the background acoustic noise were made close to Donna Nook. The aim was to measure the mean background noise level at each location. In addition, attempts were made to record representative samples of the background noise from anthropogenic noise sources which are common to the area, including the noise from shipping traffic. These measurements were all taken during daylight hours during 21st and 22nd February 2007.

Temporal variation of ambient noise

Longer term monitoring of the noise was also be undertaken at a central location within the windfarm site. This was done for an extended period of 18 hours so that the longer term variation in background levels could be determined. For this, samples of the background noise were recorded using a remotely deployed hydrophone from a fixed buoy. Note that another buoy was also deployed at a location as close to Donna Nook as was permissible. However, due to inclement weather on February 22nd this buoy was lost and no data was retrieved.

3.2. EQUIPMENT AND INSTRUMENTATION

For the measurements at selected locations, broadband low-noise hydrophones were deployed from the vessel. The hydrophones were attached to weighted cables during deployment, allowing the devices to be deployed at depths in the range from 5 m to 10 m. Two different types of hydrophone were deployed: Reson TC4032 hydrophone with a nominal sensitivity in the frequency range 250 Hz to 25 kHz of -169 ± 1 dB re 1 re 1 V/µPa (about 3.55 mV/Pa); and a Reson TC4014 hydrophone with a nominal sensitivity in the frequency range 250 Hz to 200 kHz of -187 ± 1 dB re 1 re 1 V/µPa (about 0.45 mV/Pa).

All hydrophones used have been calibrated over their full operating frequency range with the calibrations traceable to national measurement standards maintained at the National Physical Laboratory, UK. Free-field hydrophone calibrations at NPL are performed in the frequency range from 250 Hz to 1 MHz using either the open tank facilities or the open water facility. NPL also uses a pistonphone calibrator for calibrations in the range 5 Hz to 315 Hz.

The hydrophones were used in conjunction with a PC-based broadband analysis system allowing signals with frequencies up to 200 kHz to be recorded. For the recordings, a Brüel & Kjær Pulse system was used which allows time recording and broadband analysis (526 kS/s and up to 24 bit resolution recordings). In addition, an NI-DAQ 6062 E (500 kS/s and 12 bit resolution) and NI-DAQ 9162-USB (500 kS/s and 12 bit resolution) were used for extra measurements and as a back up.

The hydrophones deployed remotely from the buoy were HS70 hydrophones (manufactured by SRD Ltd in UK). These were connected using custom built preamplifiers to a solid state recording system in watertight housing. These were capable of digital recording with a bandwidth of 20 Hz to 22 kHz (16-bit resolution). With an 8 GB memory capability, continious recording could be made for over 24 hours. An on board microprocessor control system also gave the recorders the capability to ‘time sample’ over preprogrammed intervals extending the total measurment period. The system was powered by high capacity rechargable batteries with an overall opertaional period of greater than 24 hours.

The environmental conditions during the measurements were recorded using a YSI 600QS sonde which recorded information such as including water temperature and salinity as a function of depth. Information was also recorded regarding the weather, wind speed, wave height, etc. In addition, information about the local shipping traffic was recorded.

All measurement stations were GPS position fixed and time stamped to better than 1 s accuracy. A portable GPS tracking system was used to track the position during measurements. The GPS system on the vessel was used when positioning the vessel for measurements.

To eliminate any acoustic noise from the vessel, the engines were shut down before measurements were begun. To eliminate residual noise and any interference from electrical equipment on the vessel, the generator was also shut down before measurements to enable “quiet running”. The echosounder was used to determine the water depth at the location, and then was shut down to eliminate interference from this source.

All measuring instrumentation including hydrophone amplifiers, data acquisition instrumentation and notebook computers were run using DC supplies from batteries, thus avoiding the need for connection to mains supply (which was absent without the generator operating).

3.3. VESSEL

A suitable vessel was chartered from Technical Marine Services Ltd in Caistor, Norfolk. This is the MV Genesis, a 12 tonne 37 ft catamaran workboat used in light offshore work. This provided excellent access for deployment of measuring hydrophones and measuring buoys. The boat has a GPS system for accurate positioning, and an echosounder for accurate depth recording. It is also capable of quiet working. Quiet conditions were maintained during the acoustic tests requiring that the engine, echosounder and generator be switched off for temporary periods. The vessel has two permanent crew members with extensive experience of conducting marine measurement operations, including for off-shore windfarms.

Figure 3.1 shows images of the vessel. A specification is listed in Appendix A.

Figure 3.1 The vessel used for the deployment in the harbour at Grimsby.

3.4. MEASUREMENT LOCATIONS

Figure 3.2 shows the track of the intended route which was outlined in the proposal, including the positions of intended measurement points. These are the locations for the minimum number of measurements that would be attempted at locations denoted A, B, C, D and E, as well as the location B2 in the centre of the windfarm site, and the location at Donna Nook. Addional measurements were made at mid-positions of the transects shown.

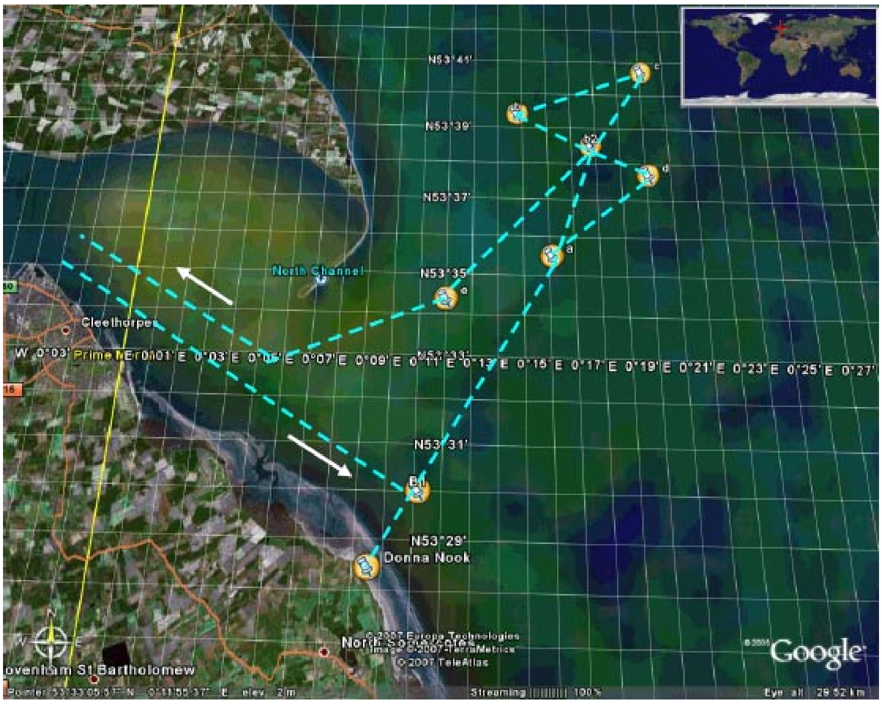


Figure 3.2 Proposed route showing minimum measurement points

Figure 3.3 shows the actual track of the vessel on February 21st read from the GPS system used to set the way-points.

The coordinates of the locations of all the measurement points is given in Table 3.1. Buoy number 1 was positioned on a transect from Donna Nook to point A as close to Donna Nook as possible within the confines of safe boat operation. Safe operation required a minimum depth to cope with the draft of the vessel, and required the vessel to operate outside the restricted area around Donna Nook military firing range, and to avoid drifting into shipping lanes. Point A represents a point just outside windfarm site perimeter close to the most southerly proposed turbine position.

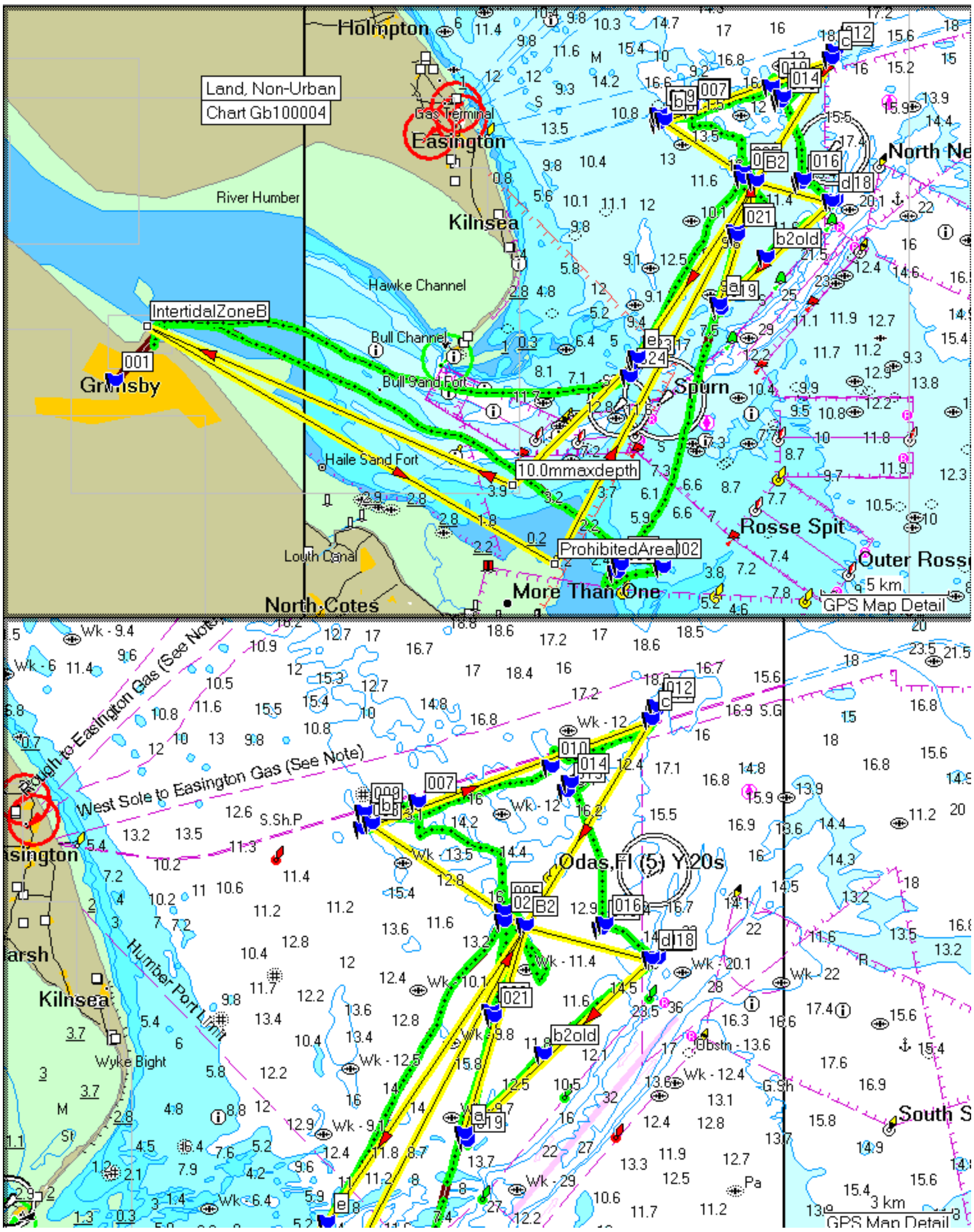


Figure 3.3 Actual route from GPS tracking system with measurement points indicated by way-points shown in overall view (upper) and close up on the windfarm site (lower).

The second buoy position (B2) was selected as close to the geometric centre of the array site. Points A, B, C and D were selected to be on transects from a point (B2) in centre of the array to points just outside the array site perimeter *corners*. Point E was selected as being away from the array site but just north of the shipping lanes.

The provisional work plan was designed to take advantage of full daylight hours on February 21st 2007. Additional measurements were made at locations at the mid-points of transects joining the positions A, B, C, and D with B2. In the table, these are designated as using both labels, for example "A:B2" etc.

Position	Northing	Easting	Water depth (m)	Comments of shipping traffic
A	53º 35.500 N	00º 16.100 E	15	Distant shipping traffic.
B	53º 39.334 N	00º 14.960 E	13	Many distant ships.
C	53º 40.872 N	00º 20.211 E	17	Distant shipping.
D	53º 37.700 N	00º 20.100 E	21	Bulk carrier passing within 2 miles.
E	53º 34.235 N	00º 13.129 E	17	Car transporter passing through shipping lane.
B2	53º 38.302 N	00º 16.951 E	16	Two visits made. Only distant shipping on first visit. Ferry passing in vicinity on later visit..
D:B2	53º 38.133 N	00º 19.118 E	17	Distant shipping.
C:B2	53º 39.795 N	00º 18.292 E	17	Car transporter, LPG tanker, 2 bulk carriers (all passing within 2 miles).
B:B2	53º 39.676 N	00º 15.123 E	17	Distant shipping. Little local traffic.
A:B2	53º 37.038 N	00º 16.681 E	16	Many distant ships.
B:C23	53º 40.113 N	00º 17.974 E	18	Many distant ships.
DN	53º 29.290 N	00º 12.465 E	17	Distant shipping passing. Waves on beach. Low flying jet aircraft (not measured).

Table 3.1 Coordinates of the measurement points along the track. The labels containing the colon symbol denote mid points between two locations. The buoys were deployed at B2 and DN (Donna Nook). Also shown is the water depth measured using the vessel echosounder (to the nearest metre) and comments on the shipping traffic.

4. RESULTS OF MEASUREMENTS

4.1. SUMMARY OF DATA ACQUIRED

Measurements were collected at all locations listed in Table 3.1 on February 21st 2007. The first measurement was begun at 11:38 and the final measurement was begun at 17:56. At each location measurements were made using both broadband systems (maximum frequency 204 kHz) and audio band systems as a back up (maximum frequency 25 kHz).

Measurements were also made of the environmental conditions using the sonde.

Long term audio recordings using the buoy were made at position B2 for a total of 16 hours starting from 17:30 21st February and finishing at 09:45 on the February 22nd 2007. The B2 buoy (deeper water) was recovered earlier than planned due to deteriorating weather conditions.

The buoy B1 (intended to be used at Donna Nook was lost due to inclement weather (approaching gale force winds on February 22nd) and it was not possible to retrieve any data.

4.2. ENVIRONMENTAL CONDITIONS

During the measurements on February 21st, the weather was reasonably fine with no rain, a moderate breeze (wind speed of about 6 m/s), and a maximum wave height of between 1 and 2 metres with fairly frequent white horses. A sea-state of between 3 and 4 was estimated.

The sonde was used to measure the water temperature and salinity at a number of the locations. The water was well mixed with little temperature gradient. Figure 4.1 shows an example of one of the measurements of temperature with depth (for position D in this example). Other measurements produced very similar results with the overall variation temperature at depths of between 5 m and 10 m ranging between 8.0 ºC and 8.7 ºC over all locations. The measurements with the sonde showed that after stabilisation the salinity was typically 32 parts per thousand at a depth of 10 m. These are within expected values for this environment at this time of year.

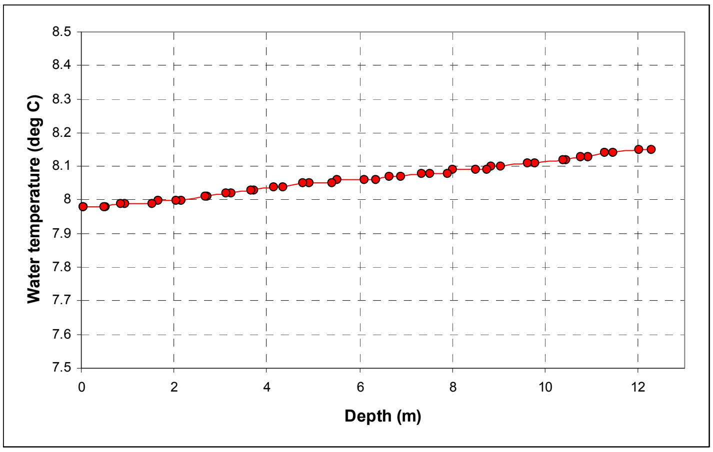


Figure 4.1 Example of results for water temperature versus depth (taken at position D).

4.3. DATA ANALYSIS

The time data recordings were first scaled to account for the hydrophone sensitivity and amplifier gain. The mean background noise values were calculated by processing the measured data using the Matlab programming language. The sequences of data recordings each had a typical length of 1 minute. Over 40 recordings were measured over the area of the windfarm site. To obtain the power spectral density levels for display in the figures in Section 4.4, the recordings were processed by segmenting the data into windows of 4 seconds (corresponding to approximately 1 million waveform points for a sampling frequency of 526 kS/s) and calculating the power spectral density using a Welch average, applying sliding window of size 32,768 with 25% overlap between adjacent windows. The data from the segments were then averaged to form the mean PSD for the record.

Although measures were taken to minimise the influence of noise originating from the vessel, one intermittent problem which occurred was that of "water slap" on the hull of the boat. This seemed to occur when the vessel drifted into particular orientations relative to the waves and took the form of a low frequency impulsive sound – a dull thud. Their occurrence was noted and attempts were made to remove these from the data record where they could be identified. However, it is unlikely that all occurrences will have been spotted and there may be some contribution from this source at low frequencies. Similarly, it is very difficult to completely eliminate other sources of low frequency self-noise such as flow noise around the hydrophones (the flow can be significant in shallow coastal currents). Noise may also be communicated by the rigging used to mount the hydrophones in spite of attempts to minimise this by careful design.

4.4. NOISE RESULTS FOR SELECTED LOCATIONS

The following plots show the measured ambient noise data for the selected locations indicated in Table 3.1. In each case, the red curve is the mean noise level averaged over the duration of the recording. Where present, the blue dotted curves represent the maximum and minimum values of the noise levels measured at each frequency. Unless otherwise stated, all measurements shown were made on February 21st 2007.

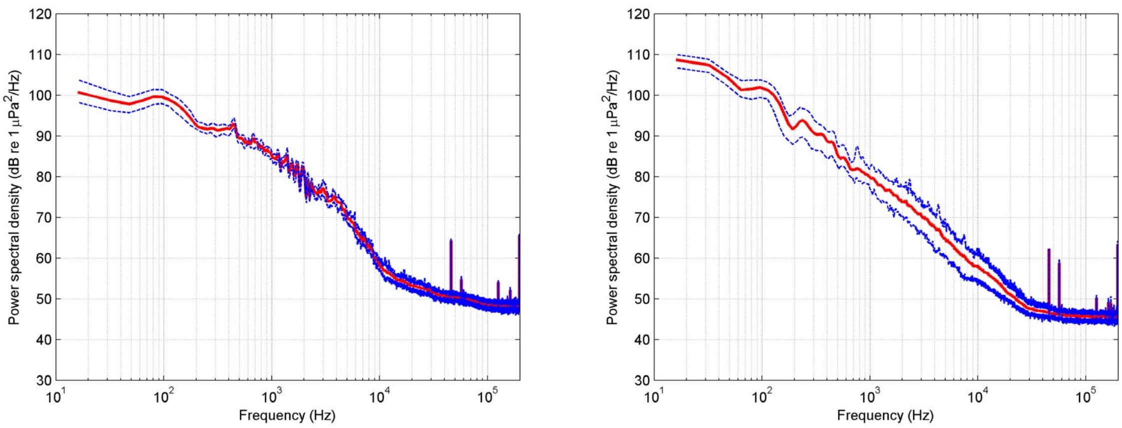


Figure 4.2 Measured noise plots for: (a) position B2 at 13:05 (left); (b) for position B at 13:50 (right).

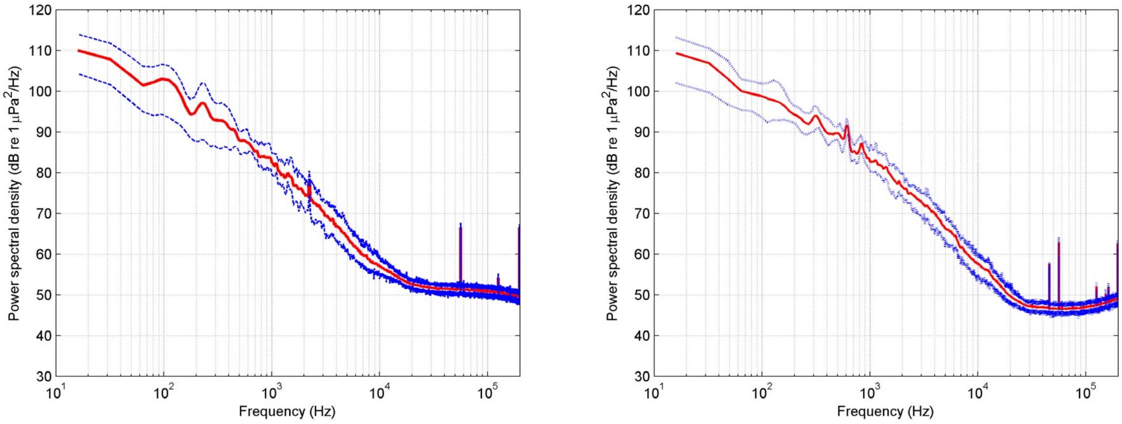


Figure 4.3 Measured noise plots for: (a) position C at 14:26 (left); (b) for position D at 15:11 (right).

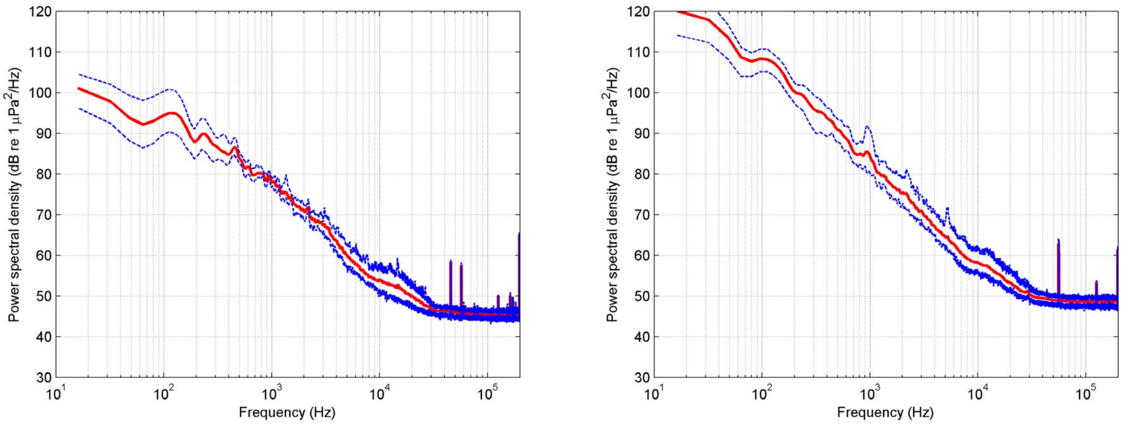


Figure 4.4 Measured noise plots for: (a) position B:B2 at 13:15 (left); (b) for position C:B2 at 14:45 (right).

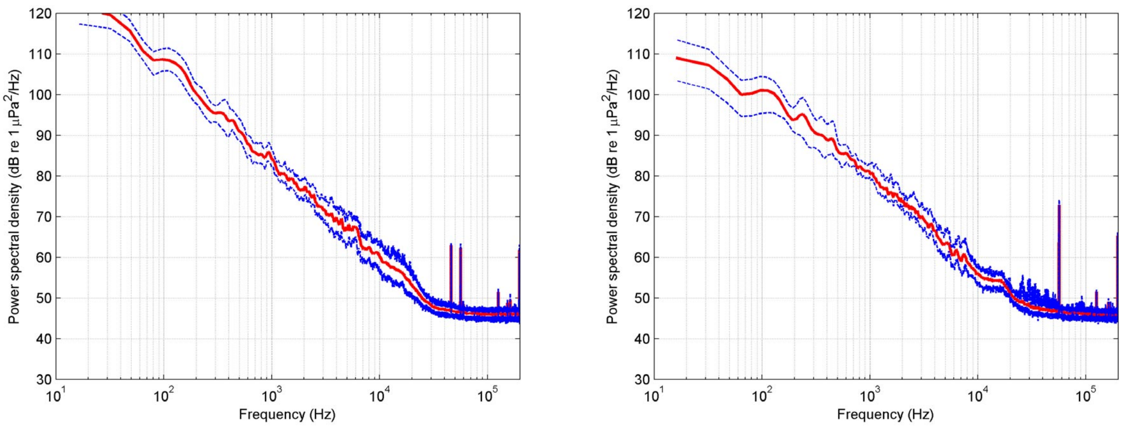


Figure 4.5 Measured noise plots for: (a) position D:B2 at 15:01 (left); (b) for position B:C23 at 14:11 (right).

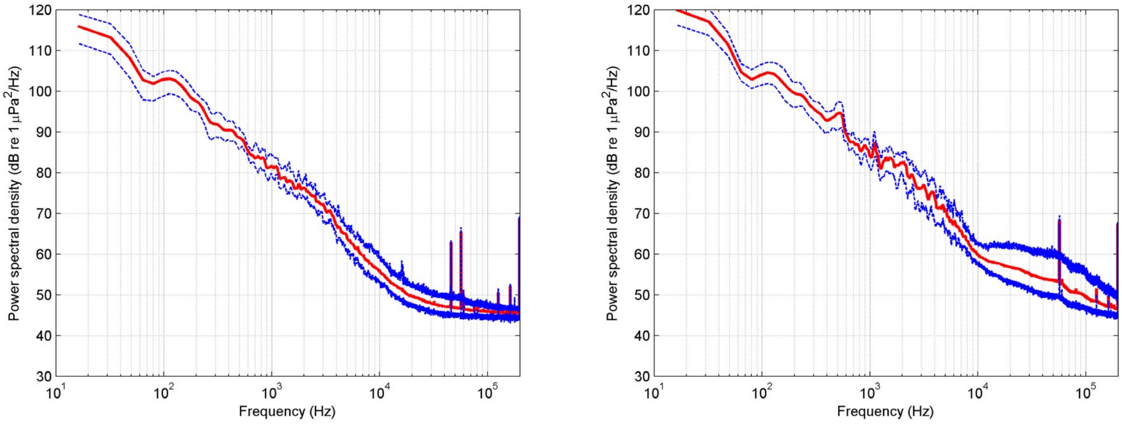


Figure 4.6 Measured noise plots for: (a) position A:B2 at 15:01 (left); (b) for position B2 at 16:17 (right).

The results of Figures 4.2 to 4.6 show a number of general features. The decreasing level with increasing frequency (up to about 100 kHz) is characteristic of noise in the ocean. However, there is considerable variability between data measured at different locations. Since the data were not all measured simultaneously, it is not possible to make definitive conclusions regarding the spatial variation of the noise. It is likely that the underlying spatial variation of the noise level is only gradual, with higher levels found toward the shipping lanes converging on the mouth of the Humber. The explanation of higher levels in a specific location is more likely to be due to the passage of shipping in the vicinity, with lower levels coinciding with its absence. Reference should be made to Table 3.1 for guidance of the shipping levels. The elevated levels shown in some of the curves are characteristic of noise from shipping with elevated levels in the range 50 Hz to 500 Hz (compare Figure 4.6(b) with Figure 4.2(a)) and with occasional tonal frequencies present in the range 100 Hz to 5 kHz (see Figure 4.3(b)). At no point were any commercial ships close to the Genesis during measurements (typically there were a number of vessels within a range of 2 to 5 nautical miles).

Elevated levels are also observed in some of the plots in the 500 Hz to 5 kHz range that is characteristic of noise produced by waves and wind. The sea-state was estimated as being sea-state 3, perhaps rising to 4 later. It is possible that there are contributions from other sources such as industrial noise from the terminals, refineries and rigs in the area.

A number of higher frequency tonal components were also observed. At first, it was thought that these caused by electrical pickup if some kind in spite of the fact that all electrical generating equipment on the boat was switched off and all instrumentation was run from batteries. This explanation cannot be ruled out, although the signals were present in two independent systems. This seems more likely for the 56 kHz and 198 kHz tonals which were present to varying degrees in almost all the measured data. Alternatively, these may have been generated by other acoustic systems from vessels operating in the area.

Some contribution to the very low frequency noise (tens of hertz) may have been made by the self-noise mechanisms described in Section 4.3.

Figure 4.7 shows the means of the data records plotted on the same axes for comparison.

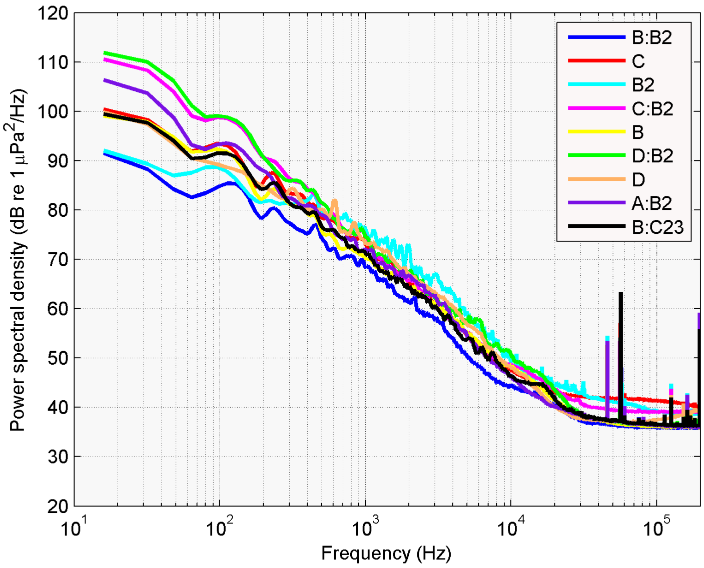


Figure 4.7 The means of the data records from Figures 4.2 to 4.6 plotted on the same axes for comparison. The legend gives identifies the location of each measurement.

Measurements were also made with a lower frequency hydrophone at audio frequencies as a back up to the broadband system (sampling rate 65536 Hz, both at 16 and 24 bit resolution). These measurements were taken in the same locations as the measurements shown in the above figures but were measured separately (usually 5 to 10 minutes later). Figure 4.8 shows the comparison of the levels for these measurements for frequencies up to 10 kHz, presenting the data in an analogous manner to Figure 4.7. In spite of being an entirely separate set of measurements, the overall levels and spread of values is similar to that shown for the broadband system.

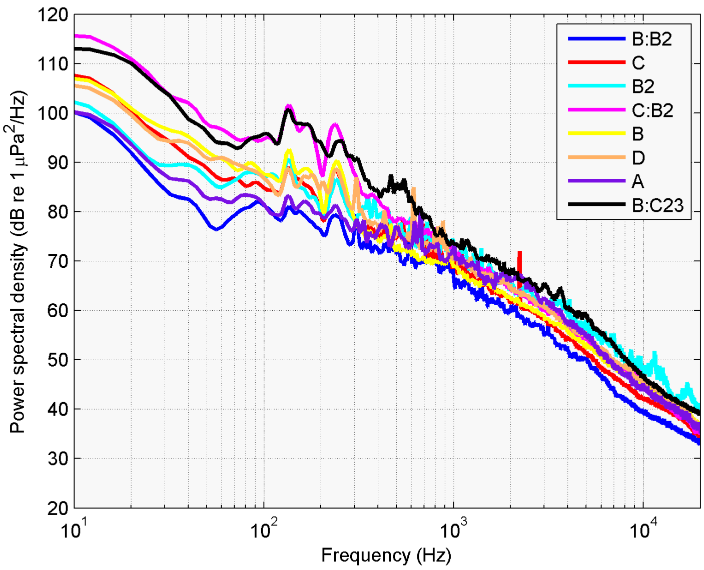


Figure 4.8 The means of the data records from the low frequency hydrophones plotted on the same axes for comparison. The legend gives identifies the location of each measurement.

Two sets of measurements were made at position B2, one at 13:05 and one at 16:17. This enables a comparison to be made for this location. The high frequency content of the data was much the same, on both occasions. However, on the later occasion, the results show elevated levels at frequencies of up to 1 kHz. This is most likely due to the presence of commercial shipping (in particular an approaching ferry) at the later time which was not present for the earlier measurements. The results are shown in Figure 4.9.

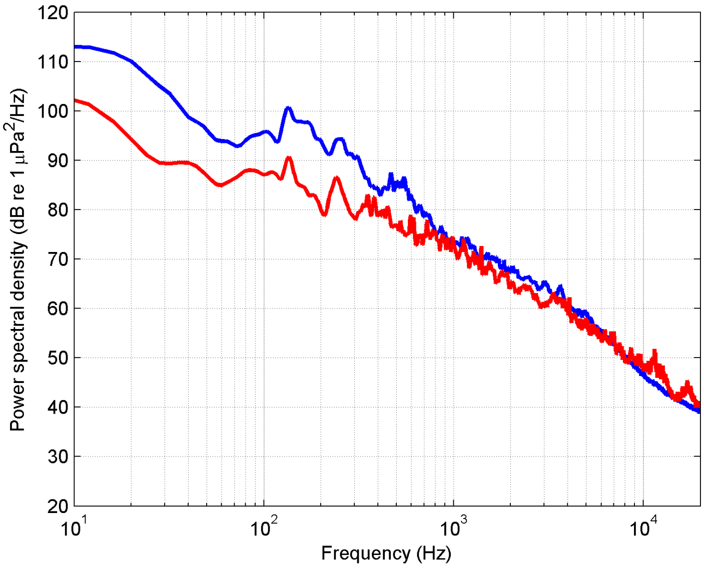


Figure 4.9 The results for two separate measurements at position B2, the first at 13:05 (red) and a later one at 16:17 (blue). During the later measurements, a ferry was approaching.

To test the variation with depth, hydrophones were deployed at differing depths to make measurements. Figure 4.10 shows the results of measurements made at depths of 5 m and 10 m at position B2, and at 5 m and 7.5 m at position B. As can be seen, little variation is seen over this range of depths. The water depths for these locations are 16 m for B2, and 13 m for B.

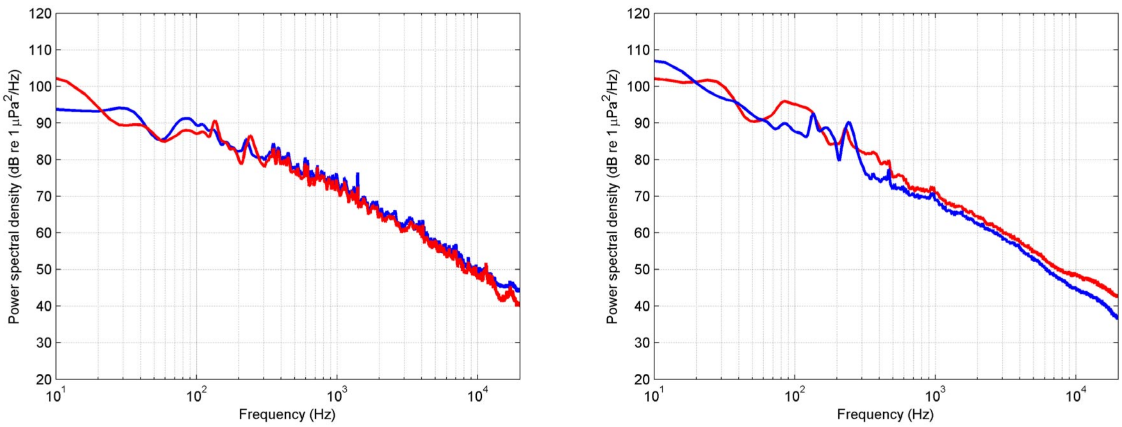


Figure 4.10 The results for measurements at differing depths, with the red curve for the shallower position. Results are for: (a) position B2 at depths of 5 m and 10 m (left); (b) position B at depths of 5 m and 7.5 m.

A final example of the effect of approaching shipping is provided by Figure 4.10. This shows results obtained from position A, while a commercial ship was passing at a range of about 2 miles. Measurements were taken when the ship was distant on the horizon (exact range unknown) and when at its closest pass. The difference in levels is clearly seen in the plots as is the presence of tonals.

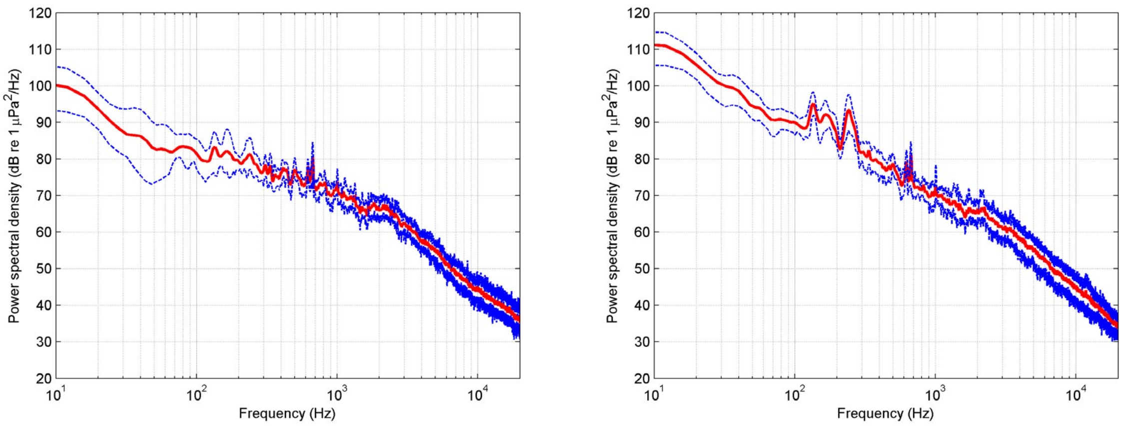


Figure 4.11 The results for measurements at position A during (a) a relatively quiet time with a distant approaching cargo ship (left), and (b) during the passage of the cargo ship within a few miles of the measurement position.

4.5. MEASUREMENTS AT DONNA NOOK

Measurements were also made at a position close to Donna Nook. Although this position is more remote from the main shipping lanes into the Humber, there were still a number of distant ships passing during the measurements. Results for this position are shown in Figures 4.12 and 4.13. This location is relatively close to the shore and may be influenced by wave noise and surf noise, perhaps giving rise to the slightly elevated levels at frequencies from 2 kHz to 10 kHz. The low frequency levels do not generally seem lower than those at the windfarm site itself. A second set of measurements were made shortly after which showed elevated low frequency components and for a short time the presence of tonal components at a few hundred hertz and at 1 kHz.

One issue that was particularly of note at Donna Nook was the presence of low flying military jet aircraft. Donna Nook is the location of an active military firing range just south of the area. Live ordnance is not used at the range and a form of "electronic firing" at moored targets is instead used. However, jet fighter aircraft make repeated low level passes over the area. This airborne noise is highly likely to make a considerable contribution to the water-borne noise for the duration of the passage of the jet. While approaching Donna Nook, several jets assumed attack positions and "attacked" the targets, creating substantial overhead noise. Unfortunately, the exercise ended just before arrival on station and it was not possible to undertake measurements during the flights.

Due to restrictions posed by the firing range, it was not possible to get any closer to the coast at Donna Nook than the position occupied. In this matter, the advice of the vessel skipper was decisive (it was essential to observe the strict regulations). A number of seals were observed swimming off the coast during the measurements made (including during the passage of the military jets).

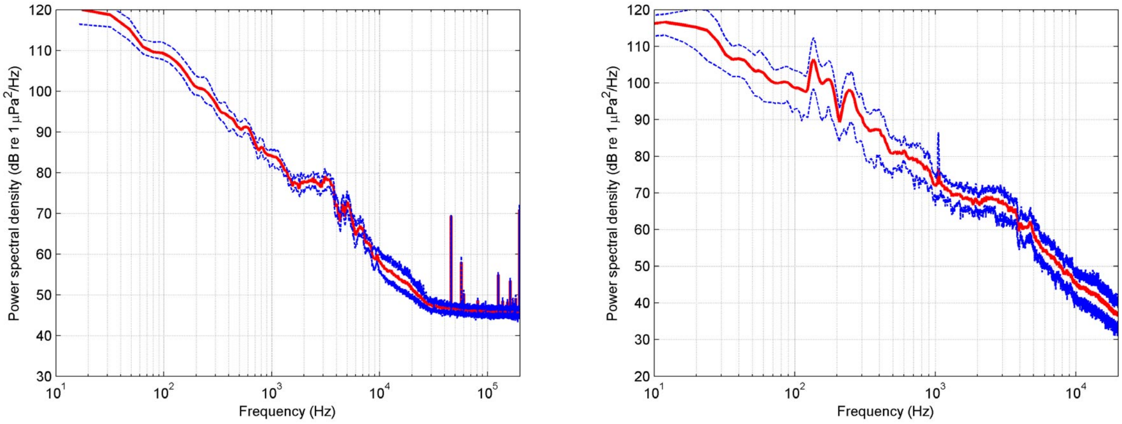


Figure 4.12 Measured noise for the position DN at Donna Nook measured at 11:40 (left) and 11:50.

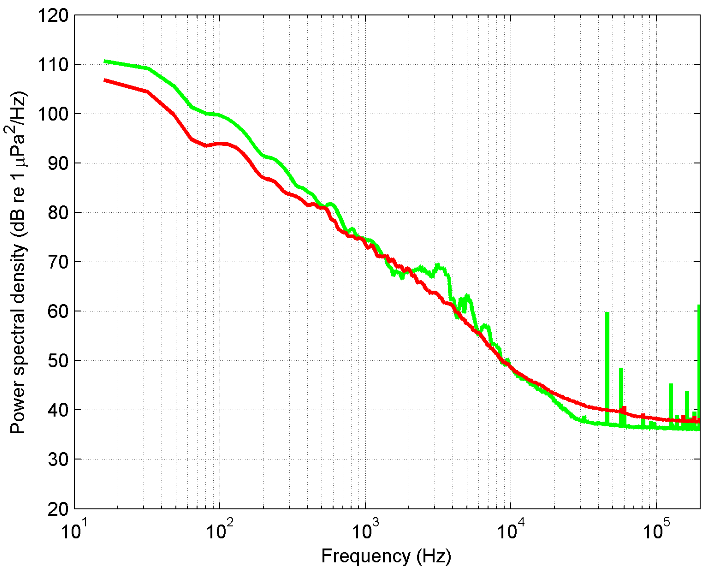


Figure 4.13 Measured noise for the position DN at Donna Nook compared to the average for the windfarm site.

4.6. MEAN NOISE LEVELS

Figures 4.14 and 4.15 show the overall means for the measurements within the windfarm site at all the locations. To obtain these curves, *all* of the original raw data files were averaged using the same 4 second window sequences as before (rather than just averaging the mean data shown in figures 4.2 to 4.6).

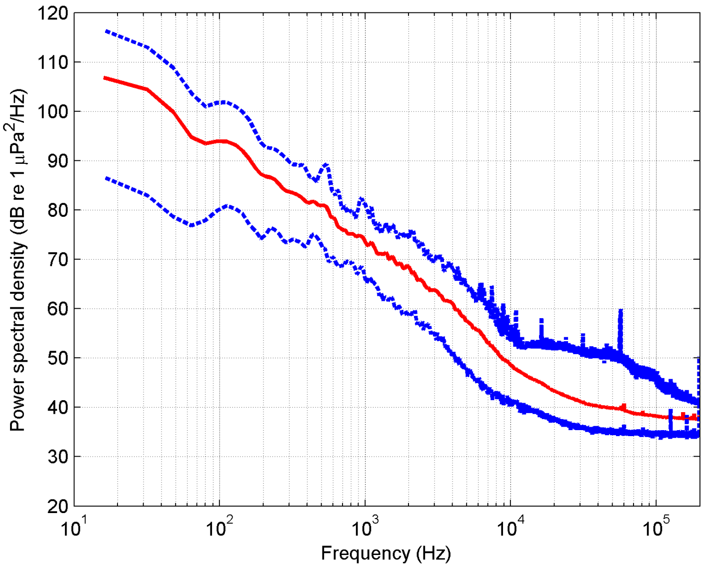


Figure 4.14 Mean noise level for the locations within the windfarm site only (broadband system).

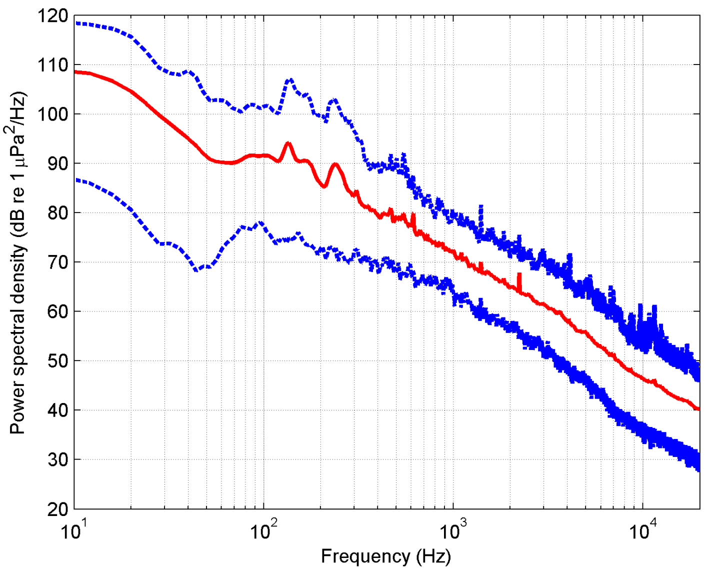


Figure 4.15 Mean noise levels for the locations within the windfarm site only (low frequency system).

4.7. TEMPORAL VARIATION OF AMBIENT NOISE FROM BUOY DATA

Data from buoy 2 position was processed performing spectral analysis to a 1 Hz band. Using a seventy five percent overlap, a *sliding* series of time windows were then averaged over a five minute period giving the average power spectral density over that period. Figure 4.16 shows a series of these five minute segments over a 1.7 hour period starting at 20:06 on the 21st February.

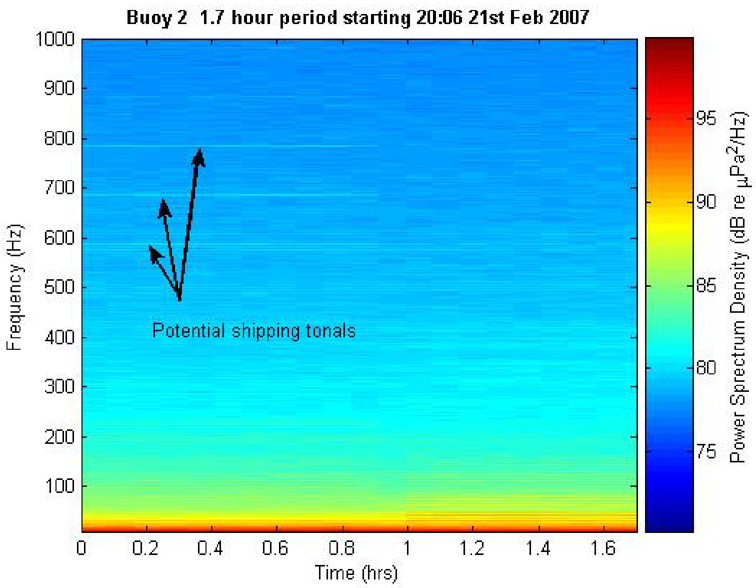


Figure 4.16 Mean power Spectral Density for a 1.7 hour sequence buoy 2 recording.

Figure 4.17 shows a relative stable low frequency component over the 1.7 hour period. However there is evidence of tonal components at 586, 686 and 786 Hz in the beginning half of the sequence, most likely due to nearby shipping. These tonals then drop in level until undetected above background levels. This can be seen in figure 4.16. The tonal component at 686 Hz drop by around 2 dB at around 0.8 hours into the sequence, by comparison the 20 Hz and 100Hz levels remain relatively stable.

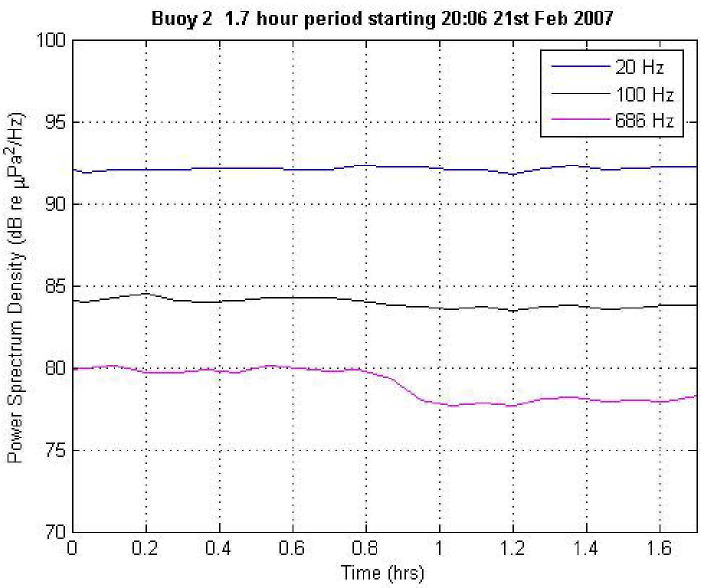


Figure 4.17 Individual frequency component levels for a 1.7 hour sequence buoy 2 recording.

Figure 4.18 shows an 11 hour sequence recorded during the night starting at 22:30 showing again a relatively stable average background levels. From Figure 4.19, the levels observed in Figure 4.17 can be seen to have risen around 6 dB at the higher frequency and 10-11 dB at 20 Hz. This increase possible due to deteriorating weather conditions between the sequences but then remaining relatively stable during the night and following day. No identifiable long term shipping tonals were observed during the longer sequence.

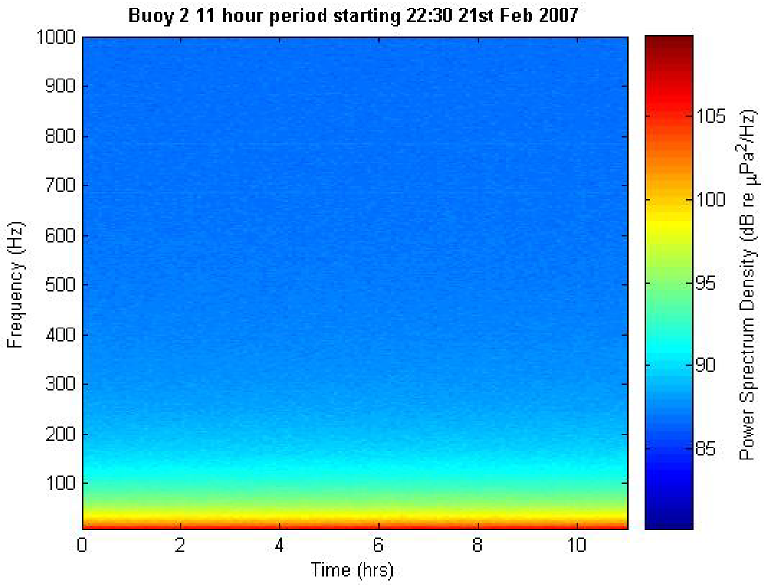


Figure 4.18 Mean power Spectral Density for a 11 hour sequence buoy 2 recording.

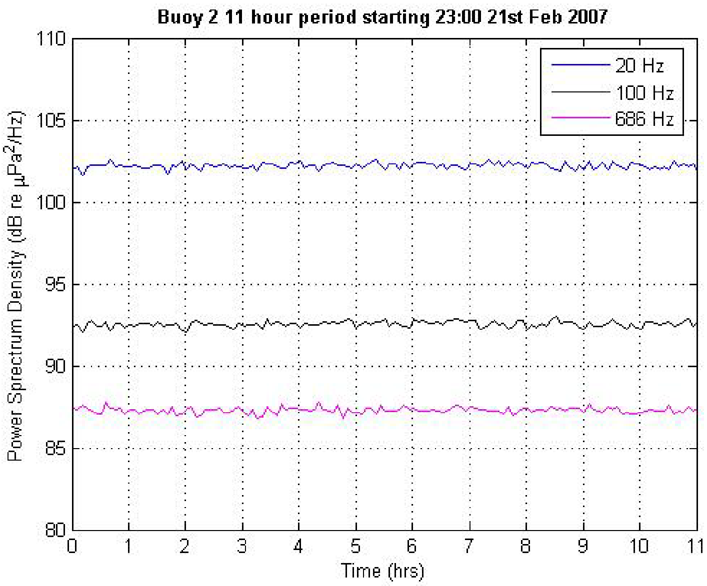


Figure 4.19 Individual frequency component levels for a 11 hour sequence buoy 2 recording.

5. CONCLUSIONS

This report describes the baseline measurement of underwater acoustic noise at the site of the proposed Humber Gateway windfarm.

For the work, the background noise was sampled both spatially and temporally by measuring at selected locations through the site of the proposed windfarm. Measurements were also made at a location close to Donna Nook, 15 km away from the proposed windfarm site and the site of a colony of grey seals (Atlantic seals). Long term audio recordings using the a recording buoy were made at one position for a total of 16 hours starting from 17:30 21st February and finishing at 09:45 on the 22nd February. The buoy was recovered earlier than planned due to deteriorating weather conditions. A second buoy (intended to be used at Donna Nook) was lost due to inclement weather (approaching gale force winds on February 22nd) and it was not possible to retrieve any data from this.

The results presented in this report show the characterisation of the noise in terms of spectral level as a function of frequency, including levels at ultrasonic frequencies (up to a maximum of 200 kHz). The data show that the underwater background noise is quite high in the locality, by comparison with deep ocean noise. It is also slightly higher than the mean levels reported for other sites around the UK coastal waters.

The higher levels are almost certainly due to the high ship traffic present during the measurements. Since this traffic is present almost continuously in the Humber estuary area, it is likely that it is characteristic of the area. The shipping noise may be expected to have a diurnal variation in level due to the frequency of shipping. However, the long term monitoring showed no reduction in overnight levels (though the port is busy 24 hours a day).

It would be reasonable to assume that the levels presented here are typical for the area and that the results provide a reasonable baseline for background noise. However, some caution should be shown when extrapolating this data to other weather conditions. The sea conditions were lively and worsening over the measurement duration and reduced levels may be observed in very calm conditions. Similarly, rough conditions will increase the overall levels. Inevitably, such a short study cannot sample the background noise comprehensively and the results shown represent a “snapshot” taken on a specific date.

The general levels at Donna Nook were not significantly different to those found at the windfarm site. At the Donna Nook site, as the coast is approached the levels will be dominated by noise generated in the surf zone (only partially sampled here).

6. REFERENCES

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APPENDIX A: VESSEL SPECIFICATION

TECH MARINE SERVICES

Techmarine Services
West Acre,
Chapel Lane,
West Caister,
Norfolk NR30 5TA

Tel/Fax: 01493 728076
Mobile: 07802 838403
Web: www.techmarineservices.co.uk
Email: tfarman@techmarinesevices.co.uk

MV GENESIS

Our multi-role workboat 'Genesis' is capable of high cruising speeds and is both stable and manoeuvrable. The speed at which it transits to your worksite often makes it more cost effective than conventional vessels. Inside the wheelhouse we have an area allocated for survey and computer equipment, complete with UPS mains power supplies. The back deck has a good-sized working area and her crew have gained experience setting up and using the boat in numerous roles. Techmarine undertake marine contracts direct or 'Genesis' can be chartered to support your various survey, diving and ROV projects.

SPECIFICATION

Name	: Genesis
Gross Tonnage	: 12,00
Length	: 37 ft
Breadth	: 16 ft
Date of Build	: 1991
2 x 300 BHP	: Iveco Turbo
Fuel Range	: 300 NM
Speed Over Ground	: 18-20 knots
Aft Deck Space	: 10 ft x 16 ft
License	: Brown Code

WHEEL HOUSE EQUIPMENT

Icom IC-M56 VHF Radio
Kelvin Hughes Compact VHF Radio
Furuno 4-Tone Daylight Display Radar
Koden High Resolution Radar
Cetrek Autopilot
Trimble Navtrac XL GPS Navigator
JMC V-103 Colour Depth Sounder
Cetrek Profish 12 Chart Plotter
Magnetic Compass

ADDITIONAL EQUIPMENT

3m Daughter Craft - 9.9 HP Johnson o/b
4&8 kva Generator 110&240V ac (silent running)
H.P. Air Compressor 200 Bar (optional)
500 kgs SWL HIAB Deck Crane
Separate galley with hot and cold food and drinks
Toilet facilities onboard

For more information please contact Mr. Trevor Farman on the contact details above.

APPENDIX B: SEA STATE KEY

Beaufort number	Wind	Wind speed (m/s)	Sea surface description	Sea state	Mean wave Height (m)
0	Calm	<0.5	Mirror-like	0	0
1	Light air	0.5 – 2.0	Scale like ripples, no foam crests	0	0
2	Light breeze	2 – 3	Small wavelets, Crests, glassy, not breaking	1	0.0 – 0.3
3	Gentle breeze	3 – 5	Large wavelets, Crests begin to break	2	0.3 – 0.6
4	Moderate breeze	5 - 8	Small waves, fairly frequent white horses	3	0.6 – 1.2
5	Fresh breeze	8 - 11	Moderate waves, Many white horses	4	1.2 – 2.4
6	Strong breeze	11 - 13	Large waves, white foam, Crests, some spray	5	2.4 – 4.0
7	Moderate gale	14 - 16	Sea heaping; foam begins to be blown in streaks	6	4.0 – 6.0
8	Fresh gale	17 - 20	Moderately high waves, marked foam steaking	6	4.0 – 6.0
9	Strong gale	21 - 24	High waves, rolling seas, spray reduces visibility	6	4.0 – 6.0
10	Full gale	24 - 27	Very high waves, overhanging crests, sea white	7	6.0 – 9.0
11	Storm	28 - 33	Exceptionally high waves, ships lost to visibility	8	9.0 – 14.0
12	Hurricane	34 +	Air filled with foam, visibility very poor	9	14.0 +