The distribution and intensity of ambient and point source noises in the Shannon estuary

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Summary

Marine mammals live in an acoustic rather than visual world, so sound and not sight is the primary sense used for such activities as navigation, foraging and communication. Concern has arisen that increasing noise levels introduced into the marine environment by human activity could have deleterious effects on marine mammals. The Shannon estuary is Irelands' busiest waterway and has recently been designated a candidate Special Area of Conservation as it is the site of the only known resident group of bottlenose dolphins in Ireland. This study was undertaken to provide an accurate baseline record of background noise throughout the estuary from which changes over time can be measured and to quantify point sources of noise that may have a significant impact on the dolphins. The results from this study will be discussed in relation to the dolphins use of the estuary and provide recommendations and advice that can be used in conservation management.

Ambient noise in the Shannon estuary was dominated by low frequency noise, which is typical of the marine environment. At some sites (Ballybunion, Kilcredaun, Beal and Carrig), on some days, high densities were also recorded in the higher frequency range. Some of this may be attributed to sounds generated by snapping shrimp but this does not explain all high frequency ambient noise and the source is unclear. Ambient noise levels were around 80-100 dB west of the ferry crossing between Killimer and Tarbert and around 80-90 dB lower, east from Shannon ferry to Shannon airport. Generally, most upstream sites were 10 dB lower than downstream sites, across all octave bands analysed but up to 30dB at some sites. Wind and waves are significant contributing factors to ambient noise but these factors were largely absent as sea state was 0-1 during recording. Thus ambient densities presented here may indeed be close to the minimum that occur in the estuary.

A number of point sources both static (Moneypoint power station, Aughinish Alumnia) and mobile (tour boats, bulk carrier, helicopter) were recorded. In all cases the point source noise levels were above ambient noise. Data from static point sources did show a decline in high frequencies with decreasing distance from source but the data were hard to interpret due to contamination from other noises in the estuary. Of the mobile point sources the highest densities were recorded for a bulk carrier travelling within 400 yards of the receiver and a helicopter directly overhead at 100 yards. For both these sources low frequencies were dominant but densities elevated across the octave band. Dolphin tour boats are potentially the greatest source of acoustic disturbance as these target dolphins to watch. There was up to a 15% increase in spectral density, even at distances up to nine times greater, in all octave bands, when tour boats were in transit compared to idling.

Ambient noise spectral densities from the Shannon estuary, were lower than that reported from the Sado estuary in Portugal which is also the site of resident bottlenose dolphins. All average densities in the Shannon were below the minimum reported from the Sado estuary and similar to those reported from a site on the south coast of England. The latter used a fixed hydrophone in an area with transient bottlenose dolphins.

Ambient spectral density levels were within those levels thought to be tolerated by bottlenose dolphins. Maximum densities of point sources seem to dominate in low frequency octave bands and thus disturbance is thought to be minimal. It does not appear that acoustic site characteristics have a major influence on the distribution of bottlenose dolphins in the Shannon estuary. The biggest potential acoustic disturbance is from mobile point sources, especially tour boats as they are in close proximity to dolphins for extended periods. A minimum distance from dolphins prior to full power would be a good practice and should be incorporated into the codes of conduct for the Shannon estuary cSAC. However it was not possible to derive such a recommended distance from the present analysis and will require further study.

This study is the first investigation in Ireland, of the acoustic environment in which dolphins inhabit. It provides a baseline and will hopefully stimulate further acoustic studies in the future.

Contents

1.0 Introduction

Marine mammals live in an acoustic rather than visual world, so sound and not sight is the primary sense used for such activities as navigation, foraging and communication. Concern has arisen that increasing noise levels introduced into the marine environment by human activity (especially industrial) could have deleterious effects on marine mammals. This could happen unexpectedly since sound travels faster and further in water than air and, at certain frequencies, with less attenuation. This means far-field sources could cause interference with an individuals' ability to detect calls from conspecifics, echolocation pulses, or other important natural sounds. ***Elevated background noise levels caused by man-made noise may prevent detection of these and other sounds, which are important to marine mammals (Richardson et al. 1995).***

The Shannon estuary is one of the busiest waterways in Ireland with around 1,800 vessel movements per annum, servicing ports at Foynes, Shannon airport and Limerick city as well as jetties at Moneypoint and Tarbert power stations and an aluminum plant east of Foynes. A car ferry crosses the estuary throughout the year with up to 60 crossings per day during the summer. In addition, recreational craft, fishing vessels and other potential users all produce noise, which could significantly elevate ambient background levels within the estuary.

The Shannon estuary is home to the only known resident group of bottlenose dolphins (*Tursiops truncatus*) in Ireland (Berrow et al. 1996). Although many hundreds of individual dolphins have been recorded in the Shannon estuary the number that is resident, and occur all year around, is probably quite small. Rogan et al. (2000) derived an abundance estimate of 113 (95% CI; 94-161) individuals but only 22 of these dolphins were recorded on 5 or more occasions during a two-year study, suggesting only a proportion of the transient dolphins are resident. Bottlenose dolphins in the Shannon estuary exhibit some degree of habitat stratification with sighting clusters recorded around two sites: Kilcredaun Head near the mouth of the estuary and Moneypoint power station, approximately 10 nautical miles further up the estuary. These sites are characterised by strong currents and steeply sloping bathymetry and dolphins are often observed foraging at these locations (Rogan et al. 2000). Commercial dolphin watching is also expanding rapidly from two ports in County Clare (Kilrush and Carrigholt) (Berrow and Holmes, 1999) with over 400 trips per annum now being carried out. These boats operate from April to October and seek out groups of dolphins to show their customers so may be a significant source of acoustic disturbance to dolphins.

The Shannon estuary is designated as a candidate Special Area of Conservation (cSAC) under the EU Habitats Directive. Dúchas, who are responsible for managing the site for conservation, seek to ensure that the dolphin population and their habitat are maintained in a favourable conservation status. In order to manage the Shannon estuary SAC for dolphins it is essential to understand the environment in which they live and the potential threats that may occur. Such dangers may include pollution, fisheries interactions, habitat degradation and disturbance. Although concentrations of organochlorines in the blubber of resident bottlenose dolphins in the estuary were elevated compared to other species, they were not thought to threaten the health of the dolphins (Berrow et al., 2002). Commercial fishing in the estuary is limited to salmon drift and line fishermen and the seasonal occurrence of pelagic trawlers (herring) in the mouth of the estuary. There are no data on the impact of fishing through either entanglement or competition for fish. Commercial tour boats are monitored each year as part of the consent issued by Dúchas to dolphin watch within the SAC.

As part of an ongoing programme to try and identify potential threats to the dolphins and improve our understanding of the dolphins' ecological requirements, a study of the acoustic environment within which the dolphins live was carried out during August 2002. This study was carried out under licence from Dúchas (C29/2002), which permitted deployment of a hydrophone to record underwater acoustics.

The objectives of this study were to:

i) *map the distribution of ambient noise in the Shannon estuary,*
ii) *quantify the frequency range and intensity of ambient noise in the Shannon estuary (concentrating on the frequency range used by dolphins).*
iii) *provide spectral analyses of point sources of sound including tour boats, to established the degree of overlap with bottlenose dolphin frequency range and the level of attenuation with distance,*
iv) *use these two measures of acoustic impact to improve the general knowledge of the effects of noise pollution on the behaviour of marine mammals.*

This study was therefore undertaken to provide an accurate baseline record of background noise throughout the estuary from which changes over time can be measured and to quantify point sources of noise that may have a significant impact on the dolphins. The results from this study will be discussed in relation to the dolphins use of the estuary and provide recommendations and advice that can be used in conservation management.

2.0 Data Acquisition

The ambient, or background, noise found in any particular area can, and does, change in composition both temporally and spatially. The ideal method to monitor this physical parameter therefore is to deploy an array of static measuring instruments around the area/volume of interest. In the case of underwater sound this would entail a grid of submerged hydrophones connected back to a recording centre. The cost and complexity of such an undertaking can be prohibitive therefore for this project a boat and one sensor were used. This mobile platform transported a recording system to pre-selected monitoring points located throughout the Shannon estuary and approaches. The stations, eighteen in total, were selected primarily on an area cover basis. Specific sites of interest, such as static point sources, would be visited separately and monitored in greater detail than the ambient, background noise stations.

It is essential when conducting the work by this technique that the selected vessel can be silenced during the recording period. A rigid inflatable boat (RIB) was used, which had the duel advantage of being able to safely and quickly cut off the engine on station and was also a fast vessel that could cover the whole measuring transect in the same day. Travel between stations and the recording session took, on average, 30 minutes. Therefore the 18 locations required approximately 9 hours and, including travel to and from the end points, 10-11 hours total travel time.

An important factor when considering the monitoring protocol to establish the background noise is the length and/or frequency of the measuring session in order that the sample will be representative of that site. This requirement is not a trivial matter since the levels can change over both the long and short-term time scale (e.g. hour, day, season). Combined with this statistical criterion for acoustic monitoring surveys, is the practical consideration of the size of data file the recording will generated and/or the time required to manipulate the records in post processing.

2.1 Ambient Noise

As stated above the ambient noise measurements were made throughout the Shannon estuary at eighteen pre-determined sampling stations, programmed as waypoints into a Garmin 12 channel eTrex GPS receiver (accurate to within 6m). Sites were selected to include the range of hydrographic features throughout the estuary including areas of strong tidal currents and sheltered bays throughout the area where dolphins have been reported (up to Shannon airport) as well as sites known to be used regularly by dolphins. Areas with potentially significant point sources of noise such as Moneypoint power station and at the crossing of the Shannon ferry were also selected.

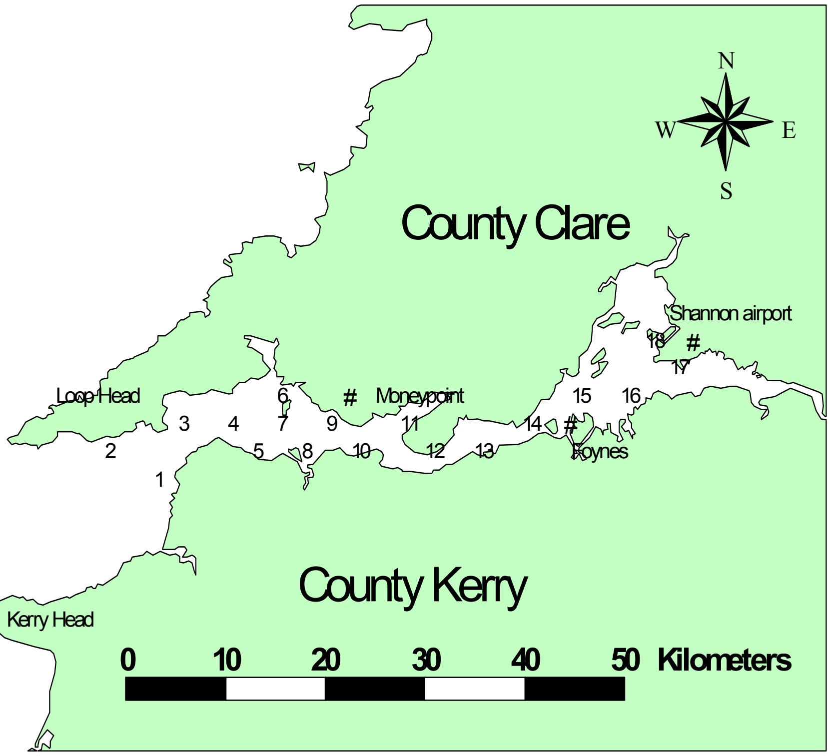


Figure 1. Location of sampling points for ambient noise measurements in the Shannon estuary.

Sampling stations were reached using a 5.5m Lencraft RIB with an 80hp Yamaha engine. The stations stretched from the outer estuary to 60km up river at Shannon airport (see Figure 1 and Table 1).

Table 1. Sampling sites for ambient noise measurements in the Shannon estuary.

Station	Location	Latitude	Longitude	Water Depth
1	Ballybunnion	52º 32.009	9º 42.015	16m
2	Rehy	52º 32.958	9º 45.234	25m
3	Kilcredaun Battery	52º 34.715	9º 41.813	20m
4	Beal	52º 34.747	9º 39.979	30m
5	Littor	52º 34.855	9º 36.217	12m
6	Poulnasherry	52º 27.245	9º 32.823	7m
7	Carrig	52º 35.509	9º 30.330	30m
8	Ballylongford	52º 34.699	9º 28.890	5m
9	Moneypoint	52º 35.953	9º 25.242	37m
10	Shannon Ferry	52º 35.993	9º 22.172	57m
11	Clonderlaw	52º 36.902	9º 19.881	5m
12	Glin	52º 34.809	9º 18.041	40m
13	Loghill	52º 36.169	9º 12.761	20m
14	Rinelon	52º 36.836	9º 08.329	17m
15	Aughinish	52º 38.533	9º 05.437	36m
16	Reeves Rock	52º 39.237	9º 00.782	10m
17	Shannon Airport	52º 40.271	8º 57.384	10m
18	Fergus estuary	52º 41.369	8º 58.548	4m

Upon reaching a station the engine on the RIB was shut down and the boat left to drift on station. Water depth was verified by an inboard Hummingbird Depth Sounder to ensure safe deployment of the equipment. A MAGREC HP30 hydrophone was then lowered to a depth of 5m and suspended from a 3m boom attached on a thin, elastic cord, in order to damp any low frequency cable strum which may be caused by the slight rocking motion of the boat at drift. During surveys the sea-state and swell were minimal (state 0 – 1) so self-induced noise should also have been minimal. Ambient noise measurements were taken at fixed stations on 19, 20 and 22 August 2002.

The MAGREC HP30 hydrophone housed a benthos AQ-4 transducer and miniature 30dB preamplifier at its front end. The preamplifier electronics incorporated a first order 200Hz high pass filter, which gently reduced low frequency noise below 200Hz (by 20dB per decade). The frequency response of the HP30 system was flat ± 2 dB from 200 Hz to 30 kHz, and the amplitude response across this range was –172 dB re 1V/uPa.

The hydrophone signal was recorded on to a SONY TCD-D7 Digital Audio Tape (DAT) recorder for around 5 minutes at each station. The recording mode was set at manual and the gain adjusted to an appropriate level (and noted) at each station. Selecting the gain was necessary to prevent dynamic range saturation from high noise environments, or to boost the signal in low noise environments. Known gain settings were thereafter mapped onto voltage calibration curves for the recorder. The DAT frequency response is flat ± 1dB or better, from 20 Hz to 22 kHz

2.2 Point Source

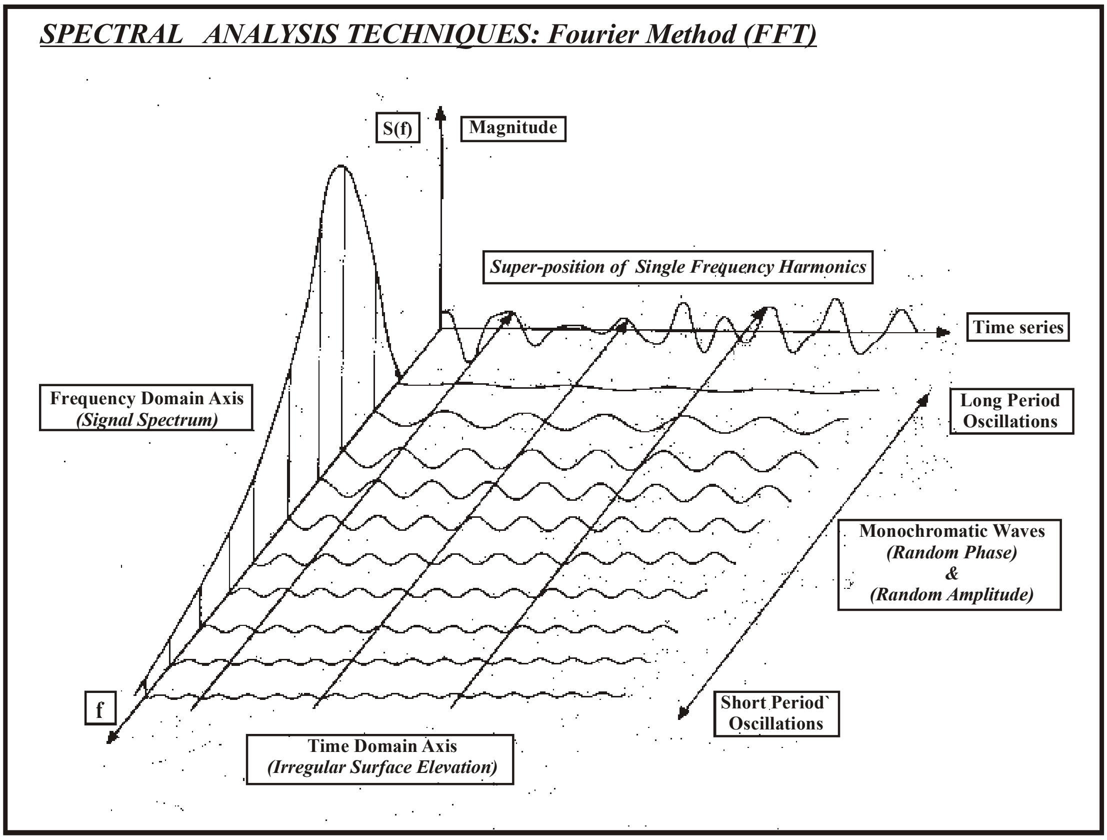
In addition to fixed station transient noise measurements from specific point sources were also recorded. These may be static (ie. power stations) or mobile (ie. dolphin tour boats). Point source measurements were made from the RIB to the same protocol as the ambient noise measurements; however, on these occasions an attempt was made to determine the range to the noise source. This was important, as noise level will get louder as the sound source gets closer to the receiver.

For the mobile targets the range from the hydrophone to the noise source were determined using a Nikon Laser Rangefinder. The noise source vessel was aligned in the cross hairs of the eyepiece and an infrared laser beam pulsed onto the hull. The reflected signal of the laser beam was detected by the rangefinder and used to determine distance to the target vessel to within 1 yard. The rangefinder gave readings in yards, but these were converted to metres for noise calculations. Theoretically ranges of up to 800 yards could be measured, but in practice 500 yards was about the maximum under typical field conditions. The majority of point source measurements were made on 22 August.

3.0 Data Analysis

The principle technique adopted to examine the measured acoustic signal was that of spectral analysis. This is a mathematical tool, which enables transformation of a signal between the time and frequency domain, in this instance from the pressure time series to its power density spectrum. The relationship between the two domains can be seen in Box 1. The same diagram also explains the basic concept of harmonic analysis, that is: any irregular wave trace can be separated into a set of monochromatic oscillations with random phase angle and, in theory, random amplitude. The single frequency components can be represented as a spectral diagram (as shown) where the ordinate is selected to suit the research. In this case the power spectral density in decibels referenced to the underwater hearing threshold (1uPa) was used. All the results presented in this report are therefore based on Fourier analysis methods, and in particular the Fast Fourier Transform (FFT). This is a computationally efficient method, the algorithm of which is found in most modern signal analysis program. The output from such packages should in fact be represented by a histogram of discrete harmonic ordinates of fixed (δf) frequency steps rather than the continuous curves presented. The accepted practice is, however, as shown since the frequency component step is usually very fine and set by the measurement period (1/T).

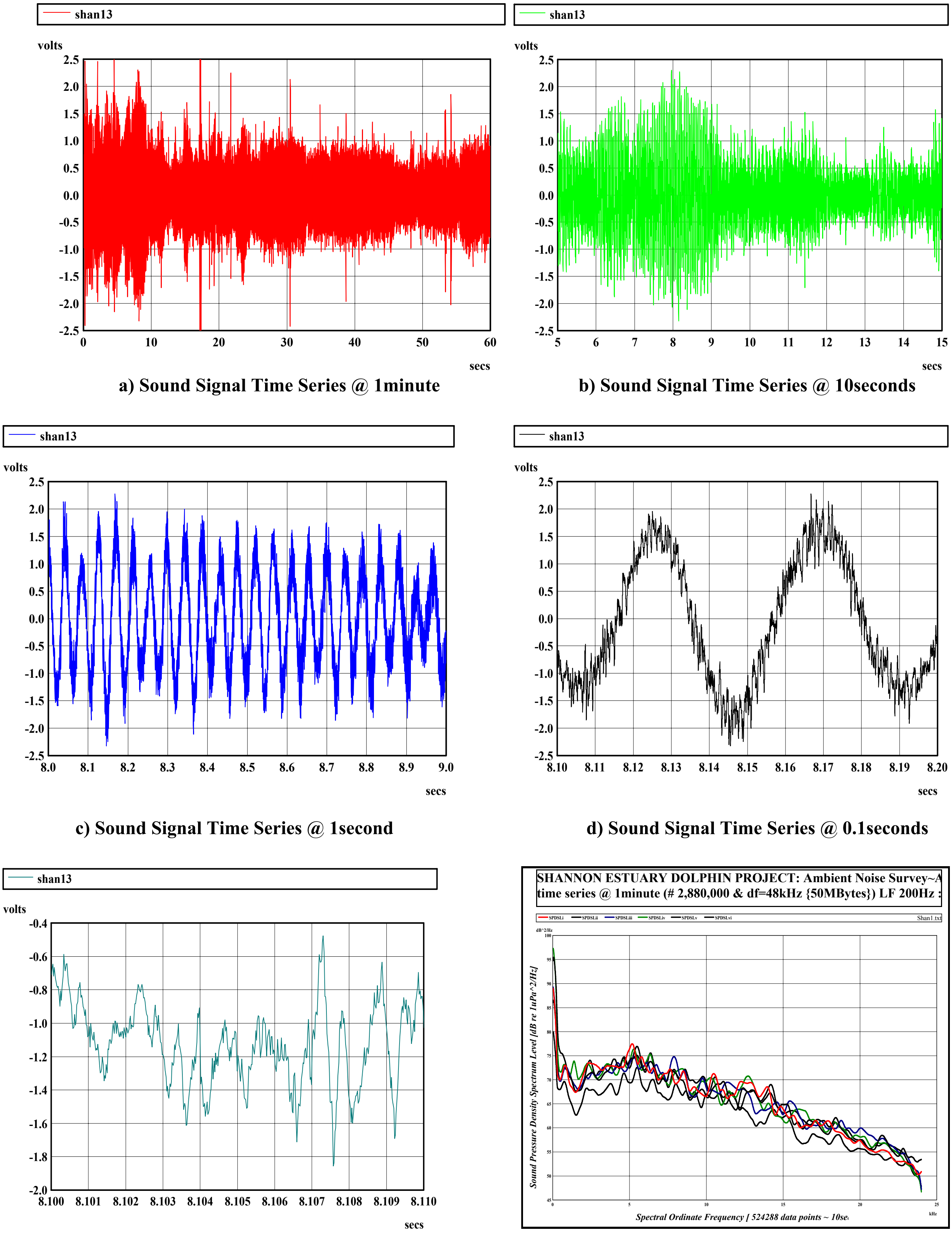
Box 1. Diagrammatic representation of mathematical transformation of a signal by FFT.



As stated in Section 2.0, a Digital Audio Tape (DAT) recorder was used as the initial storage device. This imposed two important criteria. Firstly, it provided a large sequential storage medium which, although slow to read later due to the real time nature of file handling, has the advantage of allowing long record length to be reviewed and selected sections downloaded for continued analysis. Secondly, the tape deck specification dictates the acquisition rate that can be used and therefore the nyquist frequency for the signal processing work. The selected rate was 48kHz to comply with the systems 22kHz cut off frequency.

The sound recordings from the field measurements were downloaded onto computer disk via an IOTech Wavebook 512 interface. A section of sound, 1 minute in duration, was downloaded as a representative sample from each noise station and point source recording. The resulting data were therefore of 2,880,000 data point (60 x 48,000 Hz) which produced ASCII files of 50Mbytes in the computer. This record length was compatible with the primary Fourier analysis technique but was adjusted for the detailed secondary harmonic techniques to a Fourier compatible 2^N integer. For the initial, general signal processing the wave data files were imported into MATLAB and the amplitude scale converted to voltage using a scaling factor determined from pre-calibration of the DAT recorder with known voltage sine wave signals across a range of amplitudes and gain settings. Once scaled to voltage, the noise wave data was converted to physical units of pressure amplitude in micro-Pascal, using the voltage response value of the HP30 hydrophone.

The calibrated and converted audio signal was also independently investigated by the IMC signal processing package FAMOS. This program could deal with record lengths of up to 524,288 data points, ($2^{19} \approx 11$ seconds). Figure 2 shows the detail of a typical acoustic signal recorded during the survey, in this instance archived as file Shan13. Figures 2 a-e depicts the sound signal referenced to an enlarging time scale (abscissa). Figure 2a shows the full 1-minute signal, Figure 2b magnifies the time base to 10 seconds and therefore shows the record length analysed in FAMOS. Figure 2c expands the



a) Sound Signal Time Series @ 1minute

b) Sound Signal Time Series @ 10seconds

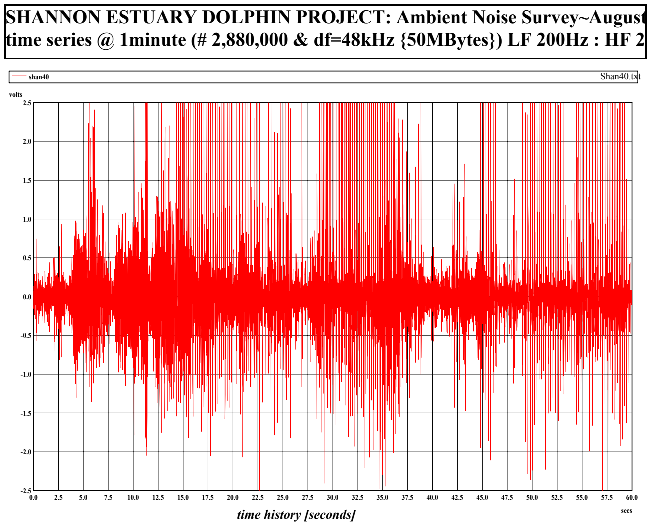
c) Sound Signal Time Series @ 1second

d) Sound Signal Time Series @ 0.1seconds

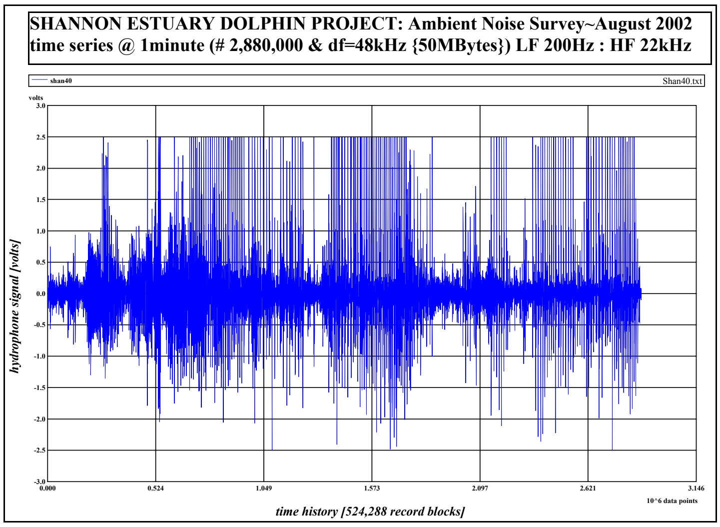
e) Sound Signal Time Series @ 0.01seconds

f) Spectral Analysis of Sound Signal

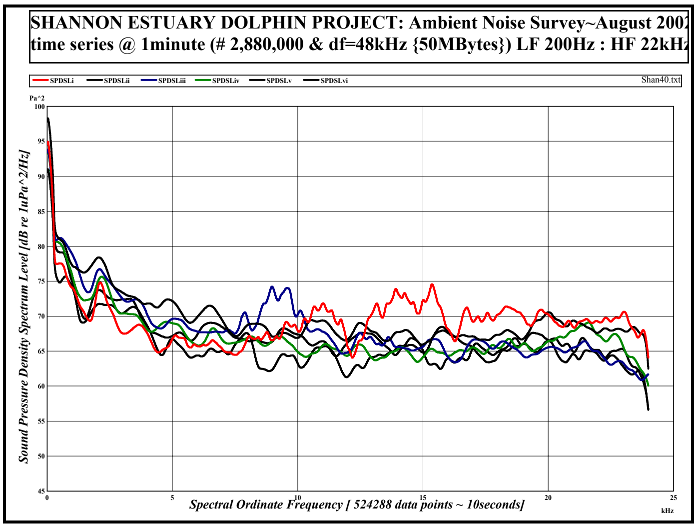
Figure 2. Acoustic signal containing background noise; abscissa history magnification



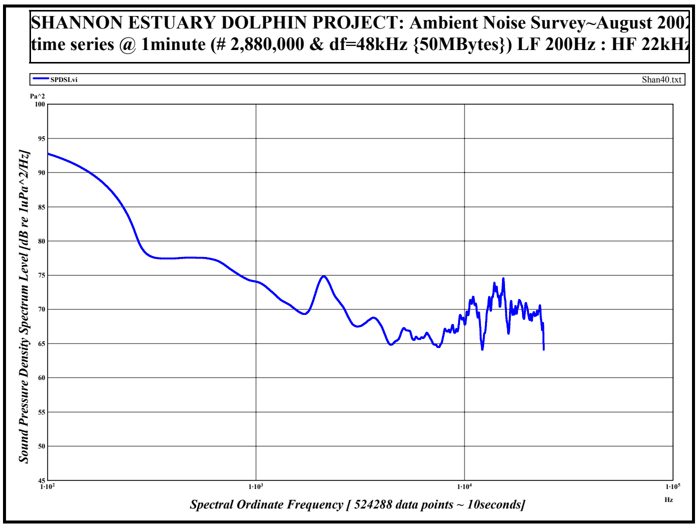
a)] Raw signal time series [abscissa seconds]



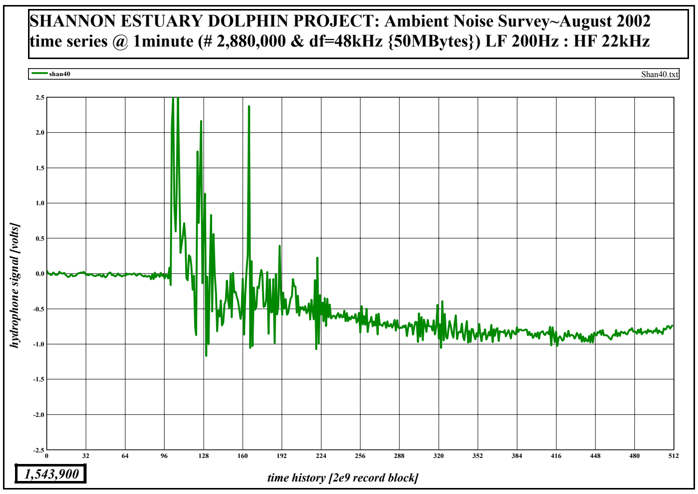
b) Raw signal time series [abscissa data points]



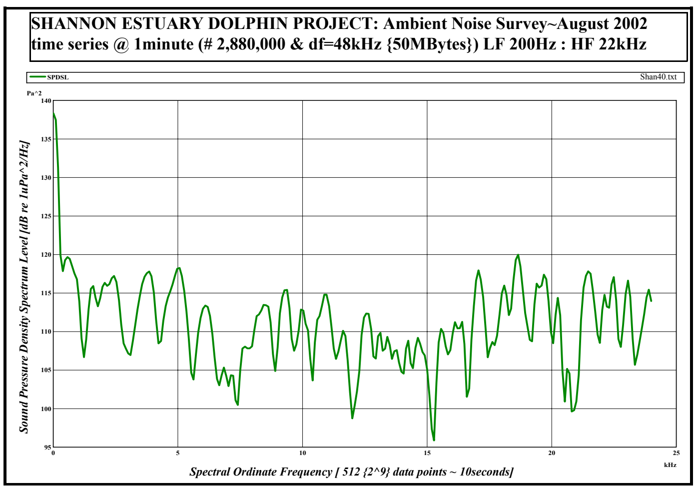
c) Spectra of each signal segments [abscissa LINEAR]



d) Spectrum of whole signal [abscissa LOG]



e) Time series of dolphin call



f) Spectrum of dolphin call

Figure 3. An example of an acoustic signal containing dolphin communication sounds

history to 1 second and in Figure 2d to 0.1 seconds. The change of form seen by this magnification process is obvious and helps explain the results produced by the FFT procedure. Figure 2e zooms in to a 0.01 second time series and is therefore equivalent to the 512 data point procedure conducted in the MATLAB general signal analysis process. Finally Figure 2f shows a raw, non-smoothed spectral density plot produced from this signal with the final smoothed version superimposed on the results. This smoothing is conducted over a 512 rolling ordinates procedure provides the same results obtained by the advancing harmonic averaging obtained from the high DoF main analysis procedure without reducing the number of calculated harmonics.

Also shown as Figure 3 are the time and frequency domain results obtained when dolphin vocalizations are present in the base signal. Figure 3a shows the full, raw 1-minute recording. Figure 3b depicts the same trace but with the time axis divided into the separately analysed segments. Figure 3c shows the sound pressure density spectrum for each segment of the signal between the confident frequency limits of 200Hz to 22kHz beyond which the high and low pass filters progressingly influence the readings. The similarity between the different sections of the primary signal is clear and when considered in association with the signal time series indicates the record length required to achieve result fidelity. The frequency scale in the first instance is linear whilst the harmonic ordinates are logarithmic, having been converted into decibels and reference against the standard hearing threshold for underwater acoustics. Figure 3d shows the spectral graph with the abscissa converted to the conventional logarithmic scale. Figure 3e shows a time history detail of 512 data points, approximately 0.01 seconds in length. The trace depicts a signal dolphin vocalization, which is spectrally analyzed in Figure 3f. The latter graph is smoothed over only 2 ordinates.

3.1 Ambient Noise

For the bulk of the data analysis a spectral density average was obtained of the 1-minute noise sections from the fixed station recordings. A sliding FFT analysis was applied to the noise sections, using a hanning window length of 512 waveform points, advancing in steps of 256 points. The individual power density spectra obtained from the advancing window were summed and finally averaged by the number of steps through the wave data sequence (11,250). Spectral resolution was about 100 Hz per frequency bin, (Δf / T where T = 0.01 seconds from 512/δf) the FFT window length captured frequencies of 100 Hz and above, although frequencies below 200Hz were not included in analyses in any case due to the hydrophone filter. Values above 22kHz were similarly ignored due to the response of the DAT recorder.

Graphs of noise power spectral density were plotted for each station. Electrical noise of the recording system was also plotted on these graphs as a base reference level to ensure that acoustic noise exceeded the systems electrical noise. Since noise is additive, the system electrical noise was subtracted from the measured acoustic noise before plotting, although this made little difference to the curves except where acoustic noise dropped very close to system electrical noise.

The acoustic noise spectra were then summarised by obtaining average spectral density levels in six octave bands centred on 0.5, 1, 2, 4, 8 and 16 kHz respectively. These octave spectral density levels were effectively average spectral density levels in the appropriate frequency bands. This is not the same as octave spectrum levels, which are the summation of energy within octave bands, and which are often used to determine equivalent loudness levels at a single frequency (sometimes used in noise exposure measurements). Octave spectrum levels have not been computed for this report, as it was felt that average spectral density levels would be more intuitive measure and direct noise exposure was not being addressed.

3.2 Point Source

The same procedure for analysis was adopted with point source measurements both mobile and static. Where range did not change appreciably during each sub-sample, then an average noise spectrum was obtained as above. When range did change appreciably, a spectrogram analysis was performed. The spectrogram showed changes in spectral density with time, and was used to pick out an appropriate feature in the noise spectra (e.g. the noise spectrum at closest approach). A much shorter average spectrum was thereafter obtained, perhaps across a few seconds, at the time when distance to source was at a minimum. The extracted noise spectrum was again plotted as with ambient noise, and summarised into octave bands. Spectral plots were recorded for a number of vessels including; i) a bulk freight carrier travelling from 400 yards, ii) Dolphin-watching boats idling at 40 yards distance, iii) Dolphin watch boat underway from 300 yards and iv) an overflight of a Sikorski air-sea rescue helicopter from100 yards.

3.3 Data Presentation

Sound has two basic components; intensity and frequency. Frequency is measured in hertz (Hz) and humans typically hear between 20 – 20,000 Hz. Many animals (e.g. dolphins, bats and dogs) can detect ultrasounds (>20,000 Hz) and some animals (elephants, pigeons and baleen whales) can detect infrasounds (<20 Hz). Sound receivers (e.g. ears, hydrophones) are sensitive to sound pressure, which is measured in micropascals (μPa). Sound detection is non-linear thus a logarithmic scale is used to describe sound intensity and is known as decibels. Thus when studying underwater sound the measured physical property is pressure not intensity. In this report the power density spectral plots with a linear not log scale have been presented.

4.0 Results

4.1 Ambient Noise

For each recording, at every site, on all recording days spectra were plotted and are shown in the Appendix. A total of 38 graphs were generated. Electrical noise of the recording system was also plotted on these graphs as a base reference level to ensure that acoustic noise exceeded system electrical noise. The system background clutter was obtained by recording a data set in completely silent conditions, in this case insulated in the on-shore office. Since noise is additive, the system electrical noise was subtracted from the measured acoustic noise before plotting, although this made little difference to the curves except where acoustic noise dropped very close to system electrical noise.

The shapes of these plots are as expected with dominant low frequency background noise. Increasing frequency generally coincides with decreasing noise spectral density, however, this was not uniformly the case. At some sites, on some days, spectral plots maintained high densities in the higher frequency range (1.5-2.0 kHz), for example stations 1 and 3 (Ballybunion and Kilcredaun) on the 19 August, station 7 (Carrig) on the 20 August and station 4 (Beal) on the 22 August (see Appendix for plots).

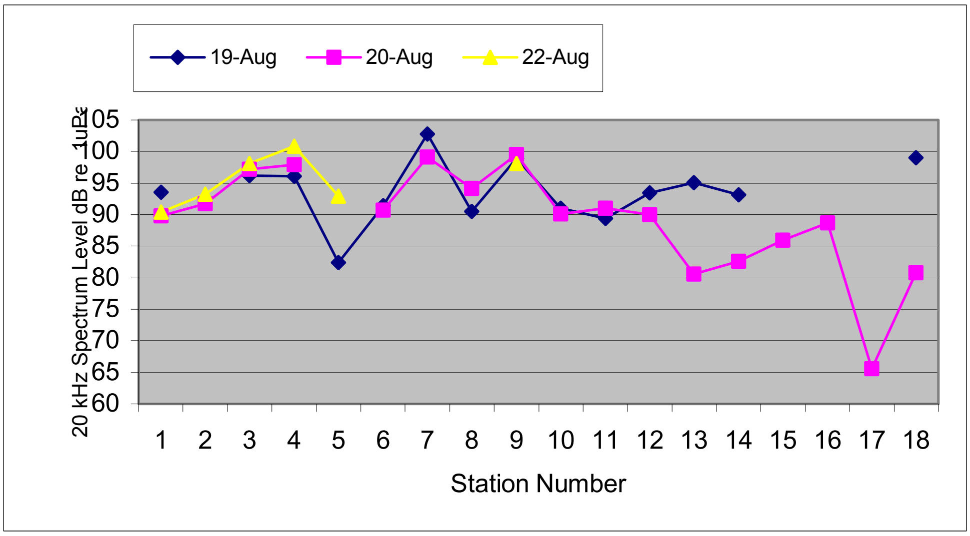


Figure 4. Total noise spectrum levels summed for each octave band at each station.

The total spectrum noise levels for each site between 200 Hz and 20 kHz were plotted for each station in order to detect any trends in ambient noise levels in the estuary (Figure 4). Noise levels were around 90-100 dB at stations 1-10 (omitting station 5) and lower at 80-90 dB from stations 11-18 (omitting 17). Generally it was quieter in the inner estuary compared to the outer estuary, which might be expected, depending on the environmental contribution, especially wave action. At stations 5, 10, 11, 13, 14, 17 (Littor, Shannon ferry, Clonderlaw, Loghill, Rinelon and Shannon airport) on the 19 August and 15, 16 and 18 (Aughinish, Reeves Rock and Fergus estuary) on the 20 August the ambient noise level dropped below measurable limits across a portion of the spectrum. On only one occasion, station 17 (Shannon airport) on 19 August did this occur across the entire frequency range (200Hz-20kHz).

If the total spectrum is broken down into octave bands the noise bands in which any changes may occur can be seen (Figure 5a-d). Octave bands, which sum the energy within standardised frequency ranges, can be more useful in estimating direct noise exposure, but this was not done during this project as ambient noise was the main interest. The octave bands, showing the average spectral density level, have further been summed for all stations downriver (1-10) and upriver (11-18) with the area around the ferry crossing taken as a midpoint. Mean levels in all octave bands were considerably lower at upriver stations compared to the outer estuary by at least 10 dB in all octave bands and, in some cases, there was as much as 30 dB difference between stations.

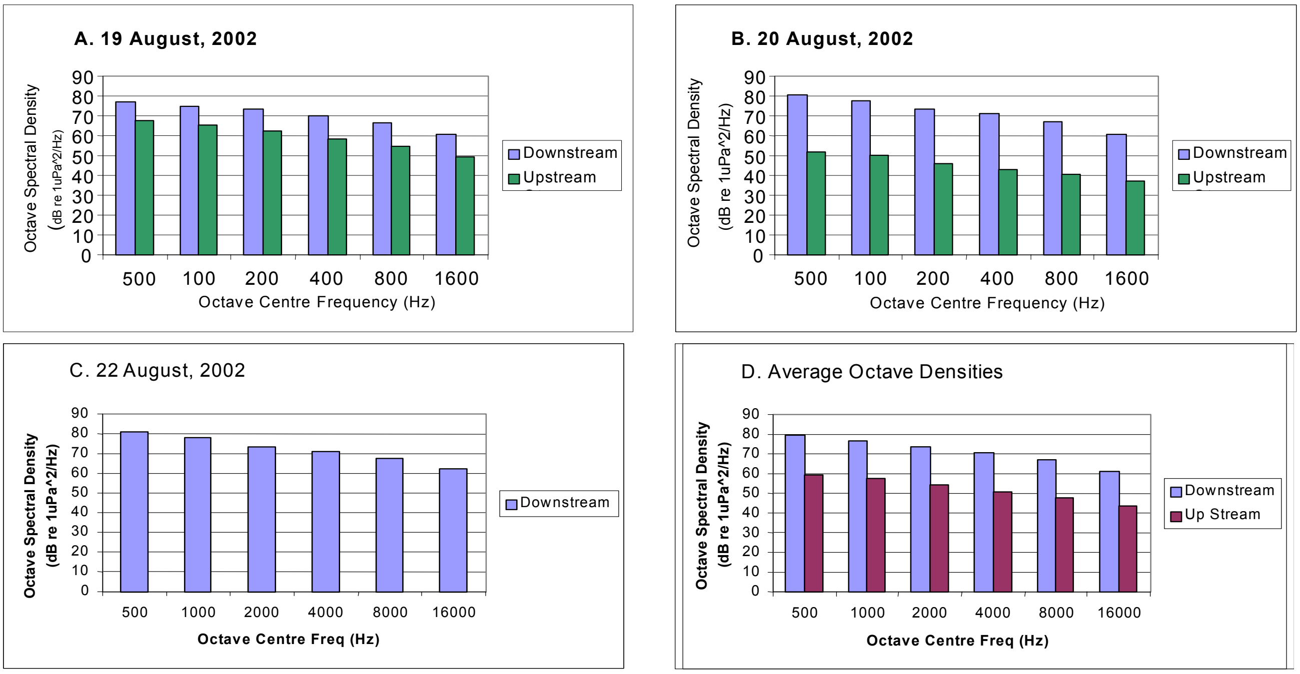


Figure 5a-c. Mean octave spectral density levels in six octave bands in the Shannon estuary and 5d. Average octave spectral densities for 19-22 August combined.

If the three variables are combined (spectral density, octave band and station) a three-dimensional plot can be generated, which demonstrates the trend in ambient noise levels (Figure 6). Although ambient noise drops in all octave bands from stations 1-18, the most dramatic decline was in the higher frequency octave bands centred around 8,000 and 16,000 Hz.

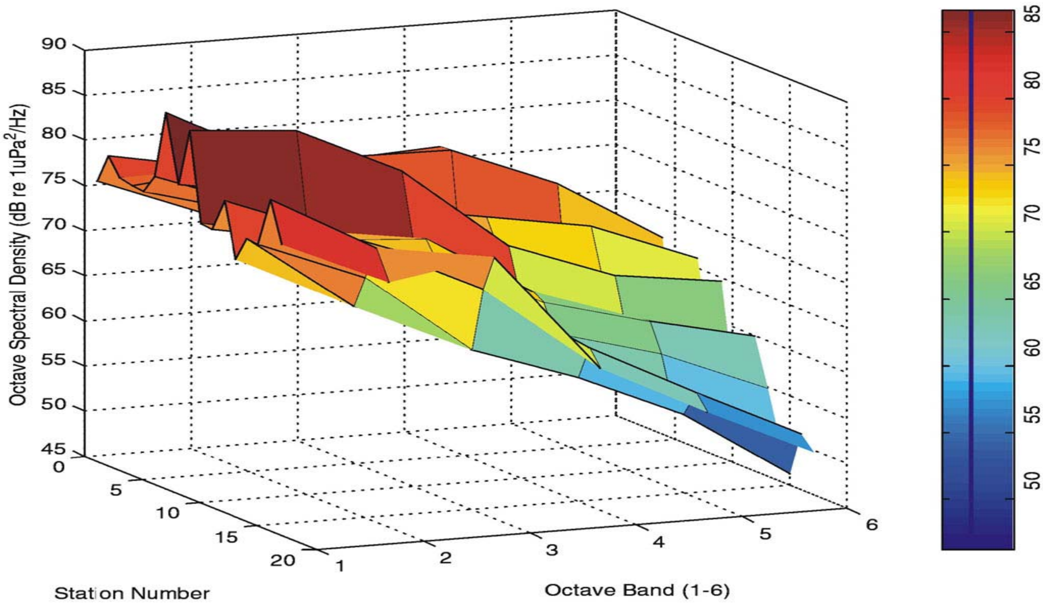


Figure 6. Three-dimensional plot of spectral density in each octave band at stations 1-18.

4.2 Point Source

Noise density spectral plots from a number of fixed point sources are presented in Figures 7-8.. Octave spectral density values for mobile sources were also calculated and presented alongside the mean ambient noise measurements and are presented in Figures 9-11. In all cases the point source noise levels were above ambient noise.

4.2.1 Static Sources

a) 2km south of Station 9 b) Station 9, Moneypoint c) Moneypoint outlet pipe

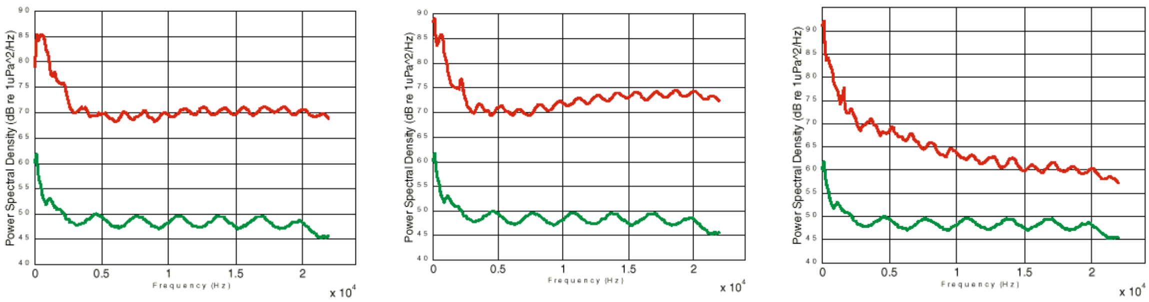


Fig. 7. Spectra from three sampling stations at various distances from Moneypoint power station on 22 August 2002.

A series of spectral plots at varying distances from Moneypoint power station are shown in Figure 7. At 2km from the potential noise source the plot was constant at 70 dB through frequency ranges from 5-20 kHz. At 1 km distance there was an increase in higher frequencies between 2 and 1 km but this decreased rapidly at the outfall pipe.

A point source measurement was also attempted off Aughinish Alumina but a tug was also present at a minimum distance of 500 yards (Figure 8). This has resulted in a spectral plot with very high densities in the low frequency range (up to 100-110 dB) and still elevated densities at the high frequency range (15,000-20,000 Hz).

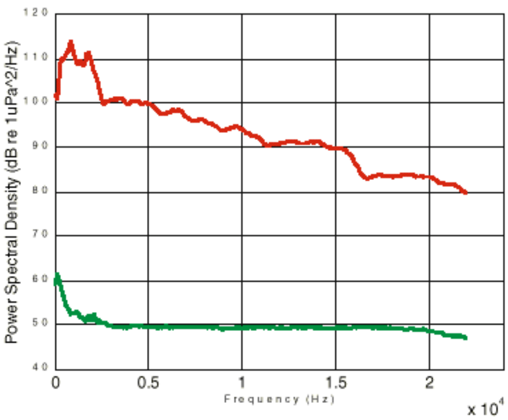


Figure 8. Spectral plot off Aughinish Alumina with tug at a minimum distance of 500 yards

4.2.2 Mobile sources

Spectral density plots for a number of mobile point sources including tour boats, a bulk carrier and helicopter are presented and octave spectral density graphs with ambient noise measurements alongside in order to demonstrate the increase in spectral density created by the point source above ambient levels.

4.2.2.1 Tour boats

Spectral plots of a dolphin tour boat idling within 40 yards of the hydrophone and in transit within 360 yards are shown in Figure 9. When idling spectral density was greatest in the low frequencies (up to around 85-90 dB) and declines in the high frequencies (75 dB). However when in transit, and the engines are on full operational power, spectral density increased to 95-100 dB even at nine times the distance. Doppler effect may play a part in this shift.

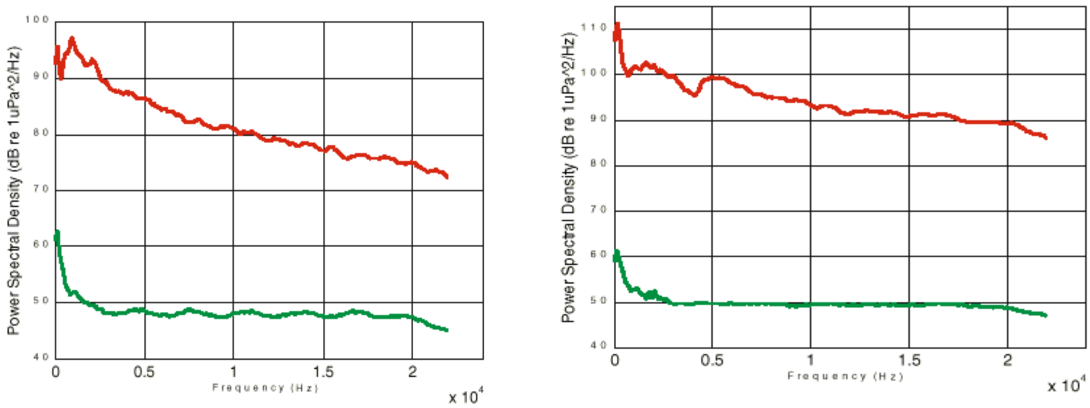
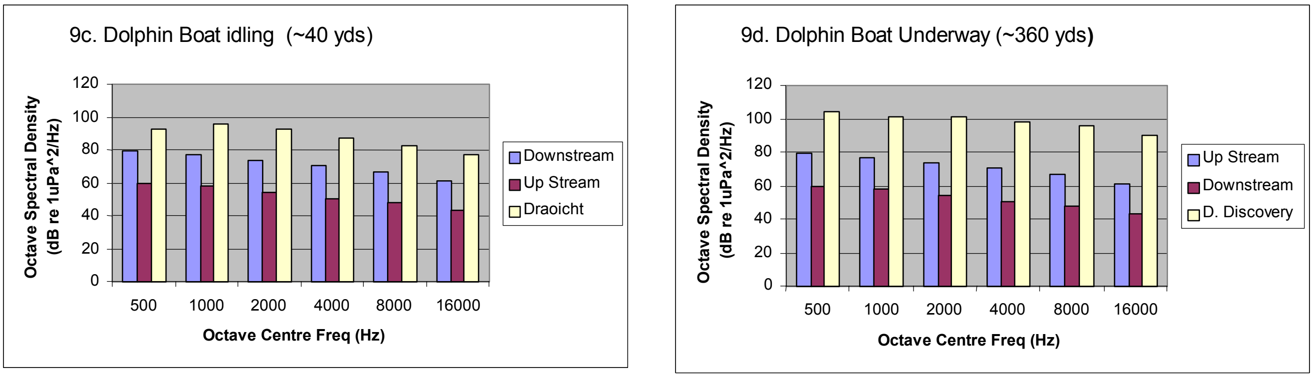


Figure 9a. Dolphin tour boat passing at 40 yards. 9b. Same vessel at 360 yards

It can be seen from Figures 9c-d that all octave bands were elevated but especially in the lower frequency bands. An idling tour boat increased noise levels by 10-15 dB and a tour boat underway by 25-30 dB, however the proportional increase when compared to ambient noise was similar across the octave bands by a maximum of around 30%.



9c. Octave spectral density of tour boat idling at 40 yards and 9d. underway at 360 yards.

4.2.2.2 Bulk carrier

Noise from a bulk carrier dominated at low frequencies, and had the quality of a loud, low frequency rumbling (Figure 10a-b). The peak densities were apparent in the octave band centered around 800 Hz as compared to 1000 Hz for the idling tour boat, but were similar to the tour boat in transit.

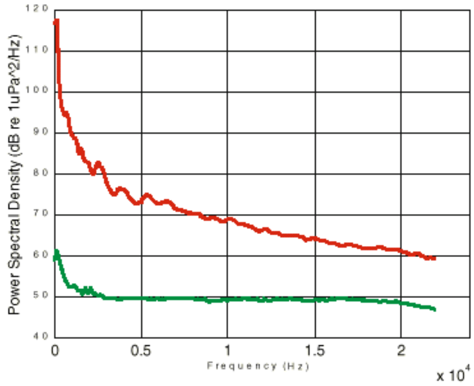
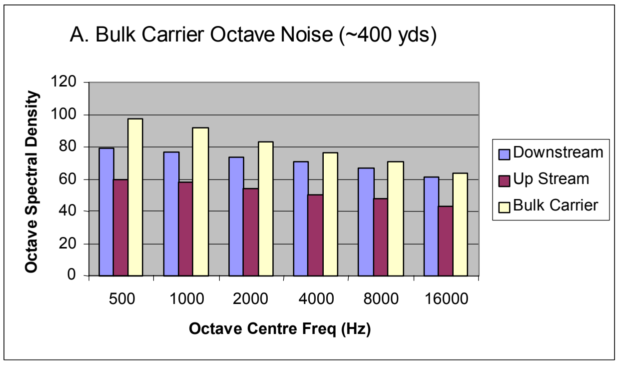


Figure 10a. Spectra of bulk carrier.



10b. Octave spectral density of bulk carrier

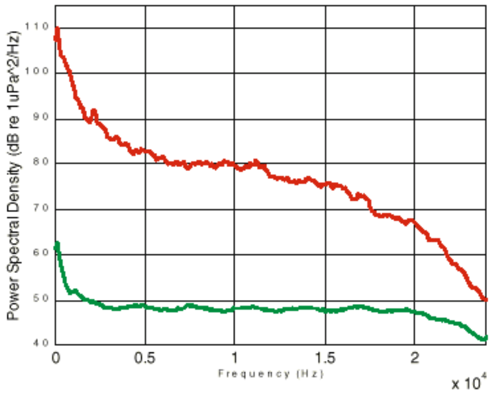
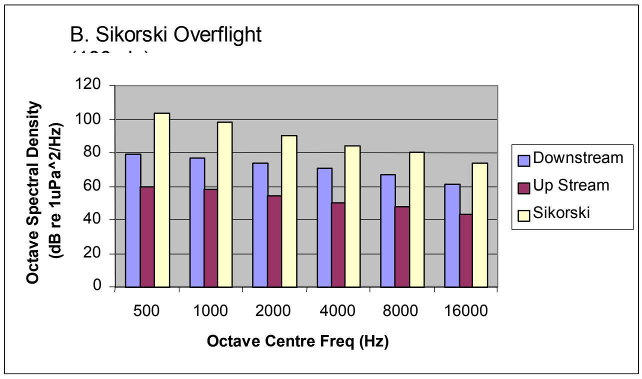


Figure 11a. Spectra of Sikorsky helicopter.



11b. Octave spectral density of Sikorsky helicopter.

4.2.2.3 Helicopter

The air-sea rescue helicopter had a quite different underwater noise characteristic. Due to the large impedance mismatch when sound travels from air to water, the penetration of airborne sound energy from the rotor blades was largely reflected from the surface of the water. However, a small fraction of the sound energy was coupled into the water. At grazing angles, when the helicopter is displaced horizontally from the hydrophone, sound coupling into the water was refracted (bent) due to the different sound conduction properties of the two media. In essence sound tended to duct along the surface until the critical angle of incidence occurs. The refracted sound wave then penetrated into the water column and the penetration angle increased as the helicopter came closer to the zenith position. Once overhead, a fairly broadband characteristic was present in the received sound, elevating noise across all octave bands. The greatest increase, however, was at low frequencies, similar to the bulk carrier.

5.0 Discussion

The study of underwater acoustics can be difficult as there are many variables and uncertainties, which are beyond the control of the researchers. In the ocean, ambient noise arises from wind, waves, surf, ice, organisms, earthquakes, distant shipping, volcanoes, fishing boats and many more (Richardson et al., 1995). At any one place several of these sources are likely to contribute significantly to background noise. Ambient noise varies with season, location time of day and frequency.

The usage of the Shannon is such that some form of powered vessel noise is nearly always present. In fact it is debatable whether to describe the ambient noise measurements as truly ambient, rather than background noise. Given that vessel noise is nearly always present from a number of distant sources, we might consider that this forms a part of the ambient noise.

5.1 Ambient noise

There is, approximately, a doubling of ambient noise in each octave band between sea state 0 to 6 and an increase of one-third from sea state 1 to 6. Similarly, wind speed at the sea surface is directly related to noise production with intensity increasing by 5 dB with each doubling of wind speed between 5-75 km h^{-1} (Richardson et al. 1995).

During sound measurements in the Shannon estuary, the weather conditions were perfect to minimise the effect of wind and waves as sea-state were 0-2 throughout. This enabled minimum recordings of ambient noise to be collected to provide a baseline for comparisons with other sites or this location on different dates. As found at other sites (Richardson et al. 1995) low frequencies dominated ambient noise in the Shannon estuary. Intensity was typically around 60-70 dB in all frequency bands in the outer estuary (west of the ferry crossing) and 40-65 dB in the inner estuary (east of the ferry to Shannon airport). Variation in ambient noise intensity at the same station over three days is difficult to explain. With sea conditions so calm it is possible that differences between sites each day and between days at each sites may have been masked by self-induced noise, generated while taking measurements. If differences between measurements are small and subtle they may not have been recorded as even the recording equipment generates noise, which at some stations was greater than ambient. Deployment of a fixed hydrophone may mitigate against this factor. Alternatively the variability may be genuine due to the atmospheric change.

Although generally spectral density declined with increased frequency this was not always the case. At Kilcredaun the raised high frequency noise was most likely due to the presence of snapping shrimp (*Alpheus macroceles* (Hailstone)). These shrimp create sharp, impulsive 'snaps' with their powerful claw and are known to be an important component of background noise (Goold and Coates, 2002). Interestingly the distribution of this species in Ireland has been poorly studied and acoustics offer an efficient and accessible method of surveying this genus. However *Alpheus macroceles* does not explain all high frequency ambient noise and the source of raised high frequencies from Ballylongford to Moneypoint is unclear.

Although there are many studies of ambient noise there are few in relation to sites with bottlenose dolphins, which are of interest to those charged with management of the Shannon estuary. dos Santos et al. (1995) reported minimum ambient noise levels of 122 dB re 1 µPa and a maximum of 151 dB in the Sado estuary, Portugal where a resident group of bottlenose dolphins occur. Total noise level in the present study (Figure 4) were all below 105 dB re 1 µPa, although we might be summing noise across different frequency ranges. Harland and Williams (1996) recorded similar intensities to the Shannon estuary with a maximum of 75 dB at 50 Hz declining to 60 dB at 15,000 Hz. The latter study used a fixed hydrophone mounted in an area with transient bottlenose dolphins.

5.2 Point sources

The nature of sound means it travels from generation in all directions, thus identifying sources can be difficult. It is easiest to think of the noise source (i.e. the boat) radiating sound outwards in a spherical shell from the point of origin. As the surface area of the shell expands, the energy within it is spread over an increasing area hence the sound level at the shell boundary (the wave front) is decreased.

It was evident that point sources such as boats create significant elevation of ambient noise even when they are at substantial ranges (hundreds or even thousands of metres) from the hydrophone. The most significant point source measured in the present study was from a tug passing within 500 yards and the dolphin boats when they were underway, and these noises clearly dominated over ambient noise in all octave bands. When idling, either searching for, or watching dolphins, the increase noise over ambient was much less significant.

In comparison a helicopter is almost inaudible until it is very close to passing directly overhead. When overhead the transmission is vertical and at that point the loudest sound is received underwater. This type of sound has the potential to startle marine mammals, and direct over flights of dolphins should be discouraged.

5.3 Effect of ambient and point source noise on bottlenose dolphins

In order to determine the potential affect of ambient and point source noise on bottlenose dolphins it is necessary to convolve noise spectral characteristics with dolphin audiograms. We have not attempted such a comparison within the scope of this report, since this presents another tier of analytical procedures, which could not be accommodated in the available time schedule.

In general we can say that low frequencies dominate, and such frequencies correspond with reduced sensitivity in the dolphin audiogram. However, many plots show elevated mid frequency noise levels, and these could be significant in terms of masking dolphin signals. Such speculation will need critical examination. Limited studies on the distribution of dolphins in the estuary have shown that there is some stratification of habitat use with high sighting rates off Kilcredaun Head and off Moneypoint. These areas are thought to be important for foraging. From an acoustic perspective these sites were characterised by relatively high spectral densities (95 – 100 dB) including elevated levels in the higher frequency octave bands. Thus it would appear that these elevated densities and frequencies are not intense enough to exclude dolphins from these preferred foraging sites. There is no evidence from studies of the dolphins distribution and relative abundance, that sites with lowest spectral densities (Littor, Loghill and Shannon airport) are regularly used by dolphins, however only limited dolphin surveys have been carried out upstream of the Shannon ferry.

From these limited observations it does not appear that acoustic characteristics have a major influence on the distribution of bottlenose dolphins in the Shannon estuary.

5.4 Implications for conservation management

What are the implications of this study for the understanding of dolphin ecology in the estuary and conservation management of the Shannon estuary?

Bottlenose dolphins have been recorded in the Shannon estuary since 1835 and most probably much longer. The Shannon has long been a busy waterway with shipping contributing to ambient noise for many years. Ambient noise levels were consistent with marine sites reported elsewhere and lower than that reported for the Sado estuary, which also has a resident group of bottlenose dolphins. Thus ambient density levels are within those levels thought to be tolerated by bottlenose dolphins.

Maximum densities of point sources also seem to dominate in low frequencies and thus disturbance is thought to be minimal.

The greatest source of acoustic disturbance is from powered vessels. Large vessels such as bulk carriers dominate in the low frequencies and tend to travel within the channel, thus dolphins may accommodate easily to their presence. Tour boats behaviour differently as they seek out dolphins to watch. Tour boats can minimise their acoustic impact by only putting engines on full power when they are in transit looking for animals and not in the vicinity of dolphins. A minimum distance from dolphins prior to full power would be a good practice and should be incorporated into the codes of conduct for the Shannon estuary cSAC. However it was not possible to derive such a recommended distance from the present analysis and will require further study.

Acoustics disturbance does not seem to be a major threat to dolphins. However it is important to develop a monitoring protocol to determine long-term trends in ambient noise. This will be best achieved by deploying fixed hydrophones, which record ambient noise throughout tidal, diurnal and seasonal cycles. The biggest potential acoustic disturbance is from mobile point sources, especially tour boats as they are in close proximity to dolphins for extended periods.

The study and interpretation of acoustics in the marine environment is a great challenge. This study is the first investigation in Ireland, of the acoustic environment in which dolphins inhabit. It provides a baseline and will hopefully stimulate further acoustic studies in the future.

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Goold J.C. and Coates R.F.W. (2002). Acoustic Monitoring of Marine Wildlife. ISBN 1-904055-02-8

Harland, E. and Williams, R. (1996). Characterising underwater ambient noise. European Research on Cetaceans – 10. 57-62.

Richardson, W.J., Greene, C.R., Malme, C.I. and Thomson, D.H. (1995) Marine Mammals and Noise. Academic Press, London.

Rogan, E., Ingram, S., O'Flanaghan, C. and Holmes, B. (2000) A survey of bottlenose dolphins (*Tursiops truncatus*) in the Shannon estuary. Marine Resource Series 9, 48pp.

Appendix:

Spectral plots of fixed stations for ambient noise measurements

(See Table 1 for location)

Station 1: Ballybunion

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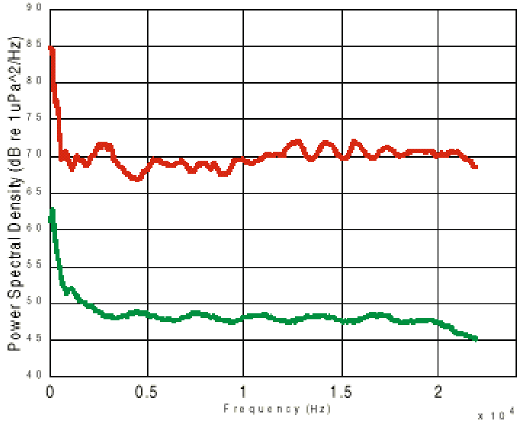

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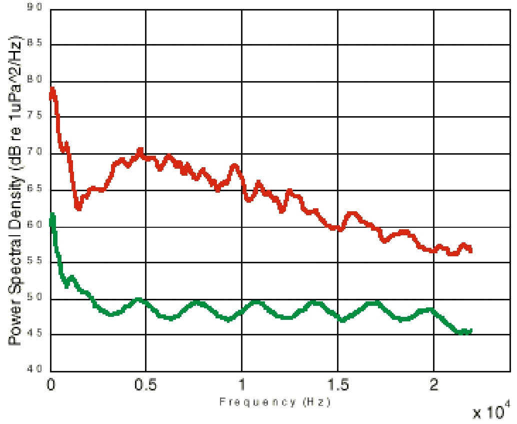

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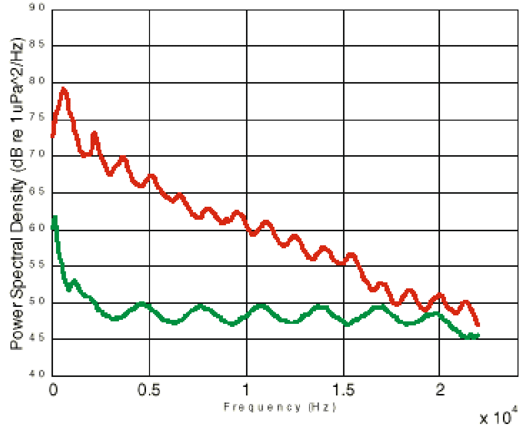

Station 2: Rehy

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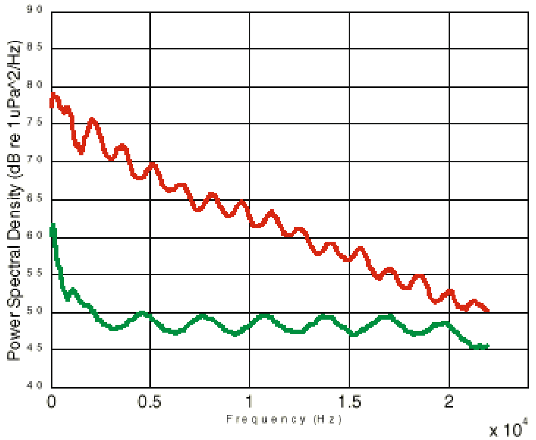

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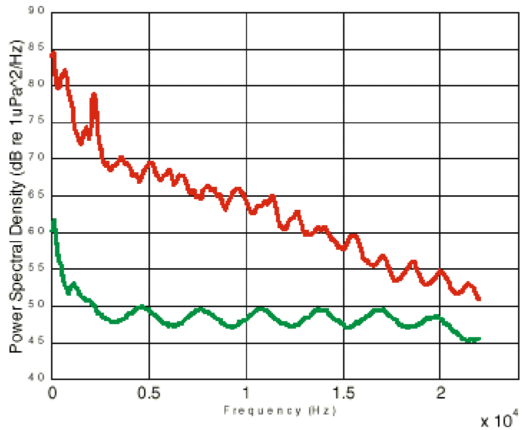
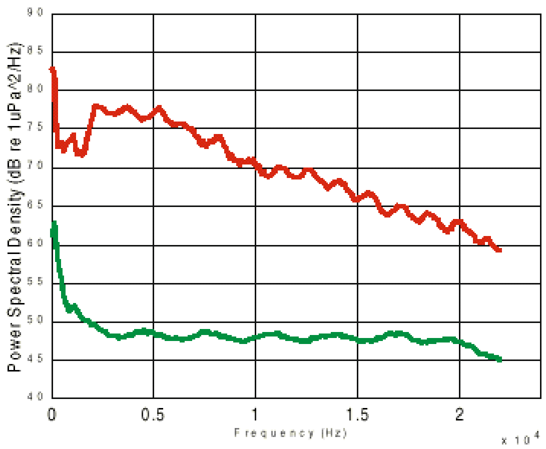


Station 3: Kilcredaun

19th August, 2002



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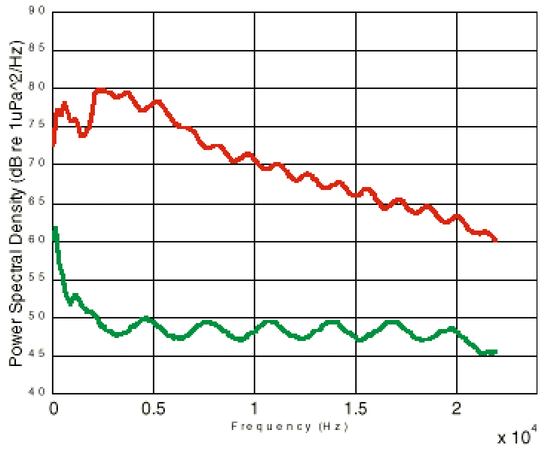

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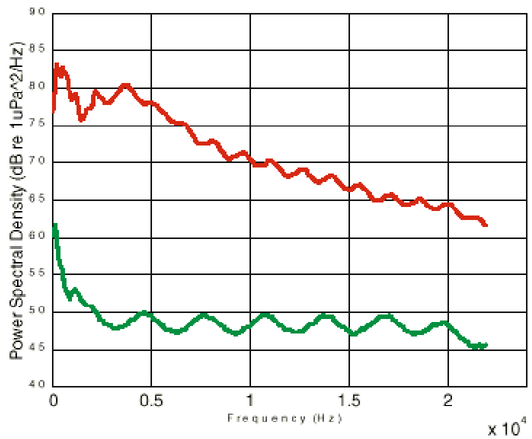
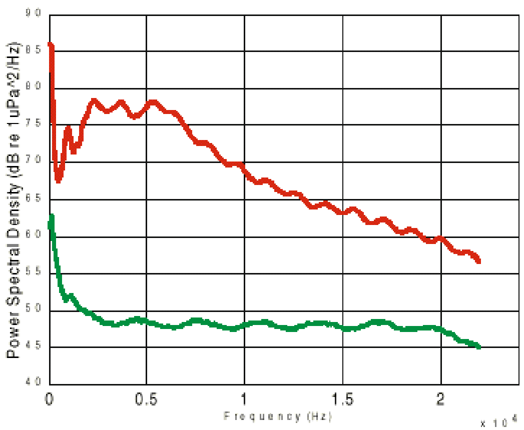


Station 4: Beal

19th August, 2002



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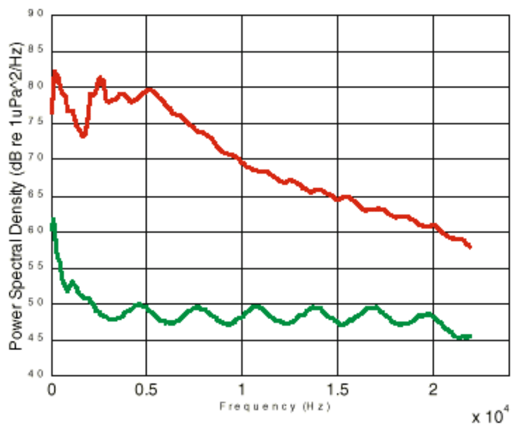

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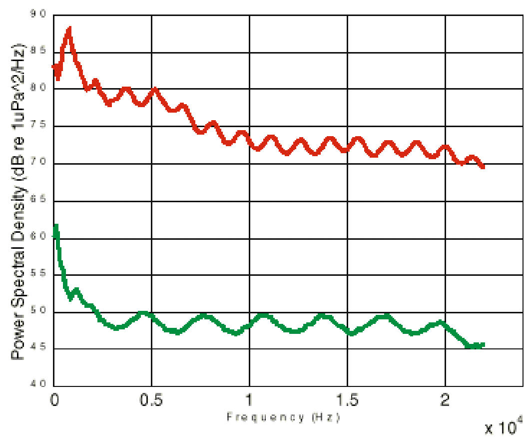
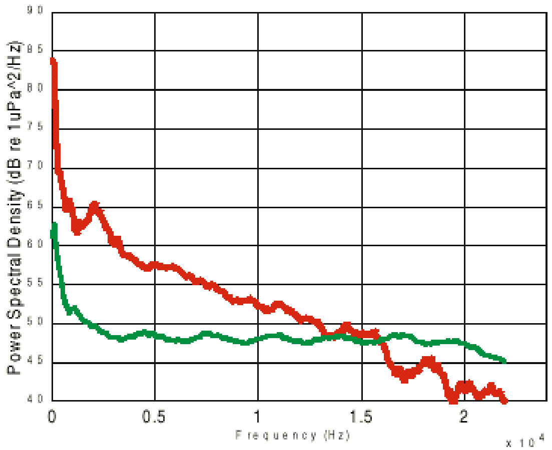


Station 5: Littor

19th August, 2002



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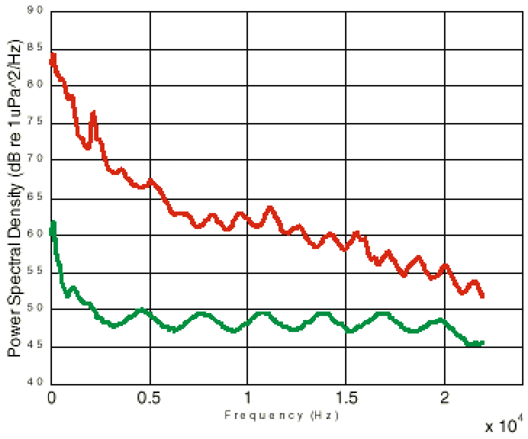
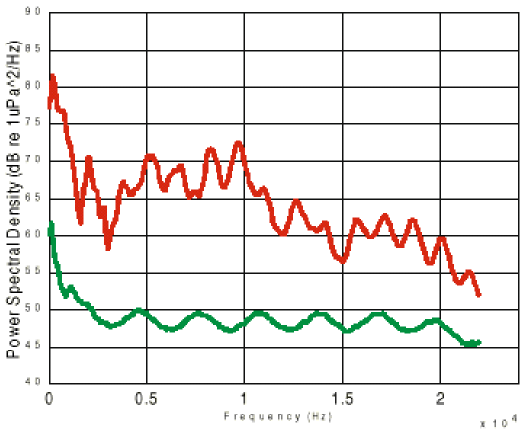


Station 6: Poulnasherry

19th August, 2002



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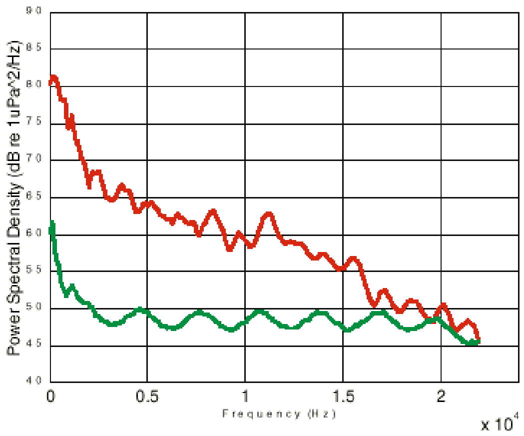
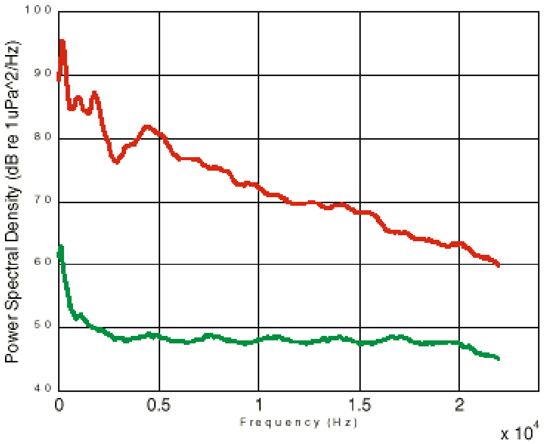


Station 7: Carrig

19th August, 2002



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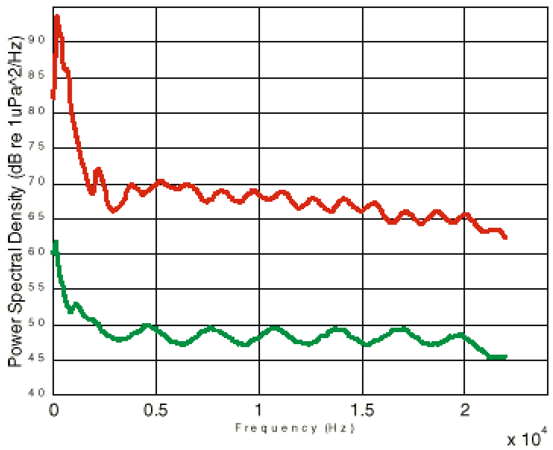
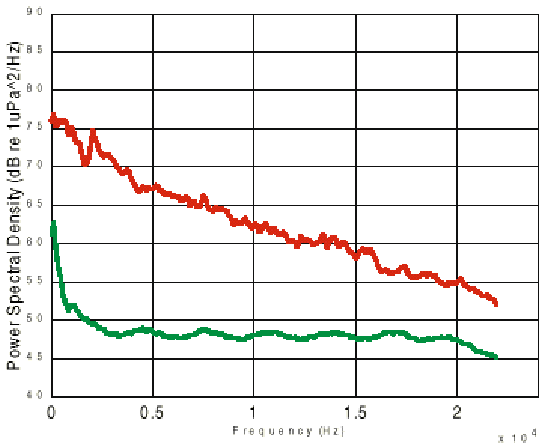


Station 8: Ballylongford

19th August, 2002



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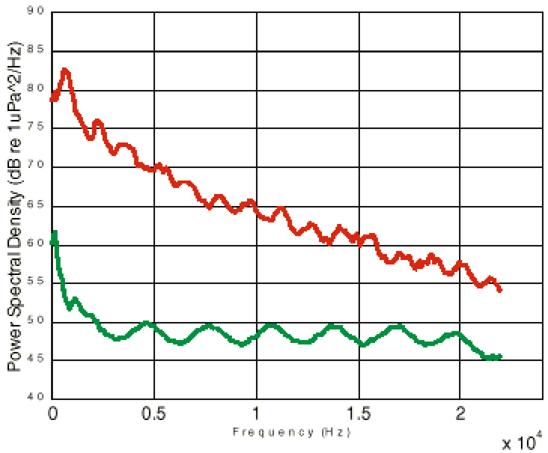

Station 9: Moneypoint

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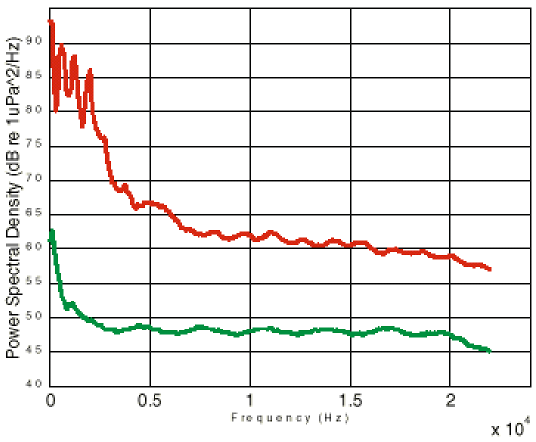

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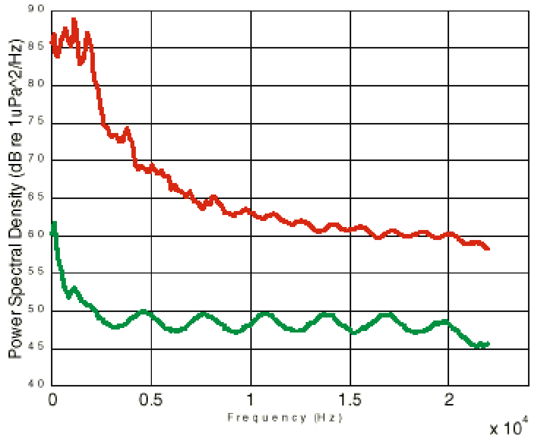

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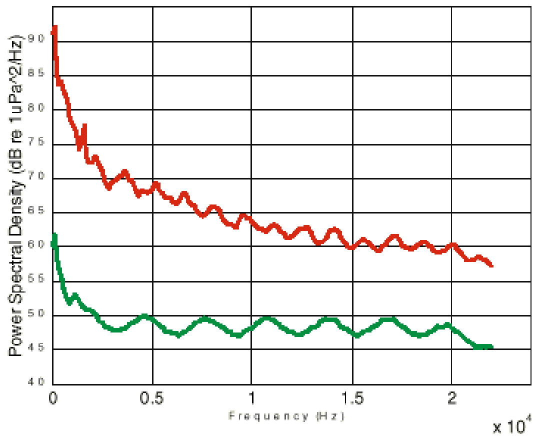
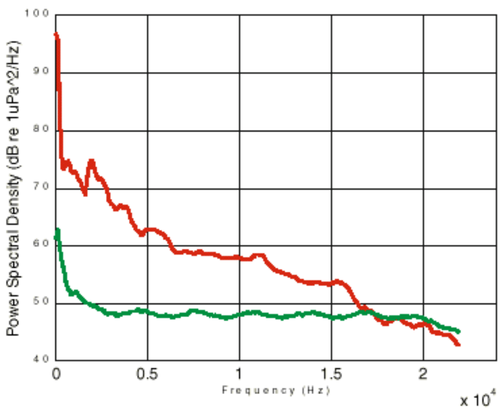


Station 10: Shannon Ferry

19th August, 2002



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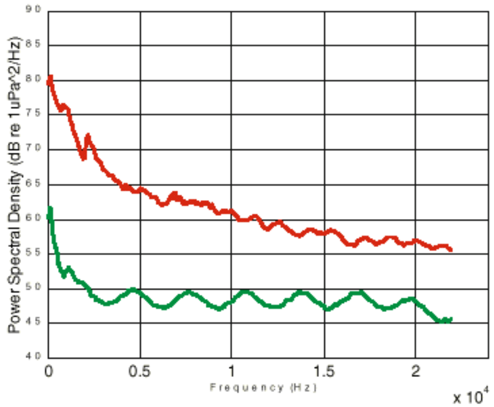
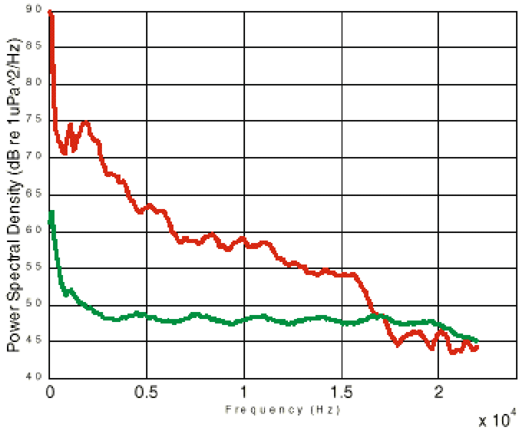


Station 11: Clonderlaw

19th August, 2002



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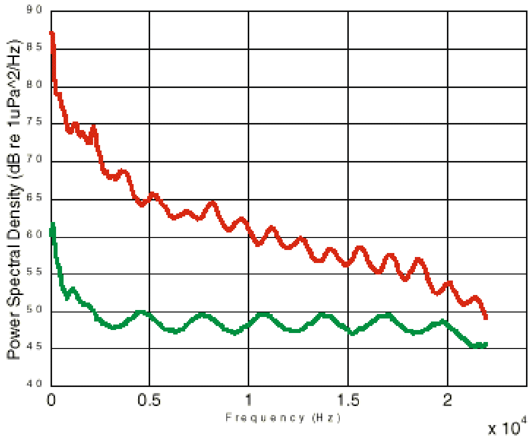

Station 12: Glin

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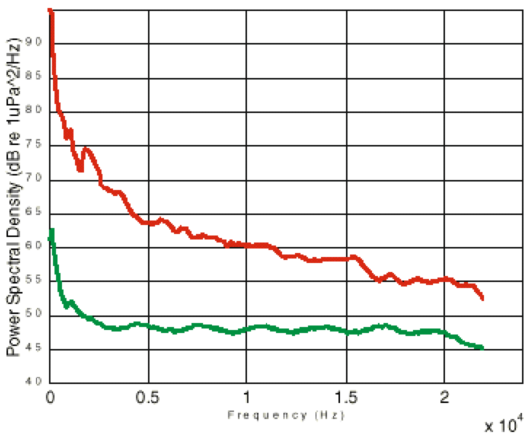

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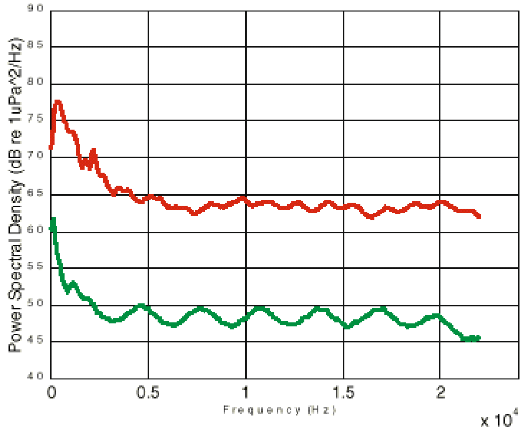
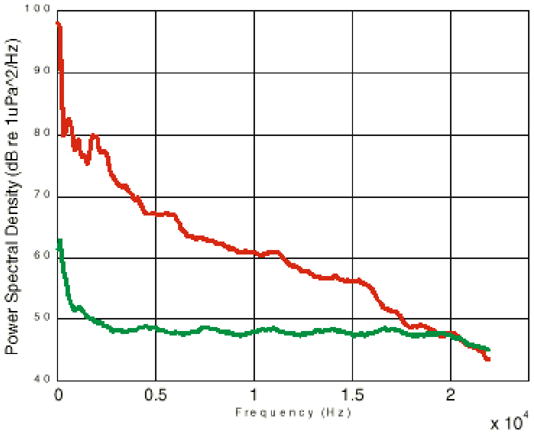


Station 13: Loghill

19th August, 2002



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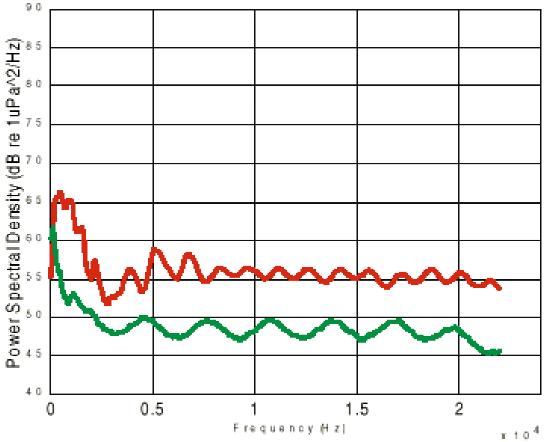
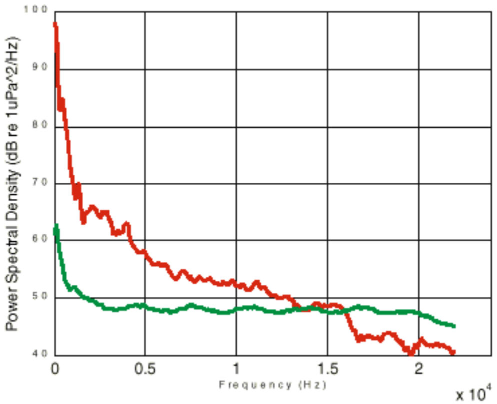


Station 14: Rinelon

19th August, 2002



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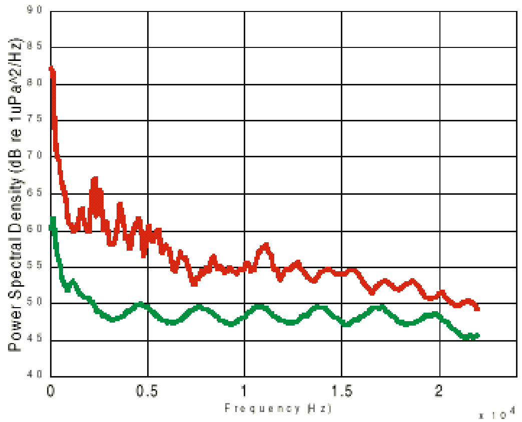
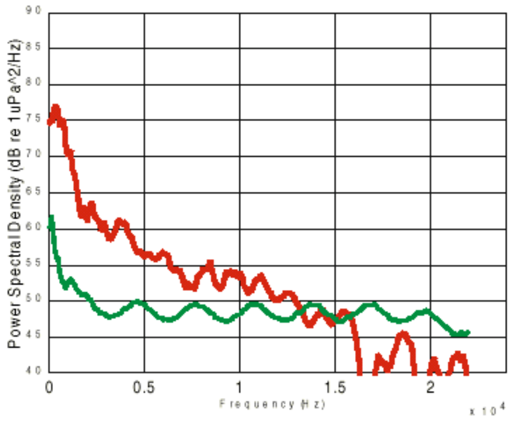


Station 15: Aughinish

20th August, 2002



Station 16: Reeves Rock

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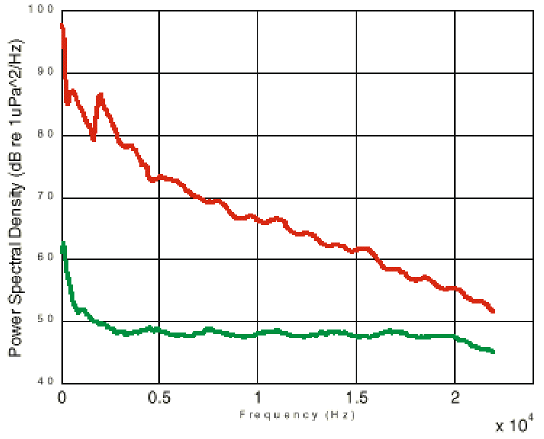

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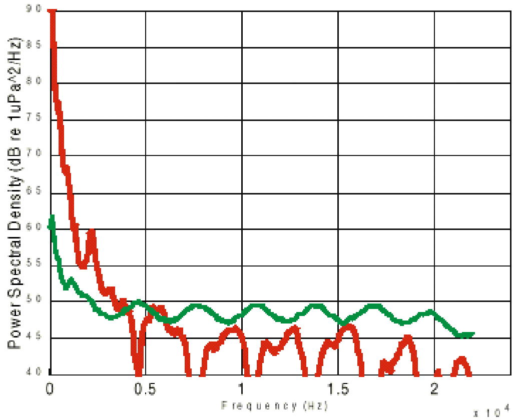
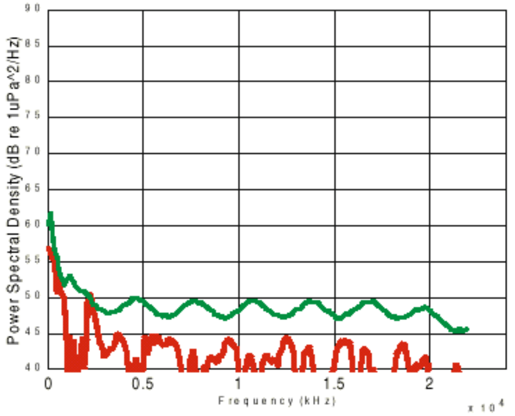


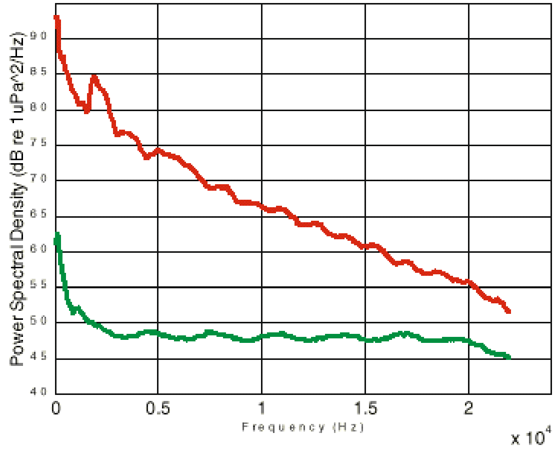
Station 17: Shannon Airport

19th August, 2002



Station 18: Fergus estuary

19th August, 2002



20th August, 2002