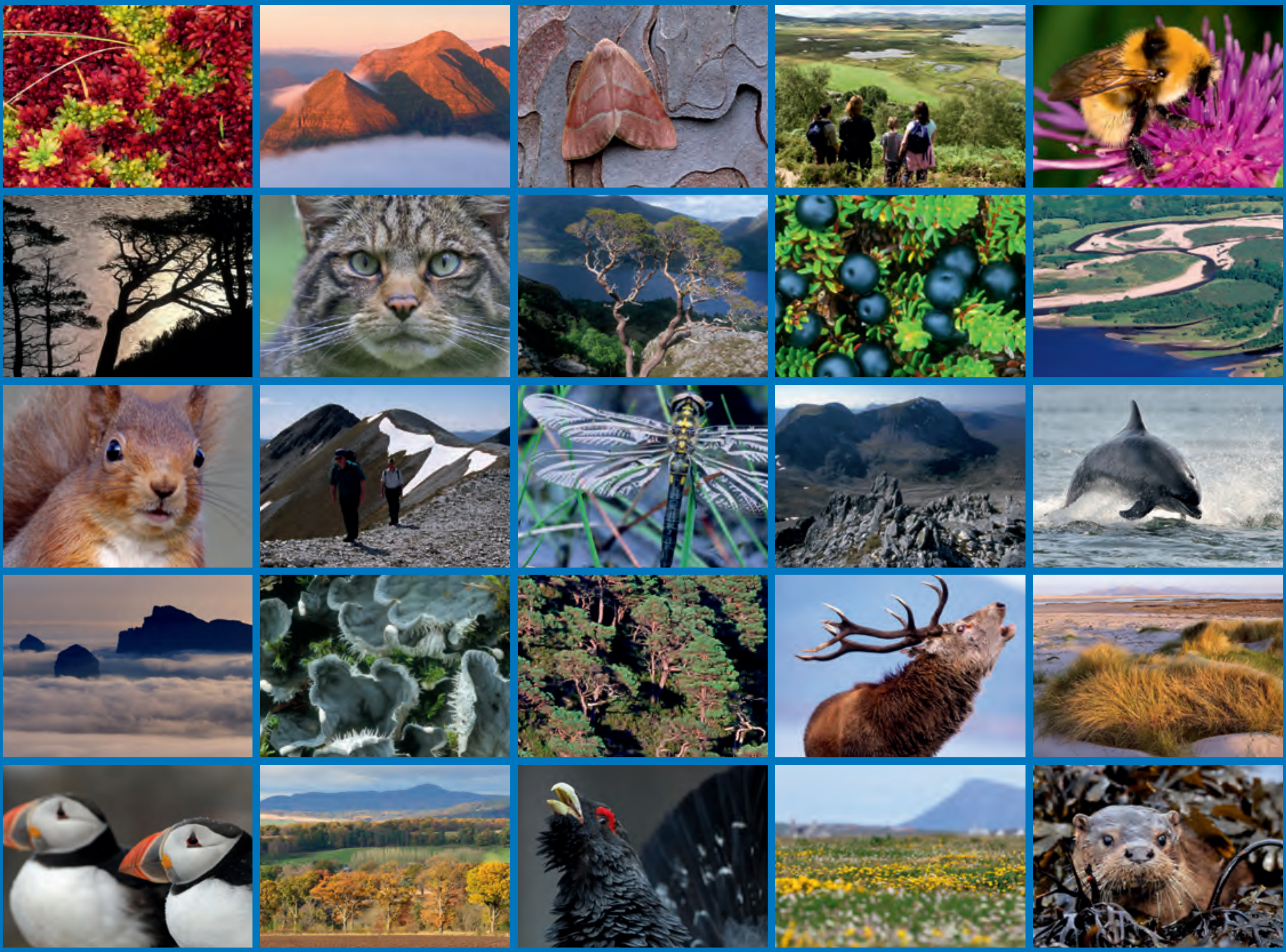
Scottish Natural Heritage
Commissioned Report No. 563

Fall of Warness Tidal Test Site: Additional Acoustic Characterisation



Scottish Natural Heritage
Dualchas Nàdair na h-Alba
All of nature for all of Scotland
Nàdar air fad airson Alba air fad

EMEC ORKNEY
The European Marine Energy Centre Ltd

COMMISSIONED REPORT

Commissioned Report No. 563

Fall of Warness Tidal Test Site: Additional Acoustic Characterisation

For further information on this report please contact:

Fiona Manson
Scottish Natural Heritage
Battleby, Redgorton
PERTH
PH1 3EW
Telephone: 01738 458641
E-mail: fiona.manson@snh.gov.uk

This report should be quoted as:

Harland, E.J. 2013. Fall of Warness Tidal Test Site: Additional Acoustic Characterisation. *Scottish Natural Heritage Commissioned Report No. 563.*

COMMISSIONED REPORT
Summary

Fall of Warness Tidal Test Site: Additional Acoustic Characterisation

Commissioned Report No.: Report No. 563
Project no: 13124
Contractor: EMEC / E.J. Harland
Year of publication: 2013

Background

Chickerell BioAcoustics was contracted by the European Marine Energy Centre (EMEC) to carry out work to further characterise the ambient noise field at their Fall of Warness tidal energy test site in Orkney, UK. The project was funded by Scottish Natural Heritage (SNH) and follows on from previous acoustic characterisations of the test site carried out by the Scottish Association for Marine Sciences (SAMS), Oban, UK (funded by Highlands & Islands Enterprise).

The work carried out by SAMS went some way towards characterising the baseline noise present at the site in the absence of any tidal energy converter (TEC) devices. This work quantified the ambient sound levels at the site in both ebb and flood conditions. Investigating the origins of the sounds was outwith the scope of the SAMS studies and this has been addressed in the current study.

The scope of the current SNH-funded project was to incorporate a review and identify any requirements for additional analysis of existing acoustic surveys at the site and to extend the acoustic dataset to provide a more comprehensive characterisation of the test site. This encompassed investigation of noise sources, including noise contributed by the presence of TECs. While the characterisation of noise from specific devices operating at the site was outwith the scope of this project, such characterisation could be an area of consideration for future work.

The current project called for three surveys to be carried out using drifting acoustic recorders. Initial surveys were carried out using the existing EMEC drifting hydrophone equipment but later surveys used an upgraded system, the Drifting Acoustic Recorder and Tracker (DART) system developed by Chickerell BioAcoustics and EMEC.

This report presents the results of analysing the data collected to date and shows that flow noise is a significant contributor to the ambient noise field within the test site. Other significant contributions to the noise field include shipping noise and noise from TEC devices operating in the test site. The report concludes that the noise from the TECs operating on site during the survey period is unlikely to significantly impact marine mammals using the area.

Main findings

Data collected and analysed during this project have enabled the ambient noise at the EMEC tidal test site to be characterised in the presence of some operating tidal energy converter devices. The following conclusions can be drawn from this study:

- The ambient noise levels measured are higher than those suggested by Urick (1975) for shallow water sites, but lower than those measured by Wilson & Carter (2008).
- The noise level of frequencies above 1 kHz can vary by at least 26 dB across the site; this is believed to be primarily due to flow-induced noise generation.
- Rain can raise ambient noise by up to 30 dB and this extends to lower frequencies than flow noise.
- It was not possible to locate the individual noise sources accurately as this was outwith the scope of this project, but future studies could investigate this further.
- Further work will be required to fully understand the effect of tidal flow on ambient noise based on experience gained from processing this dataset.
- Based on the data gathered during this study, it seems unlikely that the noise generated by tidal energy converters operating within the site would have a significant impact on marine mammals. However, further detailed studies will be required in order to gain more understanding of this.

For further information on this project contact:
Fiona Manson, Scottish Natural Heritage, Battleby, Redgorton, Perth, PH1 3EW.
Tel: 01738 458641
For further information on the SNH Research & Technical Support Programme contact:
Knowledge & Information Unit, Scottish Natural Heritage, Great Glen House, Inverness, IV3 8NW.
Tel: 01463 725000 or research@snh.gov.uk

Table of Contents **Page**

1. INTRODUCTION

This report has been produced for the European Marine Energy Centre (EMEC), Orkney, UK as part of a contract with Chickerell BioAcoustics, Dorset, UK. The work is funded by Scottish Natural Heritage (SNH) and aims to extend the acoustic characterisation of the EMEC tidal test site. This work follows on from previous studies to provide a baseline characterisation of the test site by the Scottish Association for Marine Sciences (SAMS), Oban, UK, using the Drifting Ears methodology developed for EMEC by SAMS. This study aims to verify these data, making recommendations for future additional analysis if appropriate, and to extend the acoustic dataset to provide a more comprehensive acoustic characterisation of the test site.

The EMEC tidal test site is located in the Fall of Warness between the islands of Eday and Muckle Green Holm in Orkney. Tidal currents can reach 7 knots on spring tides. The area has a hard seabed and is likely to be a low-loss acoustic environment.

Ongoing wildlife observations carried out by EMEC (commenced in 2005 and currently funded by the Scottish Government) have identified six species of marine mammal as commonly present at the test site. These are two seal species, three odontocete species and one mysticete species. The current study is scoped to characterise ambient noise at the site. However, some consideration is given to the possible effect of tidal energy converter (TEC) devices operating at the Fall of Warness test site on these species (looking only at the ambient noise characteristics and not the detailed noise signature of any specific operating device). This report also considers the likelihood of any detectable acoustic output from TECs causing any discernible behavioural change in marine mammals.

This report provides an acoustic description of the test site, taking into account data and findings from previous studies (Wilson & Carter, 2008; Wilson *et al*., 2010). The acoustic characterisation will be used as a reference by future developers deploying at the test site seeking to detect and characterise any acoustic output from their device operations.

2. REVIEW OF THE FALL OF WARNESS TIDAL TEST SITE

2.1 Physical Characteristics

The tidal test site is located in the southern part of Westray Firth between the islands of Eday and Muckle Green Holm (Figure 1).

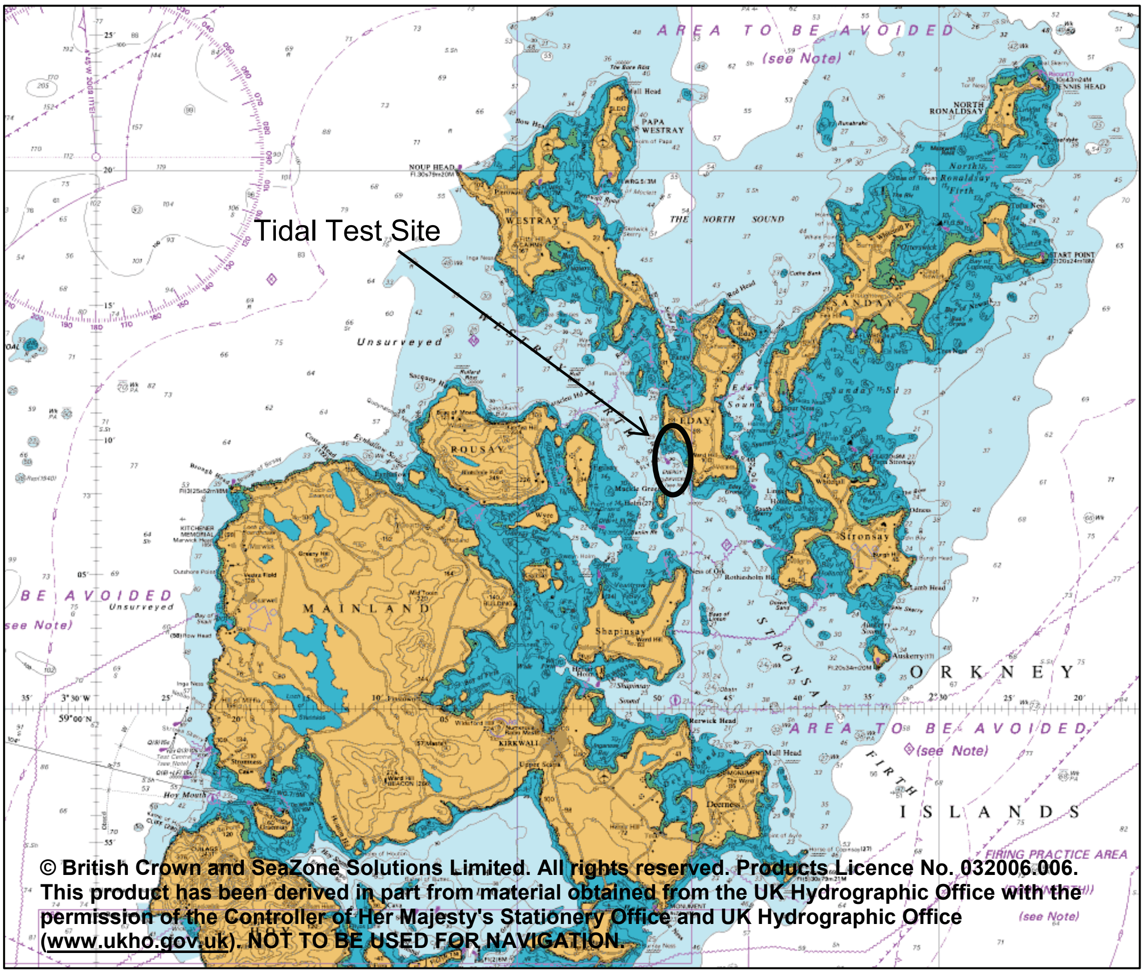


Figure 1. Location of the EMEC tidal test site at Fall of Warness.

The limits of the test site are shown by the white outline in Figure 2.

Over most of the site, the water depth is around 30-40 metres with a tidal race at the southern end between War Ness and Muckle Green Holm. The seabed is mostly rock with some coarse sand. The adjacent shorelines of Eday and Muckle Green Holm are mostly cliffs with boulders at the shoreline. Figure 2 also shows the approximate route of the cables to the individual test berths at the site.

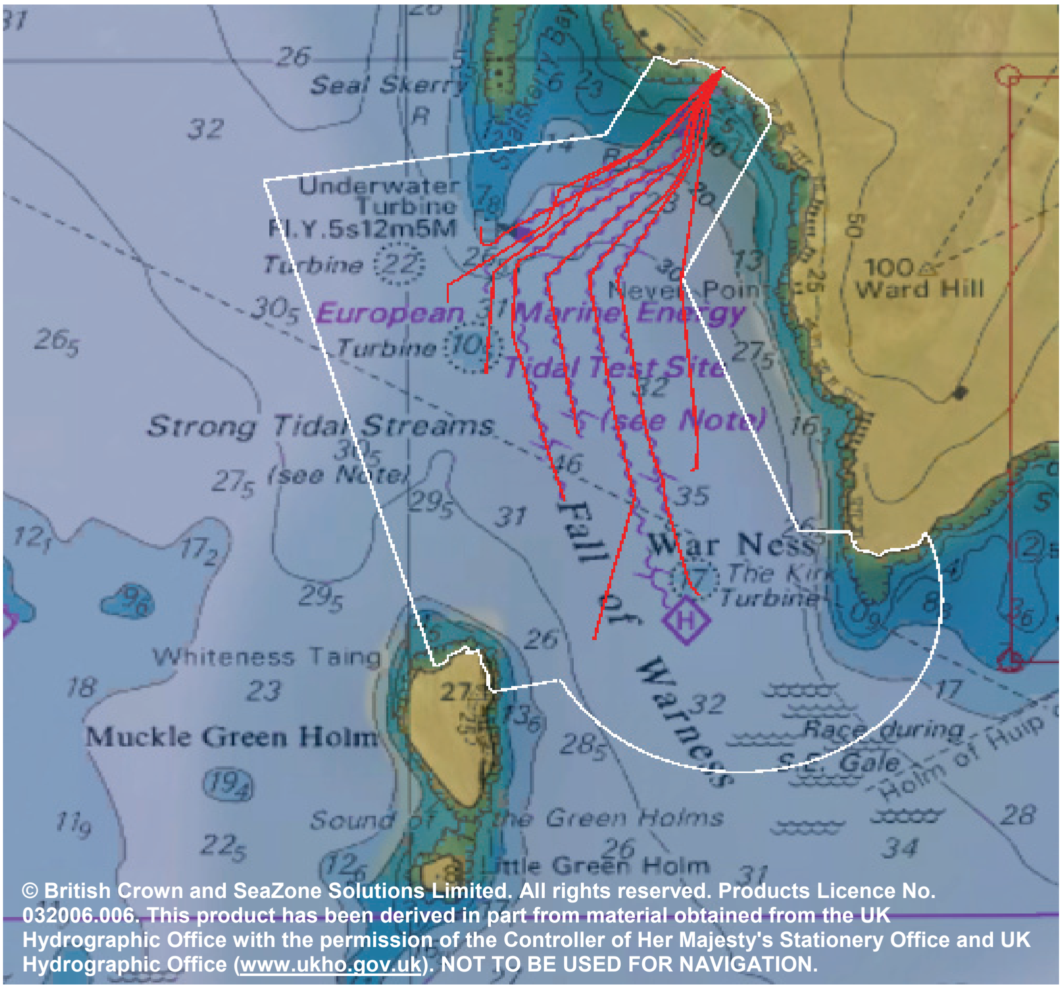


Figure 2. Limits of the EMEC Tidal Test Site and approximate route of cables to individual test berths.

2.2 Noise Sources

The area is used by local fishing boats and ferries with some larger shipping traffic passing through or nearby. Shipping noise will often be heard. A number of fish-farms operate in the area, and seal scarer devices associated with these may be heard. Construction and servicing vessels associated with onsite tidal energy devices also contribute to the noise field. As TEC devices are installed and become operational, these will also contribute to the above sources of anthropogenic noise.

The site is exposed to the north-west and south-east. Wave noise on the Eday and Muckle Green Holm shorelines will contribute to ambient noise in the area. The tidal current through the site can reach ~3.5 m/s (7 knots) during spring tides and it is likely that sediment transport and turbulent flow noise will make a significant contribution to ambient noise at the site. These strong currents will mean that the water is well mixed throughout the water column and acoustic ducts are very unlikely to form (acoustic ducts trap energy close to the surface of the water and are usually caused by vertical temperature structuring in calm water).

Wind and precipitation noise are also likely to be major contributors to the ambient noise field. Breaking surface waves will be present under some wind and tide conditions and will make a major contribution to the noise field.

Other naturally occurring sounds that can be expected to add to the noise field include the calls of marine mammals.

3. ACOUSTIC SURVEYS

This section describes the equipment used and survey work undertaken to provide data for input to this report.

3.1 Equipment Used

The initial surveys in the current project used the same Drifting Ears[1] equipment as previous surveys but the March 2012 surveys used the upgraded Drifting Acoustic Recorder and Tracker (DART) equipment. The general layout of the Drifting Ears system is shown in Figure 3. The arrangement for DART is very similar except that the electronics within the recording case have been upgraded to improve performance and reliability.

The system consists of a hydrophone deployed at about 5 metres depth, cabled to a flotation buoy and thence to a water-tight recording case. The recording case has a vertical pole with a flag attached to aid tracking, and a counter-weight to keep it upright. The recording case contains a recorder, GPS receiver, data storage and batteries. The hydrophone is suspended using shock cord to provide a degree of decoupling from surface waves. The hydrophone is suspended within a drogue to ensure that the hydrophone moves with the water mass rather than wind and surface effects.

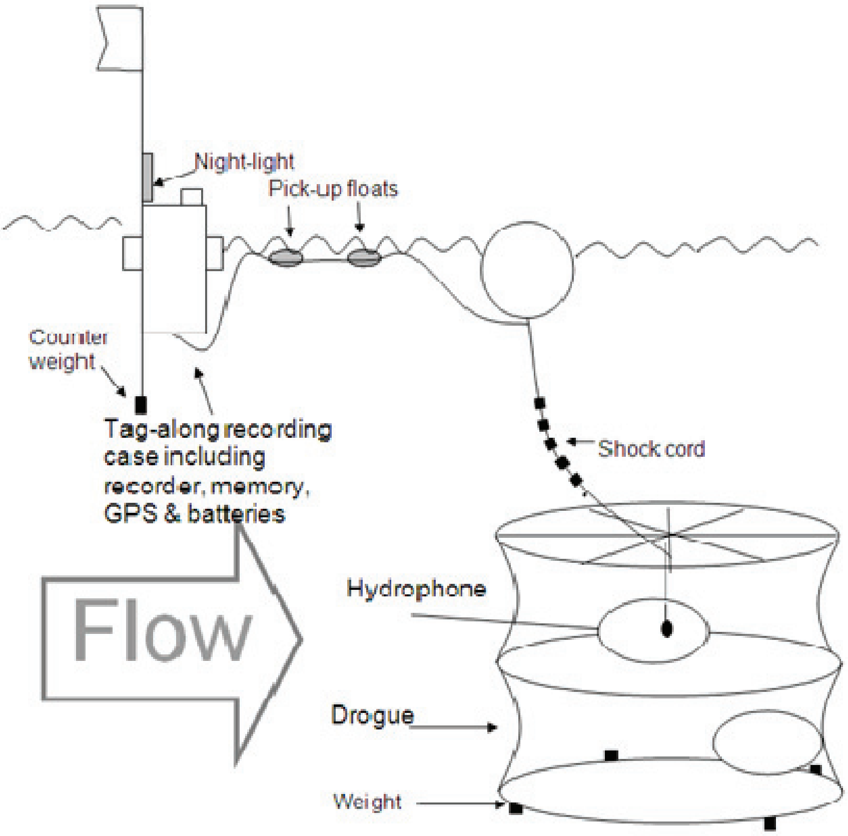


Figure 3. Components of the Drifting Ears/DART system

A free-drifting hydrophone package such as Drifting Ears/DART is used in sites with high tidal flows to overcome the problems of flow-induced noise in boat deployment systems, e.g. wave slap noise and cable strum, and the problems of securing and retrieving seabed

---

[1] See Wilson & Carter, 2008 for more information on the Drifting Ears equipment.

systems. They can also sample across the whole area rather than at a single point. They do have the limitation of travelling at up to 7 knots so the sample time in any one location is rather short. This can be alleviated by multiple deployments across the area.

Data collection can only take place under the following conditions:

- Sea state must be no greater than 4.
- Wind speed must be no greater than force 6.
- Visibility must be at least 3 miles and forecast to stay at least 3 miles for the duration of the survey period.
- All necessary safety paperwork has been produced and distributed appropriately.

These limitations are imposed by both safety and scientific requirements.

3.2 Previous Surveys

Two previous surveys of the area were carried out by SAMS, in January 2008 and June 2010. These surveys used the Drifting Ears equipment described above. Both surveys obtained good spatial coverage of the site and the resulting reports include noise maps of the area and information on the spectral content of the noise which describes the baseline acoustic characterisation representative of the site.

The following useful information can be gleaned from this work:

- A mean spectrum of noise for the site.
- An estimate of how much the noise varies across the site.
- Maps of the noise for one specific set of circumstances and for a limited spatial distribution across the site.
- An estimate of how the noise varies with drift speed.

In order to understand the noise characteristics of the site better, a deeper understanding of all aspects of the noise must be gained. Questions from previous surveys that the current project will attempt to answer are:

- Why is the noise patchy in distribution?
- Is the spatial distribution of the noise stationary? If not, what factors affect the spatial distribution?
- What are the major contributors to the ambient noise field in the tidal test area?
- What is the distribution of noise across the tidal test area in the areas not yet surveyed?

3.3 Equipment used in Current Surveys

Three surveys were initially planned as part of the current project, to be carried out in September 2011, November 2011 and February 2012. The September survey coincided with bad weather and was affected by equipment failure, resulting in just one useful run being achieved. The November survey was attempted but, as in September, bad weather and equipment failure meant that no meaningful data were collected. Due to poor weather, the February survey was delayed until March 2012.

The equipment problems encountered during the September and November surveys included issues with the battery packs required to power the various components of the Drifting Ears system, and failure of the actual recording devices.

In the DART system, the hydrophone interface, recorder and battery supplies have been replaced by a Wildlife Acoustics Inc. Song Meter SM2+ recording unit (SM2+) and improved hydrophone connection. The whole system is powered by a single battery pack. The SM2+ recorder also incorporates an integrated GPS logger so that the location of the unit is recorded along with the acoustic signal rather than in a separate recorder as with Drifting Ears. The hydrophone used, Cetacean Research C55[2], is the same for both Drifting Ears and DART, and the mounting arrangement in the drogue has also been retained to ensure compatibility between the data collected in this and previous studies. For the March 2012 survey, two DART units were available.

3.4 September 2011 Survey

This survey took place on the 20th September 2011. Three Drifting Ears units were deployed but only one unit recorded usable data, which gave a good example of precipitation noise at the site. It also detected a sound that may have been a seal scarer device. This run took place two hours after slack water on a flood tide during the neap part of the tidal cycle. Figure 4 below shows the track achieved in this run. The labels used to identify the tracks in Figure 4 and all subsequent diagrams describe the Drifting Ear/DART unit number and the run number, e.g. ‘D2R1’ refers to Drifting Ear 2, run 1.

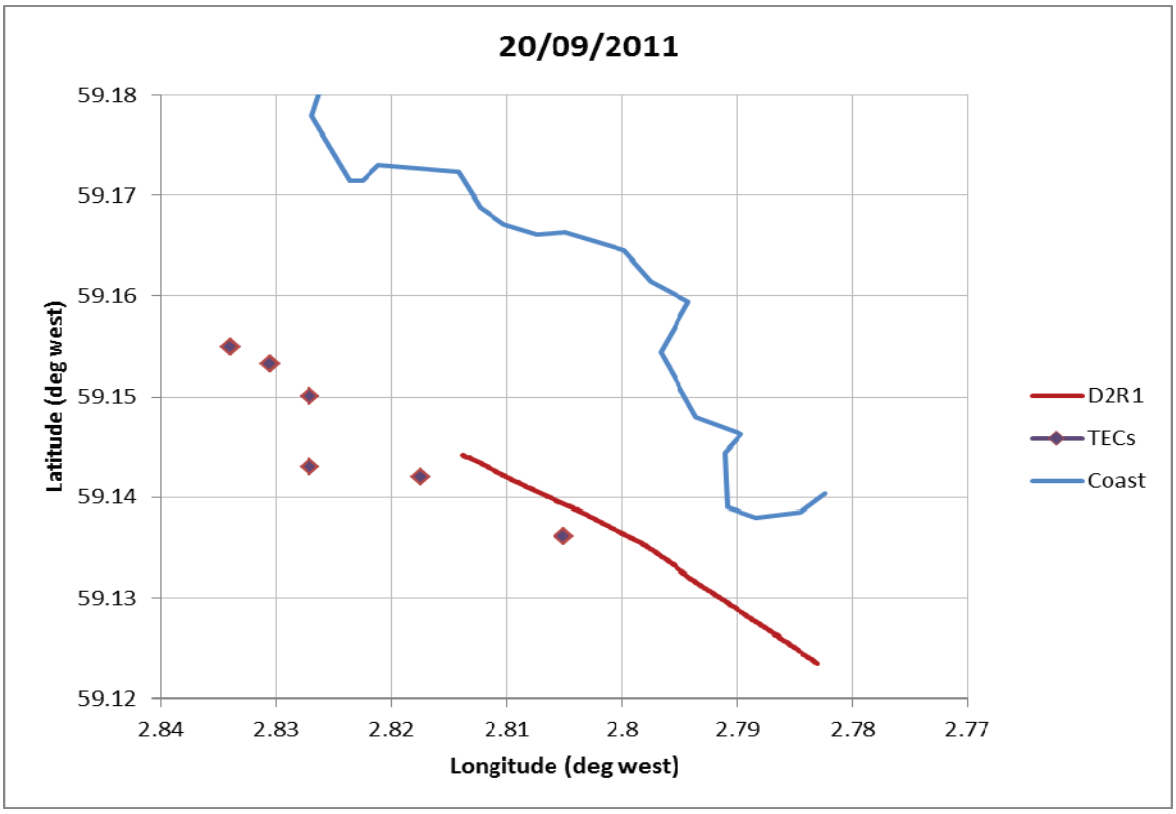


Figure 4. Track showing run achieved on 20/9/2011

3.5 March 2012 Surveys

The survey period coincided with good weather and two full days of data collection were achieved on the 23rd and 26th of March 2012. The peak of the spring tides occurred on the 23rd so the maximum tidal current was encountered.

---

[2] The C55 hydrophone is a direct replacement for the C54XRS referred to in the previous studies.

Twenty-six runs were achieved covering ebb and flood tides and slack water, using DART unit numbers 1 and 4. Analysis of the data produced noise plots for each run in a 2 kHz bandwidth centred on frequencies of 2.5, 5, 10 and 15 kHz. The aim was to capture the variation in levels across the test site at the different tidal states. The four frequencies were chosen to exclude the sound energy from the tidal generators operating on the site while capturing effects due to flow noise and wave noise. Mean spectra were also produced and the principal contributors to the sound field identified.

The runs achieved on the two survey days are shown in Figures 5 and 6 and summarised in Table 1. The red squares on these plots are the likely locations of test berths for TECs that may have been operational during the survey periods.

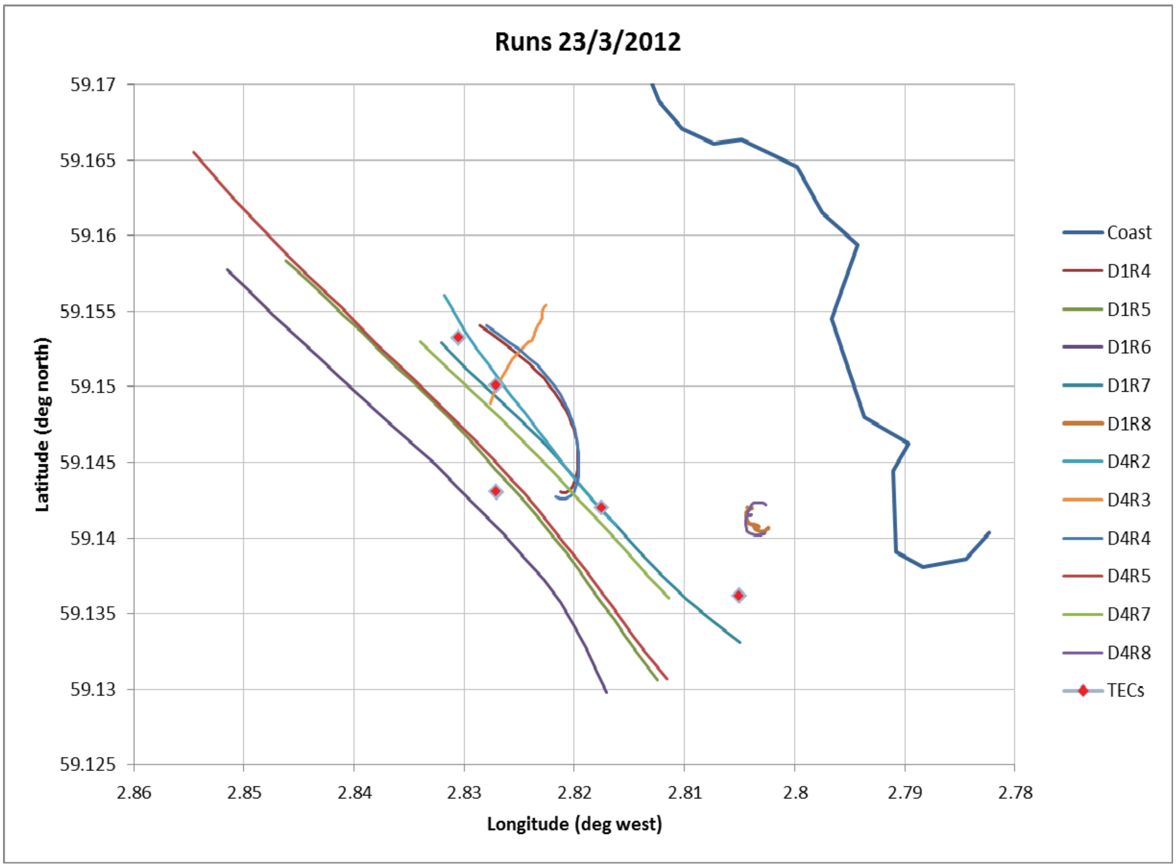


Figure 5. Tracks showing DART runs achieved on 23/3/2012

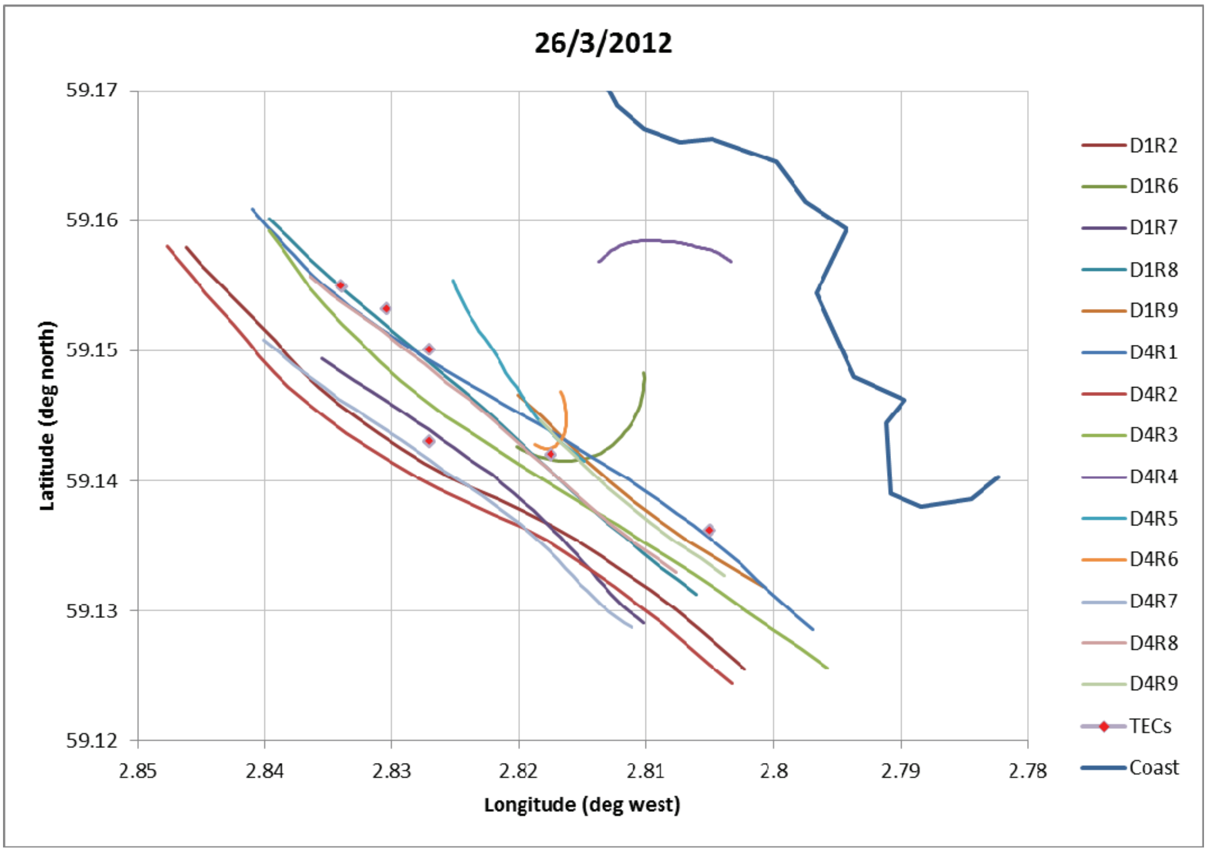


Figure 6. Tracks showing DART runs achieved on 26/3/2012

On some runs, the drift rate varied significantly (see the plots in Annex 2) and this variation is shown in the drift rate column in Table 1. Of the 26 data files containing useful data, 9 were collected on the flood tide, 13 on the ebb tide and 4 at slack water. Both DART units were deployed on all runs, but occasional problems were experienced with the SD memory cards used in the recorders. Where only one unit is shown in use in Table 1 this indicates that the other unit suffered a memory card failure. The exact reason for these occasional memory card failures is as yet unknown but one possibility is that it could be due to mechanical jarring of the units as they are deployed or recovered.

The weather on both days was fine and sunny with light to moderate winds and sea state 2. The drift rate of the DART units was calculated from the GPS information recorded with the audio data.

Table 1. Summary of DART runs achieved in March 2012 surveys

Date	Run	Deployed	Duration (minutes)	Tide	Drift rate (knots)	ID
23/3/2012	1	D4	23	Flood	6	D4R1
	2	D4	18	Flood	4.5	D4R2
	3	D4	25	Flood	0.5	D4R3
	4	D1, D4	39/33	Slack	0-2	D1R4; D4R4
	5	D1, D4	33/33	Ebb	4-5	D1R5; D4R5
	6	D1	20	Ebb	5-6.5	D1R6
	7	D1, D4	12/14	Ebb	7-8	D1R7; D4R7
	8	D1, D4	38/36	Ebb	0.5	D1R8; D4R8
26/3/2012	1	D4	37	Flood	3-4.5	D4R1
	2	D1, D4	27/28	Flood	5-6.5	D1R2; D4R2
	3	D4	25	Flood	5.5-7	D4R3
	4	D4	59	Flood	0.4	D4R4
	5	D4	25	Flood	2	D4R5
	6	D1, D4	31/32	Slack	0.5-1.5	D1R6; D4R6
	7	D1, D4	31/32	Ebb	2-4	D1R7; D4R7
	8	D1, D4	22/18	Ebb	4.5-6	D1R8; D4R8
	9	D1, D4	10/8	Ebb	6-7	D1R9; D4R9

4. DATA ANALYSIS

After each survey the data collected was scanned as an initial quality check and to identify key features to be looked at in more detail in the main analysis. This showed up a number of minor problems, including bubble noise as air escapes from the drogue rings and what appear to be collisions with drifting debris. Most of the recordings contain noise from operating TECs and some contain the noise of distant shipping, so it is not possible to fully explore the ambient noise field at low frequencies.

A full analysis of the data collected in the surveys is presented in Annex 2 of this report.

4.1 Spectra and Levels

Figure 7 below shows typical mean spectra from DART 1 on runs 2 and 6 on the 26th March. The sections of data were chosen to minimise the effect of ship and TEC noise. The plot is a one minute average of a 512 point Fast Fourier Transform (FFT). One minute was used for comparability with the results presented in Wilson & Carter (2008). The vertical axis has been corrected with the calibration factor (described in Annex 1 of this report) and also for the bandwidth of the FFT to give spectrum level.

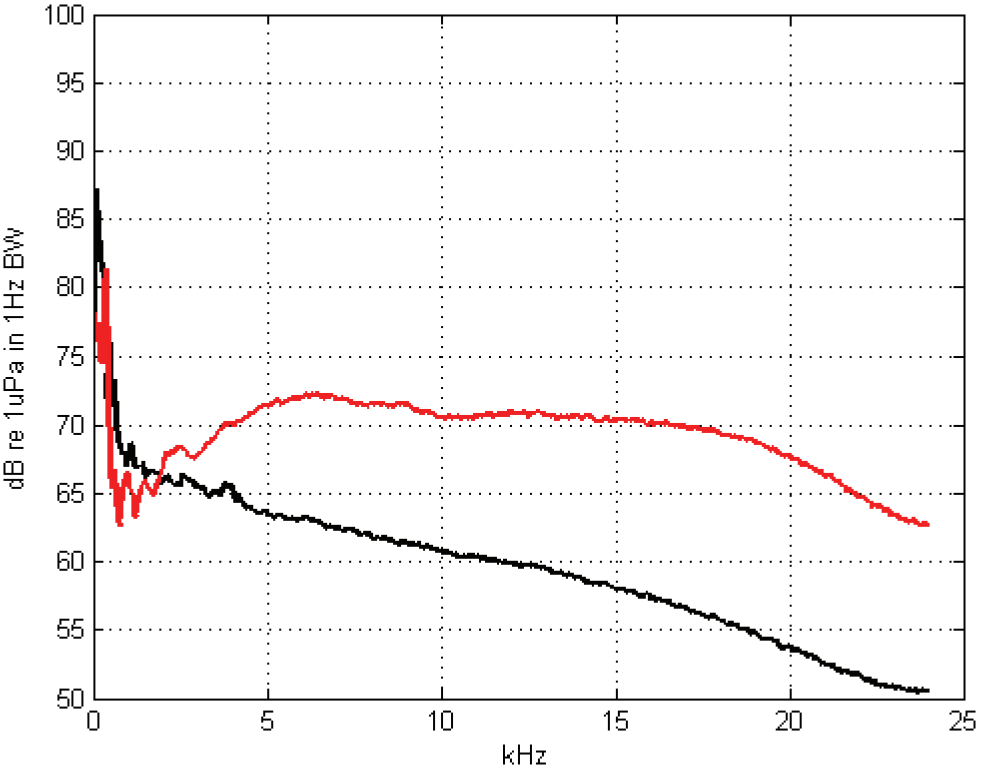


Figure 7. DART 1, runs 2 and 6 mean spectrum

The noise rises at low frequencies and this is usual at such sites. In this case, this may also include sound from the TECs present. The black plot is the spectrum at slack water while the red plot is the spectrum with 6 knots tidal current. The increase in noise above 2 kHz is very apparent. The levels at frequencies above 2 kHz are higher than those suggested by Urick (1975) but are approximately 35 dB lower than those found by Wilson & Carter (2008) as shown in Figure 9 in that report. Further work would be required in order to determine the reason for this discrepancy.

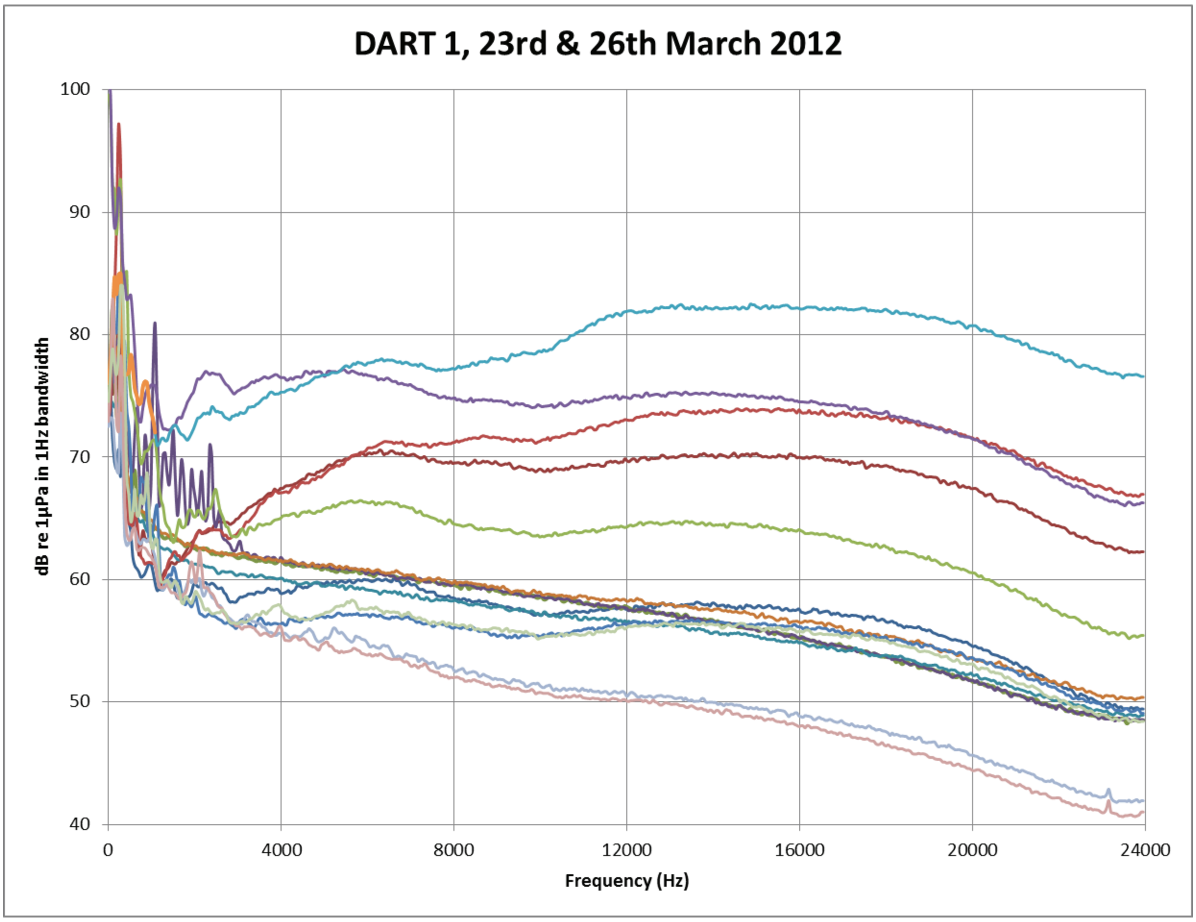


Figure 8. Composite of DART 1 runs

Figure 8 is a composite of mean spectra from the quietest and loudest parts of each of the runs for the DART 1 unit. A similar plot for DART 4 is shown in Figure 9. These plots are formed by taking one minute mean spectra for the quietest and loudest part of each run. They are grouped by DART unit. The spectra have been selected to minimise noise contributed from the support boat and self-noise effects such as rubbing.

These plots illustrate the variation that may be expected in ambient noise levels. The two major contributors are machinery noise and flow/wave noise. The machinery noise is from distant shipping and operational TECs and shows as the peak below 2 kHz. The broad peak around 15 kHz is due to flow and wave noise.

The range of spectra captured by the two units are broadly similar although it does appear there is a small difference between the two units at the lowest noise levels. The reason for this is not clear from this data set.

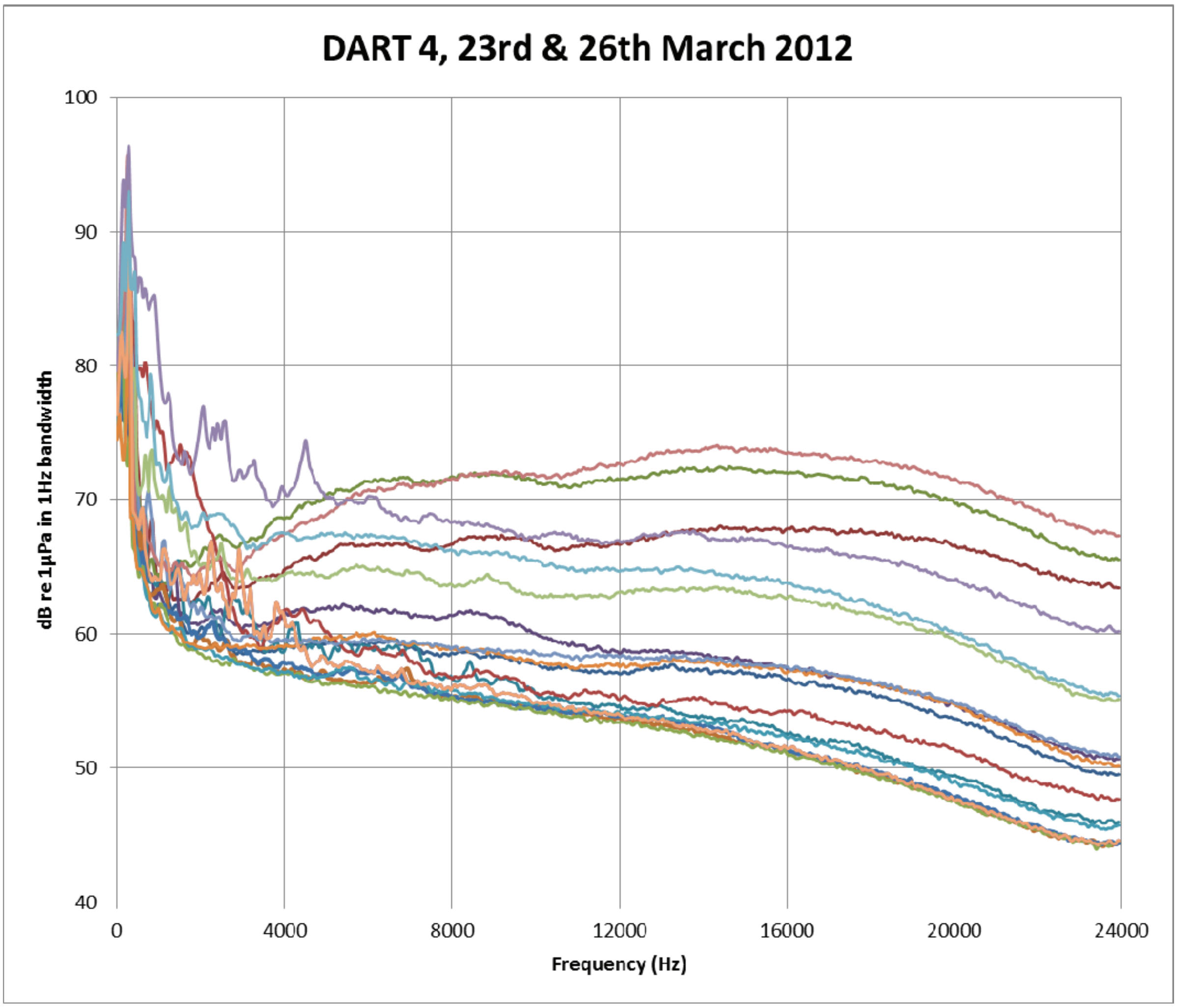


Figure 9. Composite of DART 4 runs

4.2 Variation in Sound Levels

The data for each run were processed to give sound levels in four 2 kHz bandwidths centred on 2.5, 5, 10 and 15 kHz. Examples of these data are shown in Figures 10 to 13, together with the full band spectrogram for each unit for run 2 on the 26th March. The vertical axis of the signal level plots is set at 50-100 dB re 1µPa in a 1 Hz bandwidth to ease comparison. The spectrograms cover 0-24 kHz on the vertical axis. For both plots the horizontal axis is time in minutes.

Annex 2 contains a full set of the four frequency plots for all of the runs, together with comments on the sounds observed during these runs. The plots shown here are typical examples of these plots.

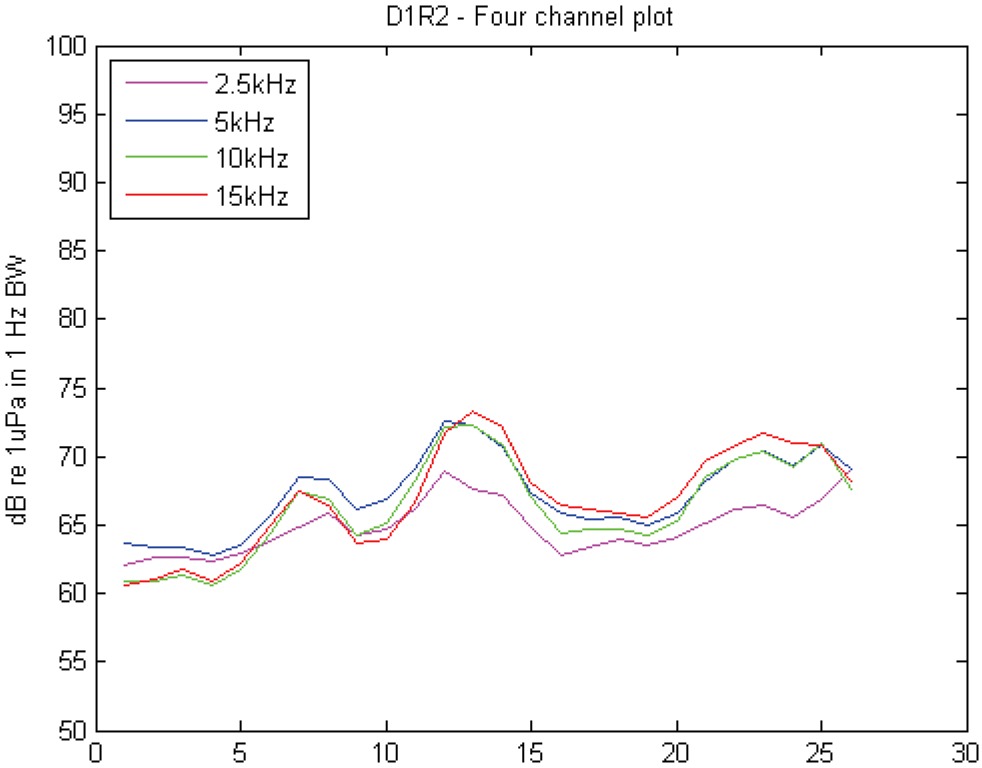


Figure 10. Sound levels, DART 1, run 2 on 26/3/2012

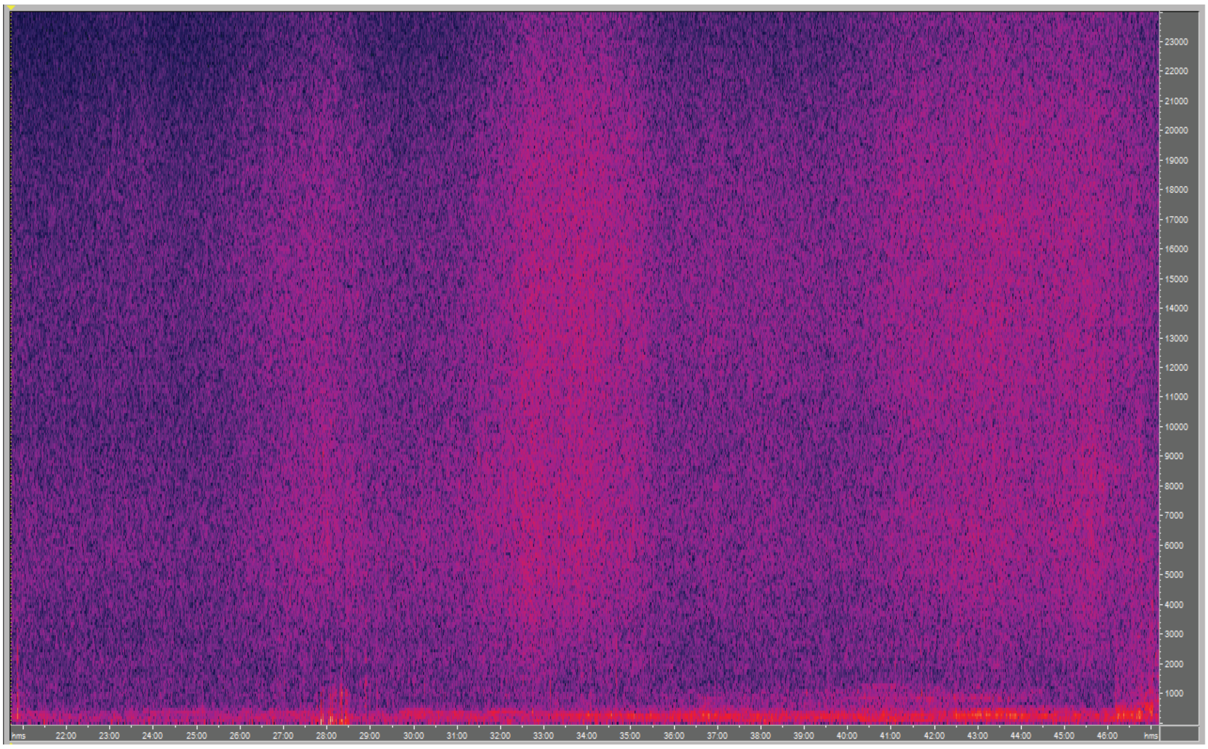


Figure 11. Spectrogram for DART 1, run 2 on 26/3/2012

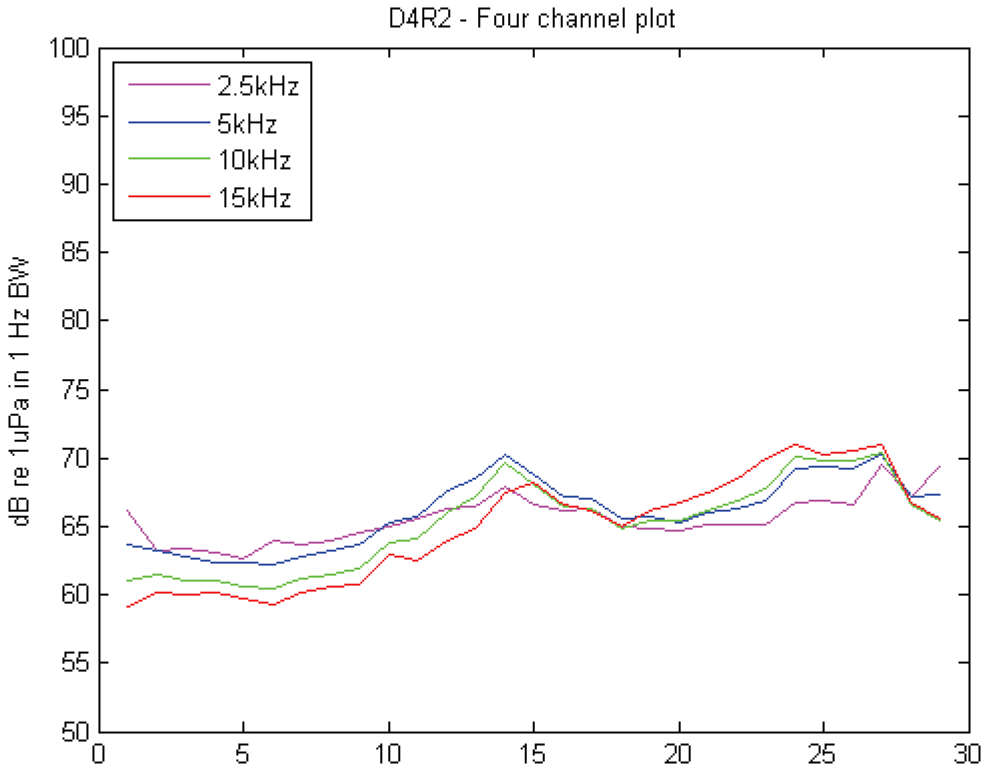


Figure 12. Sound levels, DART 4, run 2 on 26/2/2012

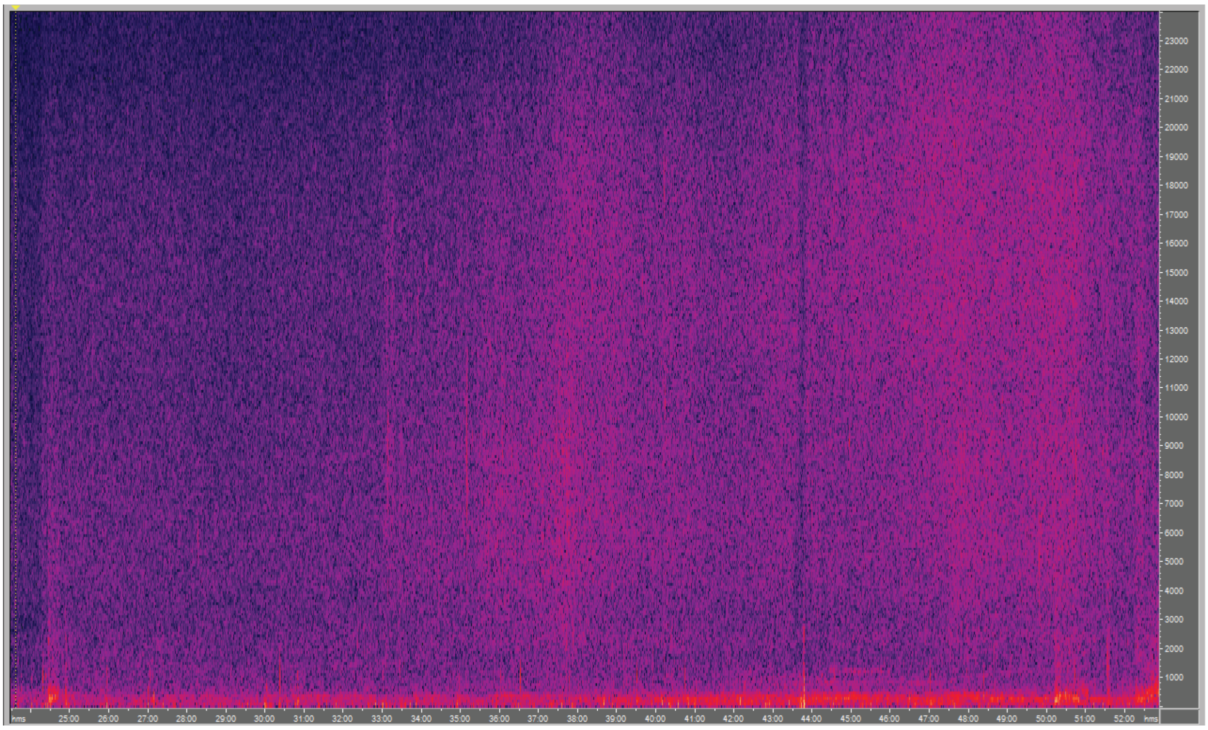


Figure 13. Spectrogram for DART4, run 2 on 26/3/2012

The sound from the operating TECs is seen as the bright band along the bottom of the spectrograms with most of the energy below 1 kHz. The unit passed close to one TEC and an increase in the low-frequency sound level can be seen about 70% across the plot. The broad bands of high frequency noise are due to flow noise and only occur when a strong tide is running. Figure 6 shows that DART 4 tracks further to the west than DART 1 and this is reflected in the plots. DART 1 detects three sources of sound while DART 4 only hears two sources and the levels from these are reduced compared with DART 1. This run was on the flood tide running at a calculated 5-6.5 knots. It can be seen from Annex 2 that at higher flow rates the sound levels can be 10 dB higher.

4.3 Dominant Components of Ambient Noise

Processing the various data files suggested that the following were the dominant sources of ambient noise.

Shipping noise

While not a primary ferry route, the area is used regularly and frequently by ferries in bad weather, so shipping noise is regularly heard. There is also occasional use by fishing boats and pleasure craft. The area is also visited by various vessels associated with installation and maintenance work at the test site. Based on data available to this study, shipping noise may dominate the sound field for around 10% of the time. Figure 14 shows a sample spectrogram from a fishing boat passing through the area. The plot covers 0-24 kHz on the vertical axis with time covering 2.5 minutes along the horizontal axis.

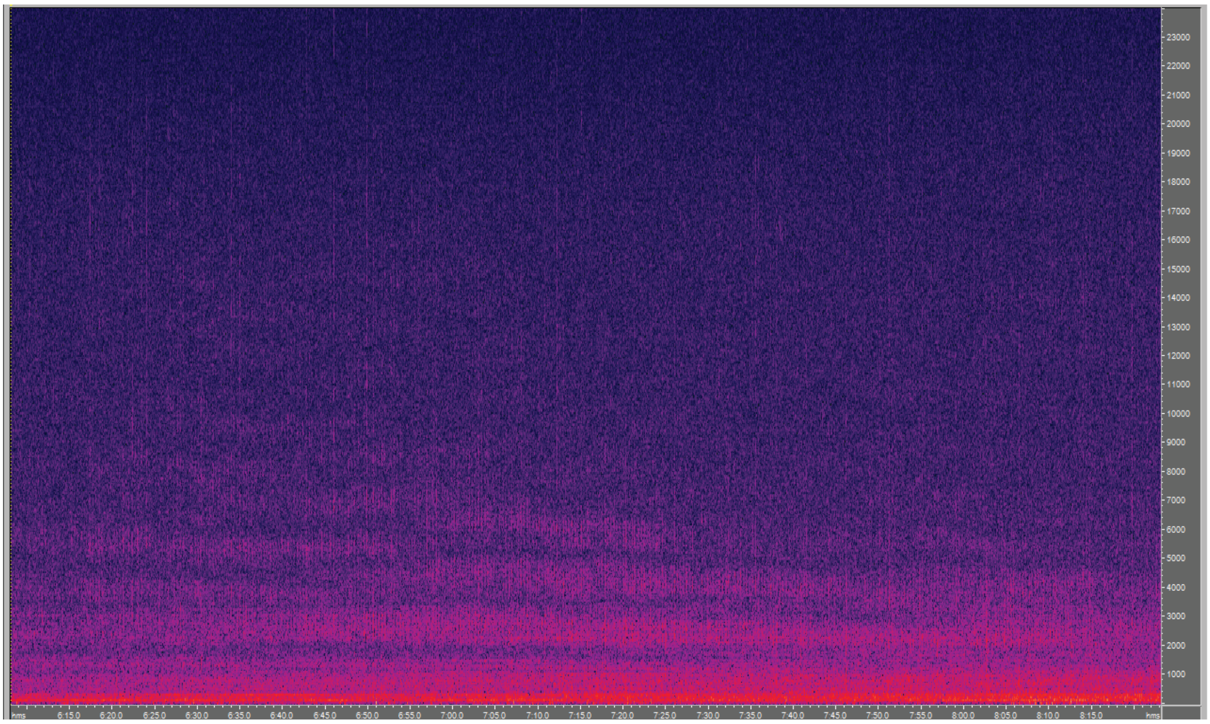


Figure 14. MV KARIN passing close to DART 4, run 5 on 26/3/2012

Tidal generator noise

A number of TECs were installed at the test site during the survey period. Three distinct sounds were identified that are believed to come from these units. These were (1) a whirring sound varying in pitch; (2) a whirring sound with steady pitch, similar to a hum sound; and (3) a regular ticking sound. These sounds will be referred to as type 1, type 2, and type 3 respectively.

An example of type 1 sound is shown in Figure 15. This is a spectrogram of the sounds with frequency on the vertical axis from 0 to 3 kHz and time along the horizontal axis covering approximately 34 seconds. The sound consists of a number of spectral components with the strongest component around 250 Hz. Harmonics can be identified up to 2,500 Hz. This sound was strongest in the southern section of the site.

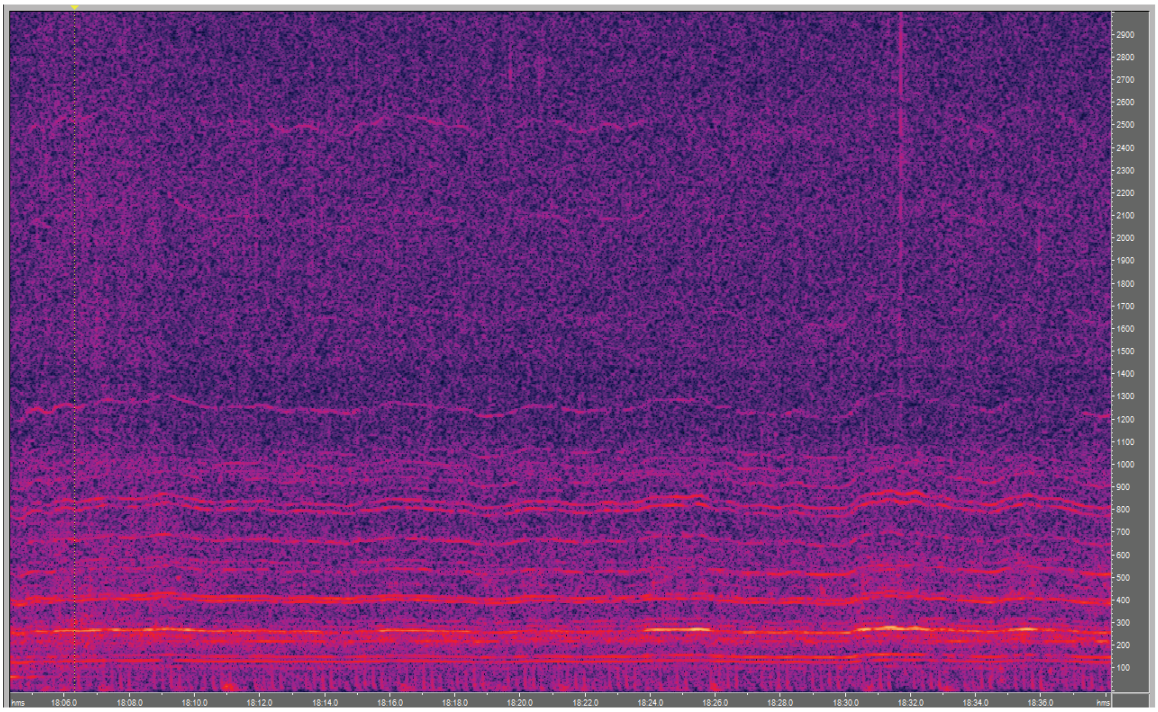


Figure 15. Tidal generator noise - varying rate. DART 1, run 7 on 23/3/2012

An example of type 2 sound is shown in Figure 16. The vertical axis is 0-3 kHz and the horizontal axis is time covering approximately 2 minutes.

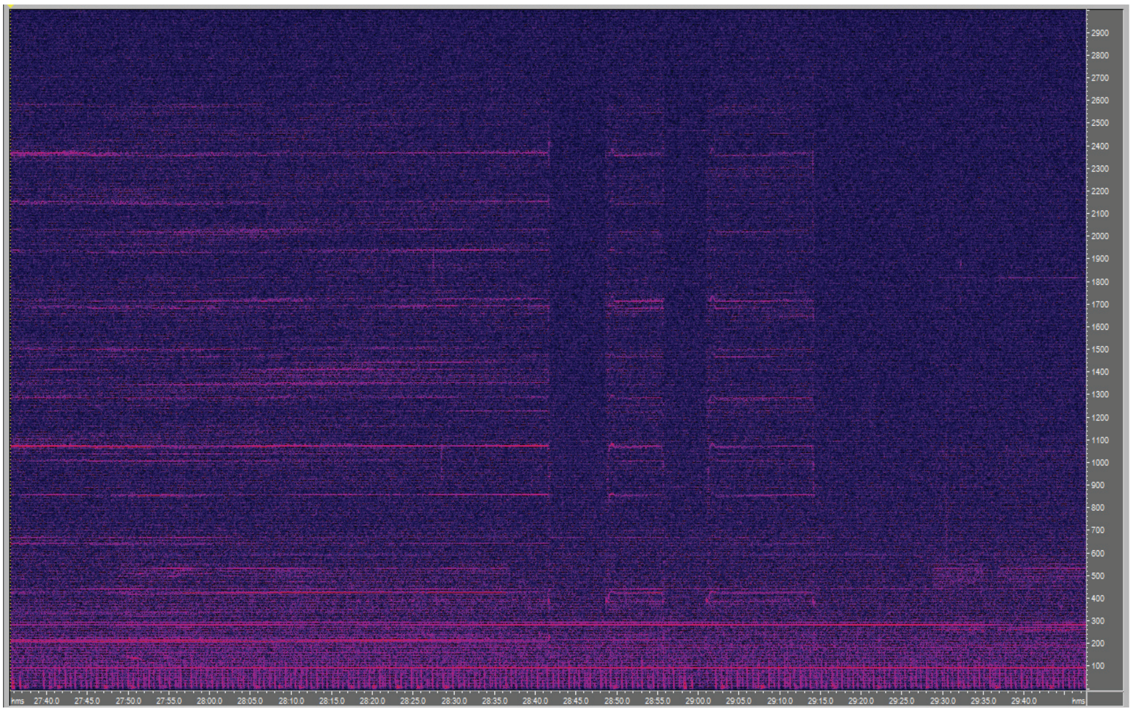


Figure 16. Tidal generator noise - constant pitch. DART 1, run 6 on 26/3/2012

There are two strong spectral components on 100 and 300 Hz which run continuously with additional machinery that turns on and off contributing components at frequencies up to 3 kHz. The machinery component can be seen turning on and off several times in Figure 16. This sound is loudest in the middle section of the site.

Type 3 sound was identified as a regular ticking not unlike that of a grandfather clock. An example is shown in Figure 17. The vertical axis is 0-8 kHz and the horizontal axis is time with a span of approximately 10 seconds.

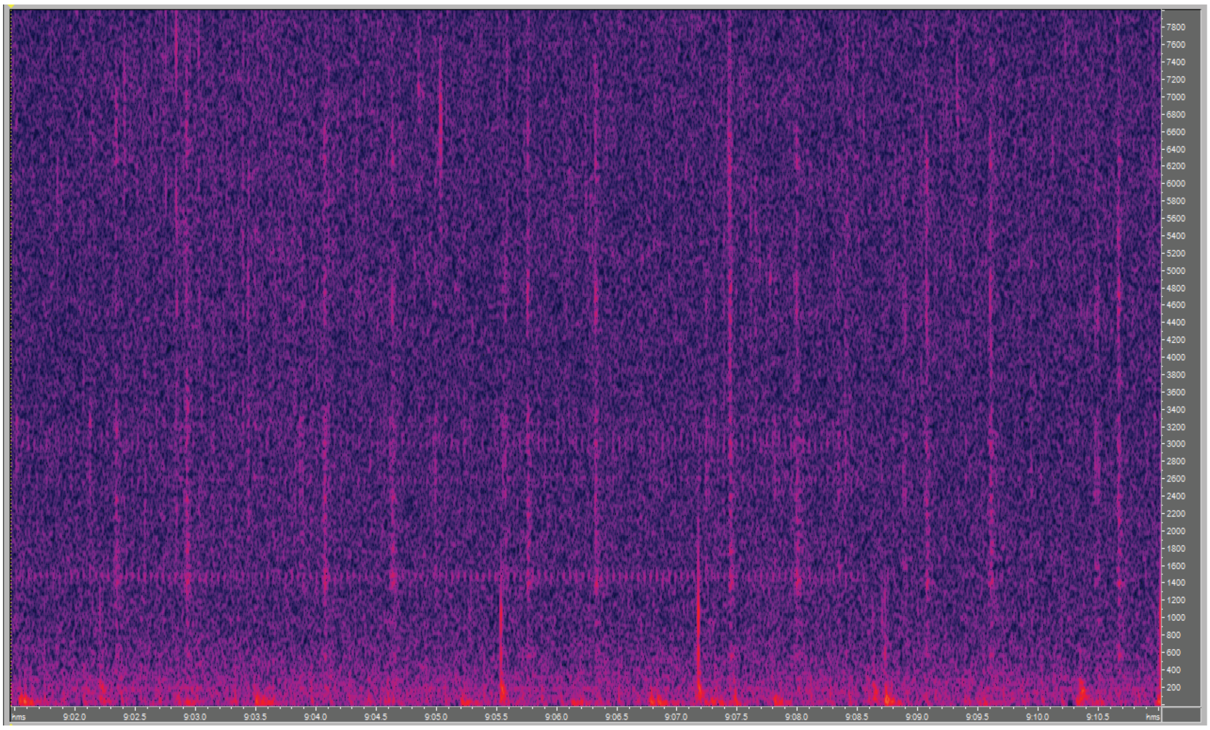


Figure 17. Regular ticking sound, DART 4, run 1 on 26/3/2012

The ticking shows as the vertical bars that occur across the plot in a regular pattern of three or four ‘ticks’. The repetition rate of the pattern was about 0.75 seconds on run 1 on the 26th March. For run 8, the repetition rate had speeded up to 0.53 seconds. One tick of each group has energy down to very low frequencies, the rest have energy above 500 Hz. There is also machinery noise which can be seen at 1.4 kHz and 2.8 kHz. This switches off about three quarters of the way across the plot. This sound is loudest in the north and east of the test site.

Wind and wave noise

These are likely to be major contributors to the ambient noise field on this site. Unfortunately they were not significant contributors to the noise field during the September and March surveys.

Precipitation noise

Run 1 on the 20th September 2011 provided a good example of precipitation noise. This is discussed in Annex 2 and the spectrogram is shown in Figure 18. The vertical scale is 24 kHz and the horizontal scale is approximately 2.5 minutes. There are two bands of noise visible from two heavy rain showers passing through. Note that it also appears that the unit is passing a source of flow noise which extends beyond where the rain has stopped. The rain noise extends to much lower frequencies than flow noise and appears to raise ambient noise levels around 30 dB. This agrees with the figures suggested by Urick (1975).

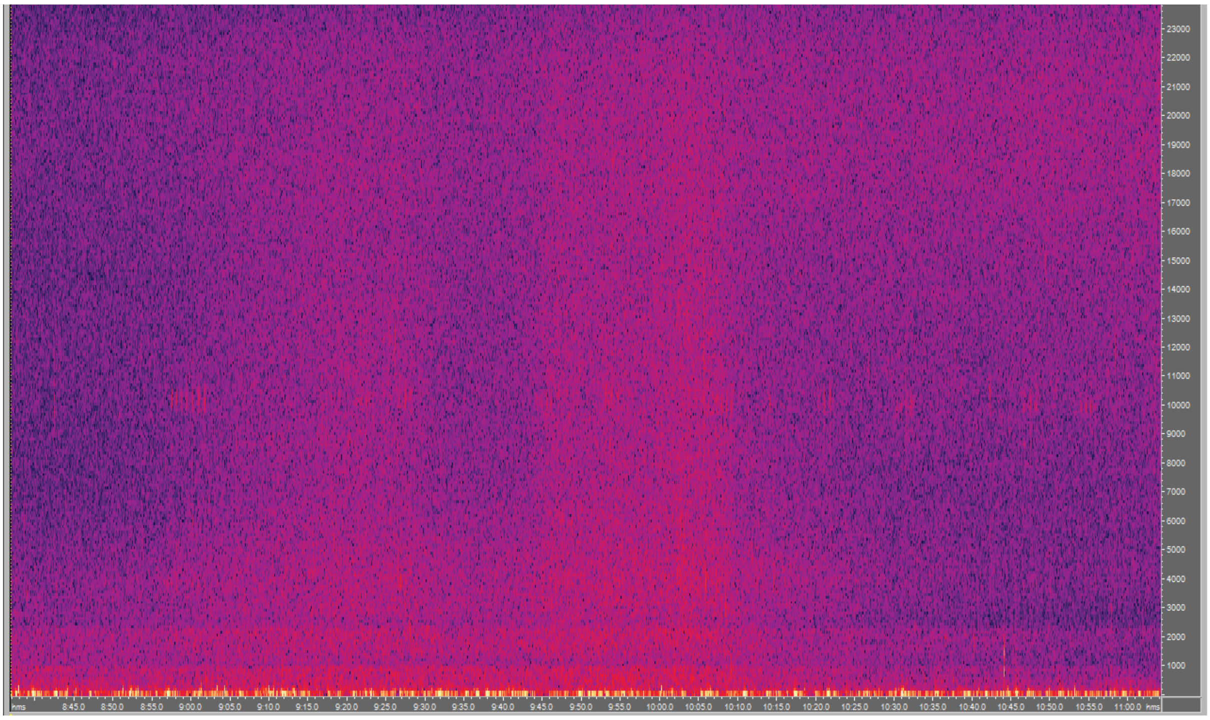


Figure 18. Precipitation noise. Drifting Ear 2, run 1 on 20/9/2011

The pulses that can be seen around 10 kHz are the possible seal scarer device discussed below.

Flow noise

The results set out in Annex 2 suggest there are at least five sources of high frequency sound within the test site and these appear to be from flow noise. The source in the south-east of the site is most likely to be the tidal race and overfalls that develop in this area during strong tides. The other sources are likely to be associated with bottom features causing strong currents around obstructions. It may also be possible that the anchoring arrangements and cabling for the TECs may be triggering the noise generation mechanism.

Chain noise

At high currents, chain noise can be heard but it was not possible to locate the source. It is a large chain as the resonant frequency is low.

Seal scarer

A pulsed sound was heard in the south-east of the area during the September 2011 survey. This sound was not present during the March 2012 survey. Figure 19 shows a sample of the signal.

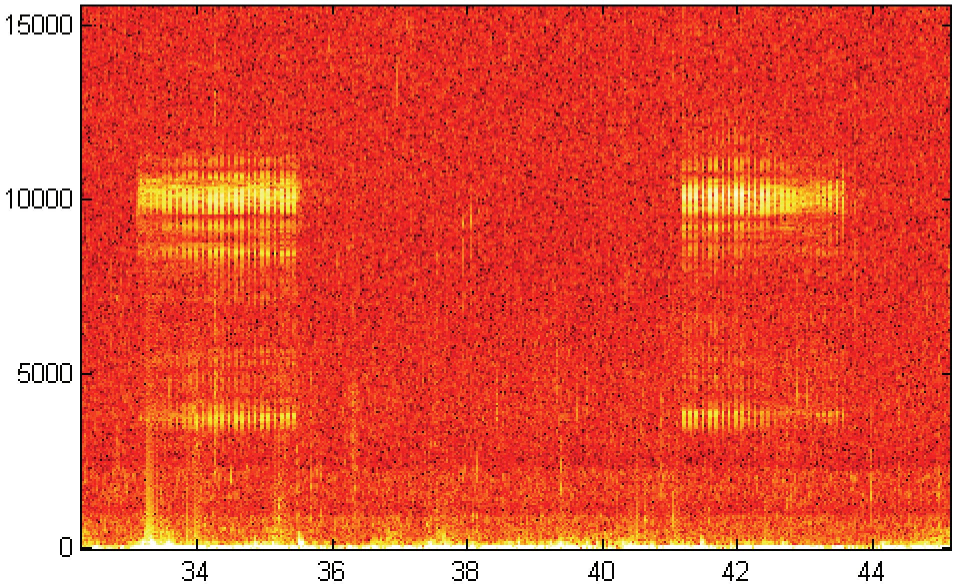


Figure 19. Possible seal scarer signal. Drifting Ear 2, run 1 on 20/9/2011

The signal is a pulsed 10 kHz signal with subsidiary signals on 3.7 and 5.7 kHz. Each pulse is 2 mS long and is repeated at 42 mS intervals. A pulse sequence contains 56 pulses. The sequence is repeated at random intervals in the range 2 – 25 seconds. The signal is up to 30 dB above the noise level at the end of the run.

4.4 Geographic Variations in the Noise

The earlier study of ambient noise in the Fall of Warness test site reported on the geographic distribution of the noise levels. In this study, the distribution of noise was also plotted and Annex 2 shows the results for four frequency bands on each of the survey days.

The plots in Figures 20 and 21 show the noise levels obtained during a group of runs on the 26th March. The RMS value of the noise across a 2 kHz band centred on each of four frequencies (2.5, 5, 10 and 15 kHz) was calculated over a 1 minute period and plotted as intensity. These frequencies were chosen to maintain comparability with the data presented in Wilson & Carter (2008). The possible location of operating TEC units was also plotted (red squares). The intensity scale varies over a 25 dB range. These figures show the results for 2.5 and 15 kHz only (please refer to Annex 2 for the full set of plots).

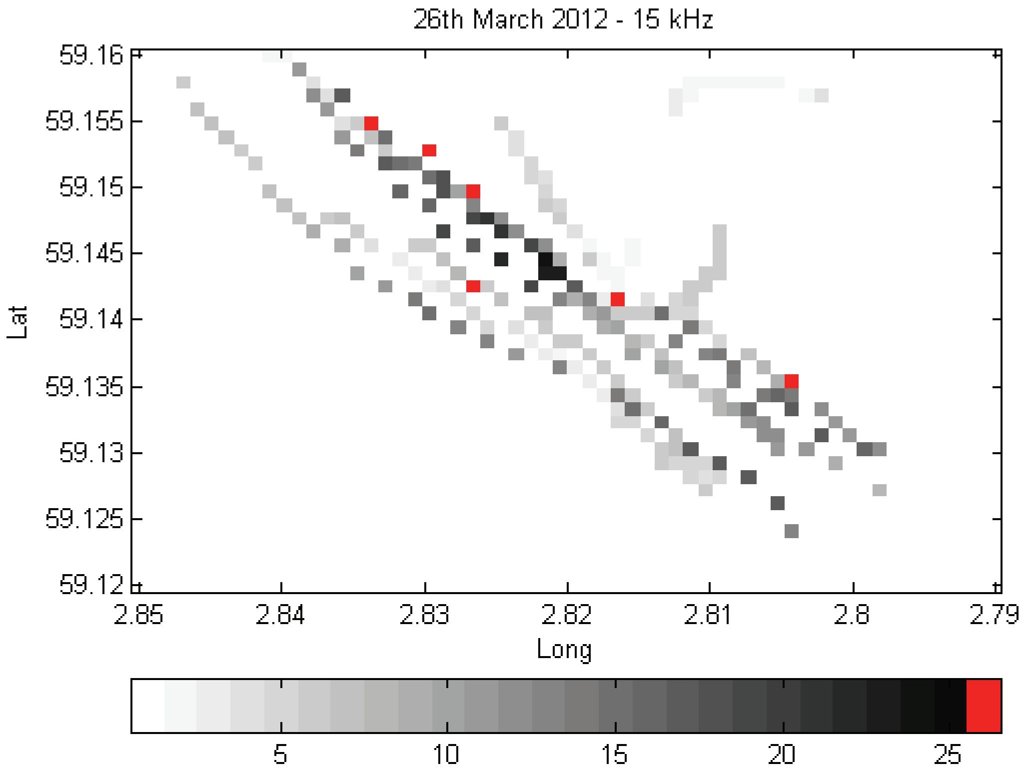


Figure 20. Geographic distribution, 15 kHz, 26/3/2012

From this it would appear that there is a significant source of high frequency sound from the approximate location 59.143N, 2.828W. The source at this location is actually three discrete sources although this is not clear from Figure 20 (see Annex 2). Further work to repeat the processing for Figure 20 at higher resolution should provide a clearer picture. There is also a source of sound in the south-east of the area and another weaker source in the north-west.

At 2.5 kHz (Figure 21) there is much less noise from these locations and other noises such as shipping and TEC device noise start to dominate and the picture is less clear.

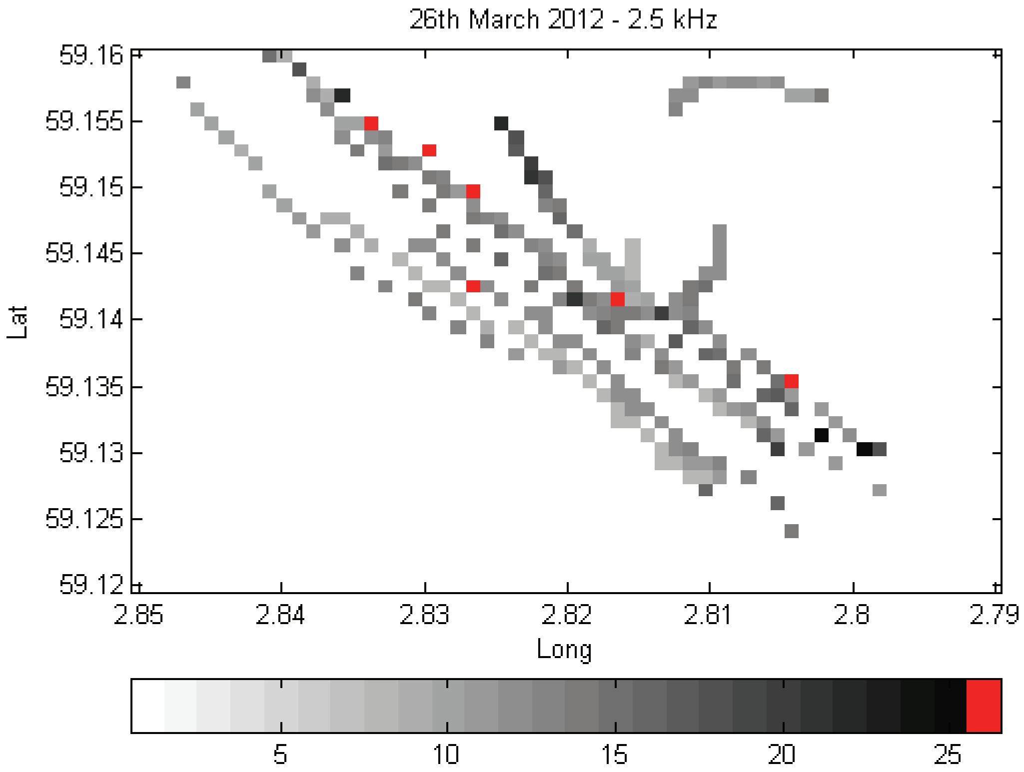


Figure 21. Geographic distribution, 2.5 kHz, 26/3/2012

4.5 Data Limitations

This study has been carried out with the data measured on two days in March 2012 and one run in September 2011 so the results presented are a snapshot of the conditions at the time of the surveys, and are only partially representative of the full range of possible noise sources and levels. Sounds at frequencies below 1 kHz are most likely attributable to anthropogenic noise (e.g. shipping, machine noise). A more in-depth study of the sources over a range of tide and meteorological conditions, with detailed characterisation of their noise output in order to distinguish between shipping and TEC sound should be the focus of future studies to provide a full acoustic characterisation of the site (e.g. more data collected around operating TECs and more detailed analysis of such data).

5. POSSIBLE EFFECTS OF TIDAL DEVICES

5.1 Marine Mammals at the Test Site

Ongoing wildlife observations carried out by EMEC have recorded sightings of marine mammals in the area of the Fall of Warness test site. The most common species seen are:

- Grey and harbour seal
- Harbour porpoise
- White-beaked dolphin
- Risso's dolphin
- Minke whale

A number of other cetacean and pinniped species are occasional visitors to the area. Lepper *et al.* (2012), although primarily covering aspects of the EMEC wave test site at Bilia Croo, include a useful summary of the hearing characteristics of these species. The seals have good low frequency hearing which extends below 100 Hz. The odontocetes' hearing range extends beyond 100 kHz as part of their echolocation capability. Although not as sensitive as the seals at low frequency, they can hear to below 250 Hz. The minke whale uses frequencies below 2 kHz, typically around 200-400 Hz, for social purposes so is likely to be most sensitive to low frequencies.

5.2 Effect of a Single Device

Deploying an operational TEC into an area such as the EMEC tidal test site will increase the noise levels. However, most of the energy put into the water will be below 1 kHz and this is true for most mechanical systems such as ship propulsion systems, hydraulic systems, and is likely to be true for the type of transmission trains generally used in TECs. This noise mostly comes from bearing and gearbox noise. It is important to remember that, whereas in a ship propulsion system the propeller drives the water, in a tidal energy converter system the water drives the propeller. It is very unlikely that cavitation will occur and this can be the dominant source of noise in ship propulsion systems (cavitation is the formation and then immediate implosion of cavities in a liquid which can occur when the liquid is subjected to rapid changes of pressure resulting in the formation of cavities where the pressure is relatively low). Provided the mechanics of a tidal system are well-designed, constructed and maintained, then they should be very quiet. However, it is important to realise that mechanical systems can develop faults that can increase the radiated noise levels considerably.

Once noise is radiated, it then propagates through the underwater environment. At the Fall of Warness test site, the seabed is predominantly hard rock and under calm conditions this is considered a low-loss environment with propagation loss likely to obey a cylindrical loss law rather than the spherical loss law of open water, particularly at low to medium frequencies where TECs are likely to produce noise. Although this study did not look specifically at propagation across the area, the general distribution of sound from the operational generators supports the hypothesis that this is a low-loss environment. It should be remembered that at higher sea states the propagation loss is increased due to scattering from surface waves. This means that the sound field from the generators will reduce in extent. The impact will be reduced both by the reduced sound field and also by masking from the increase in ambient noise levels resulting from increased wave activity.

Looking at the impact of this additional noise on marine life, based on the measurements made in this and the previous studies, there is likely to be little or no impact on the echolocation systems used by marine mammals unless the animal is very close to the generator. Within the near field of the sound source, the interaction effects become very complex due to the large size and moving parts of the device. Further study may provide more insight.

At lower frequencies used by marine mammals for tonal signals, typically 3-20 kHz for odontocetes and ~300 Hz for mysticetes, the potential range of any effects is likely to be increased. This study has looked only at the ambient noise of the area and does not have access to the detailed spectrum of noise radiated by the devices operating in the test area so it is impossible to predict the precise potential effects. However, based on the noise level measurements, it is possible to make more general comments. The most important is that none of the measurements gave levels that could be considered to cause physiological damage as described by Southall *et al*. (2007). The loudest levels measured were only approximately 30 dB above background levels. However, while some of the sounds measured will be of sufficient level to be detected by marine mammals using the site, it is unlikely that there would be any significant long-term behavioural or physical impact.

Three sounds were identified as possibly coming from TECs operating at the site (see section 5.3). Two were strong low frequency tonal signals, the other a regular pattern of clicks. The low frequency sounds were below the frequency range of tonals used by the odontocetes. These sounds may affect the communication range between mysticetes but detailed knowledge of the audiograms and of the radiated noise would be required to comment further.

The regular ticking sound could be heard across the area, but nowhere was it very strong. The source could not be identified from this dataset. It is very unlikely to impact any marine mammals in the area.

Due to health and safety and navigational safety considerations, the current acoustic measurements have been made at low sea states. The impact of noise from TEC devices must be considered over the whole range of weather conditions. At high sea states, the noise from surface waves will raise the ambient noise levels and mask the noise from the TECs. The extent of the noise field will also be reduced by increased propagation loss. During periods of high precipitation there will be further masking due to surface impact noise. A detailed knowledge of the spectrum radiated from a TEC would allow the reduced impact in bad weather to be estimated.

5.3 Effect of Multiple Devices

The EMEC test site is sufficiently large to support a number of operating TEC devices. Further detailed studies into the source levels and attenuation of any sounds generated by TECs at the site would be required in order to establish the degree of detectability of these sounds across the whole site, and therefore inform on any “barrier” effect that could potentially arise from the presence of multiple operating devices.

6. CONCLUSIONS

Data collected and analysed during this project have enabled the ambient noise at the EMEC tidal test site to be further characterised in the presence of some operating TECs. The following conclusions can be drawn from this study:

- The ambient noise levels measured are higher than those suggested by Urick (1975) for shallow water sites, but lower than those measured by Wilson & Carter (2008).
- The noise level of frequencies above 1 kHz can vary by at least 26 dB across the site; this is believed to be primarily due to flow-induced noise generation.
- Rain can raise ambient noise by up to 30 dB and this extends to lower frequencies than flow noise.
- It was not possible to locate the individual noise sources accurately as this was outwith the scope of this project, but future studies could investigate this further.
- Further work will be required to fully understand the effect of tidal flow on ambient noise based on experience gained from processing this dataset.
- Based on the data gathered during this study, it seems unlikely that the noise generated by tidal energy converters operating within the site would have a significant impact on marine mammals. However, further detailed studies will be required in order to gain more understanding of this.

7. DISCUSSION

This project set out to further characterise the ambient noise levels at the EMEC tidal test site in the Fall of Warness now that some TEC devices are installed and operational. Early surveys were hindered by poor weather and equipment failures, but two excellent datasets were collected in March 2012 and most of the information in this report is based on processing this data.

The two previous surveys of the Fall of Warness test site provided much useful information about the acoustic noise levels (Wilson & Carter, 2008; Wilson *et al.*, 2010). The 2010 survey (Wilson *et al.*, 2010) was in two parts with a cable-laying ship present for the second part of the survey. That report presents a series of plots relating the ambient noise levels to flow speed at different frequencies; however, it does not take into account geographic position. Both this current study and the previous studies have demonstrated that flow noise levels are very position-dependent. The resulting plots contain a large spread of data which have been processed to provide a site-wide characterisation. There is the potential for future studies to focus on the location of specific sound sources.

The results of this project have shown that tidal flow noise makes a significant contribution to the ambient sound field at frequencies above 2 kHz. This study has identified five locations of flow noise within the test site area and this verifies the findings of the earlier study (Wilson and Carter 2008). Flow noise levels can vary by up to 26 dB across the test site. Re-processing the data with a finer temporal resolution should improve the accuracy of the estimated location of these sources. It would be useful to carry out further work to investigate the characteristics of these sources and to locate them more accurately. This more detailed study of the sound sources would need to take into account specific bathymetric features, support structures and other infrastructure associated with TEC testing, and possibly typical characteristics of the water column (e.g. areas of turbulent flow).

As the purpose of this study was to provide a general acoustic characterisation of the site, the mean spectra were measured at a location chosen to minimise flow noise and contributions from operating TECs. This showed that levels were higher than that typically suggested for open shallow water (Urick, 1975), but lower than that measured in the previous surveys of this site. The information presented on average spectra for ambient noise could be expanded if the data were re-processed. It would be useful to investigate in more detail how the spectra vary with tidal current and geographic location. It is also not clear why there is a discrepancy in levels between this study and the previous work on this site. Further work is required to resolve this issue.

Major contributors to the sound field were identified as flow noise, precipitation noise, shipping noise and the TEC devices operating at the site. Wind and wave noise would also be expected to contribute to the noise field.

From the datasets studied, it appears that operating TECs can be heard across large areas of the site. Although these sounds are not loud, the low-loss propagation on the site means that they are likely to be heard widely by all of the marine mammal species identified at the site. However, under rough water conditions the volume insonified will decrease as the sound is scattered from surface waves and the sounds masked by increasing ambient noise.

8. RECOMMENDATIONS

8.1 The methodology used to collect the data reported here used an improved version of a drifting recorder used in previous studies. The choice of methodologies in a high energy site such as the Fall of Warness is limited with the only two options being fixed hydrophones or drifting hydrophones. The drifting recorders methodology has some limitations in that the course they take can be unpredictable in an area such as the Fall of Warness, resulting in a corresponding uncertainty that data will be collected as required. This can be alleviated by deploying multiple units so that the probability of achieving the required tracks is much improved. The use of multiple drifters also helps to localise sound sources.

Fixed hydrophones can generate continuous data and show how the noise levels vary at a single point in space through the complete tidal cycle. However, they may be subject to flow noise and debris impact noise. Nevertheless, having the data available for a complete tidal cycle would be very useful in characterising the site.

It is therefore recommended that the following changes be considered for future work:

- Multiple DART units should be deployed to improve the chance of achieving the required tracks through the area.
- The deployment of a fixed hydrophone within the test area, cabled to the shore to acquire continuous-time acoustic data.

8.2 This study measured the noise contributions under good weather conditions. This limit is imposed for two reasons. Firstly, under poor weather conditions the distance at which the DART units can be visually tracked reduces and there is a significant risk of losing a unit. Secondly, increased water movement also results in increased self-noise from the surface elements of DART and reduces the usefulness of the recorded data.

To obtain data at higher sea states it is recommended that the following should be implemented:

- A radio tracking device is fitted to the DART units with a range of at least 1 km. In its simplest form this may be an un-modulated carrier which will use a tracking receiver to localise the DART unit. An improved option would transmit the GPS position so that the location of each DART unit can be plotted at the receiving station and recovery is then simplified.
- The current mechanical arrangement of both the electronics canister and the buoy should be reviewed and modified as appropriate to minimise all relative movement of the various components that may generate unwanted noise.

8.3 It is recommended that future studies into the acoustic characterisation of the Fall of Warness tidal test site should:

- Consider why ambient noise levels measured during this study are higher than suggested by Urick (1975) but lower than measured by previous surveys (Wilson & Carter, 2008).
- Investigate why the noise level of frequencies greater than 1 kHz can vary by around 26 dB across the site.
- Identify individual noise sources and their locations, and then carry out a detailed analysis of these in order to characterise their noise spectra.
- Differentiate shipping and TEC machine noise at frequencies below 1 kHz and carry out a detailed analysis in order to characterise noise spectra of the components.

9. REFERENCES

Wilson, B. & Carter, C. 2008. *Acoustic monitoring of the European Marine Energy Centre Fall of Warness tidal-stream test site; Phase 2: Development, testing and application*. EMEC report.

Wilson, B., Carter, C. & Elliott, J. 2010. *A baseline acoustic survey of the Fall of Warness tidal test site & assessment of the acoustic output of the vessel CS Sovereign during R.O.V. & cable laying operations*. EMEC report.

Lepper, P., Robinson, S., & Harland, E. 2012. *Acoustic measurement methodology for the Bilia Croo wave test site*. EMEC report.

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.G., Greene, C.H., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A. & Tyack, P.L. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations, *Aquatic Mammals*, **33**, 411-521.

Urick, R.J. 1975. *Principles of underwater sound*. McGraw-Hill Inc.

ANNEX 1. SYSTEM CALIBRATION

The hydrophone used by both the Drifting Ears and DART units is the Cetacean Research C55 unit. This includes an internal preamplifier. The manufacturer states that the hydrophone unit has a sensitivity of -165 dB re 1V/μPa. This gives the hydrophone sensitivity relative to a device that would give 1 volt output for a 1 μPa signal arriving at the hydrophone. The specification of the hydrophone, taken from the manufacturer's data sheet, is shown in the table below.

Table A1. C55 hydrophone data from manufacturer's specification

Linear Frequency Range (±3dB) [kHz]	0.020 to 44
Usable Frequency Range (+3/-12dB) [kHz]	0.009 to 100
Transducer Sensitivity* [dB, re 1V/μPa	-185
Preamplifier Gain [dB	20
Effective Sensitivity* [dB, re 1V/μPa]	-165
SPL Equiv. Self Noise at 1kHz [dB, re 1μPa/√Hz]	46 (Sea State Zero)
Power Requirement [Vdc]	5 to 32
RMS Overload Acoustic Pressure [dB, re 1μPa]	169 to 186
Maximum Operating Depth ** [m]	460
Operating Temperature Range [ºC]	-40 to 60
Output Impedance [Ohms]	10
Dimensions [mm]	119 L x (25 to 16) dia
Integral Connector	Subconn MCBH3MSS
Directivity	Omnidirectional below 10 kHz

Cylindrical hydrophones have a flat response from a low frequency determined by the capacitance of the ceramic element and the input impedance of the preamplifier. The data sheet states this to be 20 Hz at the 3 dB point. The high frequency limit is usually determined by the resonant frequency of the hydrophone. The manufacturer states that it is omnidirectional to 10 kHz and therefore has a flat response to 10 kHz. The useable frequency range extends to 44 kHz at the 3 dB point. The recorder in DART records up to 24 kHz so it is likely that the response drop off will be significantly less than the 3 dB at 44 kHz. A reduction of around 1 dB is likely and this is considered acceptable for this type of study where the experimental error in the measurement is likely to be rather more than 1 dB.

DART includes an internal amplifier giving a gain of +10 dB. The signal is then passed to the SM2+ recorder. This means that a signal arriving at the hydrophone of +155 dB re 1uPa will give a 1 Volt RMS signal at the recorder input.

The recorder input is defined as 1 Volt RMS at the recorder input and with the internal gain set to 0 dB will give a full-scale signal at the A/D output. The WAV-format files produced, when read by MATLAB, have a full scale range from -1 to +1 units peak to peak. There is therefore a 3 dB loss from the recorder input to the MATLAB file.

WAV Calibration factor = 165 – 10 + 3 dB re 1 MATLAB unit/μPa

= 158 dB re 1 MATLAB unit/μPa

The data are then processed using the MATLAB spectrogram function. The spectrogram is formed by the repetitive application of the FFT function, each repetition being time shifted by a specified amount. This function is not normalised so the transfer function is dependent on the windowing function used and the number of input points. For a Hanning window and 1024 input points to the FFT the transfer gain was measured at 53 dB. A further correction factor has to be applied to convert the bandwidth of the spectrogram outputs to 1Hz in order to obtain spectrum level. For a 1024 input point FFT and sample rate of 48 kHz, the output bandwidth will be:

$$\text{FFT bandwidth} = 48000/(2*512)\ \text{Hz}$$

$$= 46.875\ \text{Hz}$$

Converting this to dB using 10 x $\log_{10}$ gives a bandwidth correction factor of 16.7 dB. The overall calibration factor is therefore:

$$\text{Calibration factor} = 158-53-16.7$$

$$= 88.3\ \text{dB re 1 MATLAB unit}/\mu\text{Pa}$$

DART includes a calibration oscillator that injects a 50 mVolt RMS signal at 700 Hz into the input of the +10 dB gain amplifier. The signal is injected at the start of each run and provides confidence that the system gain is as expected and has not changed due to factors such as changes in the gain of the recorder.

A typical calibration signal is shown in Figure A1.

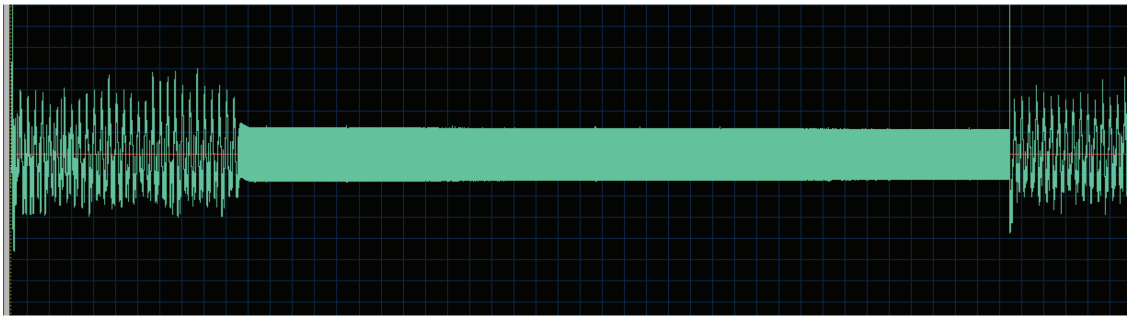


Figure A1. Typical calibration signal

ANNEX 2. DATA ANALYSIS

This annex presents the detailed analysis of each run that was processed to produce this report. The plots shown are:

- Amplitude at four frequencies through the run
- Spectrogram of run
- Mean spectrum of part of the run
- Geographic distribution of sound level from multiple runs

These are produced using the following methods:

Amplitude plot

The data were processed using a 1024 input sample FFT to produce 512 spectrum samples. There is no block overlap and a Hanning window is used. These data are then averaged for one minute to produce the plots. The data were filtered into four 2 kHz bandwidth regions centred on 2.5 kHz, 5 kHz, 10 kHz and 15 kHz. This is implemented by summing the squares of the FFT output points across the appropriate band of frequencies. The processing is implemented as a MATLAB function.

The low frequencies below 1 kHz are not used because of the high levels of sound from boats and the TECs.

Spectrogram

The whole run spectrograms are produced using the CoolEdit 2000 software. It uses a 512 point FFT with Hamming weighting and no block overlap for compatibility with the other processing functions.

Mean spectrum

The mean spectra are produced using the same FFT function as the amplitude plots. The FFTs for one minute of data are averaged to produce the mean spectra. This processing is implemented in MATLAB.

Geographic distribution

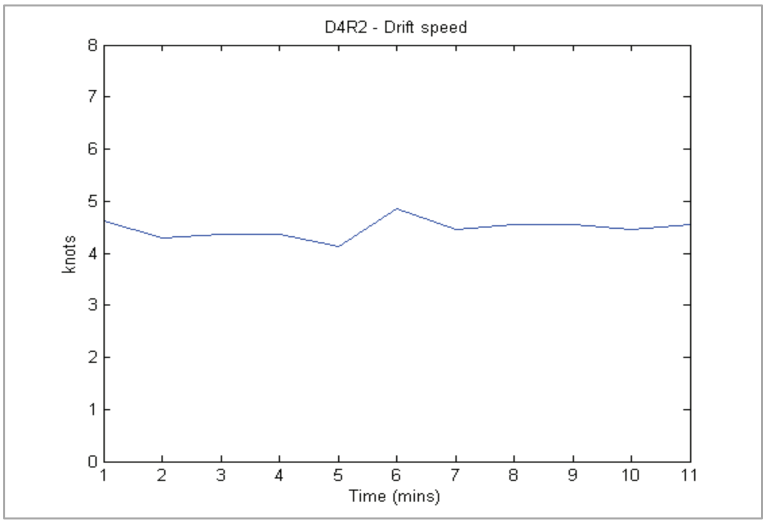
The amplitude plots are combined with the GPS data from each run. For each minute of the data the mean signal level in dB at each of the four frequencies is used to index a 25 step grey scale to determine the colour of the box plotted. A 26th colour (red) is used to plot the possible locations of tidal generation units.

A selection of plots for each run processed is presented on the following pages. They are grouped by day and run.

The three distinct sounds identified as originating from the presence of tidal energy converters are classified as:

- Type 1: A whirring sound varying in pitch
- Type 2: A whirring sound with steady pitch (hum sound)
- Type 3: A regular ticking sound

Run 2, 23rd March 2012



Data were only recorded on DART 4 during this run. The run took place as the flood tide was slackening. The unit travelled a distance of 1.52 km. The drift rate through the run is shown in Figure B.1.

Figure B.1. D4R2 drift rate

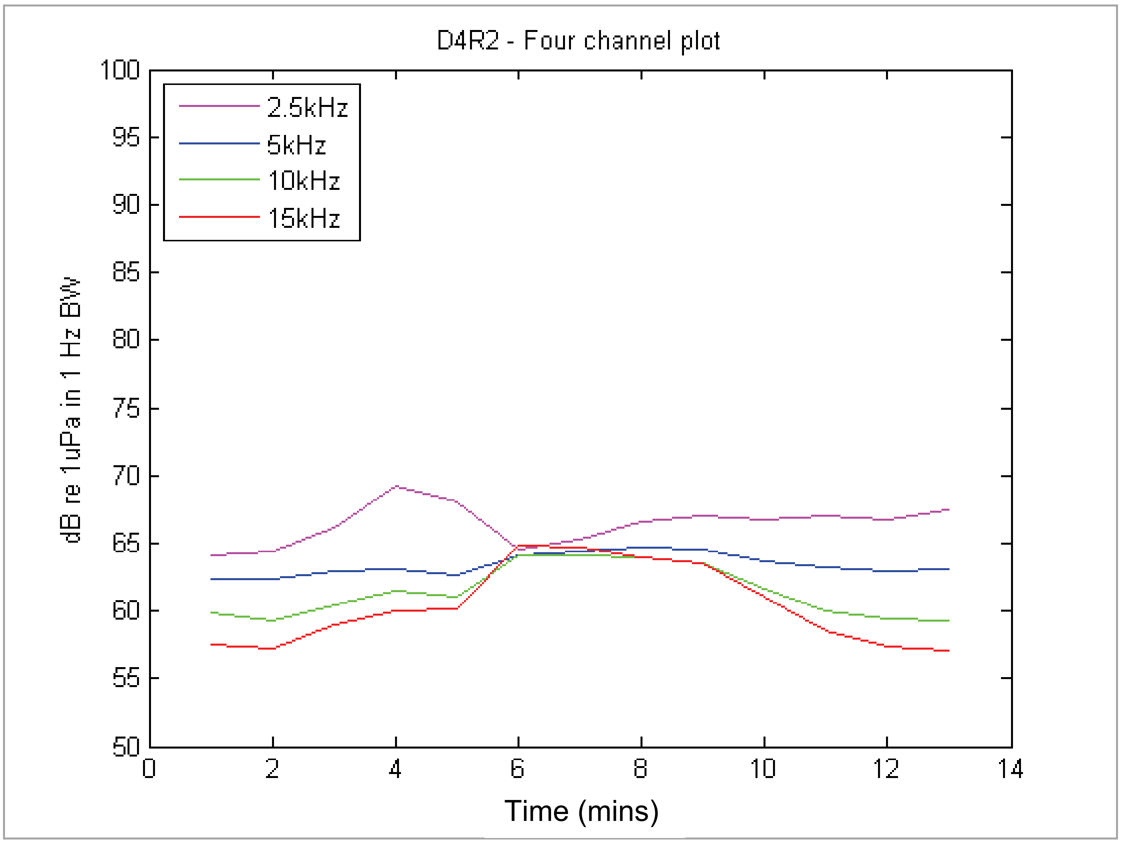
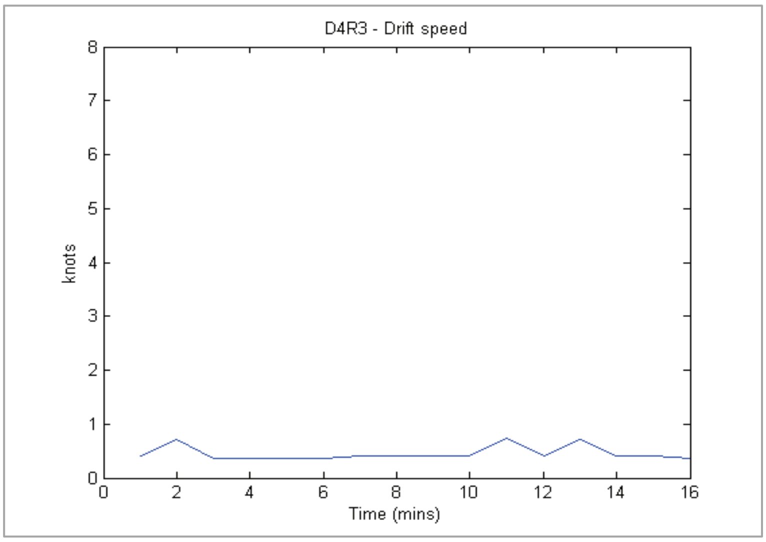


Figure B.2. Sound levels for DART 4, run 2

Throughout this run there are faint scraping noises generated within the hydrophone system of DART. The increase in noise above 5 kHz from 6 to 10 seconds appears to be flow noise although faint wave noise can also be heard. There is a distinct peak at 6 minutes with a broader band of noise extending to 10 minutes. At the end of the run, type 2 sounds can be heard peaking around 13 minutes.

Run 3, 23rd March 2012



Data were only recorded on DART 4 during this run. The run took place at slack water and the unit drifted across the normal tidal flow. The unit travelled a distance of 223 metres. The drift rate is show in Figure B.3.

Figure B. 3. D4R3 drift rate

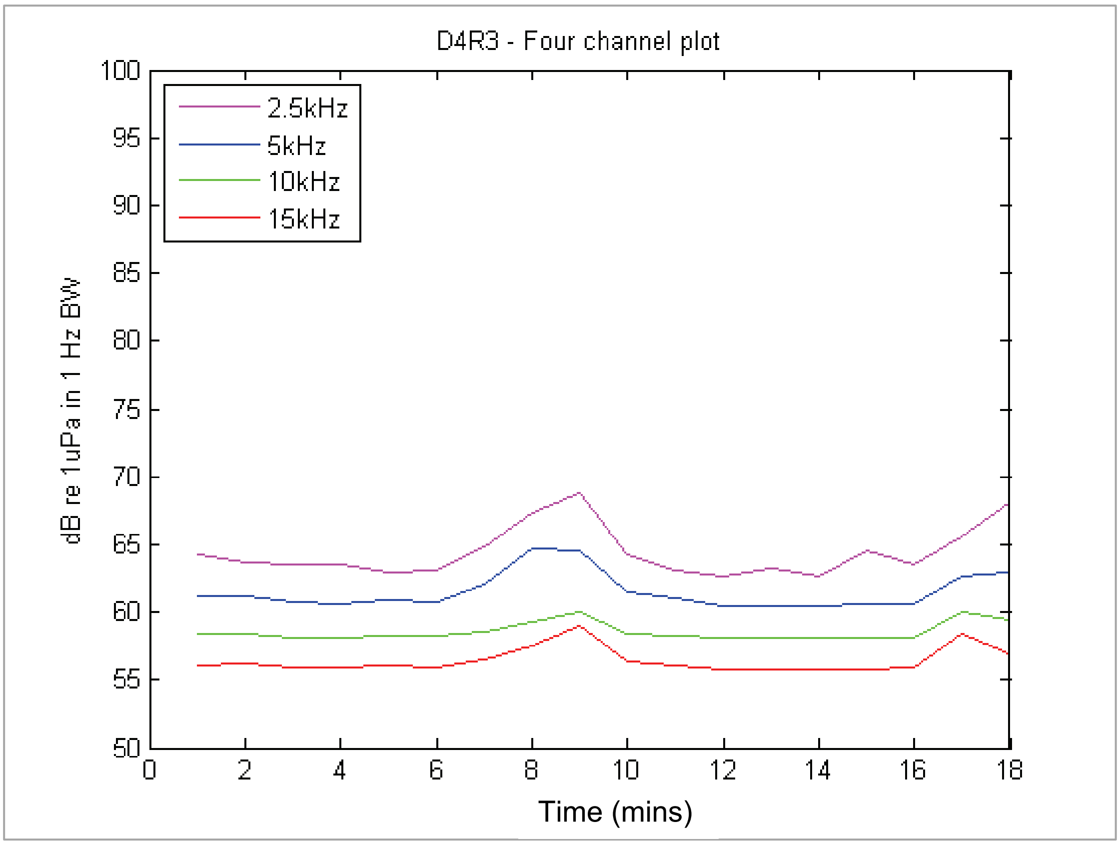


Figure B. 4. Sound levels for DART 4, run 3

The large peak around 9 minutes is due to the support boat manoeuvring to stay in visual contact with the DART units. The increase at the end is due to the approaching support boat.

This run was carried out at slack water and there are no high frequency peaks during the run. None of the sounds believed to come from the TECs could be heard at any time during the run.

Run 4, 23rd March 2012

Data were recorded on both DART units during this run. The run was carried out just as the ebb tide was starting. DART 1 travelled a distance of 1.12 km while DART 4 travelled 1.25 km. The drift rates are shown in Figure B.5.

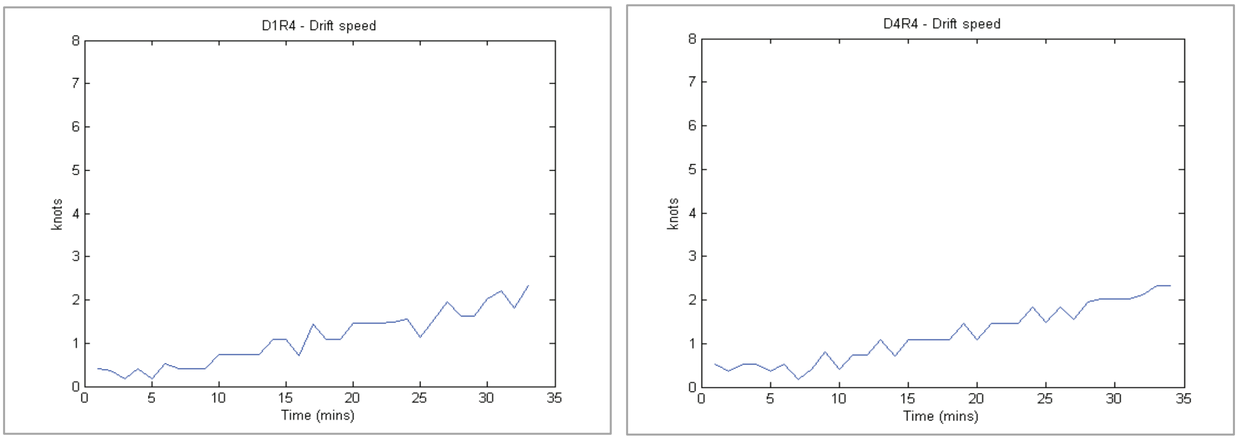


Figure B.5. D1R4 and D4R4 drift rates

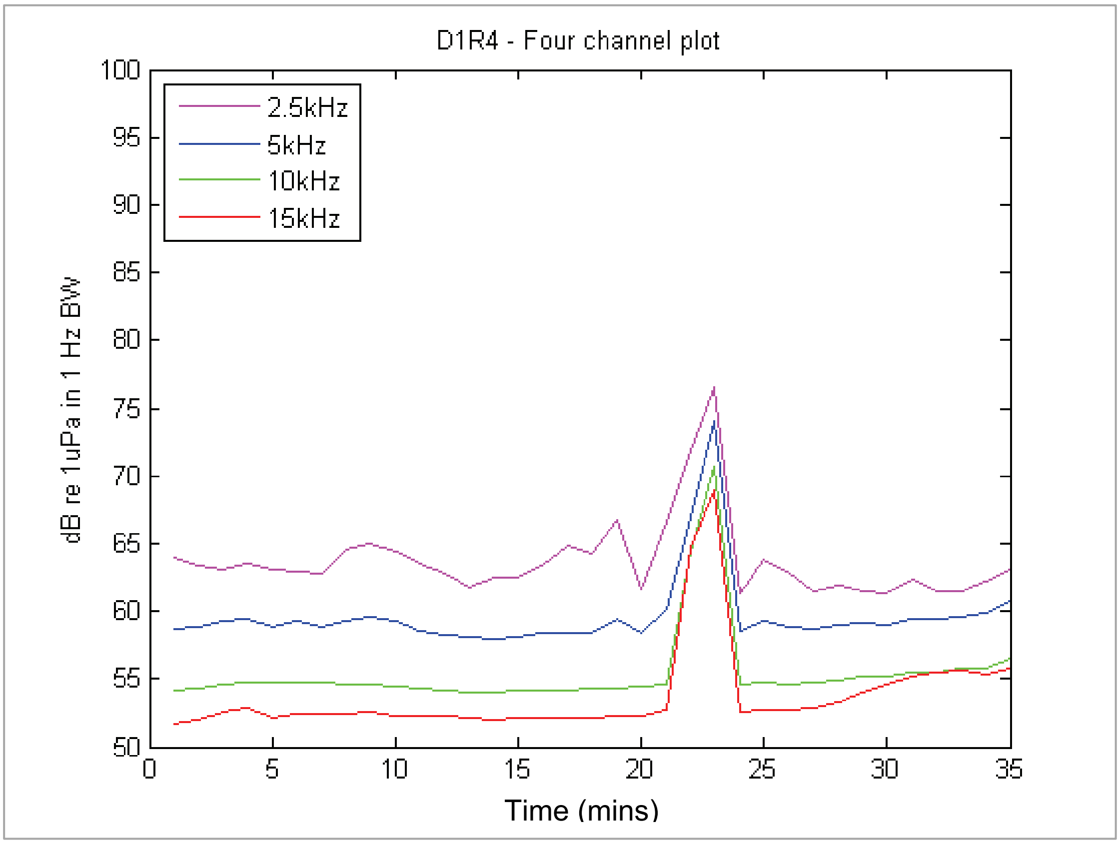


Figure B.6. Sound levels for DART 1, run 4

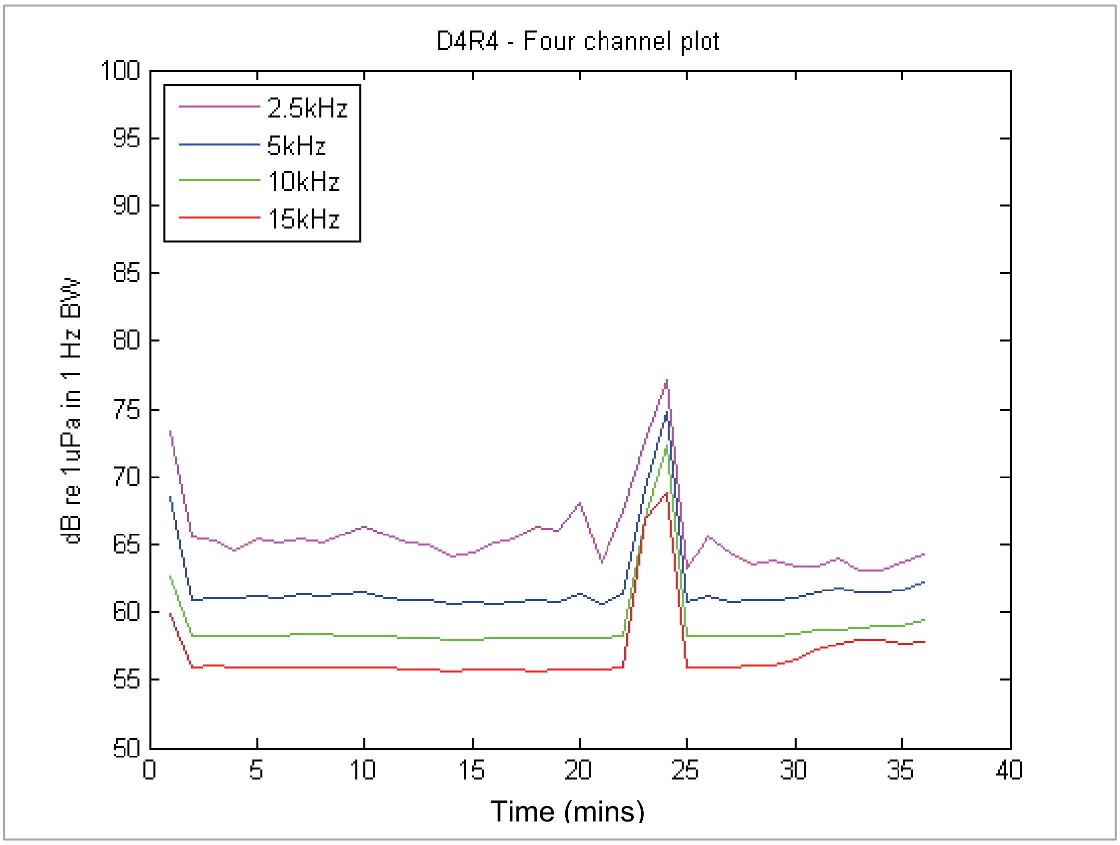


Figure B.7. Sound levels for DART 4, run 4

The track took the units in an arc to the north and west. The large peak at approximately 24 minutes is due to the support boat manoeuvring to stay in visual contact with the drifting units.

At the start of the track, type 2 sound is loud and peaks at around 4 minutes for DART 1. At the end of the run, type 2 sound is inaudible but type 3 sound can be heard quite loudly.

There are no high frequency peaks on this run suggesting the current was too low to trigger the noise-producing mechanism.

Run 5, 23rd March 2012

Data were available from both units during this run. It was carried out on an ebb tide running at 6 knots. Dart 1 drifted a distance of 3.14 km while DART 4 drifted 4.04 km. Figure B.8 shows the drift rates.

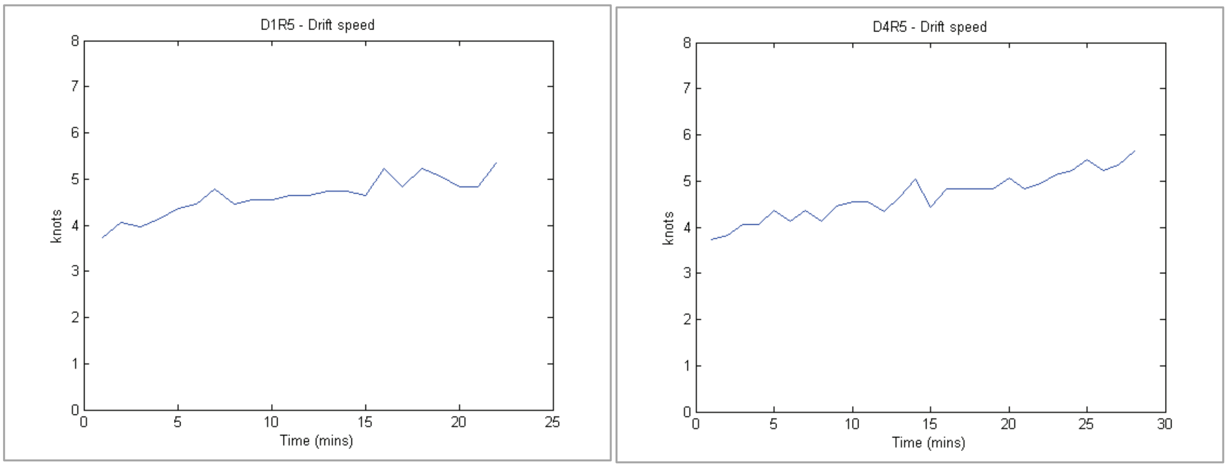


Figure B.8. D1R5 and D4R5 drift rates

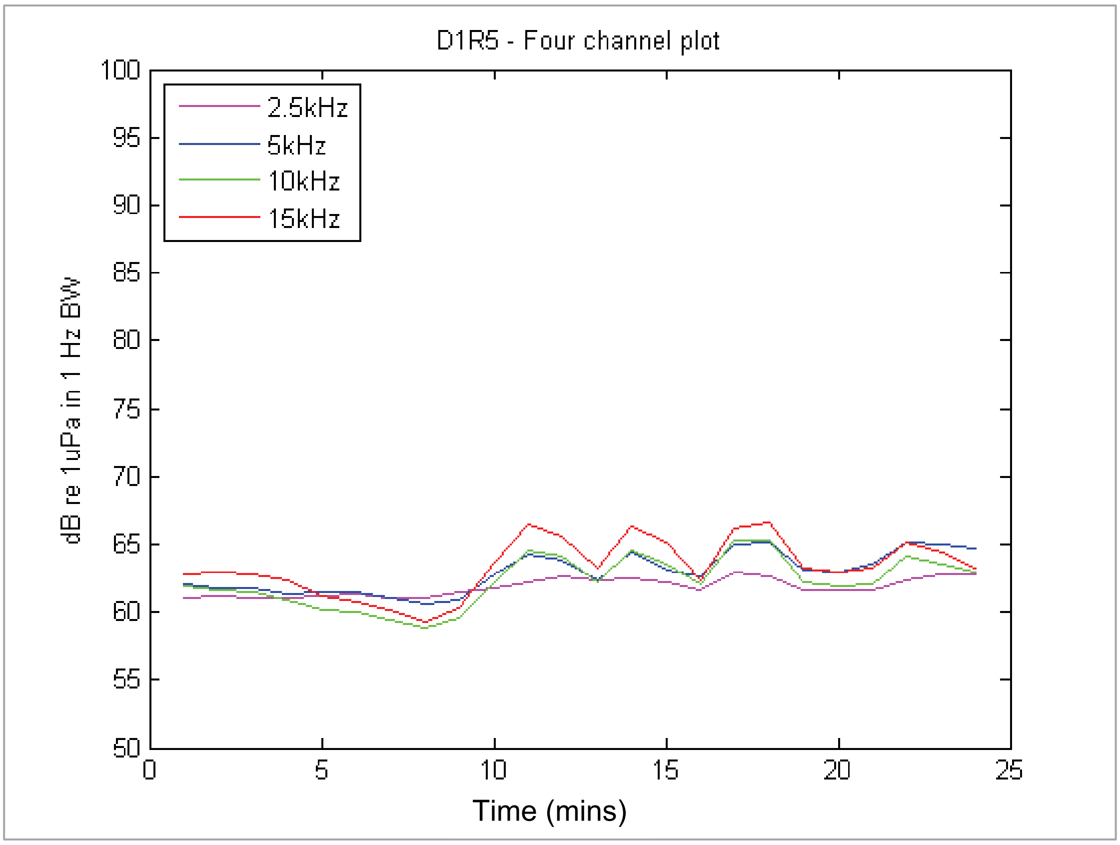


Figure B.9. Sound levels for DART 1, run 5

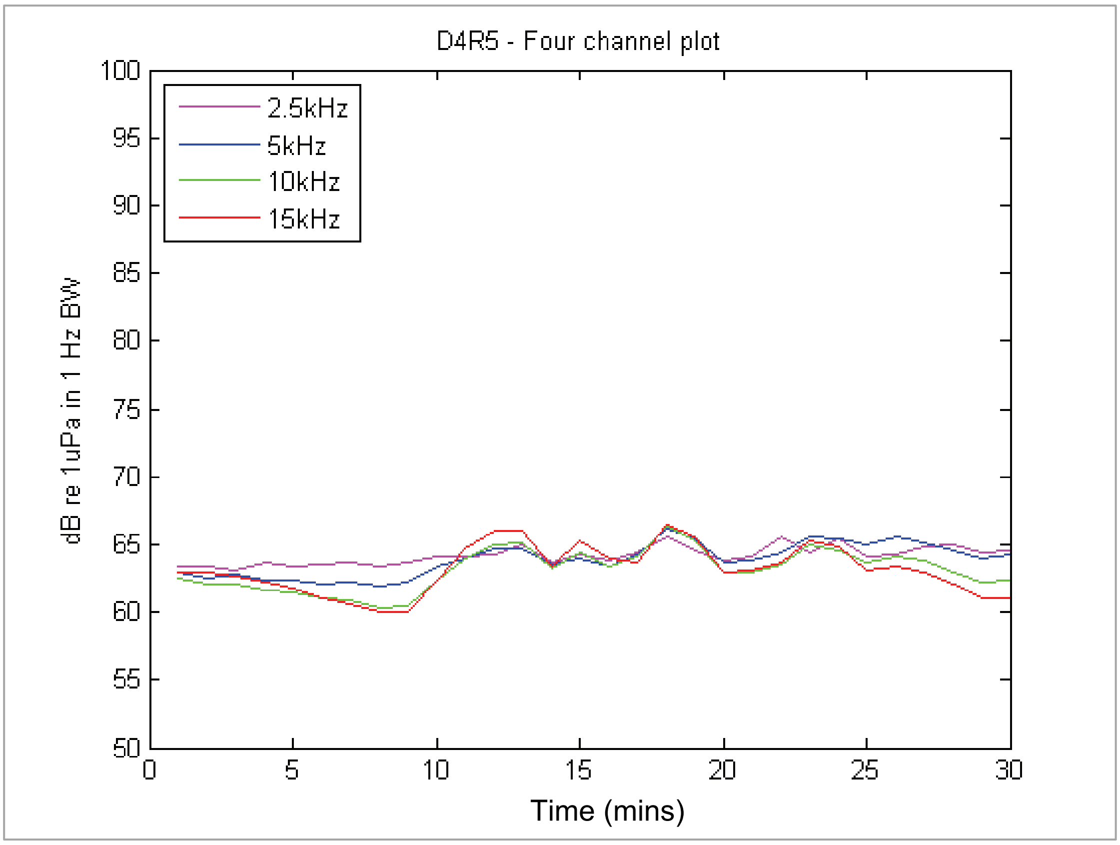


Figure B.10. Sound levels for DART 4, run 5

The type 1 sound can be heard at the start of this run with a broad peak around 4 minutes. The type 2 sound can be heard through the middle of the run peaking around 12 minutes on the DART 4 trace. The type 3 sound is also heard with no distinct peak but generally louder towards the end of the run.

Both units show four peaks in high frequency sound between 9 minutes and the end of the run. These peaks are slightly more distinct on DART 1 which was the more westerly of the tracks.

Throughout the run there is a faint squeaking sound from the hydrophone system.

Run 6, 23rd March 2012

Data were only available from DART 1 for this run. It was carried out on the ebb tide. The distance travelled was 2.91 km. Figure B.11 shows the drift rate.

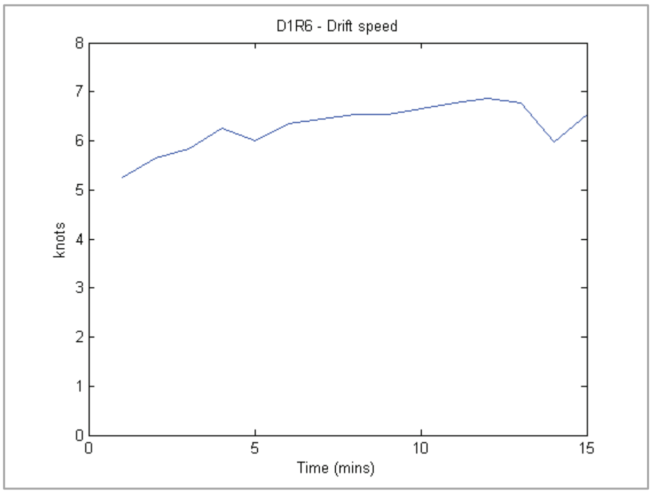


Figure B.11. D1R6 drift rate

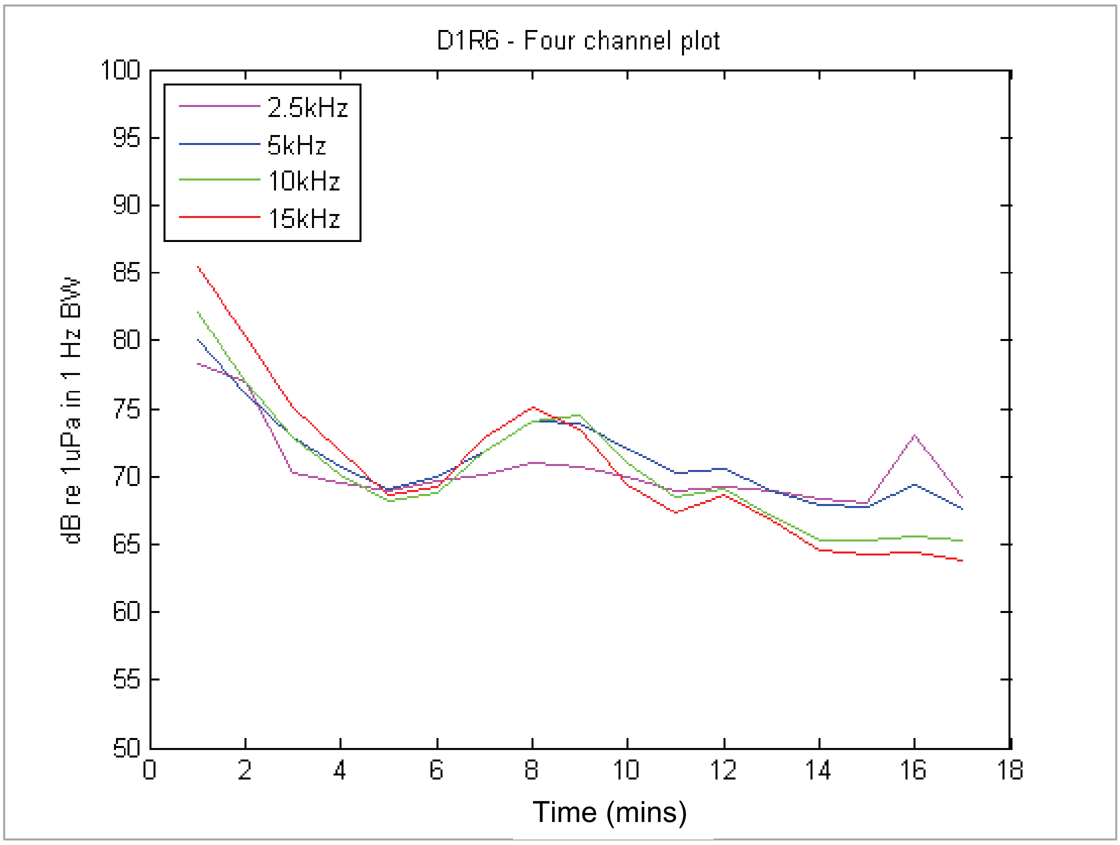


Figure B.12. Sound levels for DART1, run 6

At the start of the run the high frequency noise level is very high. Type 1 sound can also be heard and this peaks at 4 minutes. Another broad peak in high frequency sound is encountered around 8 minutes and a smaller peak at 12 minutes.

The type 3 sound was not heard on this run. Towards the end of the run a distant boat can be heard.

Run 7, 23rd March 2012

Data from both units were available for this run. It was carried out on an ebb tide. DART 1 travelled a distance of 2.02 km while DART 4 travelled a distance of 1.59 km. Figure B.13 shows the drift rates.

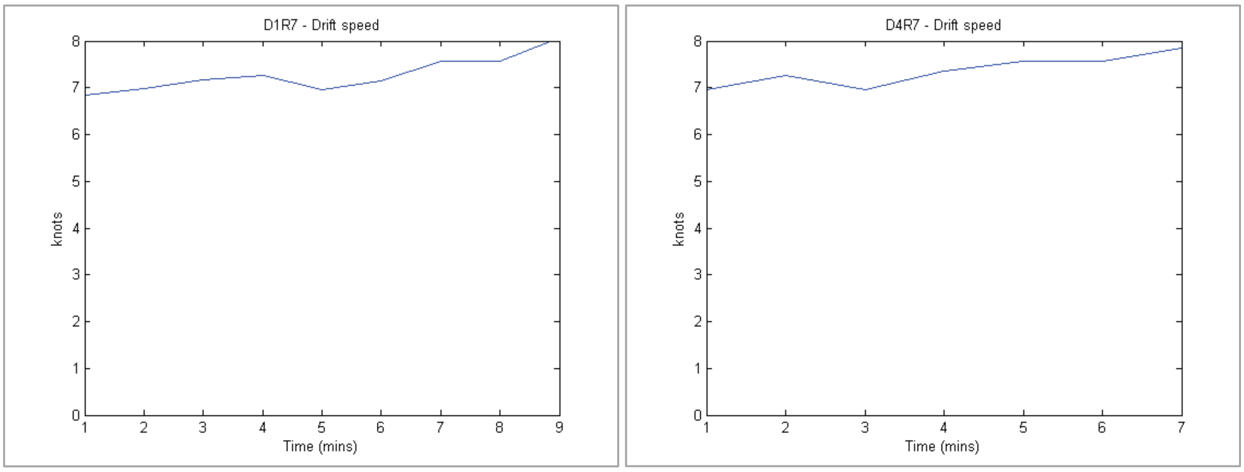


Figure B.13. D1R7 and D4R7 drift rates

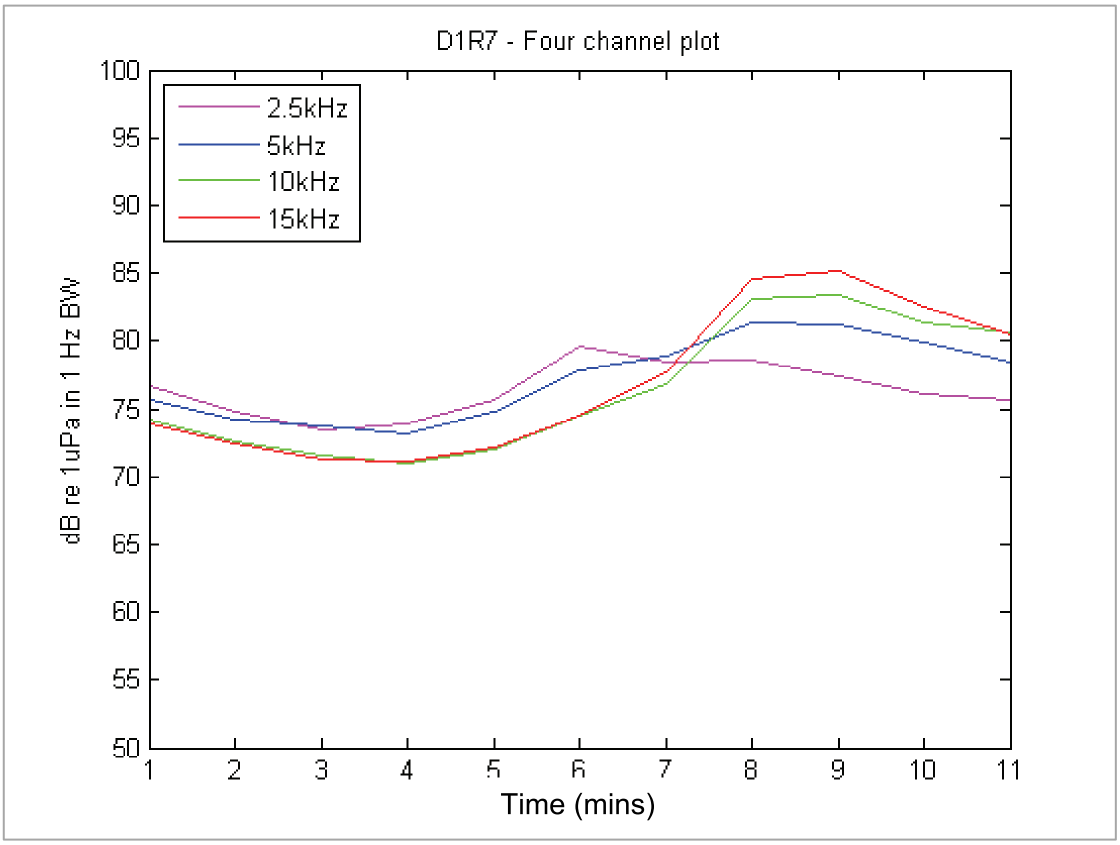


Figure B.14. Sound levels for DART 1, run 7

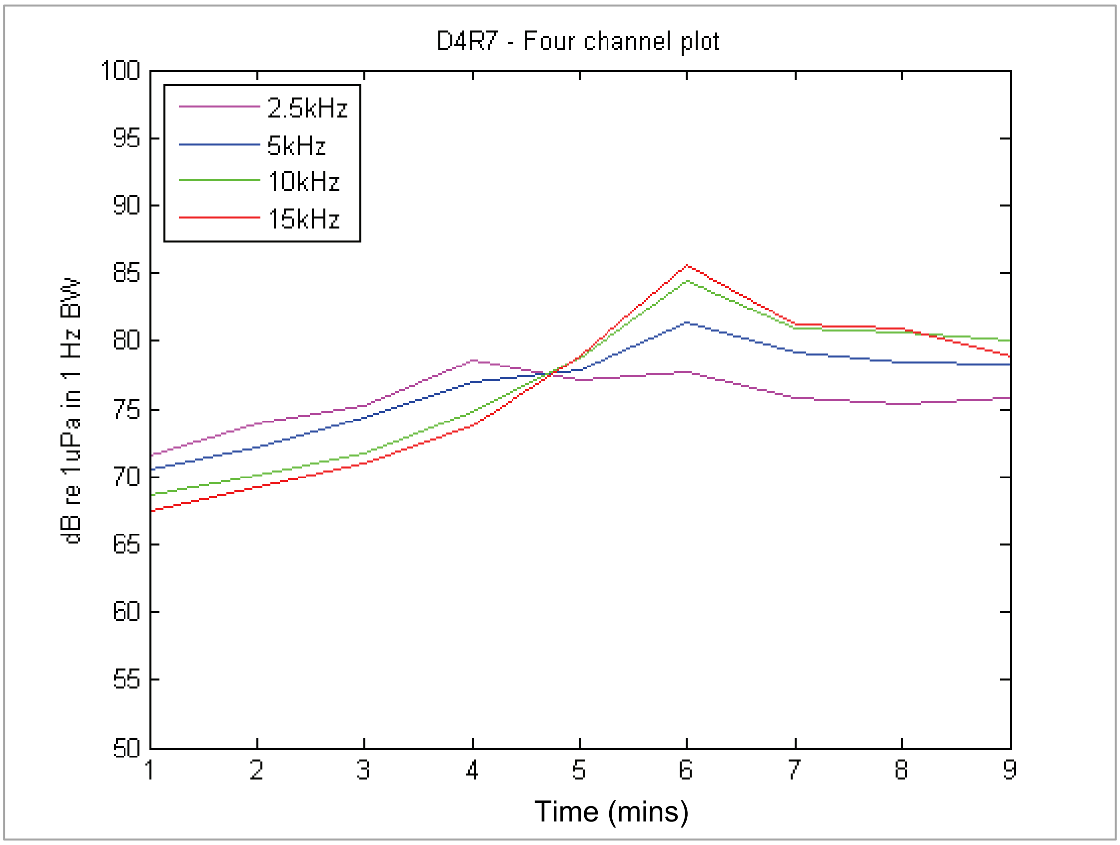


Figure B.15. Sound levels for DART 4, run 7

At the start of the run, type 1 sound can be heard but it is not very loud. Type 2 sound peaks between 3 and 4 minutes on DART 4 and there is loud chain noise. Type 3 sound can be heard faintly at 9 minutes for DART 1. There are also a series of random mechanical knocks and bangs at around ten minutes on DART 1.

There is a loud high frequency sound which peaks around 6 minutes on DART 4 and between 8 to 9 minutes on DART 1. There are three smaller peaks in the high frequency sound between 6 and 9 minutes although the one minute averaging used to produce these plots does not allow these peaks to be resolved.

Run 8, 23rd March 2012

Data were recorded by both DART units. The two recordings are very similar so only one sound level plot is shown here. Both units were in a circulating current in the south of the area. DART 1 travelled 370 metres while DART 4 travelled 450 metres. Figure B.16 shows the drift rates.

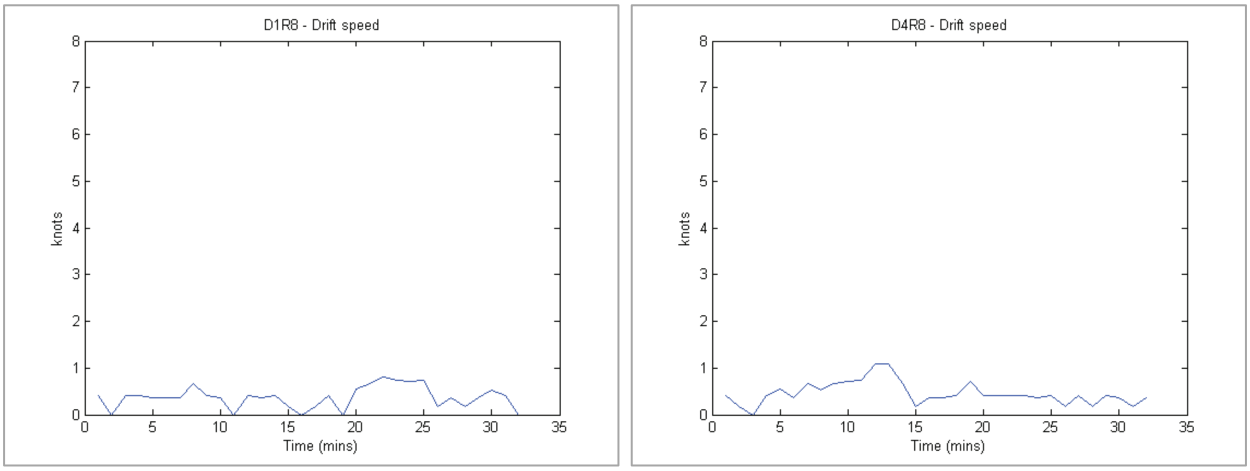


Figure B.16. D1R8 and D4R8 drift rates

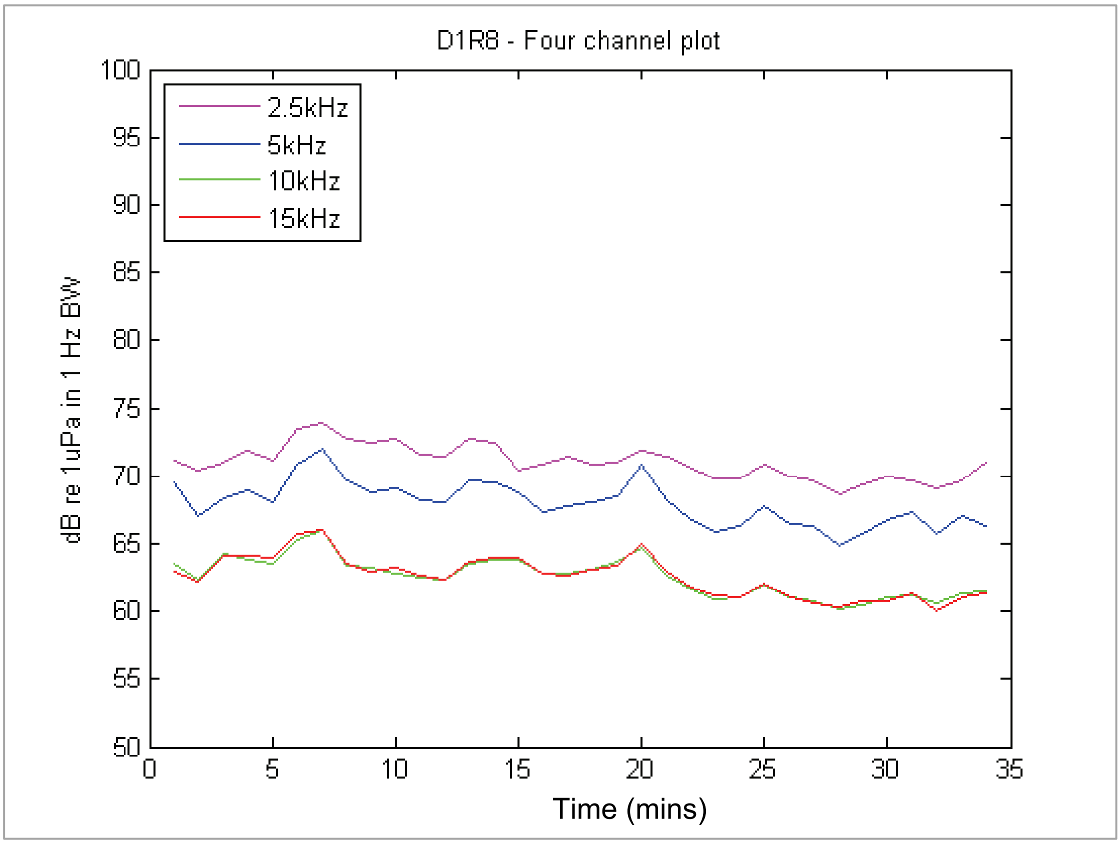


Figure B.17. Sound levels for DART 1, run 8

Throughout this run, the type 1 sound is loud. There are also bursts of scraping sounds on DART 4 which are not on DART 1 and which are believed to come from encounters with drifting debris.

There is little high frequency noise on either recording. Chain noise can be heard throughout the recording.

Run 1, 26th March 2012

Data were recorded by DART 4 only on this run. The tide was flooding. DART 1 travelled a distance of 4.08 km. The drift rate is shown in figure B.18.

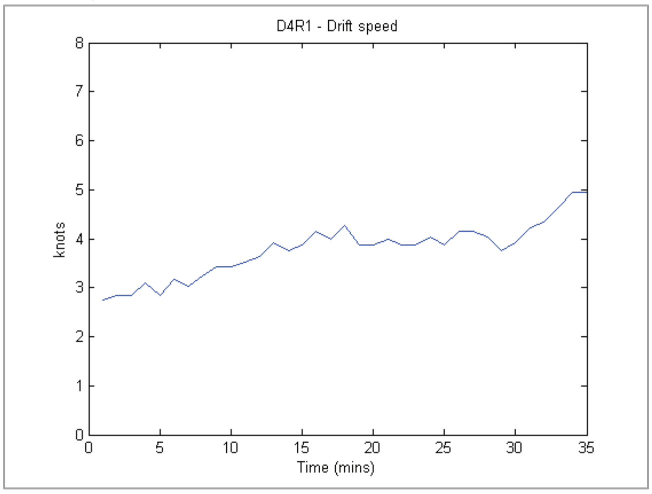


Figure B.18. D4R1 drift rate

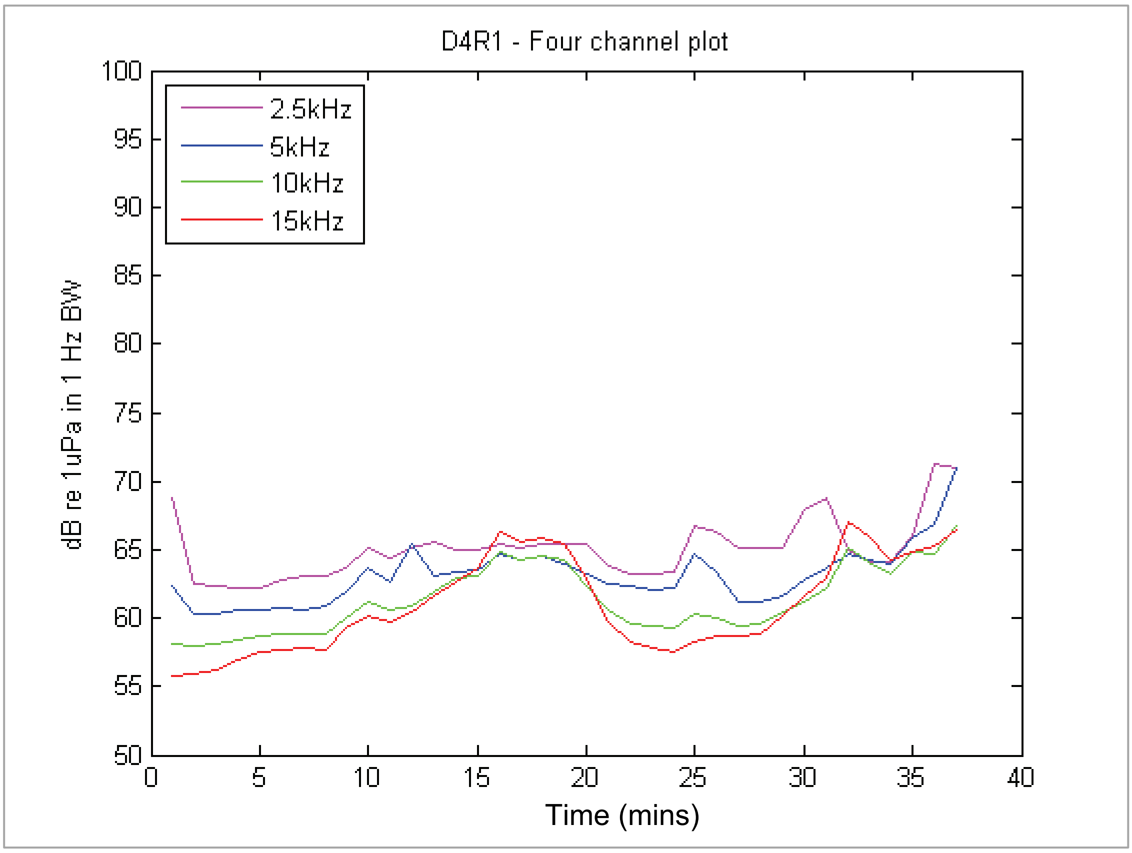


Figure B.19. Sound levels for DART 4, run 1

This run took DART 4 close to a number of the possible TEC berths. At the start of the run, type 3 sound can be heard weakly. Around the middle of the run, type 2 sound is loudest while at the end of the run type 1 sound is loudest, peaking at 30 minutes. The increase in high frequency sound shown on the plot peaks at about 32 minutes and appears to be from a separate source to the type 1 sound. Right at the end of the run the noise of the approaching support boat dominates.

The peak in high frequency noise at 15-20 minutes appears to be from a natural source, possibly flow noise.

Run 2, 26th March 2012

Data from both DART units were recorded on this run. The tide was flooding. DART 1 travelled 3.89 km while DART 4 travelled 4.37 km. The drift rates are shown in figure B.20.

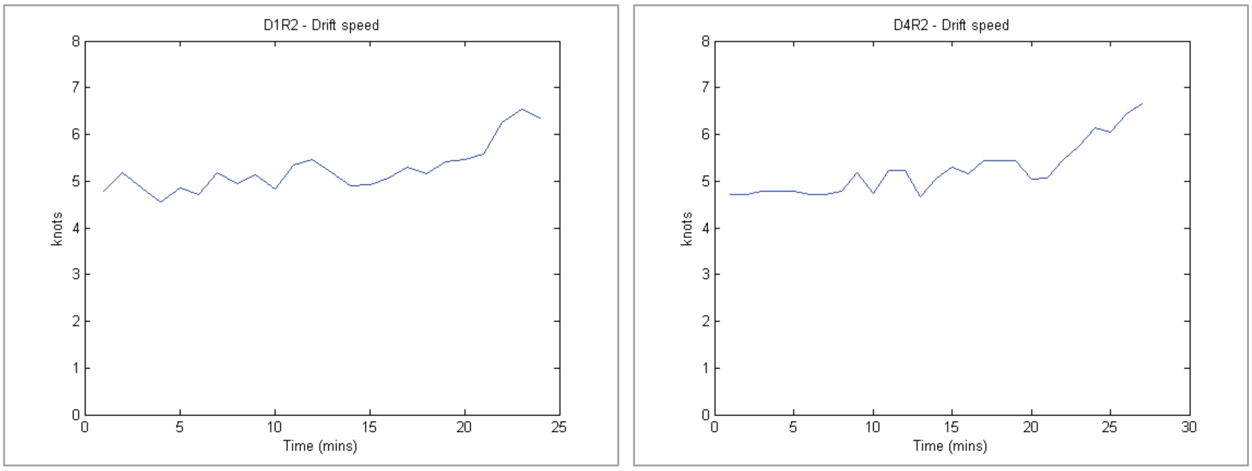


Figure B.20. D1R2 and D4R2 drift rates

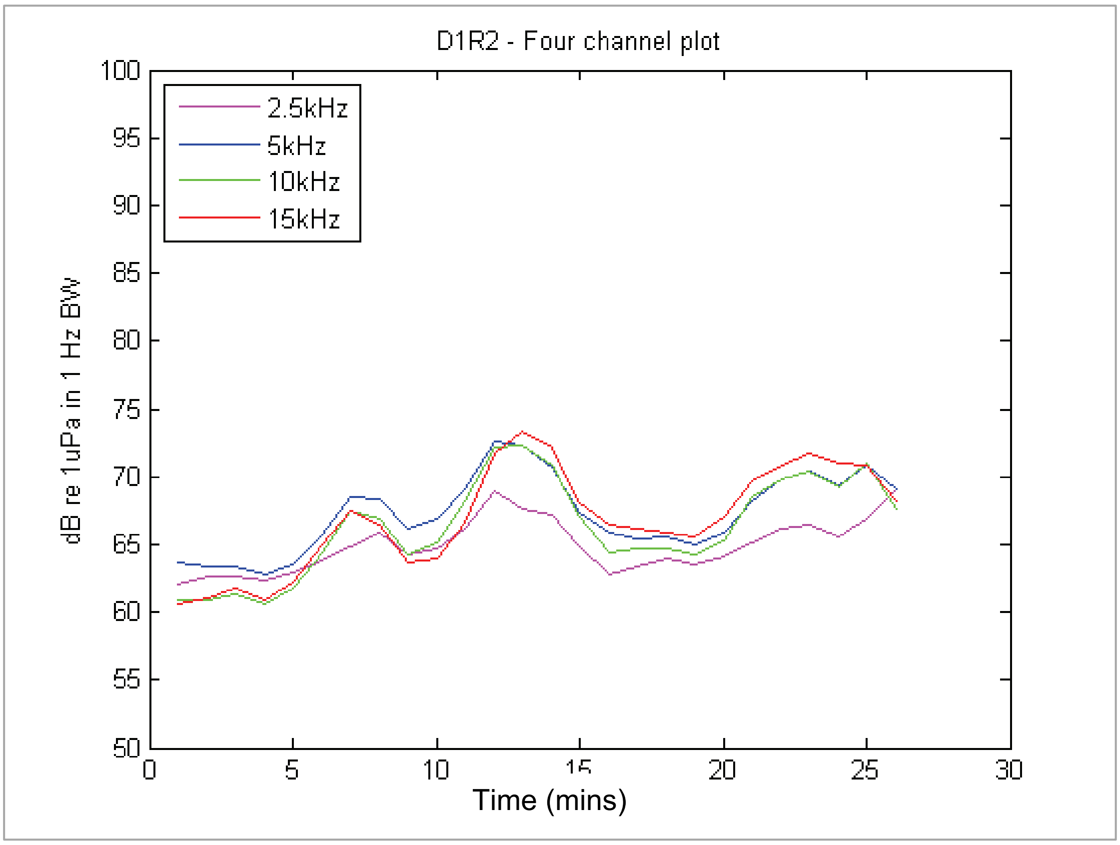


Figure B.21. Sound levels for DART 1, run 2

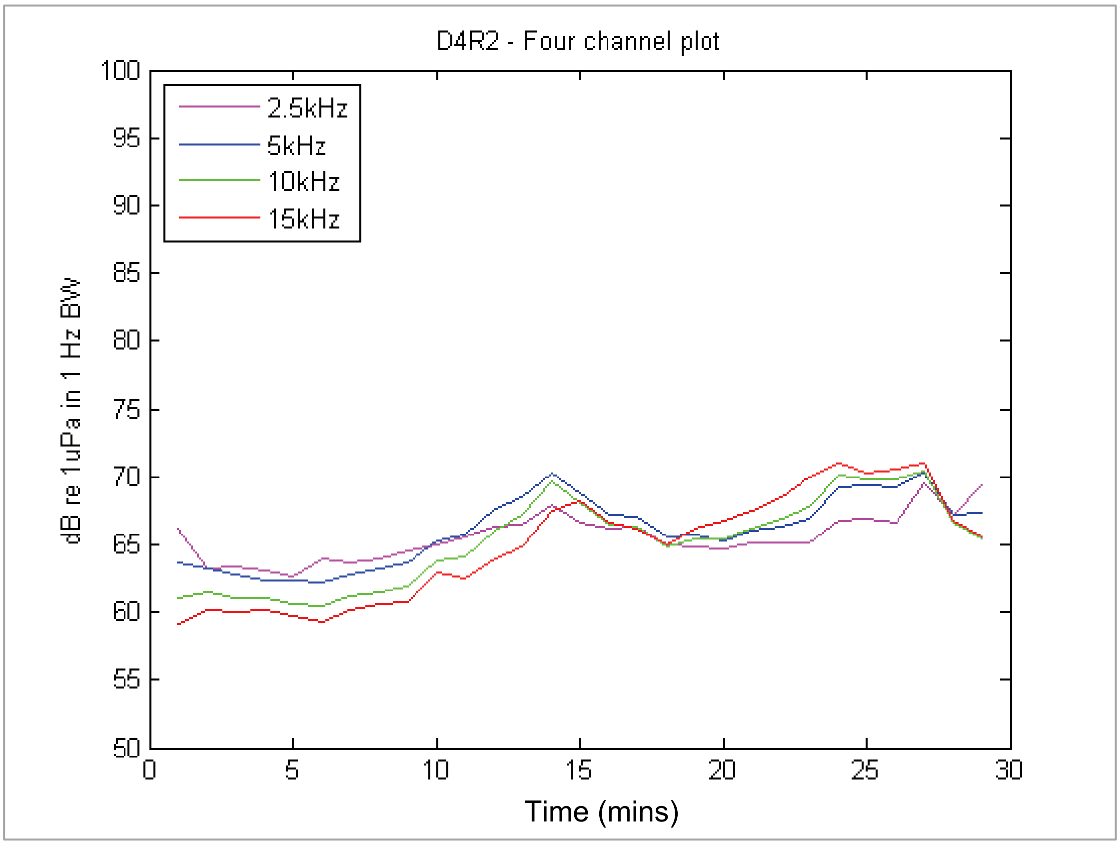


Figure B.22. Sound levels for DART 4, run 2

For DART 1, the type 2 sound is loudest at 9:30 minutes and the type 1 sound is loudest at 22 minutes. The peaks in high frequency noise all appear to be due to flow noise. The first peak at around 7 minutes observed on DART 1 is only just detectable on DART 4, which was on a track to the south and west of DART1. It is believed these peaks are due to flow noise. The peaks on DART 1 are higher in amplitude than DART 4 which suggests that its track took it closer to the sound sources.

Run 3, 26th March 2012

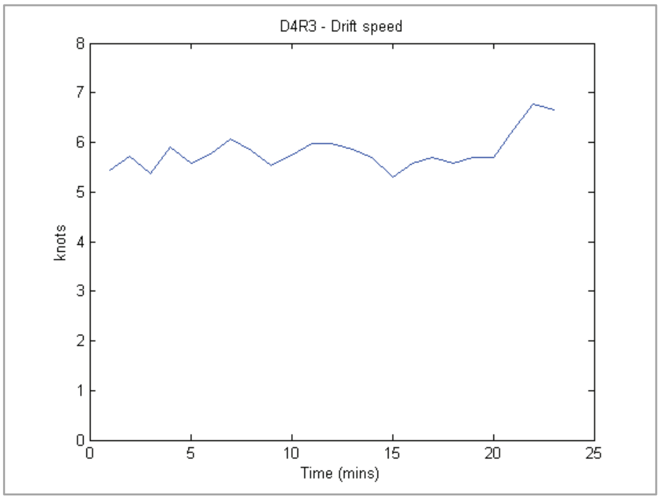


Figure B.23. D4R3 drift rate

Data were recorded from DART 4 only on this run. The tide was flooding. DART 4 travelled 4.12 km. The drift rate is shown in figure B.23.

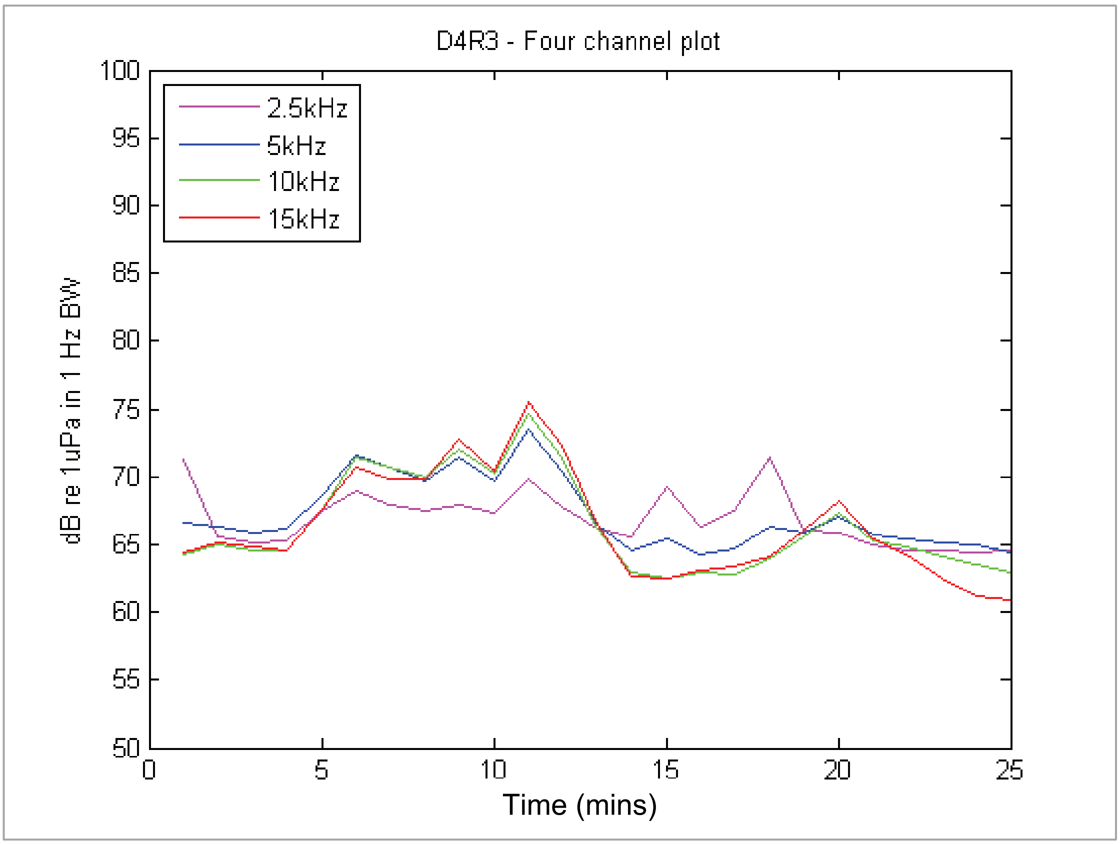


Figure B.24. Sound levels for DART 4, run 3

This run was to the east and north of run 2 and the peak in high frequency noise is higher than in run 2, again suggesting that this track is closer to the sound source than either unit in run 2. There appear to be three distinct sources of high frequency sound. Comparing levels with run 1 on the 26th March, which were much lower, suggests that this track came very close to the sound sources.

The type 1 sound is loudest around 19 minutes while type 2 sound is loudest at nine minutes. The type 3 sound is barely audible on this run and then only for the first three minutes.

Run 4, 26th March 2012

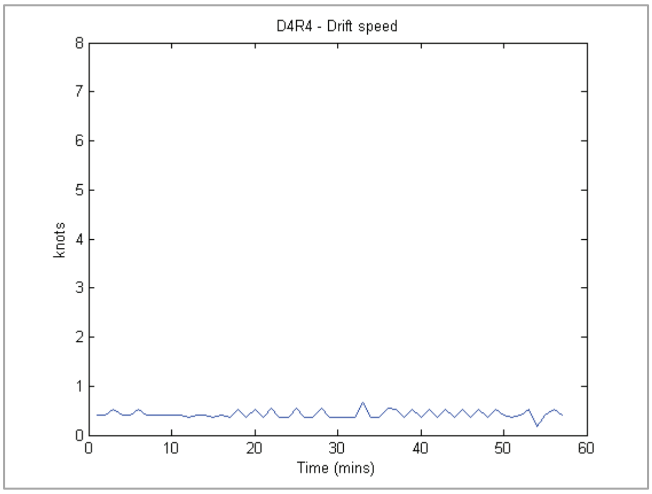


Figure B.25. D4R4 drift rate

Data were recorded by DART 4 only on this run. The tide was flooding during the run. DART 4 travelled 750 metres and the drift rate is shown in figure B.25.

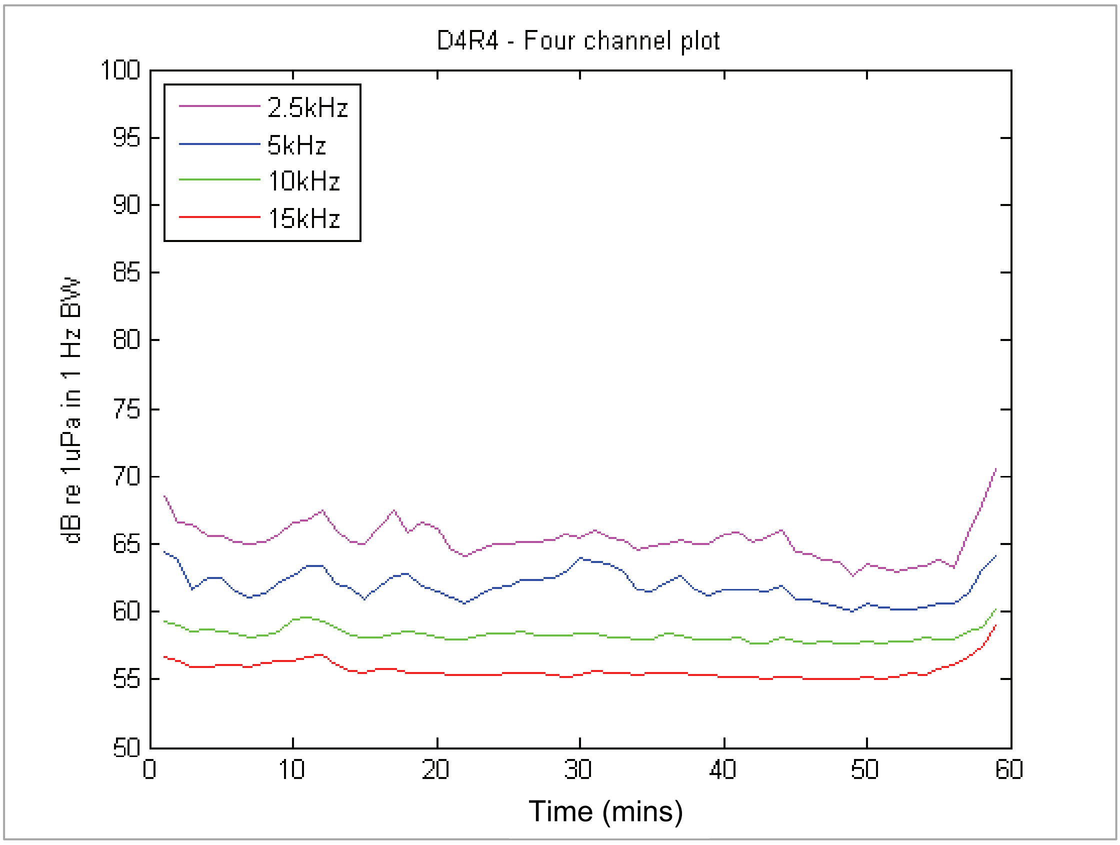


Figure B.26. Sound levels for DART 4, run 4

This run was positioned in the north-east of the area. It is out of main tidal flow so it is unlikely that TECs would be placed in the area. However, it was needed to evaluate the noise field in this part of the test site.

Type 3 sound heard elsewhere was fairly strong in this area and the subsidiary ticking, which may be machinery noise, clearly audible. The noise was strongest at the western end of the run.

The increase in noise levels at the end of the run is caused by the approaching support boat.

Run 5, 26th March 2012

Data were recorded from DART 4 only. The tide was flooding. DART 4 travelled a distance of 1.46 km and the drift rate is shown in figure B.27.

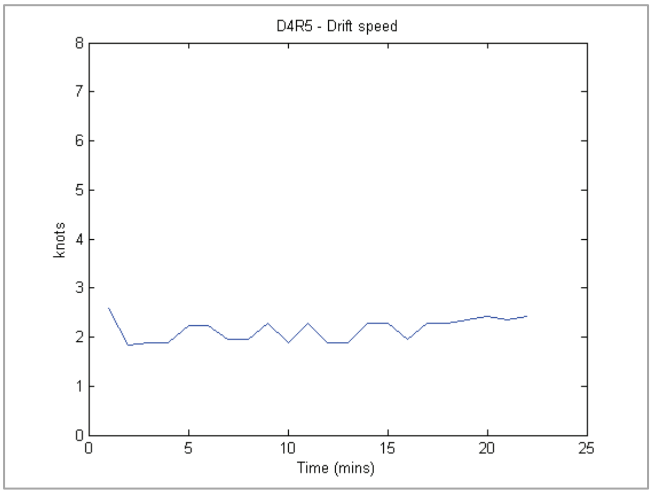


Figure B.27. D4R5 drift rate

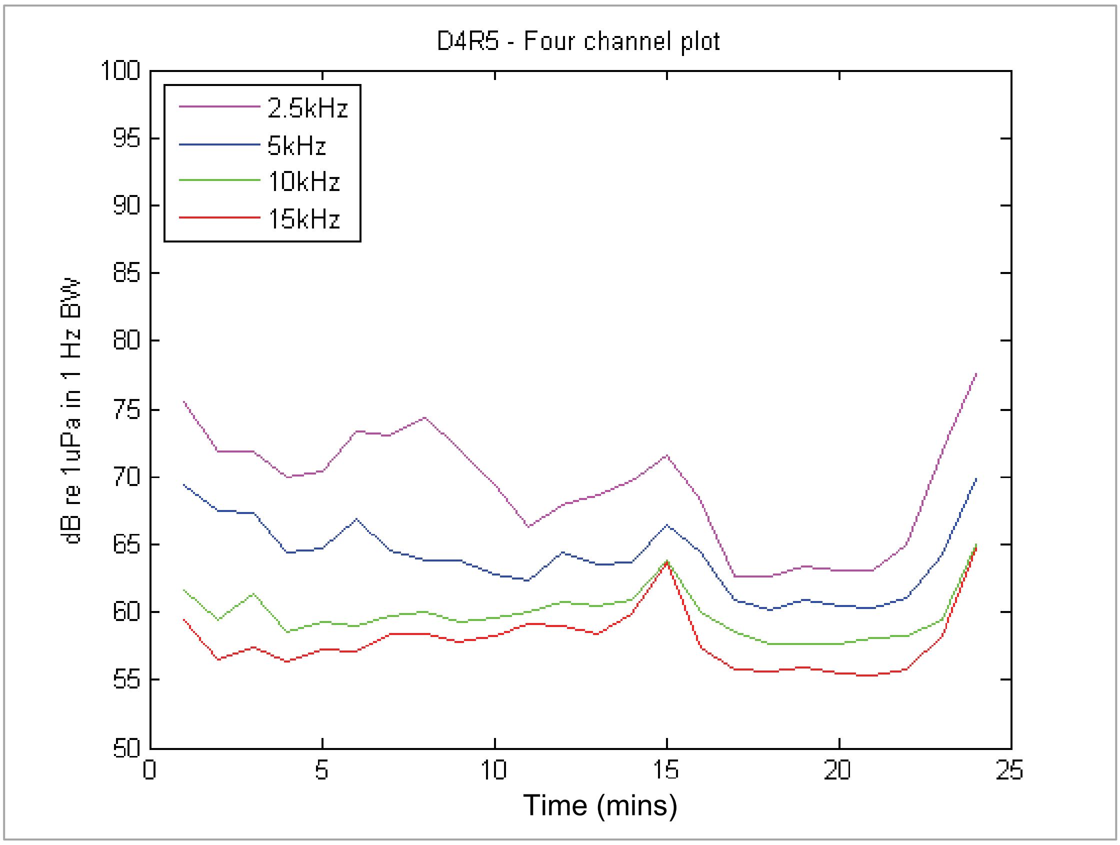


Figure B.28. Sound levels for DART 4, run 5

The first half of the run is heavily contaminated with boat noise. This stops abruptly at 15 minutes after a revving of engines. At that point, the type 2 sound is clearly audible but it is at its loudest at the end of the run. Even when the support boat went quiet, a more distant boat can be heard throughout the run. Type 1 sound is barely audible at the end of the run. The increase in noise level at the end of the run is due to the approaching support boat.

There is a sequence of wide bandwidth clicks throughout the run. They are strongest at the start of the run and fade into the noise near the end. The repetition period is very regular, around 50 ms. It is possible the boat that was heard was using some form of surveying sonar which was causing this noise.

This run occurred at the end of the flood tide and the current had slackened to about 2 knots. There is no trace of the high frequency noise sources observed during the previous runs at a higher tidal current.

Run 6, 26th March 2012

Data were recorded on both DART units during this run. It was carried out at slack water. DART 1 travelled a distance of 1.03 km while DART 4 travelled 530 metres. Both units travelled in a semi-circle as the tide turned. Figure B.29 shows the drift rates.

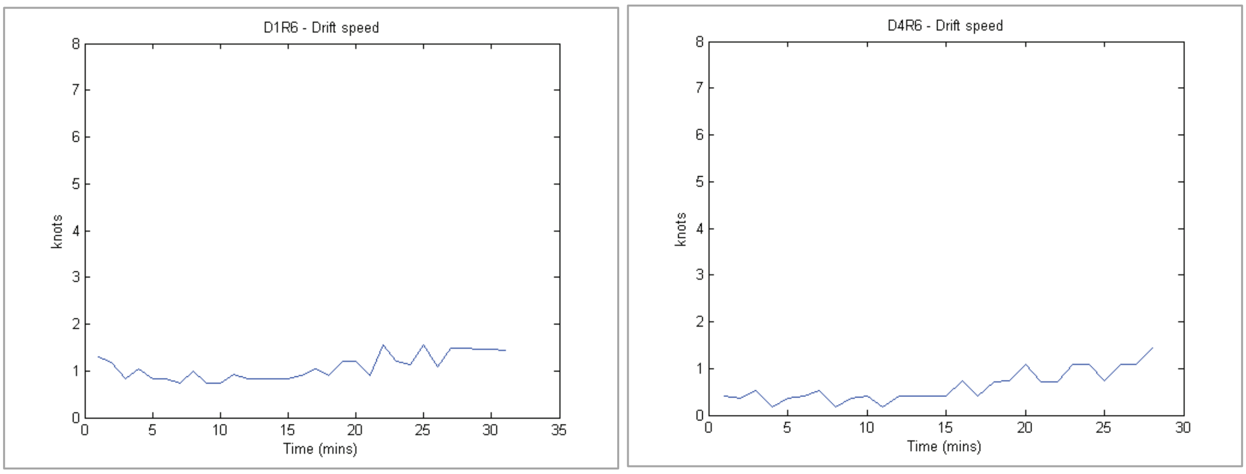


Figure B.29. D1R6 and D4R6 drift rates

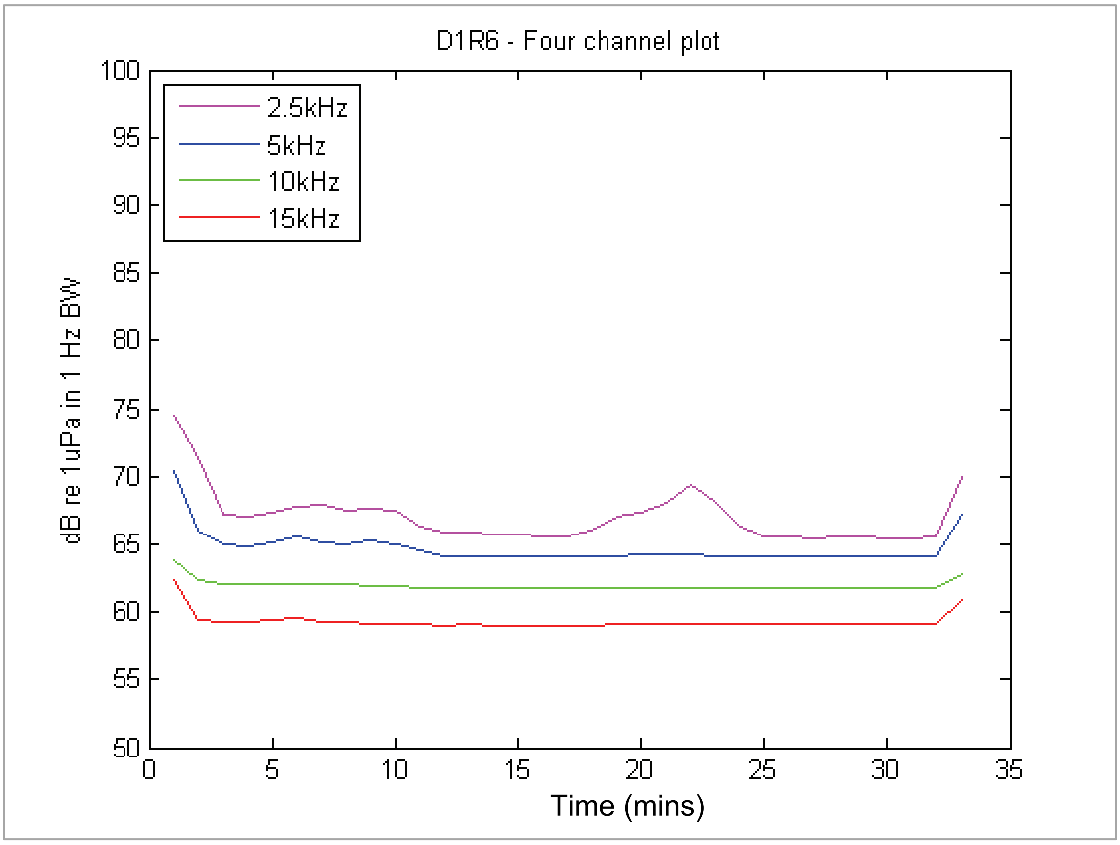


Figure B.30. Sound levels for DART 1, run 6

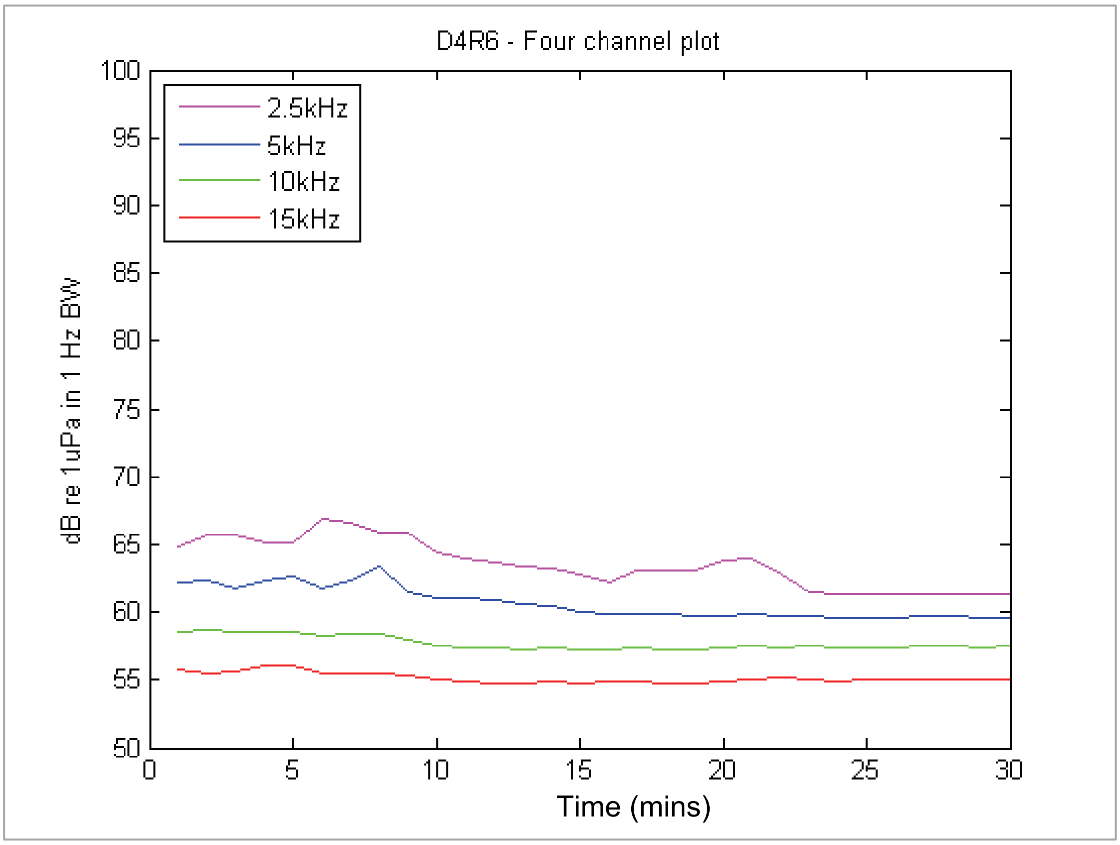


Figure B.31. Sound levels for DART 4, run 6

Both units describe an arc to the east. Type 2 sound is audible throughout the run. Auxiliary machinery can be clearly heard which starts and stops several times. The sound is loudest at 21 minutes and this causes the peak at 2.5 kHz at this time. DART 1 received the strongest signal suggesting that it went closer to the sound source.

There are no high frequency sound peaks during this run. The small peaks at the start of the run on DART 4 are due to boat noise.

The increase in noise at the start and end of run on DART 1 are due to the support boat.

Run 7, 26th March 2012

Data were recorded from both DART units on this run. The tide was ebbing. DART 1 travelled 2.35 km while DART 4 travelled 2.72 km. Figure B.32 shows the drift rates.

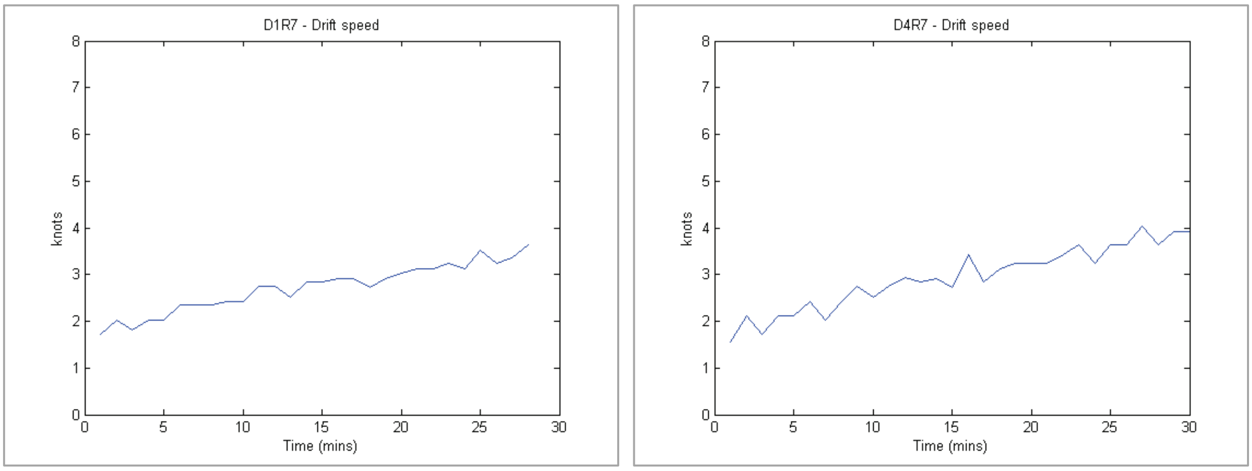


Figure B.32. D1R7 and D4R7 drift rates

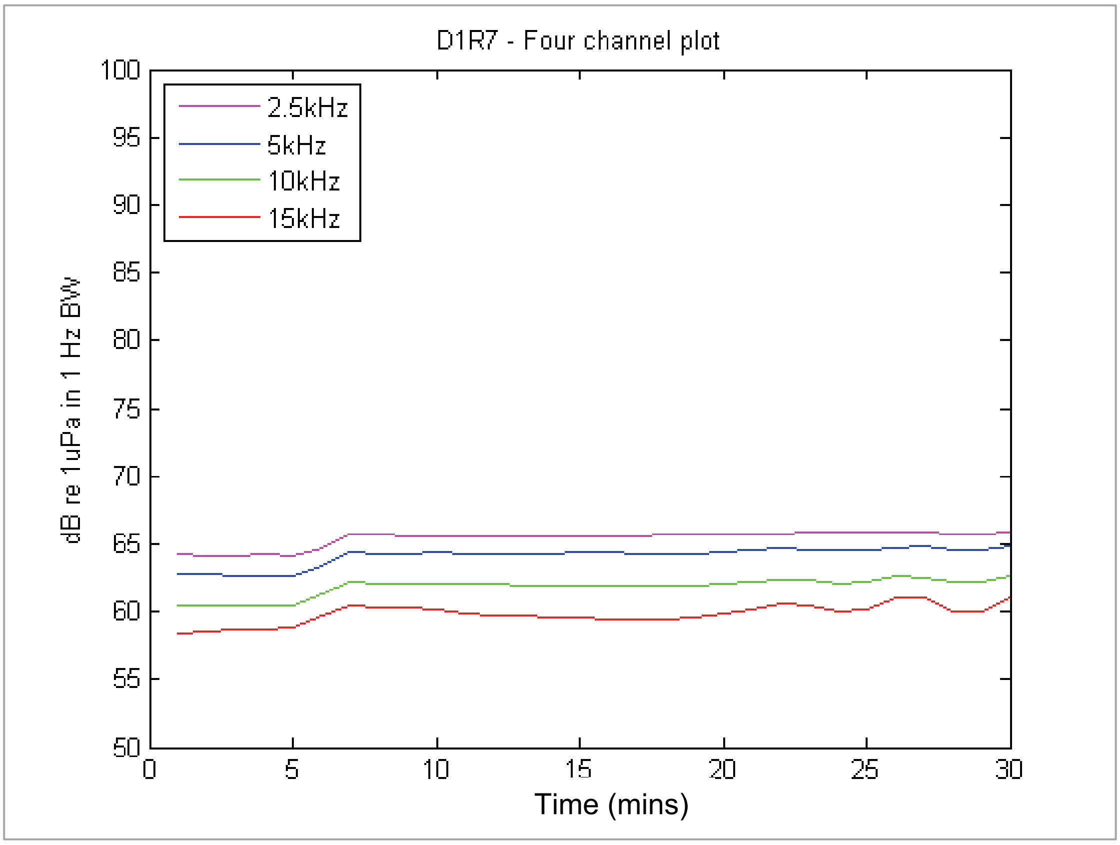


Figure B.33. Sound levels for DART 1, run 7

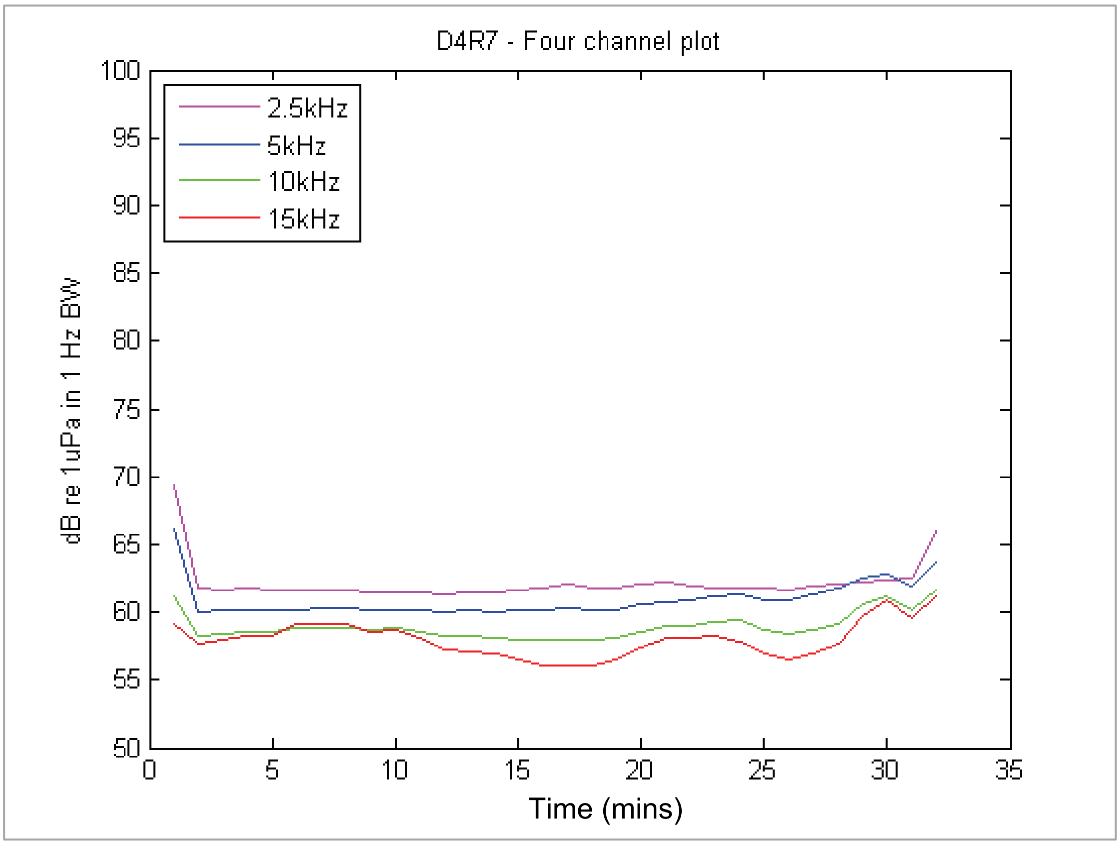


Figure B.34. Sound levels for DART 4, run 7

This run was carried out at the start of the ebb. The track took it well to the west of the possible noise sources. Type 1 sound can be heard weakly in the early part of the run. The frequency of the tone increases through the run suggesting the tidal flow was also increasing through the run. The increase in drift rate through the run also confirms the increasing tidal current. At the end of the run, the type 3 sound is audible.

The only increase in high frequency sound is around 6-7 minutes for both units. For DART 1 there appears to be a step increase in sound around this time suggesting that the tidal current may have increased to the point where the sound generation mechanism starts. Both units show a general increase in high frequency sound through the run and this may be due to the increasing current.

Run 8, 26th March 2012

Data were recorded on both DART units for this run. The tide was ebbing. DART 1 travelled 3.37 km while DART 4 travelled 2.64 km. Figure B.35 shows the drift rates.

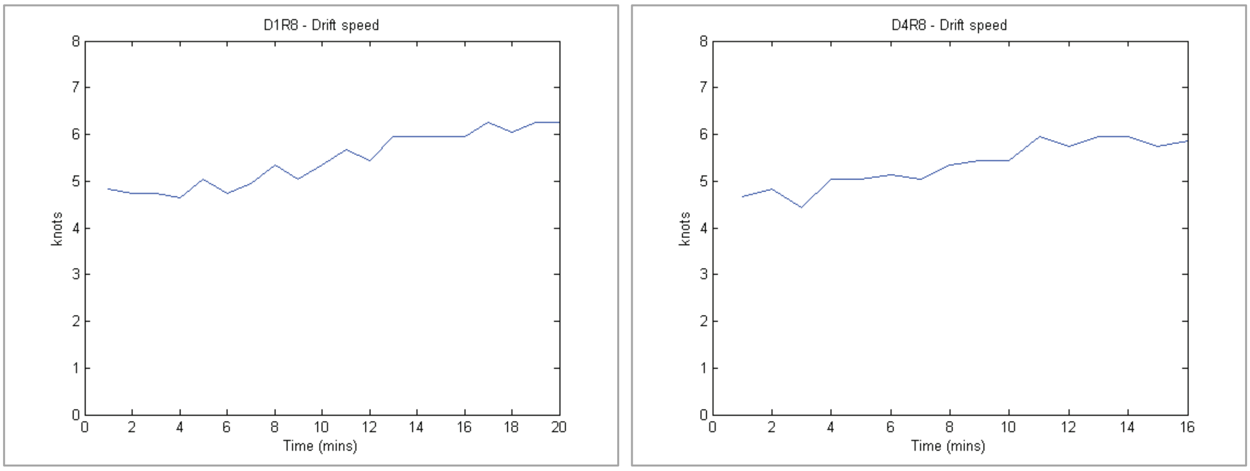


Figure B.35. D1R8 and D4R8 drift rates

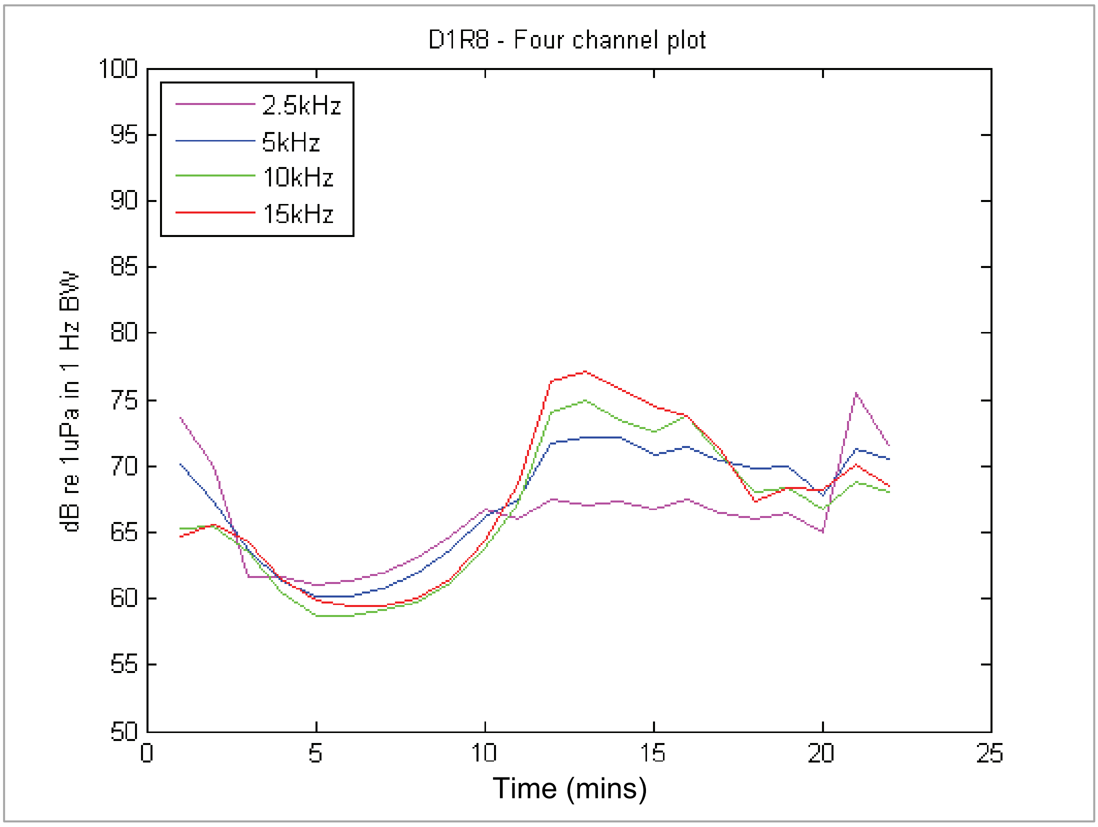


Figure B.36. Sound levels for DART 1, run 8

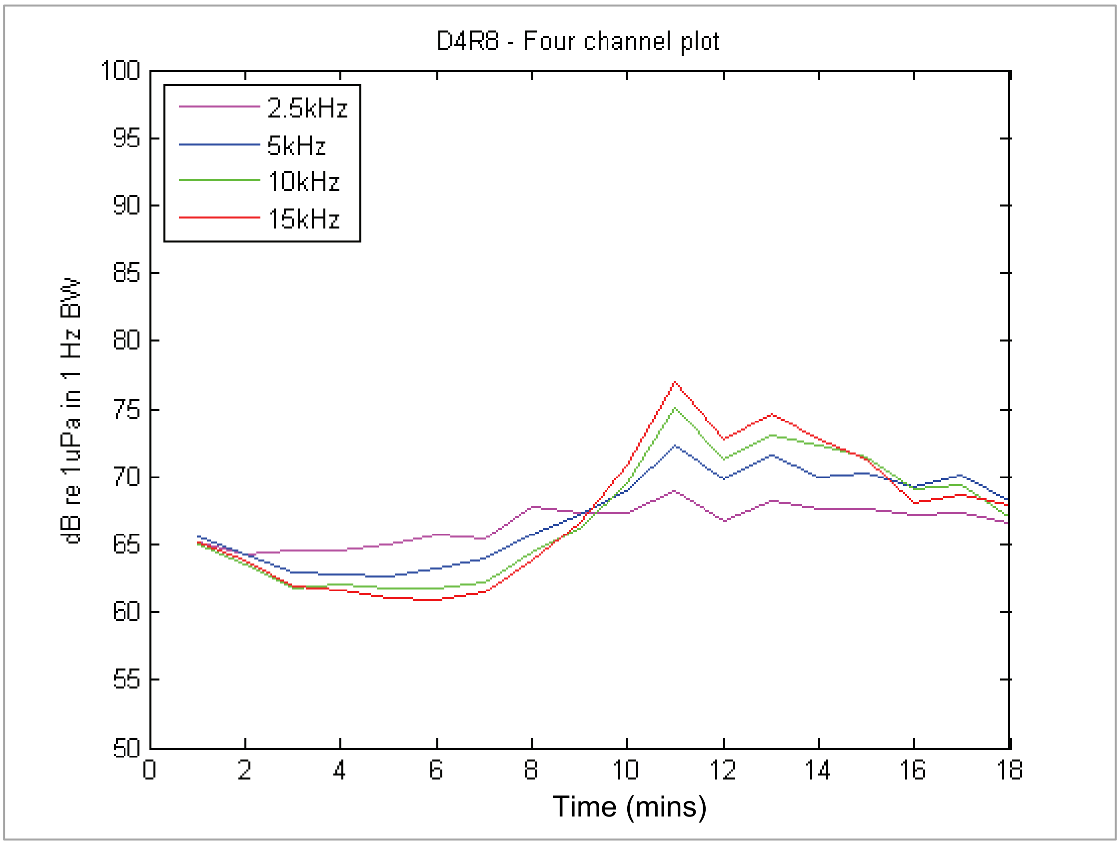


Figure B.37. Sound levels for DART 4, run 8

For this run, the tidal flow had increased to 5-6 knots and there is a clear increase in noise levels. This is particularly marked after 10 minutes into the run. The end of this run is close to the start positions for runs 1 and 3 on the same day. These were both on the flood tide rather than the ebb. Run 1 was at 3.5 knots while run 3 was at 5.5 knots. Run 1 did not hear these noise peaks while run 3 did. Run 3 also found three distinct noise sources.

Type 1 sound was loudest around 4 minutes for DART 1 while type 2 sound was loudest around 12 minutes. Type 3 sound could be heard throughout the run but was loudest towards the end of the run. Possible chain noise can be heard around seven minutes on DART 1.

Run 9, 26th March 2012

Data were recorded on both DART units during this run. The tide was ebbing. DART 1 travelled a distance of 1.55 km while DART 4 travelled 1.15 km. Figure B.38 shows the drift rates.

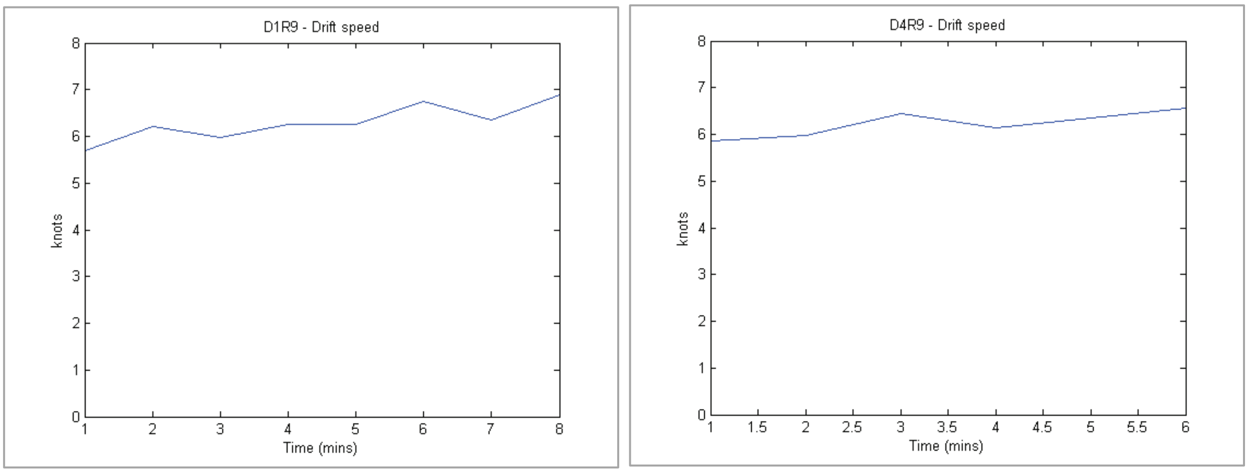


Figure B.38. D1R9 and D4R9 drift rates

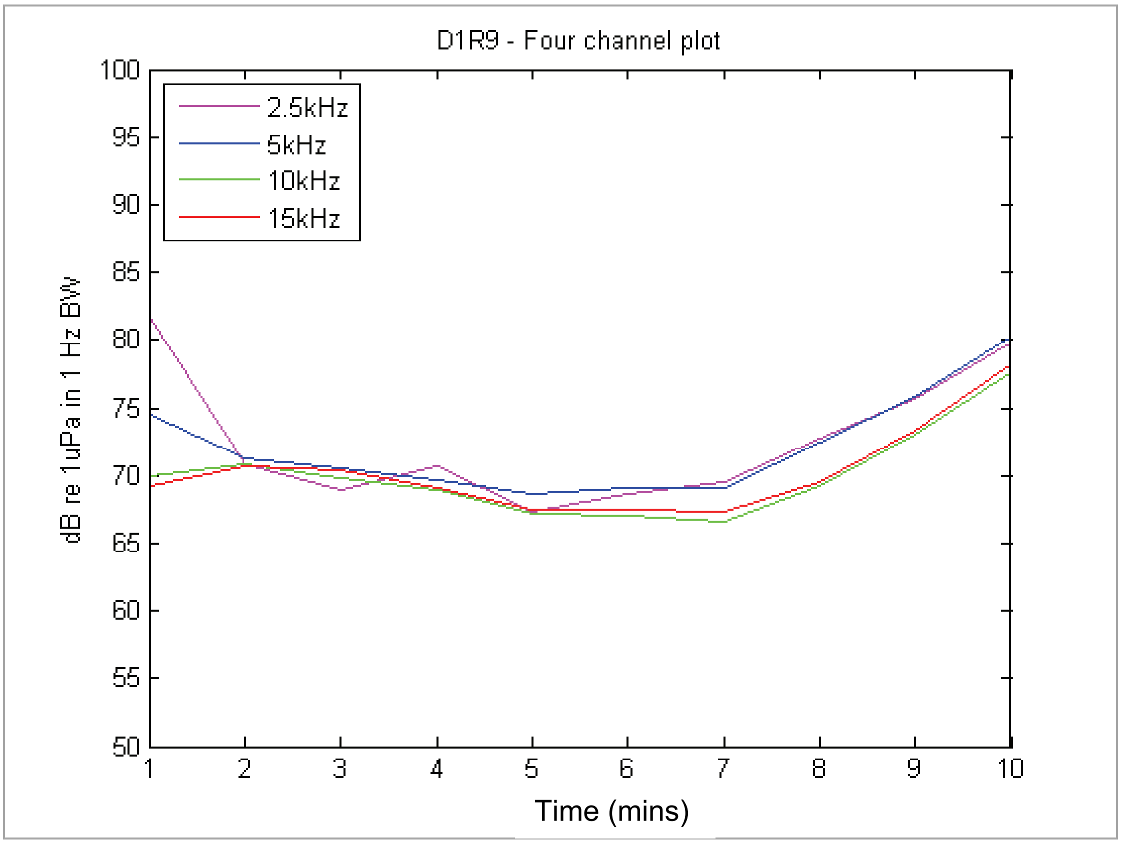


Figure B.39. Sound levels for DART 1, run 9

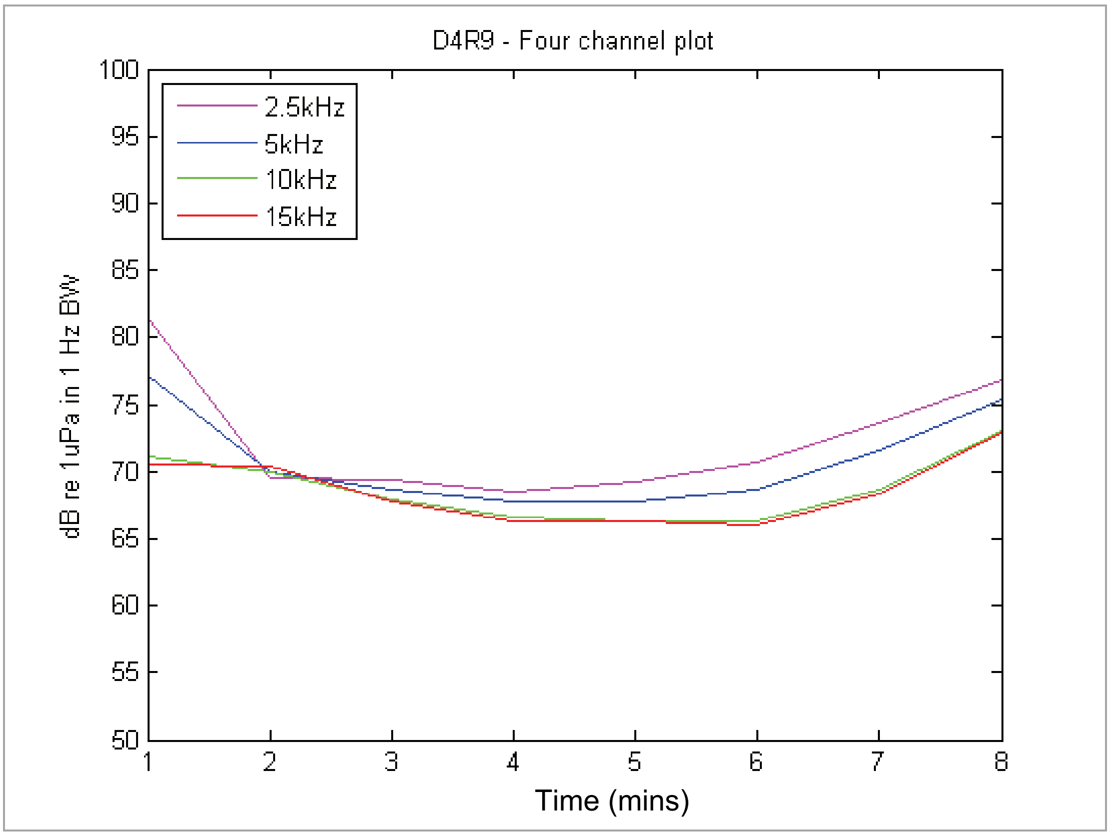


Figure B.40. Sound levels for DART 4, run 9

This run was on the strongest tidal flow of the day. The type 1 sound is particularly strong and peaks at 4 minutes for DART 1 and at 3 minutes for DART 4. The type 2 sound is at a similar level on both units and peaks at 7 minutes for DART 1.

The increase in high frequency sound towards the end of the run is evident in both units.

Run 1, 20th September 2011

Data were available from Drifting Ears unit 2 only. The run was 2 hours after slack water on a flood tide during neap tides. Drift rates are not available for this run.

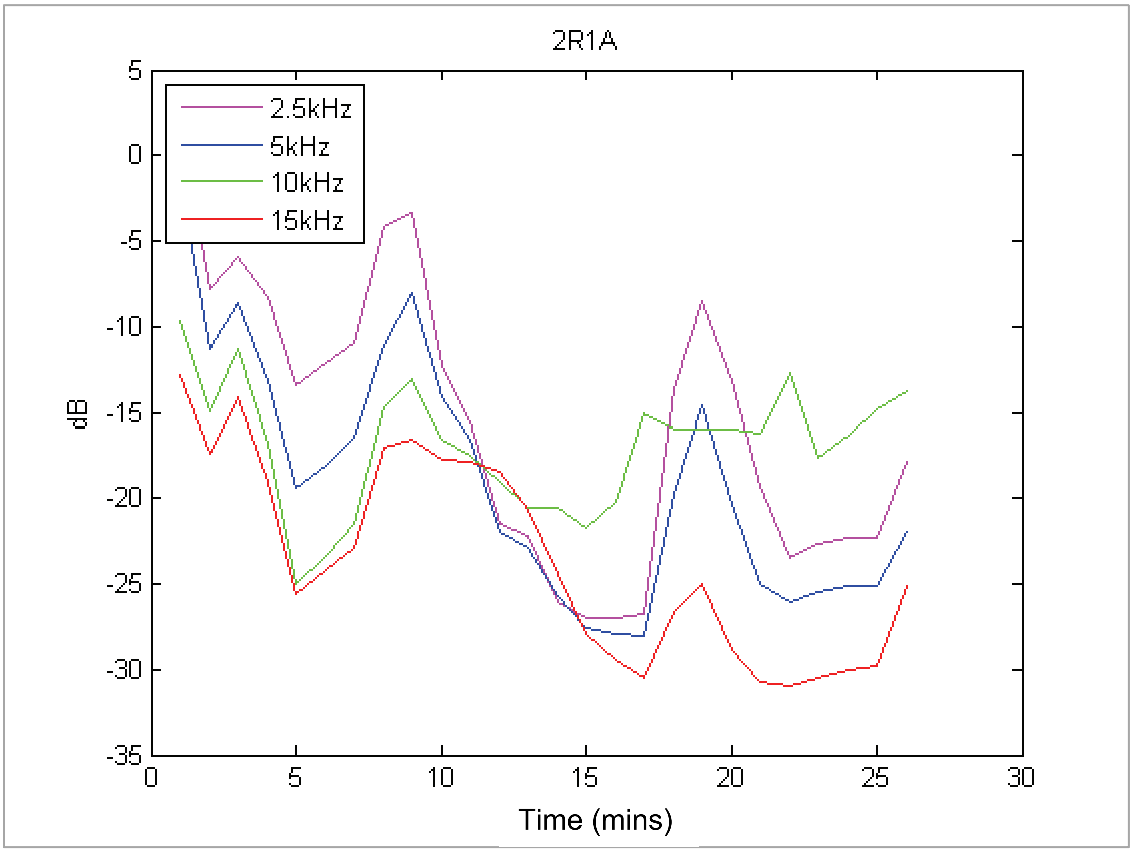


Figure B.41. Sound levels for Drifting Ears 2, run 1

The Drifting Ears units were uncalibrated so the vertical scale should not be compared with the similar plots for the DART units. The high level of sound at the start of the run is the support boat deploying other Drifting Ears units. The peak around 20 minutes is the support boat repositioning to stay in visual contact with the drifting units.

The high level of sound on the 10 kHz channel through the second half of the run is due to the presence of a sound source believed to be a seal scarer which was loudest at the end of the run.

The peak in sound around 9 minutes is due to very heavy rain. The rain was falling during the deployment of the units and this increased the noise level up to 8 minutes into the run but a very heavy squall then passed through lasting about two minutes. It then cleared away by 14 minutes into the run. The noise was increased by around 25 dB in the 2-6 kHz region by the heaviest rain. Figure B.26 shows the mean levels at nine minutes and sixteen minutes. These are the RMS values calculated for one minute. The peaks at 4 and 10 kHz are due to the possible seal scarer.

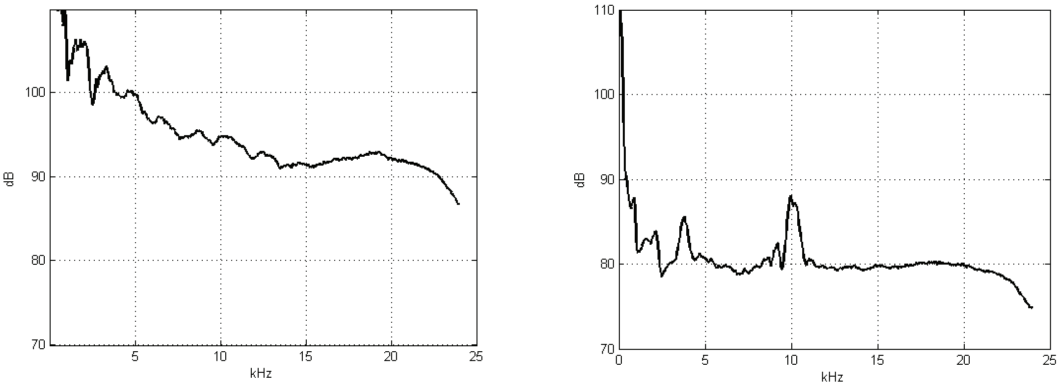


Figure B.42. RMS levels at 9 and 16 minutes

No TECs are audible on this run. There are some weak, low frequency, scraping sounds from the hydrophone arrangement.

At the very end of the run a sequence of clicks were heard that may be echolocation clicks from an odontocete. A single burst of pulses were seen with a repetition rate around 80 mS and lasting about three seconds. The general characteristics suggest a larger marine mammal such as a pilot whale or killer whale.

Geographic distribution, all runs, 23^{rd} March 2012

The data are scaled so that white is the lowest level and black the highest level. The intensity scale is in decibels but is not referenced to absolute levels. The plots are intended to show how the sound levels vary across the area.

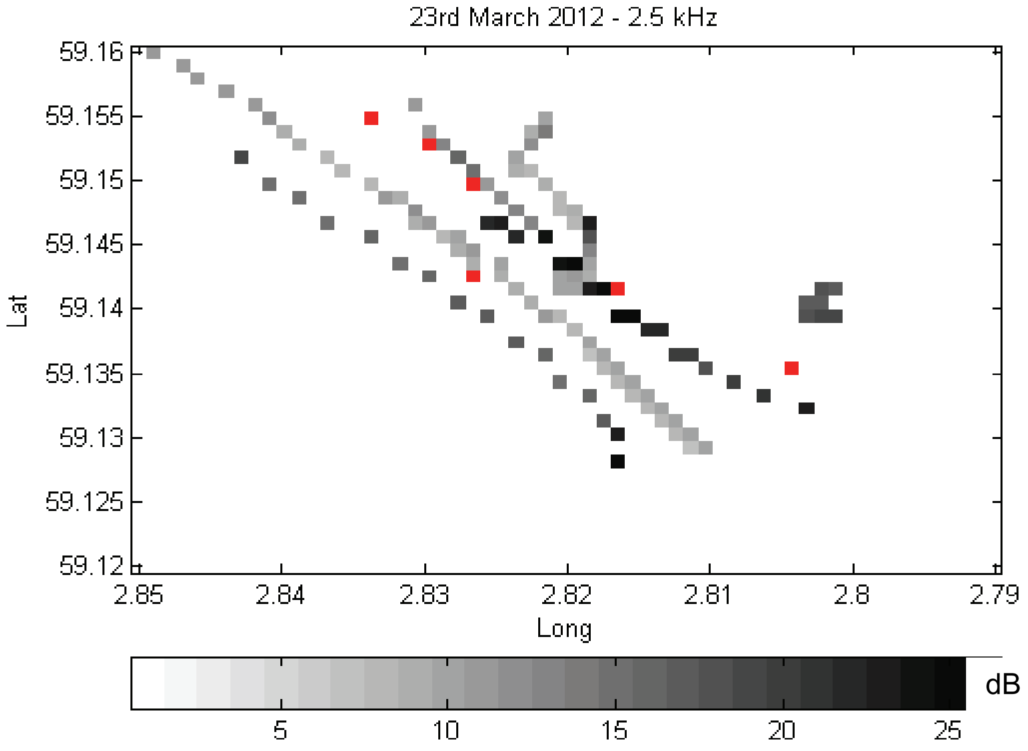


Figure B.43. Geographic distribution, 23/3/2012. 2.5 kHz

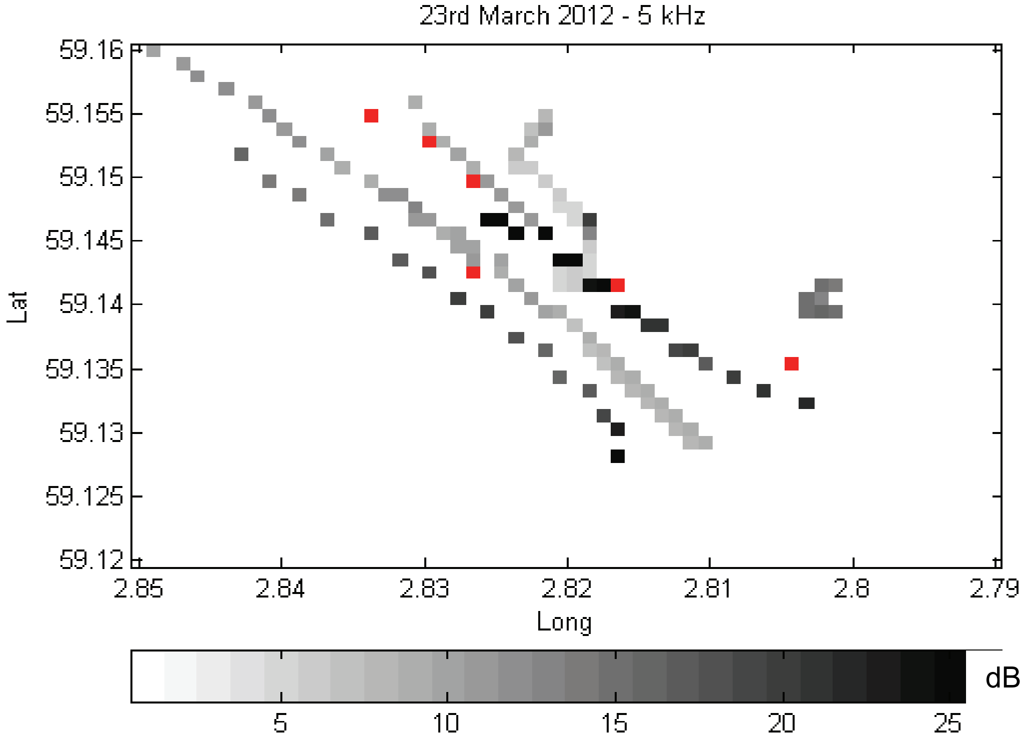


Figure B.44. Geographic distribution, 23/3/2012, 5 kHz

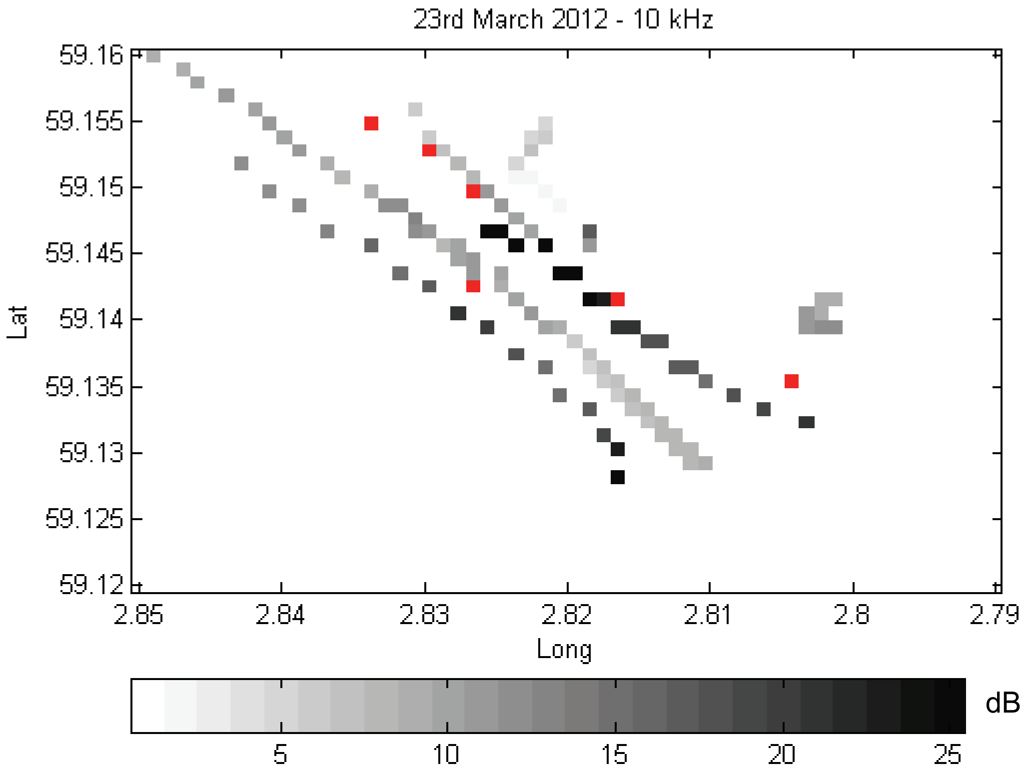


Figure B.45. Geographic distribution, 23/3/2012, 10 kHz

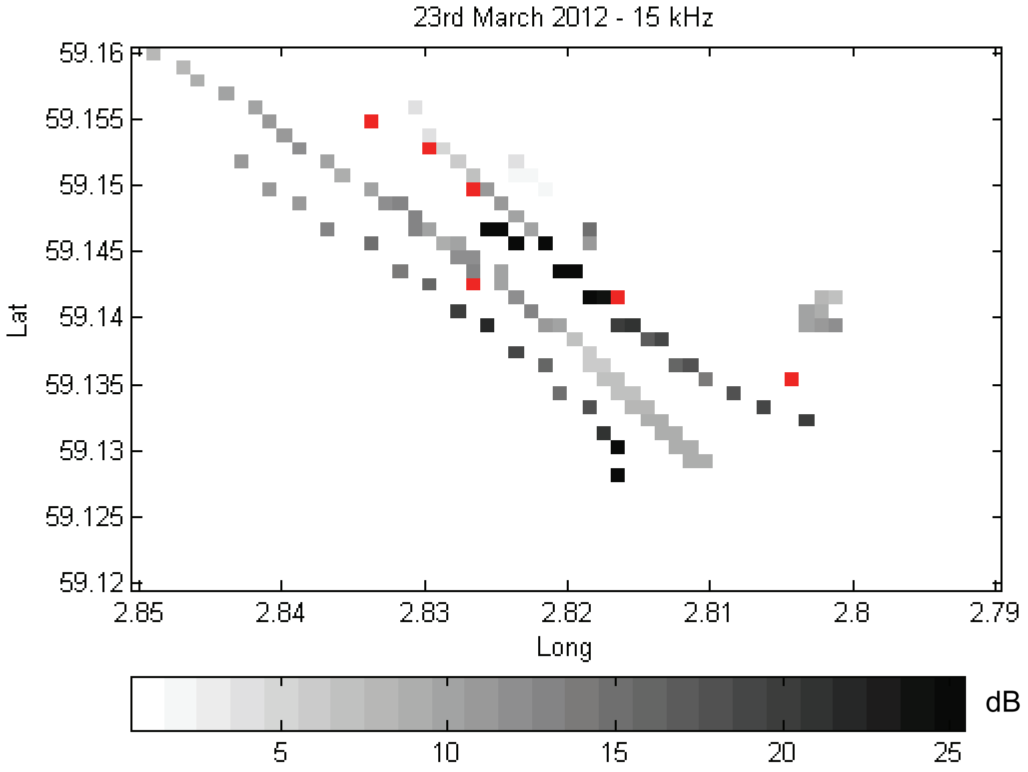


Figure B.46. Geographic distribution, 23/3/2012, 15 kHz

It should be noted that these plots include runs taken on both the ebb and flood tides and at slack water. The tracks can be identified by comparison with Figure 5 in the main text.

The loud high frequency sound heard in the south-east part of the area on a number of runs can be seen. The quieter pair of tracks for run 5 was measured at a lower tidal flow resulting in a lower sound level. During run 6 the tide was running faster than during run 5 and this may have triggered flow noise from a natural feature in the south of the area. Similarly there appears to be a source of noise around 59.145N, 2.82W.

Geographic distribution, all runs, 26th March 2012

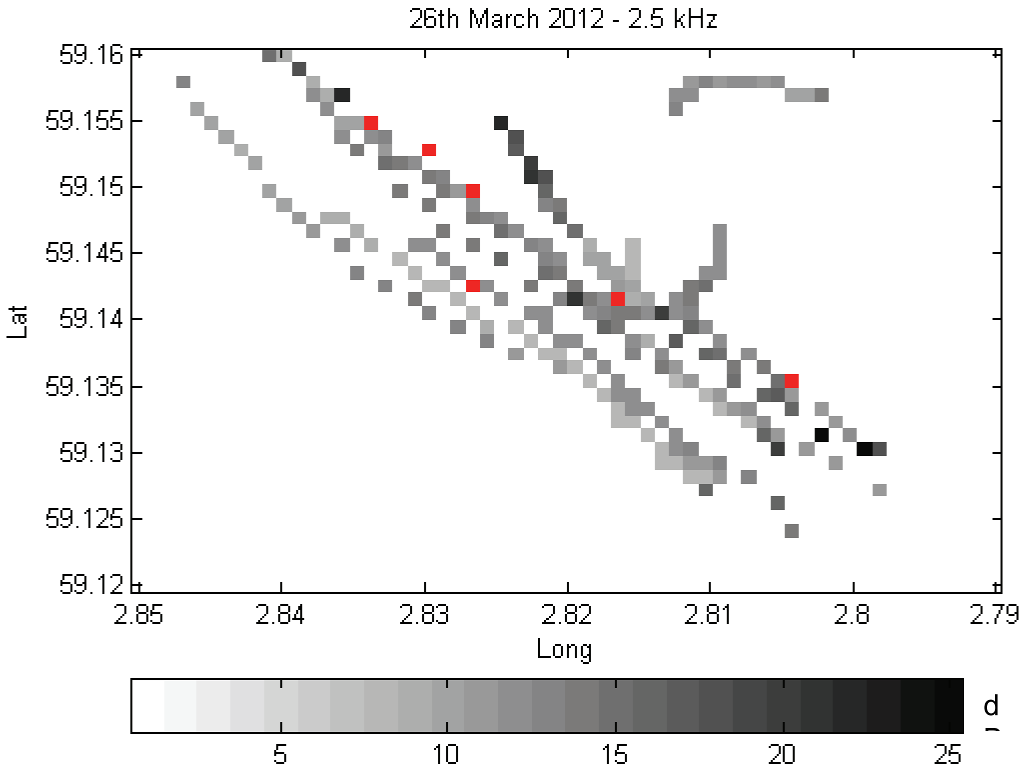


Figure B.47. Geographic distribution, 26/3/2012, 2.5 kHz

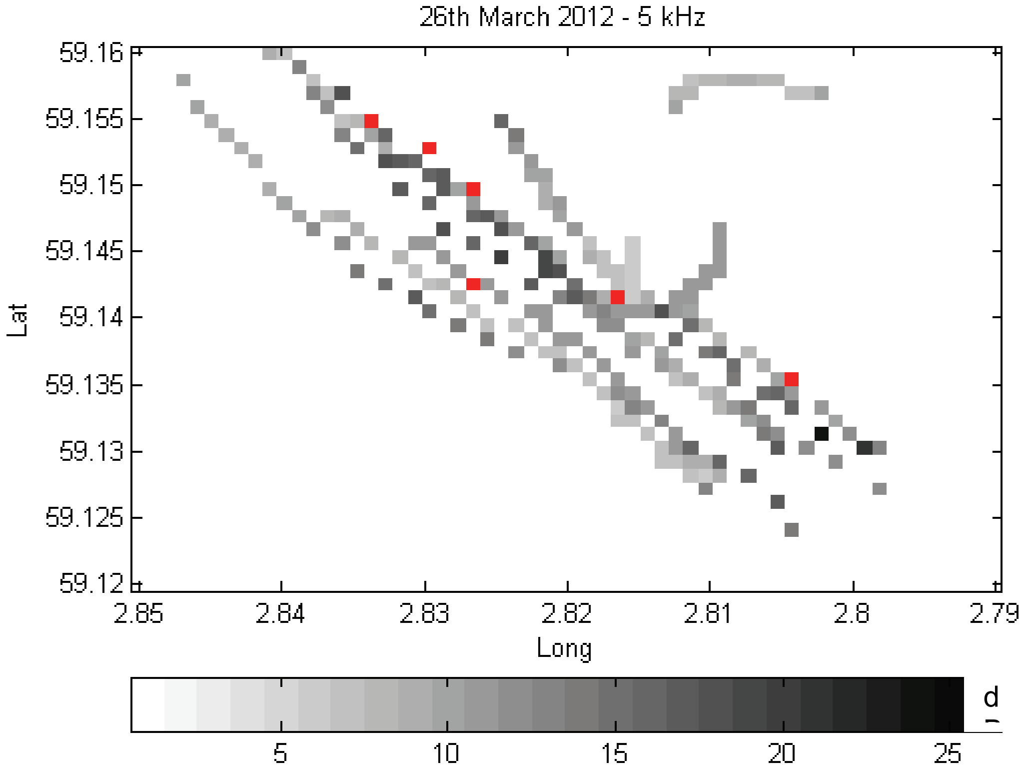


Figure B.48. Geographic distribution, 26/3/2012, 5 kHz

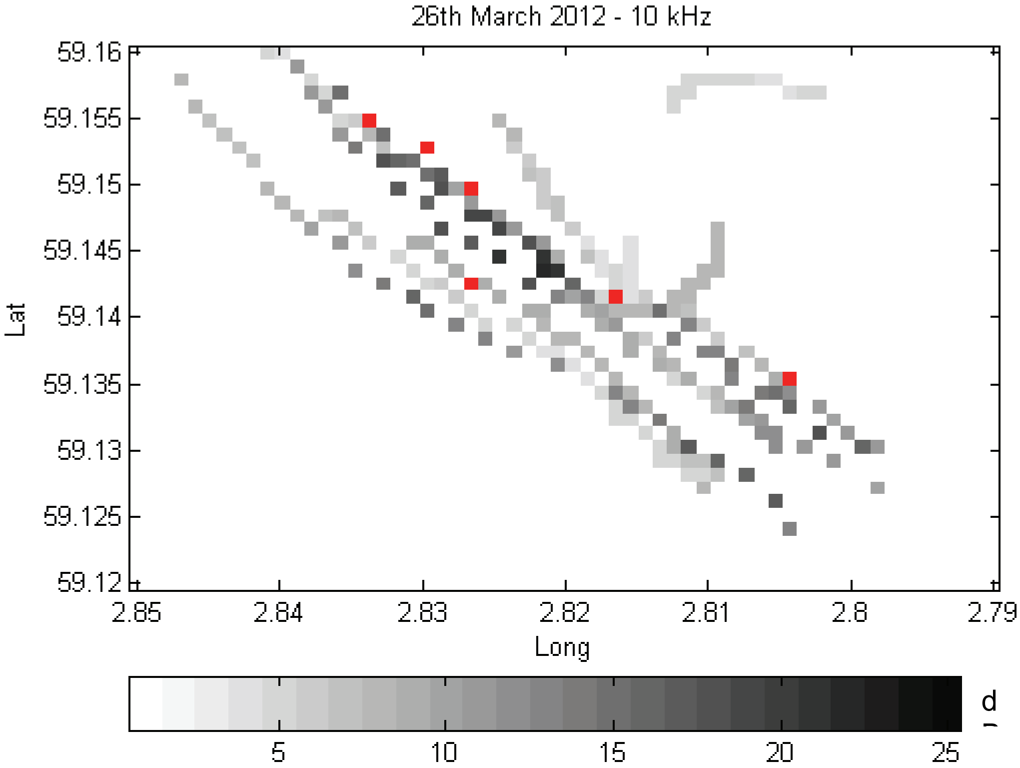


Figure B.49. Geographic distribution, 26/3/2012, 10 kHz

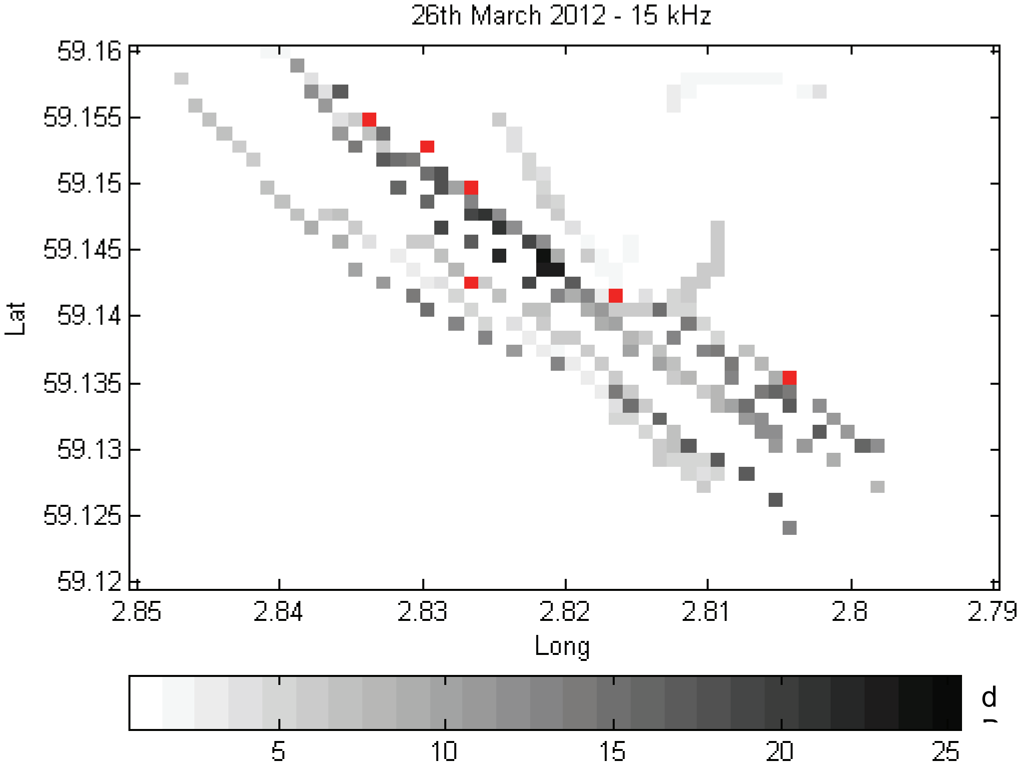


Figure B.50. Geographic distribution, 26/3/2012, 15 kHz

These plots provide an overview of the levels observed during the runs on the 26th March 2012. These runs covered flood and ebb tide and slack water. The intense sounds on 10 and 15 kHz encountered during a number of the runs can be seen around 59.145N, 2.82W. The actual source of the sounds may be further east but the runs that covered that area were carried out during slack water when the sound was not present. The increase in the high frequency sound level at the south-east end of the runs can also be seen.

www.snh.gov.uk

ISBN: 978-1-85397-948-4

Policy and Advice Directorate, Great Glen House,
Leachkin Road, Inverness IV3 8NW
T: 01463 725000

recycle

Scottish Natural Heritage
Dualchas Nàdair na h-Alba
All of nature for all of Scotland
Nàdar air fad airson Alba air fad