Do harbour porpoises target offshore installations as feeding stations?

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ABSTRACT

Three sets of field trials were performed from offshore installations in the German *Entenschnabel* sector of the Dogger Bank, North Sea. Trial 1 was undertaken from the jackup drilling rig *Noble Kolskaya* and its support vessel *Northern Seeker* in Sector B4-05 in October and November 2004. Trial 2 took place from the same rig when transferred to Sector B11-04 in December 2004 and January 2005. The purpose of these trials was to perform measurements of acoustic noise levels generated by the rig during routine activities and to undertake preliminary passive acoustic monitoring of harbour porpoises (Cetacea: *Phocoena phocoena*) using T-PODs around the rig. Trial 3 was a six-month study from August 2005 to January 2006 using T-PODS around the A6-A gas-production platform when it was isolated, when the drilling rig *Noble Kolskaya* was docked alongside, and after the rig's departure.

Sound levels generated by the *Kolskaya* were similar to previous measurements from metal-legged bottom-founded platforms, both in level (120 dB re 1µPa) and in the frequency range of dominant tonals (2-1400 Hz). Sound levels were highly variable over short periods, shifting 15-20 dB between quietest (holding) and loudest (drilling) operations. The rig was significantly quieter than its associated support vessels; rig high frequency sound levels dropped rapidly > 8 kHz.

With the exception of rig-docking/rig-departure manoeuvres, porpoise activity appeared to be independent of platform/rig activity. The greatest porpoise activity was observed during the winter months; porpoise activity and feeding rates were significantly reduced in periods of heavy weather.

Here we present data to suggest that harbour porpoises may be using installations in the Dogger Bank on a seasonal basis and that installations may enhance porpoise habitat by acting as artificial reefs and feeding stations, especially during the winter months. However, these are preliminary snapshot findings. To answer completely the question posed in the title of this paper, we would need to undertake baseline controlled and replicated longer-term studies if the story of harbour porpoise usage of offshore installations is to be fully told.

1. INTRODUCTION

The 1992 EU Directive on the Conservation of Natural Habitats and Wildlife Fauna and Flora (the Habitats Directive) imposed the establishment of protected areas for habitats and species considered to be of European importance within member states' territories. These sites form the European *NATURA 2000* network and in May 2004, Germany nominated part of the Dogger Bank to the network (Berry 2004). The Dogger Bank will also become part of the Marine Protected Area (MPA) network under the OSPAR (The Convention for the Protection of the

Marine Environment of the North-East Atlantic) and the Helsinki Convention (see Unger 2004). The harbour porpoise (*Phocoena phocoena*) is listed in Annex II of the EC Habitats Directive. Member states of the EU are required, by law, to consider the establishment of Special Areas of Conservation (SACs) for Annex II species, though no candidate or 'cSACs' have yet been established for the harbour porpoise.

The Dogger Bank is an extensive isolated shoal of submerged glacial moraine in the Central North Sea. It rises 20 m higher than the surrounding sea floor, is *ca.* 324 km long and *ca.* 120 km wide (Pantin et al. 1991) reaching its shallowest point (15 m below the sea surface) at its south-western end. It covers an area of 17,610 km^2 and is orientated ENE to WSW. The Bank is situated within the 200 nm zones and/or EEZs of Germany (eastern end), the United Kingdom, the Netherlands and Denmark [see Gubbay et al. (2002) for a comprehensive review of the nature of the Dogger Bank]. The Dogger Bank is unusual in that it exhibits year-round phytoplankton production (Berry 2004; Kroncke and Knust 1995) and is a complex ecosystem that represents important spawning grounds for key populations of commercial fish and feeding grounds for marine mammals and seabirds (see Camphuysen 2001). Marine mammals that are particularly vulnerable to man's activities in the area include the harbour porpoise (*Phocoena phocoena*).

A number of oil and gas installations operate within the Dogger Bank cSAC, and they are obliged to carry out extensive Environmental Impact Assessments (EIA) of their industrial activities, including the species listed in Annex IV (a) of the Habitats Directive (which includes the harbour porpoise). One potential impact of oil and gas activities is that of noise pollution. Although noise emanating from fixed, metal-legged platforms is generally considered to be relatively low level and at very low frequencies, near 5 Hz (DOI 2004), in recent years, both the scientific community and the general public have become increasingly concerned about the effects of such low frequency anthropogenic sound on marine mammals. In 1994, the National Research Council (NRC) issued a report titled "l*ow frequency sound and research needs"* which concluded that (1) very little is known about the effects of low frequency sound on marine mammals and (2) it is difficult to establish regulatory policy in the absence of data. The Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS) includes amongst its requirements that Range States should work towards *"the prevention of disturbance, especially of an acoustic nature"*.

Acoustic energy propagates better under water than electromagnetic forms, compelling marine mammals to rely heavily on sound for many aspects of their life history (Costa et al. 2003). With respect to toothed whales and dolphins, however, few data are available on the effects of noise from oil and gas drilling activity. While underwater sound measurements of drilling operations are present in the literature (e.g. Gales 1982; Richardson et al. 1995 and references therein), none to date have been made from jackup rigs and little is known about how jackups may impact local populations of small cetaceans. There is also scant information on how rigs/platforms may act as artificial reefs (with associated 500 m no-take fishing zones) attracting potential prey items of higher predators, such as harbour porpoises, thus possibly benefiting local cetacean populations. Indeed, recently, it has been suggested that there may be negative effects of climate change on porpoise prey (sandeels, *Ammodytes* spp.) availability which, in turn, may have serious negative effects on harbour porpoise populations in the North Sea by increasing the likelihood of starvation in spring (MacLeod 2007). If this is the case, then offshore installations may be acting as crucial feeding sites for these animals, further adding to the urgency for more research in this hitherto unexplored field.

In the literature, specific marine mammal response thresholds to the sounds of offshore activities have been determined for only a few combinations of species and noise types, and these reports tend to be quite variable even within species. In general, response thresholds are often low for variable or increasing sounds, e.g. approaching boat; intermediate for steady sounds, e.g. offshore drilling noise; and high for pulsed sounds, e.g. seismic surveys (Richardson and Würsig 1997) and see review by Parente et al (2007). With repeated exposure, many cetaceans habituate at least partially. Increased sensitivity of the animals following harassment is presumed but the long-term effects on individuals and populations are little explored and data are lacking (Richardson and Würsig 1997). There is currently no clear evidence of avoidance behaviour by small odontocetes to drilling noise. Some belugas (*Delphinapterus leucas*), for example, occur well within the ensonified zones around stationary dredges, artificial islands and production platforms (Fraker 1977) and only show behavioural reactions to playbacks of drillrig nose when received levels are high (Stewart et al. 1983 quoted in Richardson and Würsig, 1997). Captive belugas have also been shown to have brief startle responses to playbacks of drillrig noise, though the animals in that particular study did approach close enough to the projector to receive levels ≥ 153 dB re 1μ Pa (Thomas et al. 1990 quoted in Richardson and Würsig, 1997). These tolerances arise partly from the low auditory sensitivity of belugas to LF sound (Johnson et al. 1989) and it could be predicted that because of the high-frequency nature of small cetaceans vocalisations and auditory sensitivity (based on audiogram data), reactions to low frequency drilling noise would be minimal. For a review on the influences of man-made noise and other human activity on cetacean behaviour, see Richardson & Würsig (1997).

The noise sources from drilling operations are not simply restricted to the installations themselves. Numerous support vessels, tugs and safety boats, the latter which are present around the installations permanently, are often active for long periods. There have been several papers on the response of odontocetes to noise (e.g. Erbe 2002; Nowacek et al. 2001) and a review by Richardson *et al*. (1995) on the response of marine mammals to vessel noise, but again the responses vary. Many toothed whales appear to be tolerant of vessel noise and are regularly observed in areas where there is heavy traffic. Harbour porpoises, however, are known in some instances to avoid approaching boats (Polacheck and Thorpe 1990), and sperm whales have been reported to react to vessels with powerful outboard engines at distances of up to 2 km (pers. obs. and J. Gordon pers. comm.).

For passive acoustic monitoring of porpoises, this study employed T-PODS. These are autonomous devices used to collect acoustical information from dolphins and porpoises by selecting tonal clicks and recording only the time and duration of each click (see www.chelonia.co.uk for more information). The T-POD does not record sound, it simply logs the presence or absence of appropriate sound by selecting tonal clicks and recording their time of occurrence and duration (Watkins and Colley 2004). T-PODs are therefore not a conventional real-time click detector, like for example a heterodyne bat detector, but rather a 'click-timing' detector. The time and the duration of the clicks are logged in 10μs units, but the actual digitised sound from the animal is not stored. Like any acoustic device, the T-POD is designed with the assumption that the animal of interest is vocalising actively. T-PODs are entirely passive (i.e. listening devices) and consist of a hydrophone (comprising a piezoceramic transducer), an analogue processor and a digital timing/logging system. The data are then analysed through a custom-written software package called TPOD.exe that filters the data after they have been transferred to a PC.

Passive acoustic monitoring techniques have been used for many years to record cetacean clicks and while T-PODs are a relatively new development in this field, numerous studies have used them successfully (e.g. Carlström 2005; Kotzian et al. 2002; Madsen et al. 2006; Thomsen et al. 2005b; Tougaard et al. 2005a).

The present study was designed to address both the data sparseness regarding drilling activities and underwater noise and the lack of data on odontocete acoustic behaviour in the presence of oil and gas activities. This paper is a much-truncated version of the two reports submitted to Wintershall (Turner et al. 2005; Turner and Todd 2006) which totalled 215 pages and included turbidity, oceanographic and other studies as part of general Environmental Impact Assessment protocols. This paper presents only:

(a) Measurements of underwater acoustic noise levels generated by a jackup drilling rig during routine operations;
(b) Trial short-term passive acoustic monitoring (PAM) of harbour porpoise activity in the vicinity of a jackup drilling rig; and,

(c) Trial longer-term PAM of harbour porpoise activity around a gas production platform when in isolation, when a drilling rig was attached to the side and when the drilling rig departed.

Passive acoustic monitoring focussed on the harbour porpoise which is the most abundant and widespread cetacean species in European waters. It ranges widely and uses both active sonar (echolocation) and passive sonar (listening) throughout the year. These qualities make them uniquely suitable for long term and low cost acoustic monitoring, with continuous objective data (Fisher and Tregenza 2003) and potentially key indicators of acoustic pollution in their environment.

This was a snapshot study. We were not permitted to undertake any baseline, control or replicate studies to assess cetacean activity at the sites prior to arrival of the rig; conclusions, therefore, cannot be drawn about the reactions (if any) of the animals to the rig/platforms' presence or absence. Inferences can only be made about relative activity levels with varying rig/platform operations. Nonetheless, we feel that these preliminary studies should be released to the wider scientific and commercial field in order to stimulate interest in taking this work further.

2. MATERIALS AND METHODS

2.1 Timing and locations

Three sets of North Sea field trials were performed from a jackup drilling rig and from a gas production platform operating under the jurisdiction of the oil and gas branch of BASF (Wintershall AG) in the 'Entenschnabel' North East German sector of the Dogger Bank (Figure 1)

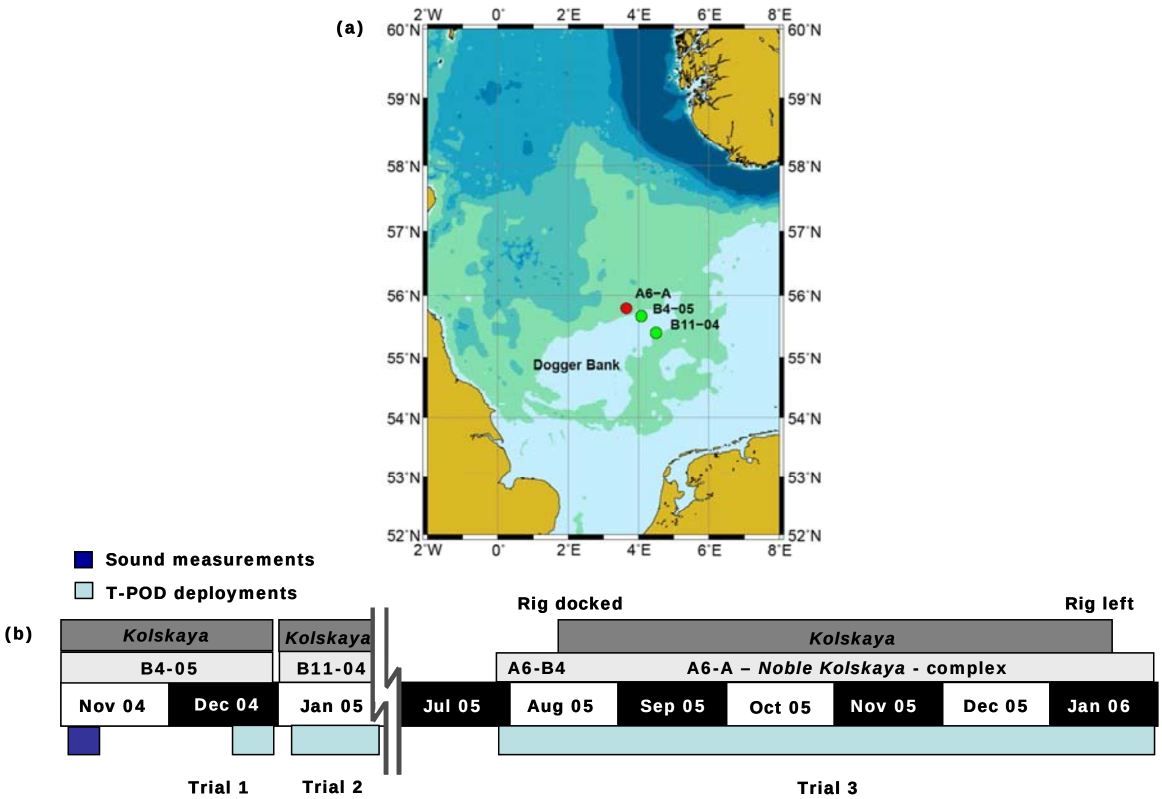

Figure 1: (a) Location of sectors B4-05, B11-04 and A6-B4 (A6-A platform) in the German sector of the North Sea. Lightest blue bathymetry region delineates 30 m contours. Map projection: Mercator. (b) Timeline of Trials 1 and 2 in all three sectors.

The jackup drilling rig *Noble Kolskaya* had a typical triangular plan-form with three legs at 53.95 m spacing and a deck area of 1765 m^2. Overall length of the hull was 69.25 m, with a depth at the centre of the hull of 8.55 m. The A6-A gas production platform had a typical six-legged steel construction with a base area of 1015 m^2. The platform was 52 m long and 33 m wide.

Trial 1 took place from the *Noble Kolskaya* in Sector B4-05 (55°40'94.203"N, 004°05'23.810"E) and Trial 2 from the same rig in Sector B11-04 (55°24'57"N, 004°32'03"E), both northeast of the Dogger Bank tail. Trial 3 took place from the A6-A gas production platform in Sector A6-B4 (55°47'28.895" North, 003°59'39.584" East) when it was in its standalone position, when the *Noble Kolskaya* was docked alongside and when the A6-A stood alone again. The three locations will be referred to as B4-05, B11-04 and the A6-A respectively.

2.1.1 Trial 1: B4-05

On October 28th 2005, the *Noble Kolskaya* was towed and positioned at the B4-05 sector. The rig was located in a water depth of 40 m on a seabed of very soft clay on a heading of 135°. On November 4th 2004, underwater acoustic measurements of routine rig activities were taken until completion of drilling the 24" section. Acoustic measurements were then transferred to the support vessel *Northern Seeker* until November 8th, to characterise the far-field (i.e. away from the rig) acoustic noise levels.

The rig was re-joined by ASL crew on December 15th 2004, following completion of the well. Three autonomous cetacean passive acoustic monitoring devices (T-PODS) were installed and optimised during a long waiting on weather (WOW) period and these operated until removal on December 26th 2004, just prior to an anticipated rig move, which was further delayed due to foul weather conditions. On January 1st, 2005, the rig was moved to the next location in Sector B11-04.

2.1.2 Trial 2: B11-04

The ASL team re-joined the rig at Sector B11-04 (11 nm away from the B4-05), on January 6th 2005, following the initial drilling of the 36" conductor (which had been drilled rather than hammered to minimise acoustic disturbance according to SAC guidelines). The seabed and depth (42 m) were very similar to the B4-05 on an identical heading. Though the sites cannot be viewed as identical replicates, various features (rig specifications, rig activities, support vessels, depth, heading and bottom type) were identical or similar. Data were regularly downloaded from the T-PODS, which were then redeployed. Weather conditions remained foul until the team left on January 11th 2005, after drilling of the 24" section. The T-PODS remained in the water until January 29th 2005, when they were retrieved in anticipation of the next rig move and the end of the trial.

2.1.3 Trial 3: A6-A

The A6-A gas production platform has been in position in the natural gas field A6-B4 since July 1999. The A6-A is 7.5 nm away from the B4-05 location and is situated in a water depth of 47.8 m on a seabed of very soft clay on a heading of 180.3°. The T-POD acoustic monitoring study took place over six months from the 30th of July 2005 to the 27th of January 2006.

At the beginning of the monitoring period, the A6-A was standing alone in its location. On 13th/14th August 2005, the drilling rig *Noble Kolskaya* joined onto the A6-A (on its southern end) to explore a new well. The A6-A-*Kolskaya* complex continued normal activities until 18th/19th January 2006, when the *Noble Kolskaya* left the A6-A. Measurements of porpoise activity continued throughout all these activities.

2.2 Tide and wave-induced current predictions

During the acoustic noise measurements in Trial 1, a SeaBird SBE-19 conductivity-temperature-depth (CTD) probe was used to assess local oceanographic conditions. Readings were recorded internally at 2 Hz during surface-to-bottom profiles; during single-depth moorings, this was set to 1/30 Hz.

The semi-diurnal tidal heights around the all three locations were predicted using POLTIPS-3 for windows (Proudman Oceanographic Laboratory Tidal Information and Prediction Software).

2.3 Weather measurements

Empirical barge weather data were collected at two-hour intervals from the *Noble Kolskaya* rig and from the associated safety boat crew. We used significant wave height and wind speed parameters in our analysis sections.

At the A6-A, the barge data became sporadic and difficult to obtain and were unavailable when the platform stood alone on location. Therefore, for the A6-A, in addition to these data, European Centre for Medium-Range Weather Forecast (ECMWF) data were obtained (see http://www.ecmwf.int). The data used were from the ECMWF's operational model, which is run in real time with an appropriate delay to get the observation data. The ECMWF runs a local area model at a resolution of 0.25°. Data were taken from the 00:00 UTC forecast each day with subsequent data at forecast time increments of 06:00, 12:00 and 18:00 hours. The ECMWF data were obtained in binary format and decoded using an ECMWF custom-written programme provided by their website onto a Linux computer. A customised batch file (written in Perl) was used to process the data.

The ECMWF data were statistically and graphically compared to concurrent empirical buoy data from the local Dogger Bank area and to the local empirically-collected barge data in order to test the model's predictions under such conditions. We were satisfied that the ECMWF model was performing optimally (analysis not presented here). From the ECMWF variables, we chose significant wave Height (SWH), wind speed and wind wave direction as the three most useful parameters to indicate extreme or clement weather periods.

2.4 Rig/platform activity logs

Each day the *Noble Kolskaya* produced a printout of the 24-hour activity log. These data were entered into an Excel™ spreadsheet that were divided into six major categories:

1. Casing & cementing
2. Completion & well-test
3. Drilling
4. Logging
5. Wellhead & blow-out prevention
6. Waiting on weather

Other activities that occurred during the study period were: 'prepare for operation' and 'rig move', but these were rare and therefore not allocated categories of their own. Tender boat and helicopter activities were also logged from the barge logbook data.

Some aspects of the A6-A activity log was entered by staff into a hand-written book each day, but electronic printouts were unavailable and thus the record was not as comprehensive as the *Noble Kolskaya*. These data were then entered into an Excel™ spreadsheet and the following categories were deduced:

1. Production stopped: (diesel engine on, gas engine off, offgas pumps off)
2. 3 well full production (diesel engine off, gas engine off, offgas pumps on)

3. 1 well production
4. 2 well production
5. Tender boat alongside
6. Fast craft rescue vessel deployed
7. Pig sent
8. Offgass compressors still on whilst producing

2.5 Rig noise measurements

The purpose of these measurements was to attempt to assess and characterise in-water acoustic emissions associated with the installation and operation of the drilling rig *Noble Kolskaya* during November 2004. No noise measurements were taken in Sector B11-04 or from the A6-A platform.

2.5.1 Equipment and techniques

Acoustic measurements were performed over various frequency bands from a few Hz to several hundred kHz using multiple recording systems. These bands were selected to cover the audio response bands of most marine species likely to be encountered in the measurement area. In addition to noise level assessment, real-time acoustic monitoring for several marine mammal species was also performed. Specialised equipment, including broadband echolocation signal detection systems, was used in conjunction with broadband (>150 kHz) real-time spectral analysis.

Two omni-directional receiver transducers were used, a 25 mm spherical hydrophone (HS70, SRD Ltd.) and a 12.5 mm (HS150, SRD Ltd.). The former has a primary frequency resonance at 70 kHz and the latter, 150 kHz. Both transducers have good low frequency (<10 kHz) sensitivities; around –205 to –211 dB re 1V/μPa. Data acquisition was made directly to a PC hard disk for low frequencies 'audio band' (<24 kHz) using a Roland UA30 digital interface to a 16-bit resolution 48 kHz sampling, and for high band-width (10 Hz - 200 kHz) a 6062E National Instruments PCMCIA interface to a 12-bit resolution 320-400 kHz sampling. Additional digital recordings were made in the audio bandwidth (24 kHz) on digital magnetic tape using a Sony TDS-D7 digital DAT recorder to 16-bit resolution. Various conditioning preamplifiers were used to maximise recording use of dynamic range and improve the signal to noise ratio. The audio-band recordings were AC coupled using a 1 Hz high-pass filters whilst the high bandwidth recordings were made with a band-passed preamplifier set from 2-150 kHz. The recording arrangement is shown diagrammatically in Figure 3. These specialised conditioning systems are all designed for application to underwater acoustic measurement.

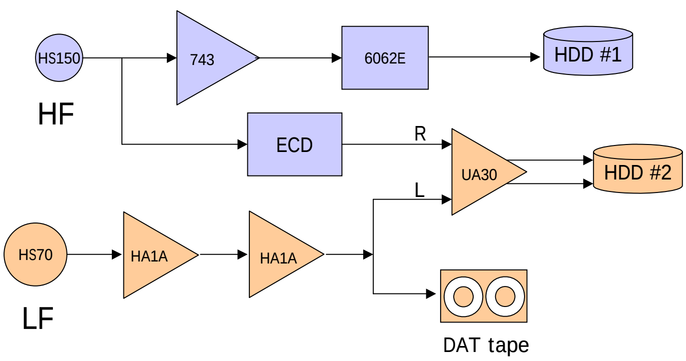

Figure 3: Experimental arrangement. The recording path for high frequency (HF) is indicated in blue, and for low frequency (LF) in brown. The Electronic Click Detector (ECD) outputs the LF envelope of any harbour porpoise vocalisations. The HA1A pre-amplifiers contain a 1 Hz high pass filter. The 743 preamplifier contains a 40 kHz high pass filter.

For passive acoustic monitoring, real-time spectral analysis was displayed to screen while the downshifted output from the electronic click detector (ECD) was also taken to one loudspeaker. Another loudspeaker played the output from the low frequency channel and this real-time spectral analysis was also displayed, on a second screen.

All equipment used in the measurements was pre- and post-measurement calibrated, using specialised electronic and tank facilities, to determine the transfer functions of individual system components.

Passive acoustic monitoring took place during the visual watches (visual data not presented in this paper), when mitigation measures were necessary, such as prior to expected drilling activities, and on an *ad hoc* basis at other times. It was not intended as an acoustic survey of marine mammal activity, for which a round-the-clock watch would be required. This function is better performed by autonomous monitoring equipment, such as the T-POD devices used later in the study.

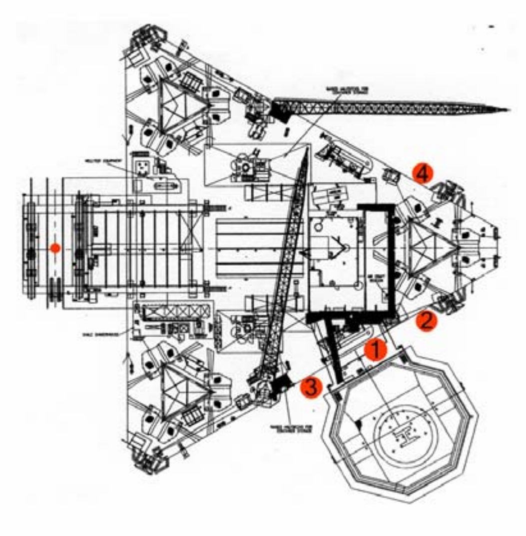

Figure 4: Sound measurement locations aboard a plan view of the *Noble Kolskaya*. 1 = Starboard rail; 2 = starboard explosives platform; 3 = container and 4 = port forward anchor. The red dot to the far left indicates the drill stem.

An attempt was made to assess acoustic conditions at various stages during the installation and operational phases of the drilling operation. Comparisons of mid-water acoustic conditions were made during these various stages. Depth profiles were also performed (4 – 39 m receiver depth) to monitor potential standing-wave acoustic field generation. These profiles were also used to monitor time variance in acoustic transmissions. Real-time monitoring of these recordings was carried out *in situ*. Detailed post analysis was then done after the operation. Recordings were made both with the hydrophones suspended at the levels and installing a bottom-mooring, using a sub-surface buoy to raise the receiver transducer from the seabed. The bottom mooring was used to minimise the effects of surface wave movement on the transducer in the water column, potentially leading to a noise component associated with transducer movement rather than an acoustic signal. In the case of surface suspended deployment this was carried out in good sea conditions (Beaufort < 3) only and abandoned when conditions worsened.

During the measurement phase, the receiver hydrophones were deployed from various positions around the rig shown in Figure 4. Measurements were also made from the support vessel *Northern Seeker* to monitor far-field acoustic propagation effects associated with the *Noble Kolskaya* operation.

Over 140 acoustic sequences were recorded over various frequency bands, during multiple phases of the *Noble Kolskaya* drilling operation. An attempt was made to correlate acoustic transmissions with various operations and these included monitoring during installation (tugs present), preloading, tank discharge, drill preparation, drilling (30” hole), drilling (24” hole) and various external operations including support vessel handling and helicopter operations. Equipment specifications, such as engine size, manufacturer, duty cycle, shaft rotation speed etc. were collected for various pieces of machinery aboard both the rig and the support vessels.

2.5.2 Close field

The close field measurements are defined as measurement made from the rig itself. Since the exact acoustic coupling mechanisms are not fully understood, many of the noise components analysed may well have been measured within the source's near field. However, without precise knowledge of how the sound is coupled, no exact meaning can be defined.

Time and frequency domain analysis was carried out on acoustic measurement files using both commercial analysis tools and custom-written software scripts.

The analysis falls into two primary bands including assessments of broadband noise and identification of tonal components associated with the drilling operation. A view of time variance in these signals was also made. All data represented in this report have been converted to received SPL in μPa or Sound Spectral Density μPa/√Hz, factoring in the receiver systems' transfer functions.

Spectral analysis was performed using Fourier techniques. High resolution Fast Fourier Transforms were performed for detailed analysis. Welch averaging techniques were also used to time windows from 43.7 to 87.4 s to reduce incoherent noise variance and assess the time stability of tonal components. Data represented in this paper will show examples of operation and time variant characteristics observed during the measurement. Additional 1/3 octave band analysis was carried out for frequencies 25 Hz to 13 kHz.

During the close field acoustic noise measurements, a pilot study using two observers on the rig throughout the installation phase until drilling of the 24" section had been completed, recorded general shipping traffic in the area. These observers performed two-hour watches (interspersed with 20 to 45 minute breaks) during all daylight hours, giving two to three watches per day (data not presented in this paper).

2.5.3 Far field

Following measurements from the drilling rig, additional recordings were performed aboard the support vessel *Northern Seeker*. The aim was to obtain far-field levels – *i.e.* far enough from the source that the entire water column was homogeneously ensonified in order to calculate source levels.

The ship was positioned 5 nm to the west of the rig and the hydrophones lowered to mid-water (20 m) off the weather side, amidships (to avoid entanglement with either the bow thrusters or propellers), and held away from the hull with an outboard arm. The intention was to perform a background measurement away from the *Kolskaya* and production fields to the east.

Weather conditions were not ideal, with 20 kts+ wind, a two-metre swell and frequent whitecaps (Beaufort 4). Measurements were made with (a) the ship's main engines running, but with propellers set to zero pitch and clutched out; (b) main engines shut down, auxiliary engine running. In both cases, the ship was observed to drift at around 0.2 kts, rolling intermittently as large swells came through, breaking on the lee side. Measurements were repeated the following day once the seas had calmed (wind 15 kts, swell still around 2 m, but no whitecaps – Beaufort 2-3).

2.6 T-POD moorings

Previous T-POD studies report high losses of their instruments in the field, mostly because of poor mooring designs. Here, moorings were designed specifically for deployment in extremely rough high-sea weather and optimised for the relatively longer-term A6-A study for periods of up to 12 wks (with a 100% success rate for the optimised design). The lines were composed of 4 mm stainless steel wire rope for almost their entire length in order to minimise any wear against the installation. The line was terminated in hard-eye splices to a stainless steel swivel. The last metre of the line configuration comprised solid braid nylon climbing rope (12 mm), designed to allow stretch and to de-couple any possible rig-generated sound transmission down through the wire towards the T-POD. Attached to the decoupling rope was the T-POD, held vertically on the de-coupling rope with heavy-duty rubber buffers, followed by varying lengths of 10 mm polypropylene line and a 45 kg weight. The T-POD was suspended one metre above the weight. Moorings were fixed to the framework of the installation on custom-made steel brackets onto which were mounted heavy-duty hand-operated winches (PFAFF Silberblau Gamma, Friedburg, Germany), with appropriate gearing ratios.

For Trial 1 (in Sector B4-05) and 2 (in Sector B11-04), three version-3 T-PODs (406, 407 & 409) were suspended in the water from the side of the *Noble Kolskaya*, at each of the three legs. T-PODs were deployed at three different depths (10 m, 25 m and 35 m). This was necessary to (a) minimise the possibility of instruments being carried into the legs by wind-induced currents, as a prior trial had found; (b) to avoid interaction with the rig's spud cans, which had not fully penetrated the seafloor, and (c) to avoid interfering with support vessel operations. The deepest T-POD was thus suspended a minimum of 5 m above the seafloor (35 m depth).

This mooring configuration had the added advantage of sampling the entire water column, as no assumptions were made about porpoise utilisation of the space around installations, despite the fact that the animals are suspected to be primarily bottom feeders in coastal areas. The legs were predicted to be the most likely sites for harbour porpoises to forage, based on prior surface observations (V. L. G. Todd, pers. obs.), thus maximising the likelihood of porpoise detection. All T-PODs were assumed to be able to monitor the entire region around the installation as Tougaard et al. (2006) showed detection of porpoises in shallow water out to about 300 m from the T-POD with a detection function equivalent to 100% detection within approximately 70 metres (Cet hi) radii, with a smooth detection function curve.

For Trial 3 (A6-A platform), three version-3 T-PODS (406, 407, 408) and a version-4 T-POD (516) were deployed. Four T-PODs were deployed because T-POD 516 became entangled in the legs and was presumed lost, but recovered at a later date and all uninterrupted data salvaged. The choices of deployment locations were more limited than from the *Noble Kolskaya* because of various health and safety regulations, cooling water vent locations, the immanent docking of the *Noble Kolskaya* on the southern end, and the splayed nature of the legs, increasing the chances of T-POD entanglement.

T-PODs were equipped with 28 MB RAM and were powered by six 3.4 V D-cell alkaline batteries (for deployments < 28 days) and 12 batteries for deployments > 28 days. T-PODs run on 6 V, but battery-voltage does not influence sensitivity as the electronics in the T-POD receive a stable voltage until the battery is drained below 5.1 V, after which the electronics turn off. The memory was generally expected to be full in 2-3 months depending on echolocation activity, background noise and software settings.

2.7 T-POD optimisation in the field and settings

For a detailed description of how a T-POD works and a definition of settings, see the manufacturer's website (http://www.chelonia.co.uk), Carlström (2005) or Thomsen et al. (2005b).

The detection software (T-POD.exe v8.17) was applied to classify the recorded click times and to assess the devices performance in field conditions and to adjust the settings accordingly. Only click trains with a high probability of originating from cetaceans 'Cet Hi' were used for the analysis. For porpoise detection, we used the normal sensitivity setting. This enabled us to use the same settings throughout a wide range of environmental conditions such as moving substrate or high frequency surface noise (e.g. rain, entrained air in waves during storms, cooling water outlets etc.), which could have created excessive numbers of false porpoise detections. This further avoided the masking of train detection by non-cetacean clicks and the possibility of filling up the memory modules during the long-deployment periods. T-POD bandwidth was not altered throughout all the T-POD trials to maintain uniformity. The scan limit was 160 (for v.3 T-PODS) and 240 for the v.4 T-POD 516. All T-PODs were set to exclude logging click durations of <10 μs, in order to avoid filling up the memory modules with short tonal pulses of non-cetacean origin.

At the beginning of each trip to the installations, T-PODs were retrieved and the data were downloaded on a laptop PC. The batteries were then replaced and the T-PODs re-deployed. At no point were all T-PODs recovered at the same time, ensuring a continuous monitoring data set.

2.8 B4-05 & B11-04 porpoise observations

For the analysis of the data during Trials 1 and 2 (in 2004), we used the current standard recommendations of primary indicators of cetacean activity according to the European Cetacean Society T-POD workshop held in Gran Canaria, 9-14th March 2003. We thus calculated the following parameters:

- **Encounter Train Positive Minutes (ETPM)**: - the number of whole minutes during an encounter with a click train, which has been classified as arising from a cetacean source. This is often termed the "*duration*" of an encounter.
- **Encounter Train Click Counts (ETCC)**: - the total number of clicks in one encounter – i.e. the sum of the click counts for all trains making up the encounter.
- **Encounter Mean Click Rate, per second (EMCR)**: - the total number of clicks in the encounter (ETCC) divided by the summed duration (micro-seconds) of individual click trains making up the encounter. This gives an indication of prevalent behaviour: it is assumed that fast trains indicate feeding activity while slow trains are related to spatial mapping.

We also calculated various other parameters, but in order to keep the length of this paper to a minimum, we have not presented the full data analysis for all these porpoise indicators and have plotted only the number of clicks in each train in relation to rig activity.
Individual encounter parameters were then used to statistically compare porpoise activity between locations (during similar rig activities), between rig activities and examine any day/night differences.

2.9 A6-A porpoise observations

2.9.1 Porpoise activity indicators

Since Trials 1 and 2 were carried out in 2004, several porpoise indicator terms have changed in accordance with workshops, literature and conferences. We have kept up to date with these changes, but again, for brevity, here we present only the porpoise encounter per day, the number of clicks per day and the inter-click interval, all explained below. The original 84 page report (Turner and Todd 2006), however, presents the full range of data analysis for the six months.

Echolocation encounters were defined as '*trains that were separated by periods of silence with a minimum duration of 10 minutes*' in accordance with the manufacturer's recommendations, previous studies (e.g. Tougaard et al. 2004; Tougaard et al. 2005b; Watkins and Colley 2004) including the Turner et al. (2005) study. The term *encounter* is used to describe porpoise detection within 10-minute periods and the encounter does not end until there is a 10-minute period in which there is no (0) porpoise detection.

Custom-written programmes in Perl were used to generate the indicators from the exported Excel files.

The main point of the porpoise analysis was to:

1. Record and analyse the animals' presence throughout the various industrial activities of the rig and the platform; and,
2. Distinguish between the animals presence and the animals' behaviour.

Preliminary analysis of data revealed that there were very few dolphin 'Cet hi' encounters, therefore we set all T-PODs to monitor 100% porpoise activity only.
Tougaard (2005a) found that the indicators most strongly affected by the construction and operation of a wind farm were the 'daily' porpoise *presence* statistics, such as daily frequency and waiting time. Though we did not analyse the same parameters as that study, we endeavoured to carry out most statistical analysis on our 'daily' porpoise activity data when observing changes in relation to rig docking/leaving, seasonal analysis etc.

The following 'Cet hi' encounter porpoise data were calculated as indicators of the porpoise *presence*:

- **Encounters per day**: This is the number of times a porpoise visited the hydrophone each day (24 hours)
- **Clicks per day**: The is the total number of porpoise clicks per day

And the porpoise *behaviour*:

- **Minimum Inter click Interval:** This is the proportion of clicks classified into two categories - those with minimum inter-click intervals of <10 ms (an indication of feeding activity) and those with minimum click intervals of >10 ms (all other echolocation activity) Porpoises click more rapidly when they are feeding (and probably when interacting socially), than when travelling. These exported data were as follows:

Again at the B4-05 and B11-04, we used the Encounter Mean Click Rate (ECMR) as a rough indication of the porpoises' prevalent behaviour. More recent literature indicates that there are better ways to achieve this, and these are outlined later.

2.9.2 Accounting for seasonal changes in porpoise encounters

At the A6-A, we investigated whether porpoise activity was correlated with day of the year. Such a correlation would indicate that the occurrence of harbour porpoises changed over the season, which could obscure potential differences in echolocation encounter rate among the categories of interest.

2.9.3 Activity of porpoises in relation to weather variables

We investigated the activity of porpoises in relation to the significant wave height as an indicator of storm activity.

2.9.4 Activity of porpoises in relation to A6-A and Kolskaya presence

At the A6-A, we asked the following question:

Q: Did the docking of a rig onto the side of a platform change the presence and behaviour of porpoises foraging around the legs?

We examined the following:

1. Activity of porpoises in relation to the A6-A when in production/no production phases during the periods that the A6-A was isolated i.e. pre-rig arrival and post-departure of *Noble Kolskaya* rig
2. Activity comparison of porpoises in relation to the A6-A during periods of rig pre-arrival, rig docked alongside platform, and post-departure of rig

2.9.5 Comparison of A6-A data with the B4-05 and B11-04 data

Careful consideration was given to the possibility of statistically comparing all the B11-04 and B4-05 T-POD data to those recorded on the A6-A. Ultimately this was not done for the simple reason that this is a time consuming project in itself. However, other important issues are that the previous data were analysed using older versions of software and data would therefore have to be re-exported using current software, which has better train detection capabilities. Furthermore, these older data were collected using different settings and a lot of time would be required to re-scale the data to the settings employed in the latter study. Thus, the comparison of the two data sets is work currently under progress.

Data were therefore not statistically compared and the reader is encouraged to compare the diagrams visually.

2.10 Statistical analysis

For consistency, T-POD data are expressed as means and standard deviations throughout, regardless of whether the data were normally or non-normally distributed. Medians, however, are the standard data presentation technique for non-normally distributed data, and are stated where deemed appropriate. Data were tested for normality using a Kolmogorov-Smirnov test and square-root transformations were carried out when the variance of the samples was similar or equal to the mean. Arc sine transformations were performed when the data were in proportions. Where transformations failed to normalise the data, non-parametric statistics such as Mann-Whitney rank sum and Kruskal-Wallis tests were employed to look at differences between groups. *Post hoc* tests (Dunn's and Dunnet's) were used to test for differences between groups of data. Data from individual T-PODs were pooled (with the exception of the v.4 T-POD, the data of which were analysed separately and used as a comparison), since (a) inter-T-POD differences were not the subject of the study and (b) the variation in sensitivity between T-PODs has been shown to be very low in comparison with natural variability, even for less-standardised, earlier, versions of the T-POD (Tougaard et al. 2003b).

3. RESULTS

3.1 Tidal and weather measurements

At the B4-05 and B11-04, the tidal heights and tidal currents were, as predicted, minimal (0.5 m, 1-2 Kts). Tidal statistics at the rig's location were:

Direction of maximum current	252^o (True)
Ellipse eccentricity	0.97
Maximum current speed	0.26 m/s (0.50 kts)

The tidal current at both the B4-05 and B11-04 thus ran essentially back-and-forth, with directions largely constrained to 080^o (flood) and 240^o-290^o (ebb).

The *Noble Kolskaya* rig move occurred during spring tides, with current speeds declining towards neaps on 05/11/04. The temperature and salinity range throughout the study was minimal (11.5-12.0°C and 34.9 – 35.2 PSU respectively) and the water column was vertically well-mixed, with no stratification.

At the A6-A, the tidal currents were again, minimal, at around 0.6 kts at spring tides and 0.3 kts at neap tides with a tidal amplitude of 1 m which was also confirmed by a Wintershall AG site report (Wintershall 2004). Most surface current was generated by the prevailing winds at the time.

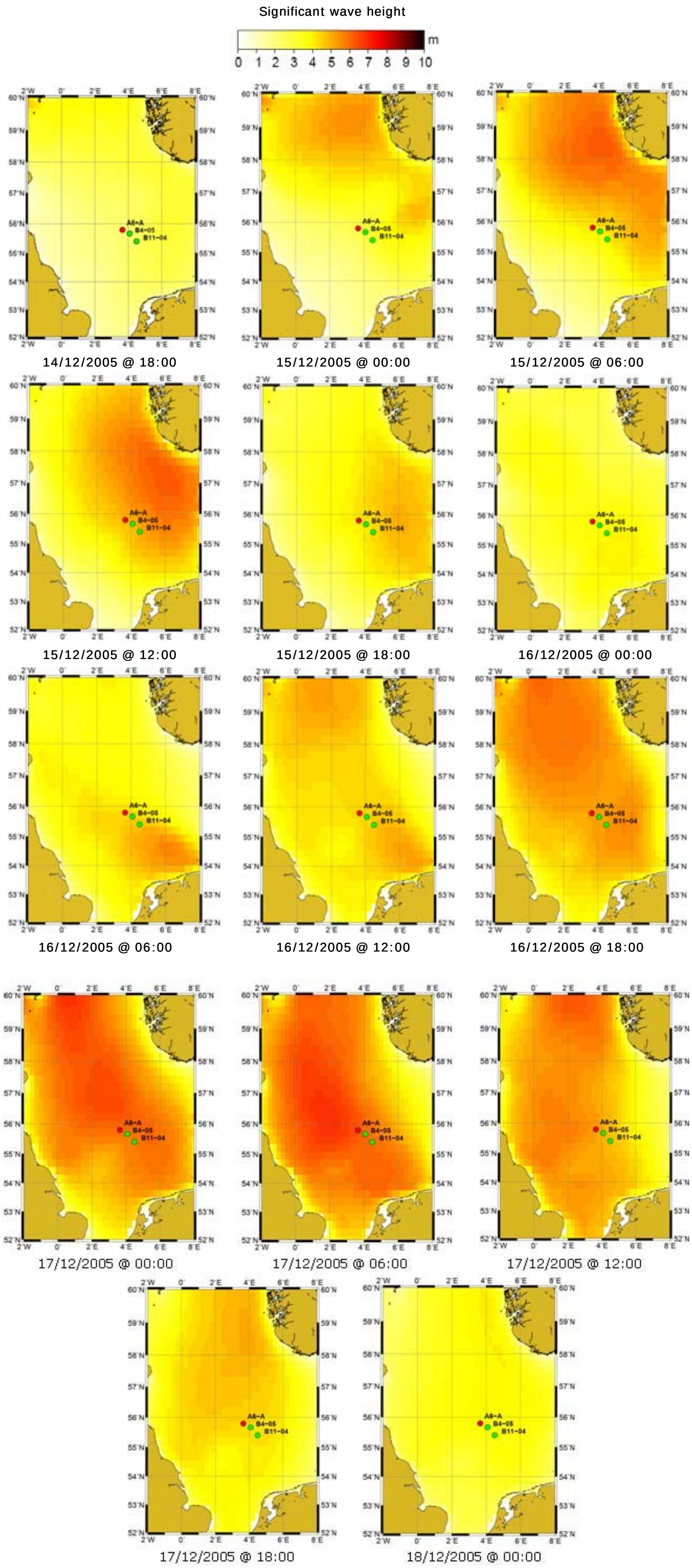

Figure 5: A6-A with plots of significant wave height at 0.25° intervals. Data from ECMWF model. Figure clearly shows development and transition of a storm event as indicated by significantly higher wind waves. Map projection: Mercator.

We used the wind wave direction (°) data, rather than the wind direction, as an indication of the surface current during the period of study. On occasion, surface-driven wind currents were sufficient to carry the T-PODs into the legs of the platform. As the tidal movements were minimal, we did not investigate porpoise activity in relation to tide at either site.

A detailed analysis of ECMWF significant wave and wind data for both the B4-05 and B11-04 are being analysed as part of another study and the data are not presented here. However, at the A6-A, ECMWF significant wave height (SWH) was highly variable throughout the study period. The mean ± SD wave height during the study period was 1.8 m ± 0.92 m (min = 0.45 m, max = 6.13 m). Wave height was generally <2 m, but there were seven periods where the SWH increased to >4 m. Of note, was a three-day storm event from 14/12/2005 until 17/12/05, with waves >5 m. Figure 5 illustrates plots of this particular storm track for the North Sea from 18:00 hrs on 01/12/05 until the storm passed at 00:00hrs on 18/12/05. This particular storm event is clearly seen on the 10th and 11th storm track plot in Figure 5. At the A6-A, the ECMWF mean ± SD wind speed during the study period was $8.52 ms^{-1} \pm 3.35 ms^{-1}$ (min = $0.1\ ms^{-1}$, max = $17.77\ ms^{-1}$). Converted into $Kmhr^{-1}$, this translates to a minimum of $3.57\ kmhr^{-1}$ (Beaufort 1) and $63.96\ kmhr^{-1}$ (Beaufort 8). Wind speed and significant wave height during the storm were highly positively correlated (Spearman Rank Order Correlation, $R_s = 0.921$, $n = 16$, $P << 0.0001$) as would be expected.

3.2 Close field acoustic measurements

Figure 6 shows an example analysis of mid-water (18m depth) audio-band analysis for an 87 s window during the drilling phase. The two middle panels' broadband sound levels show a gradual increase towards lower frequencies with a sharp fall-off above 8 kHz. Between 1 kHz – 8 kHz, typical broadband levels were between 90 and 95 dB re 1μPa/√Hz. This level gradually begins to climb below 1 kHz to around 105 dB re 1μPa/√Hz at 100 Hz and 115 dB re 1μPa/√Hz at 10 Hz. Mean broadband sound levels greater than 120 dB re 1μPa/√Hz were observed for frequencies below a few Hz. A peak spectral density level of around 130 dB 1μPa/√Hz was seen at 2.1 Hz.

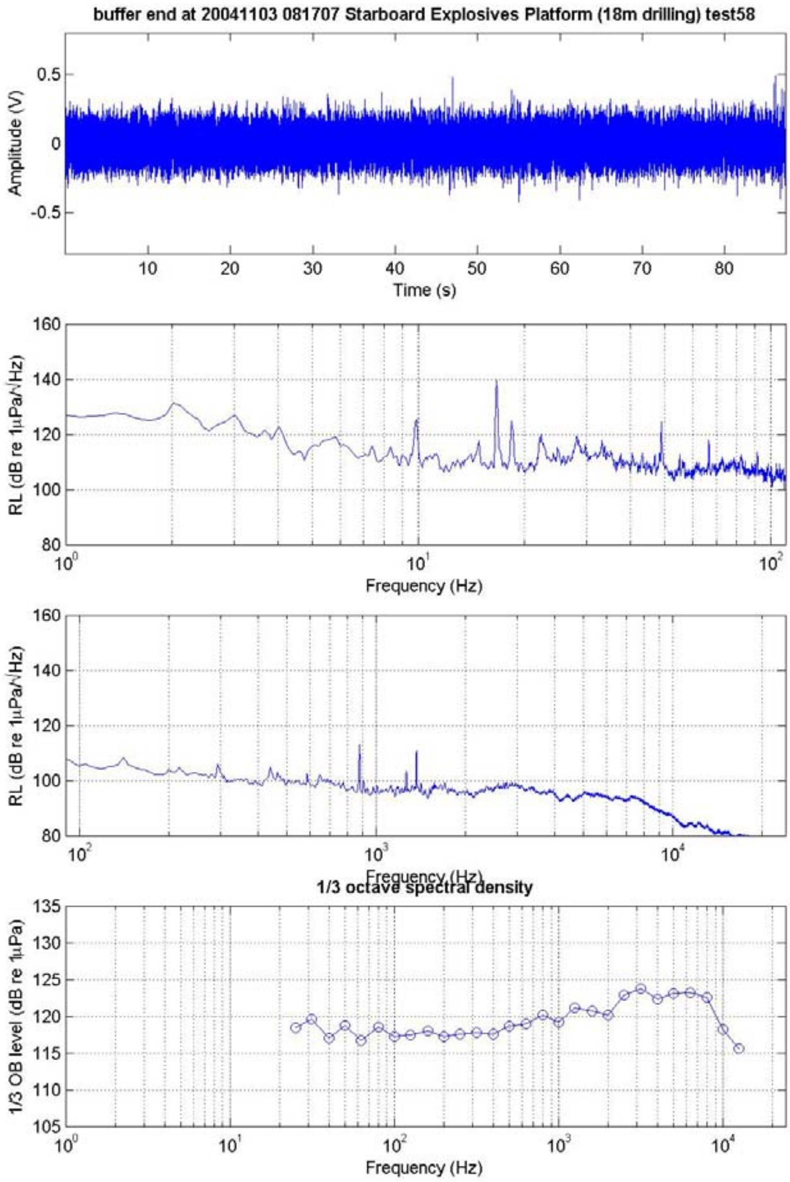

Figure 6: Time and spectral analysis of a record from the starboard explosives platform during drilling of the conductor (Receiver depth 18 m.). The upper panel shows the full analysis time-domain window. Amplitude levels in the time domain were optimised between recordings to fully use the Data Acquisition System (DAQ) dynamic range. The middle two panels show the Welch averaged receiver sensitivity-compensated Received Level (RL) Power Spectral Density (PSD) estimates to a 0.091 Hz bandwidth (second panel, analysis frequencies 1-110 Hz) and to a 2.93 Hz bandwidth (third panel, analysis frequencies 90 – 24000 Hz). Bottom panel shows received 1/3 octave spectral level estimates.

Relatively rapid variations in these levels, particularly at low frequencies, were observed across a single record and in comparison between recording sequences. In addition, a number of strong tonal components were observed above the mean sound level across the full analysis window. Strong tones can be seen at 10 Hz, 16.7 Hz, 49 Hz, 67 Hz, 880 Hz, 1263 Hz and 1373 Hz. Again a large variation in level and sometimes frequency of these tones was observed during and between recordings. The sliding window (50% overlap) averages these tones to ensure that they are consistent throughout the entire analysis window. Comparison between recordings made at (a) different depths and (b) similar depths during different operations were made to estimate levels and stability of both tonal and broadband noise components.

High frequency analysis determined that the steep decline in noise levels after about 8 kHz continues, reaching a 'floor' of around 60 dB re 1μPa/√Hz for frequencies up to the maximum recorded (150 kHz), more than 40dB (or x 100) below the low frequency power density.

Figure 7 (low frequency) and Figure 8 (mid frequency) show the received power spectral density estimates for mid-water (20–24 m) comparing the drilling, pre-drilling preparation, holding, tank discharge and floating (pre-installation, with tugs still present) operations. The quietest phase was, as expected, the holding period, when there was little operational activity. During this phase, both figures show a mean spectral density level of around 98 dB re 1μPa/√Hz ± 1 dB for frequencies 5 Hz to 3 kHz.

Recordings of the holding, tank discharge and pre-drill periods, show similar mean spectral levels between 101 and 98 dB for the frequency band 1 – 3 kHz. At lower frequencies, the sound density level gradually increases above the holding period recording. Figure 7 shows an increase of around 10 dB re 1μPa/√Hz in the sound density level for frequencies 5 – 20 Hz during the tank discharge and a further increase of around 10 dB during the pre-drill and drilling phases.

During drilling, strong tonal components are also observed at 2.8 Hz, 5.6 Hz and 10.4 Hz. The 2.8 Hz tonal observed during drilling has an equivalent peak received level of 140.6 dB re 1μPa ± 1 dB. A likely harmonic component at 5.6 Hz has an equivalent level of 128.5 dB re 1μPa ± 1 dB. In the case of the 2.8 Hz component, this is around 22 dB above the equivalent sound spectral density level for the pre-drill period. This component seems to relate directly to the drillstem rotation speed (168 rpm).

Strong variations in level during the drilling phase were observed, possibly due to changes in the substrate material being drilled. All recordings show a low-frequency level of between 110 and 125 dB re 1μPa/√Hz. Above 8 kHz, a rapid drop in spectral density to below 80 dB re 1μPa√Hz was observed for all recordings and below 75 dB re 1μPa√Hz for the drilling phase. Strong components at both 49 Hz and 50 Hz were also observed, but are almost certainly related to mains power interference and determination of acoustic emission at this frequency would be difficult to determine.

Additional tonal components can be seen at 10.4 Hz, 251 Hz, 294 Hz, 880 Hz, 1263 Hz and 1372 Hz. Equivalent peak observed received levels were 124 dB re 1μPa (10.4 Hz), 121 dB re 1μPa (251 Hz), 124 dB re 1μPa (294 Hz), 117 dB re 1μPa (880 Hz), 114 dB re 1μPa (1263 Hz) and 120 dB re 1μPa (1373 Hz).

The 251 Hz signal was only observed during the pre-drilling phase whilst many of the others were relatively stable during all the recordings. During measurements prior to lowering of the rig legs (i.e. afloat) the 294 Hz and 880 Hz tonals were present but the 1263 Hz and 1373 Hz spikes were not observed. Additional 9 kHz and 18 kHz tonals were observed above the background level in all recordings. Figures 7 and 8 also indicate the received level prior to lowering the legs at site, with the tugs in attendance. Levels are higher than any rig operations in the 15 Hz – 1 kHz band, though drilling and pre-drilling levels are higher at low frequency. All rig operations are also noisier at frequencies above 1 kHz.

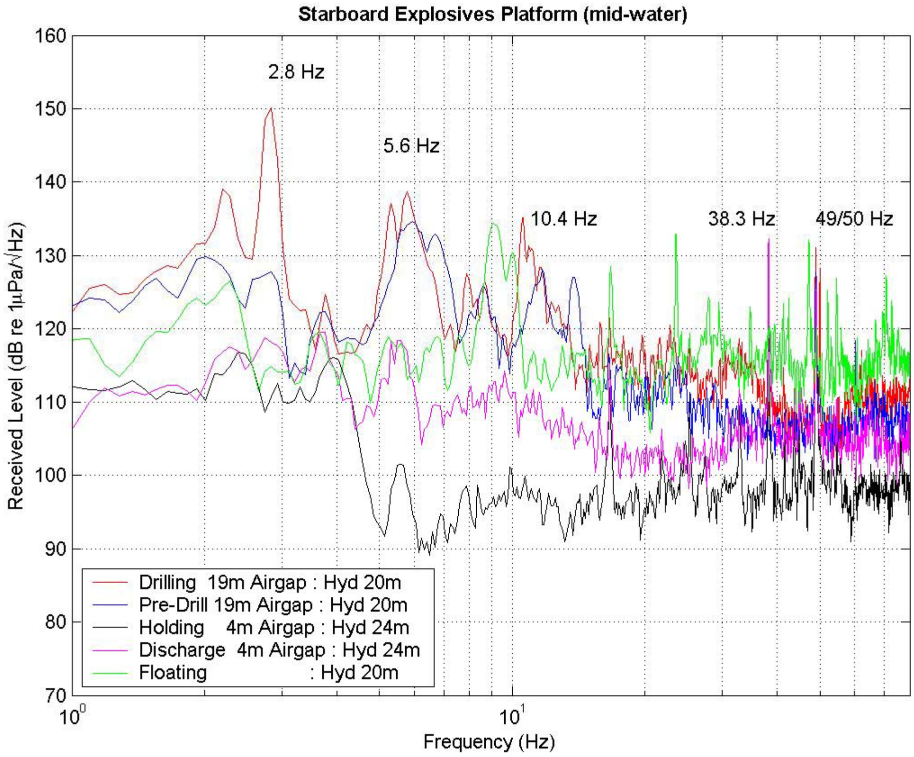

Figure 7: Welch averaged received level Power Spectral Density estimates from the starboard explosives rig. Analysis bandwidth is 0.091 Hz.

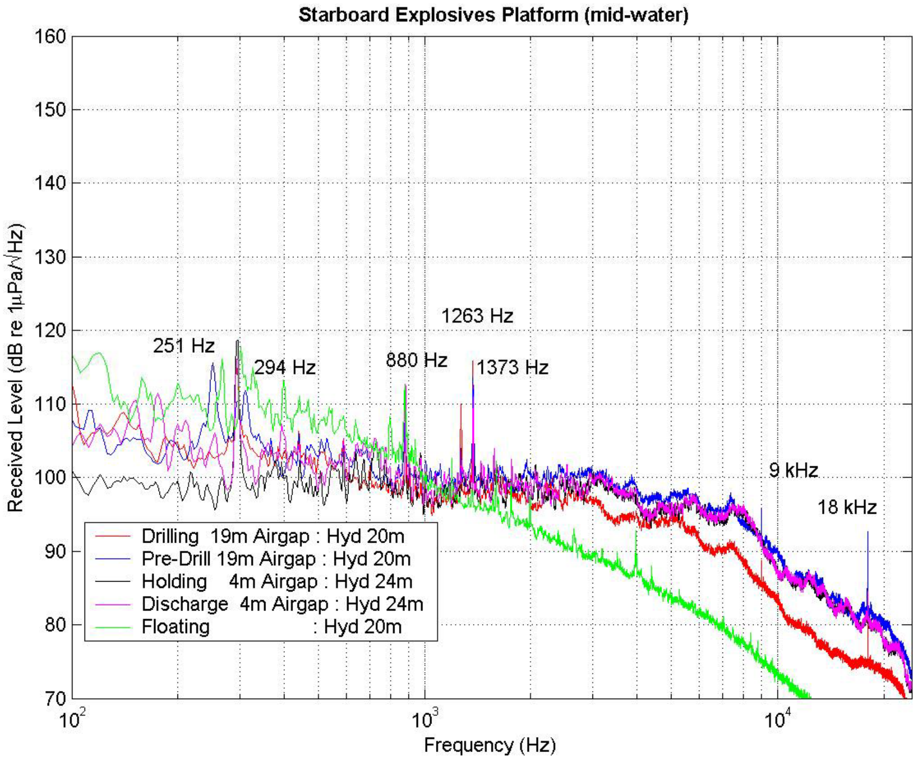

Figure 8: Welch averaged received level Power Spectral Density estimates from the starboard explosives rig. Analysis bandwidth is 2.93 Hz.

Figure 9 shows the 1/3 octave analysis for centre frequencies 23 Hz to 12 kHz. Again, increases in the mean broadband (non tonal) sound pressure density for the drill phase for frequencies below 300 Hz are evident. Above 300 Hz the pre-drill, tank discharge and holding spectral levels are very similar. Again the slightly quieter (above 300 Hz) signal level for the drilling phase can be seen. All phases show rapid reduction in mean sound level above 8 kHz.

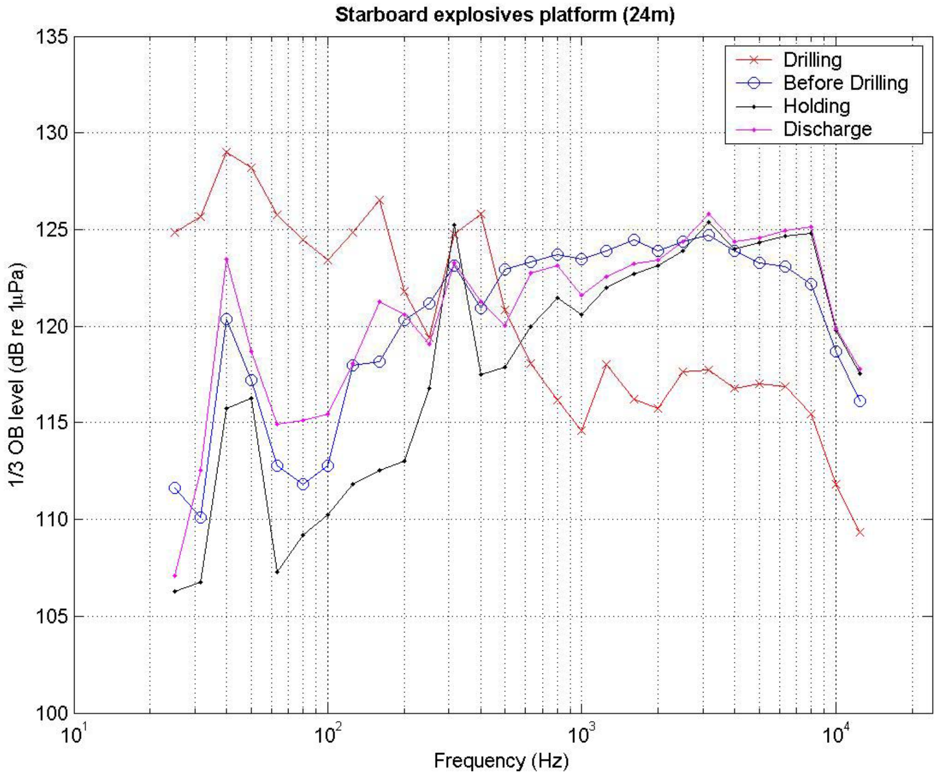

Figure 9: Third octave spectral analysis, mid-water starboard explosive platform.

Depth profiles were made to understand the variation of the acoustic signal with depth, from both the 'starboard explosives platform' and the 'port forward anchor' locations. All profiles were recorded with a single hydrophone lowered through the water column with approximately 5-minute intervals between depths. Figures 10 to 15 show these low- and mid-frequency depth profiles. In each case strong tonal components can be identified. Figures 10 and 11 show the starboard explosive platform pre-drill period. In this case a number of consistent tonal components are observed, as was seen in Figures 7 and 8. This can be compared with the drilling depth profile shown in Figures 12 and 13, again for the starboard explosives platform. Many of the relatively stable components seen during pre-drill were not observed during drilling. Other components, such as those at 880 Hz, 1263 Hz and 1373 Hz, are relatively consistent throughout.

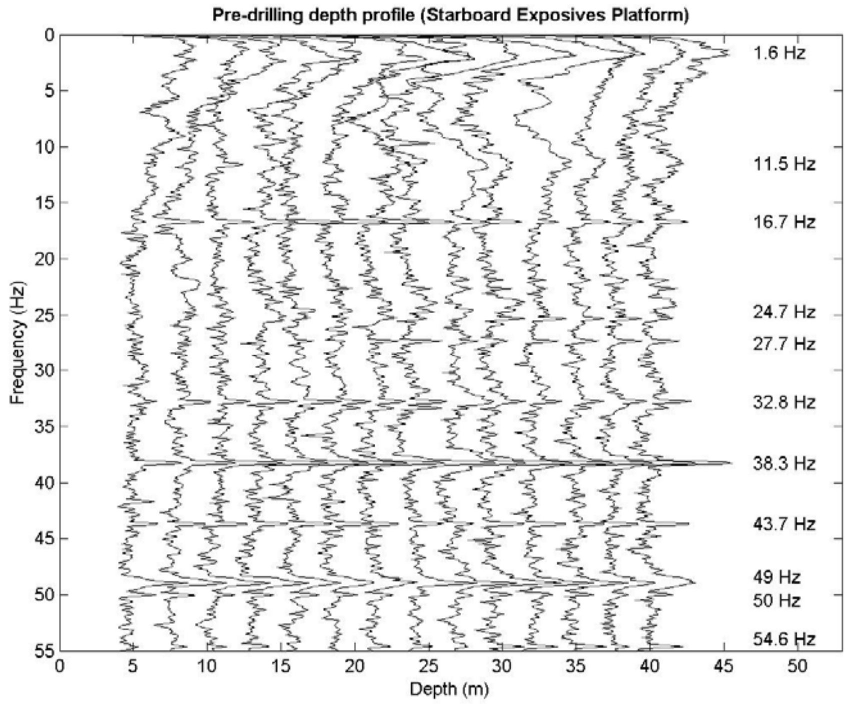

Figure 10: LF depth profile from the starboard explosives platform – pre drilling

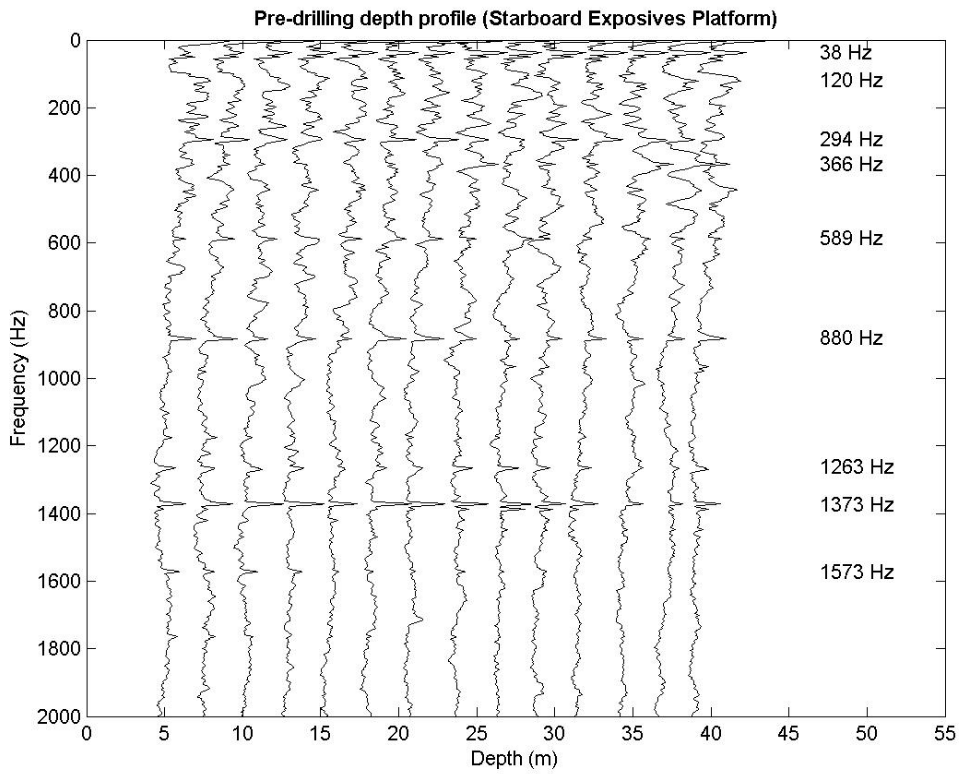

Figure 11: HF depth profile starboard explosives platform – pre drilling

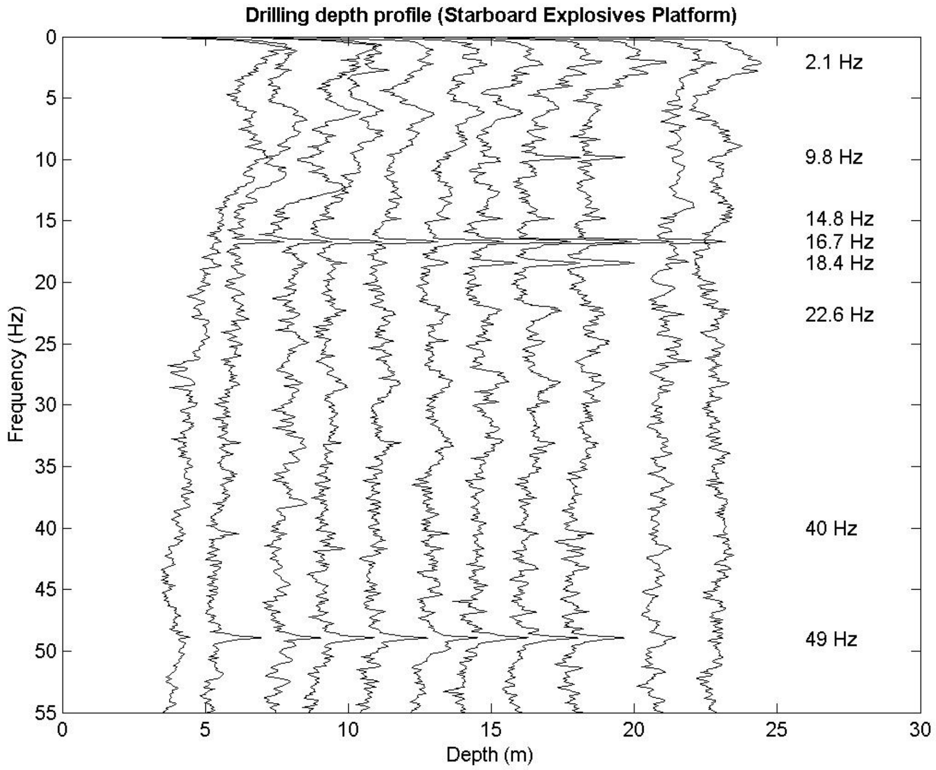

Figure 12: LF depth profile starboard explosives platform – drilling

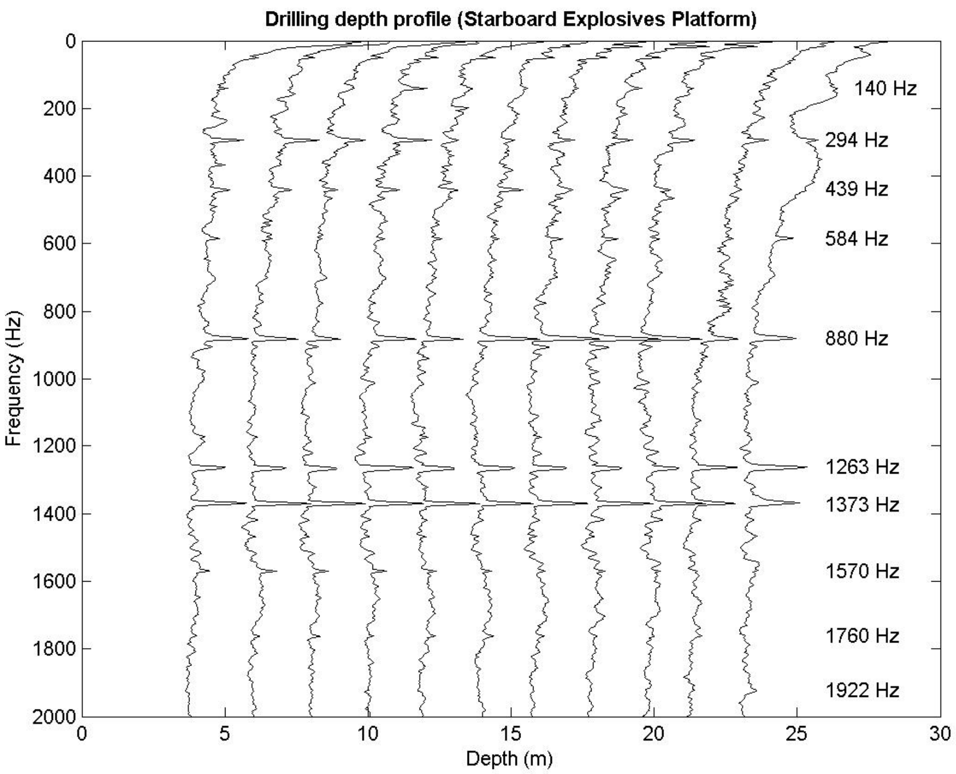

Figure 13: HF depth profile starboard explosives platform – drilling

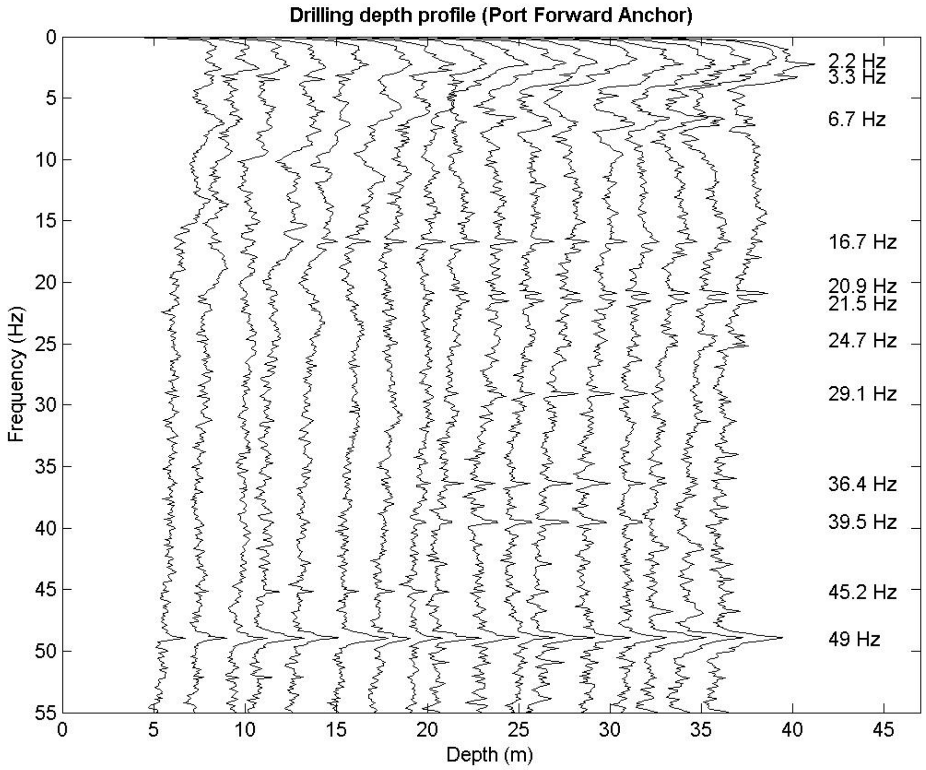

Figure 14: LF depth profile port forward anchor – drilling

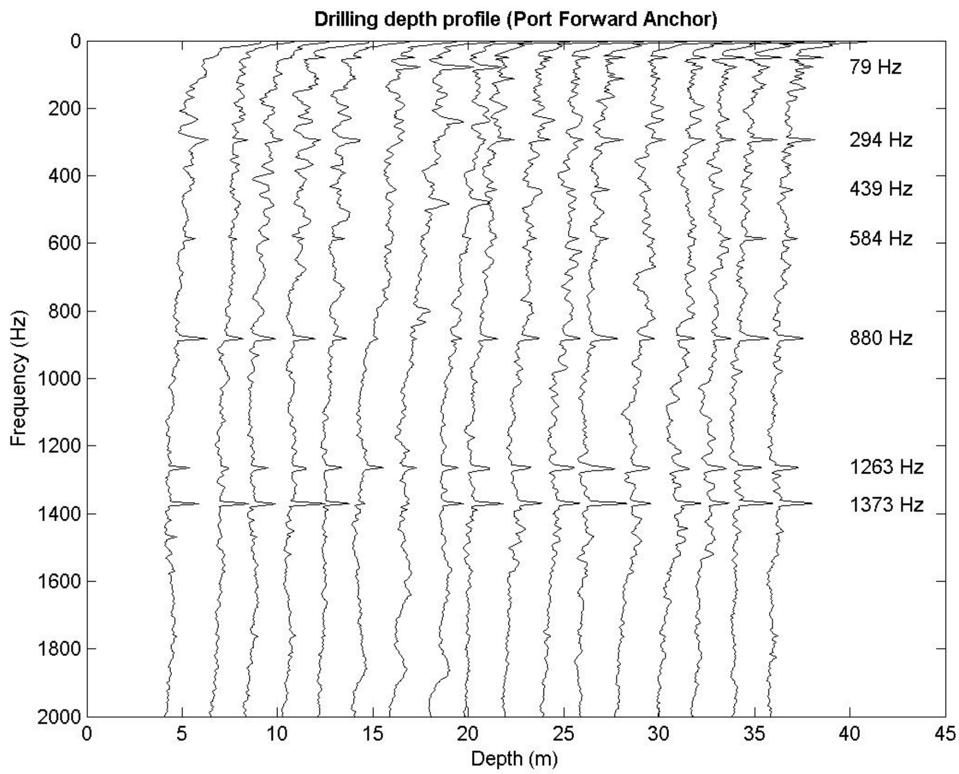

Figure 15: HF depth profile port forward anchor – drilling

All three profiles show a gradual increase in the broadband sound level with depth for frequencies below 1 kHz. This can be seen particularly in the 'port forward anchor' drilling profile, for frequencies below 5 Hz. This is assumed to be due primarily to acoustic contributions from the drill head itself. These components were highly variable, however. Figure 16 shows a strong depth-dependant component growing stronger at increasing depth at 23.4 kHz, observed during the pre-drilling phase from the starboard explosives platform. This component was not observed during other measurement periods.

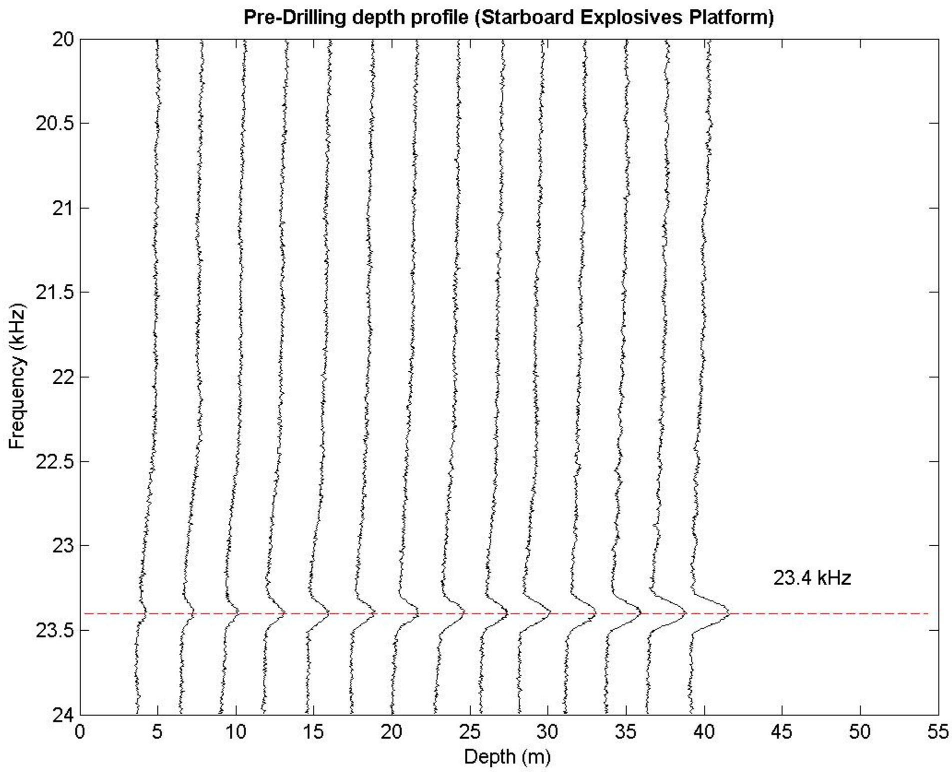

Figure 16: Depth profile starboard explosives platform – drilling

Figures 17 and 18 show comparisons of two mid-water recordings made from the 'starboard explosives platform' within thirty minutes of each other during the drilling phase. Figure 17 shows a very strong 2.8 Hz component, more than 25 dB above the broadband level, which is absent in the later recording. A similar 5.6 Hz tone (presumably a harmonic) is also observed with associated increase in the surrounding sound level density. Figure 18 shows an associated increase in the mean sound level density for frequencies up to 1.5 kHz, with tonal components at 294 Hz and 531 Hz. Above 1.5 kHz, sound level density for the two recordings is almost identical.

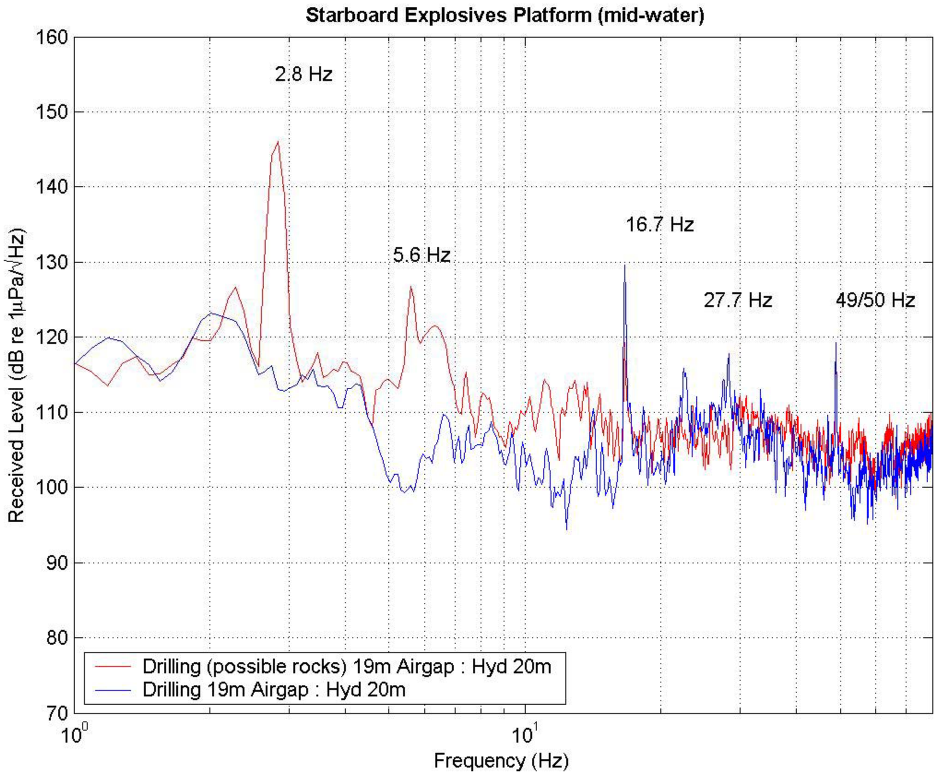

Figure 17: Mid-water starboard explosives platform LF drilling phase spectral comparison

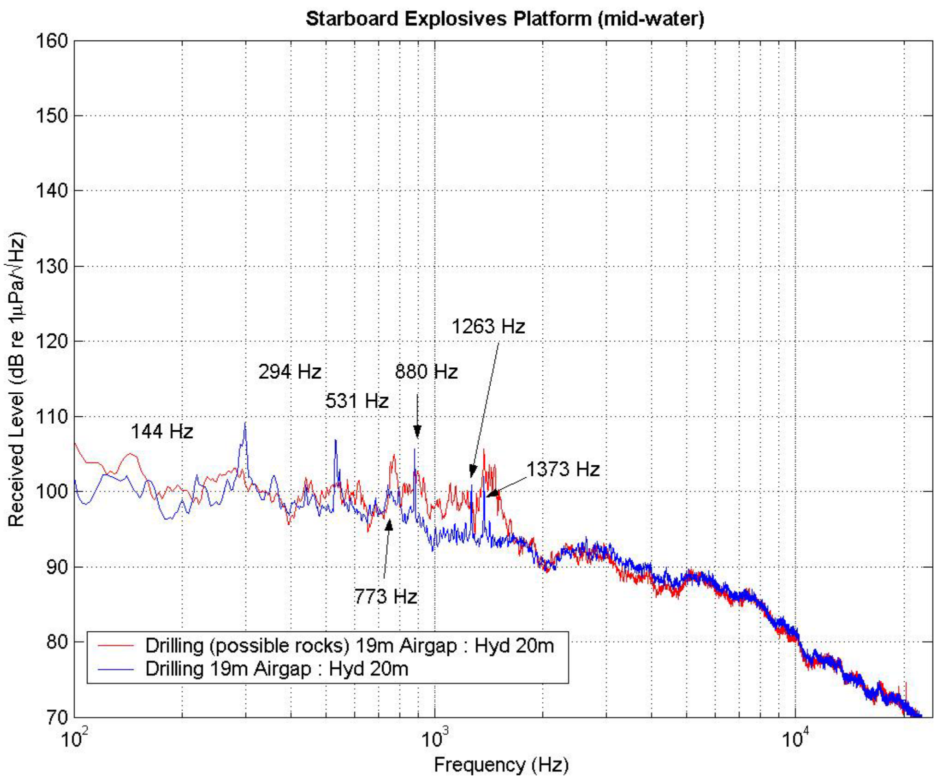

Figure 18: Mid-water starboard explosives platform HF drilling phase spectral comparison

This variation arises from changes in substrate material drilled – the strong 2.8 Hz tone is present only when boulders or similar relatively hard materials were encountered in the otherwise sandy formation and was obvious as a dramatic increase in noise levels on the rig itself.

The variation can be seen clearly in Figure 19 for a single time analysis window with the strongest contributions at 210 s and 260 s. The upper panel in Figure 20 shows the time domain plot. Strong additional components can be seen at 205 s to 222 s followed by 10 s without this component and then a gradual increase and decay of the 2.8 Hz signal. The lower two panels show the time frequency evolution. The time variant nature of the 2.8 Hz and 5.6 Hz can be clearly seen in both. The lower panel also shows the development of even lower (<2.8 Hz) closely spaced components.

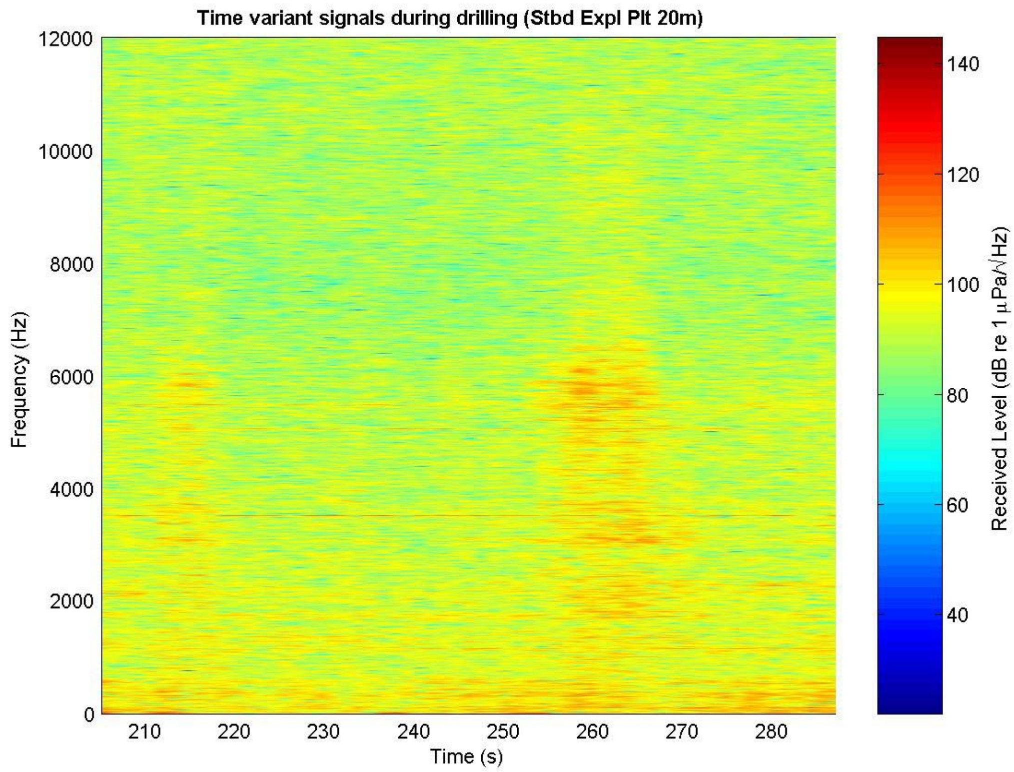

Figure 19: Mid-water starboard explosives platform drilling phase broadband time variant components.

The pilot study which monitored vessel traffic in the area resulted in a total of six and a half days of visual observations (41.35 hours). The shipping traffic in the area was intensive. During daylight hours only – and excluding safety and support vessels – 53 vessels were recorded passing the rig's vicinity during the period of acoustic measurements. Tankers, container ships and other merchant vessels made up the bulk of the traffic, with little fishing activity in the vicinity of the rig. This contributed to the ambient background noise measurements superimposed onto the rig-generated sound levels.

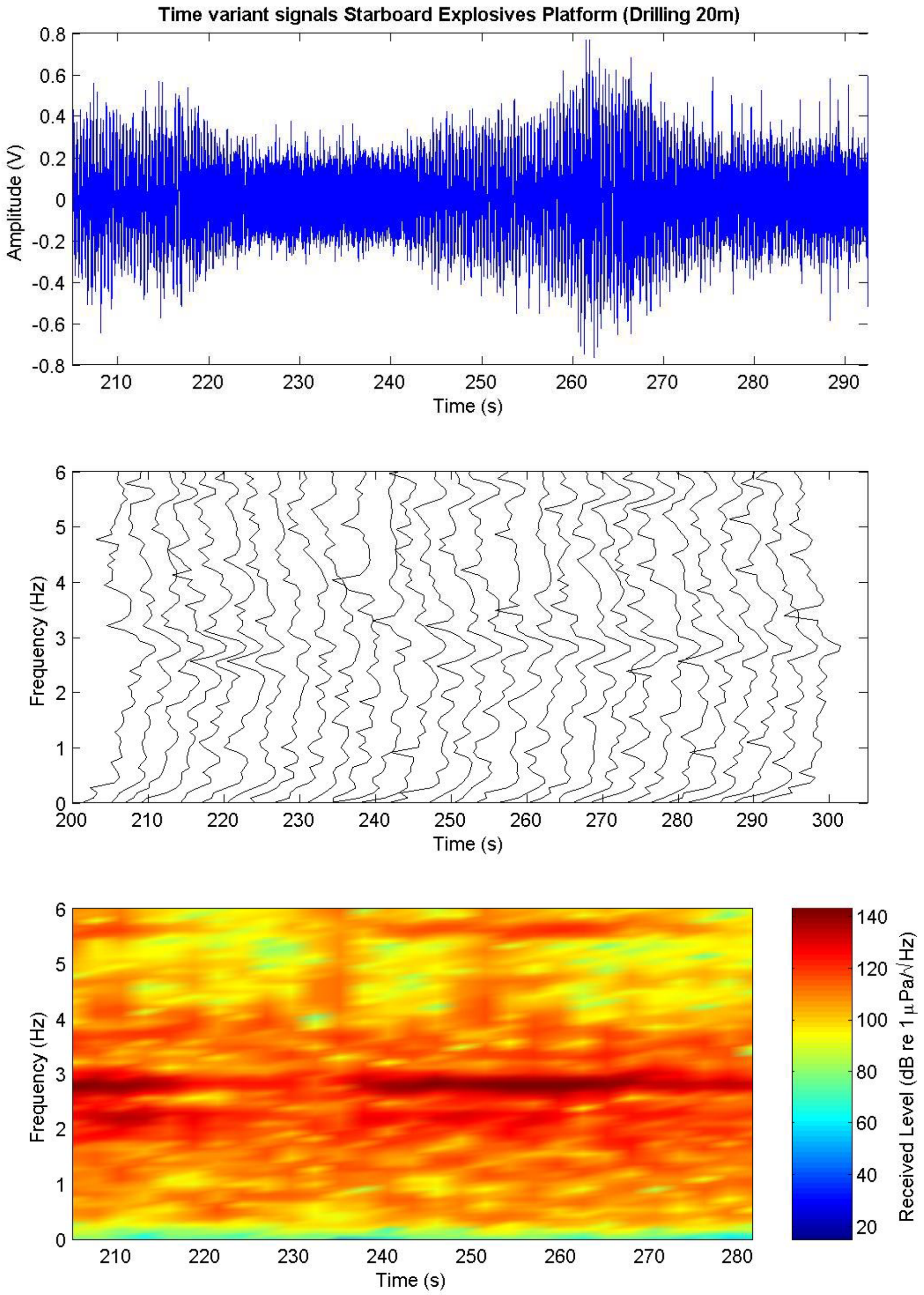

Figure 20: Mid-water starboard explosives platform drilling phase tonal time-variant components.

3.3 Tonal sources

An attempt was made to attribute the tonals to physical sources on board the rig and support vessel. Details of the diesel engines and AC generators aboard were obtained for both the *Kolskaya* and the *Northern Seeker* and are shown in Tables 1 and 2. Details of the top drive system were also obtained for the *Kolskaya*. The rotation rate of this drive is continuously variable between zero and 240 rpm and no records are kept of the actual rate used at any moment in time. Diesel engines and generators operate close to the stated rotation rate, however.

	No.	Make and model	Power	Max RPM/Hz	CFR (Hz)
Top drive	1	Maritime Hydraulics DDM650L	807kW	240/4.0	
Diesel engines	4	Warstila 8R22 (8 cylinder)	1070kW	1000/16.7	133
Diesel engine	1	Warstila 12V200 (V12)	1800kW	1500/25.0	300
AC generator	4	Stromberg HSPTL	1450kVA	1000/16.7	
AC generator	1	Leroy Somer LSA 54LP/4P	3200kVA	1500/25.0	

Table 1: Sources of noise generation aboard the Noble *Kolskaya*. CFR gives the cylinder firing rate of the engine.

	Make and model	Power, BHP	Max RPM/Hz	CFR, Hz
Main engine #1	Wickman Ax7	2100	380/6.3	44.3
Main engine #2	Bush?	?	?	?
Aux engine #1	Detroit Diesel	100	1852/31	123
Aux engine #2	Volvo Panther	300	?	?

Table 2: Engine details for the *Northern Seeker*. CFR gives the cylinder firing rate of the engine. Details supplied were incomplete.

It can immediately be seen that the various frequencies have a clear signal in the acoustic record. We attribute the 2.8 Hz tonal seen in the drilling record to the rotation of the drillstem itself, since this frequency converts to 168 rpm, a typical figure used during the drilling phase.

The 'floating' records show clear tonal spikes at the shaft rates of both eight-cylinder and twelve-cylinder diesel engines (16.7 Hz and 25 Hz). These are present at a lower level in other records, which suggests improved coupling of the engines' vibrations when the rig hull is in the water, as might be expected. The shaft rate of the eight-cylinder engines shows particularly clearly in Figure 17, during and just prior to drilling, however. The cylinder firing rates of these engines also have a clear acoustic signature, showing a tonal at 133 Hz (in the floating record) and a very clear tonal at 300 Hz in all recordings.

Similar signatures can be seen in the support vessel recordings. The main engine cylinder firing rate gives a peak around 40 Hz which is not present when this engine was stopped. The auxiliary engine gives rise to a tonal at its shaft rate (~30Hz). Lower frequency components, such as those seen at 6.6 Hz and 13 Hz, are more difficult to attribute. Though the 6.6 Hz component is close to the main engine shaft rate, it is still present when this engine is stopped.

3.4 Real-time passive acoustic monitoring

No acoustic contacts were seen in more than 70 hours of monitoring. The ECD is an excellent tool, which gives a very clear response to porpoise echolocation clicks, and we are confident that any contacts during monitoring would have been detected. The monitoring effort was highly fragmented, however, in line with its mitigation rationale, and no conclusions about the presence or absence of vocalising animals can be drawn from the lack of encounters. Sparsely distributed encounters are statistically unlikely to be detected by a discontinuous monitoring programme.

3.5 Far field acoustic measurements

The sea-state on the two measurement days actually made little difference to the received levels, indicating that its contribution to overall noise levels was small. Spectra at low - and high-frequencies are displayed in Figure 21 and 22 with the loudest spectra obtained on the *Noble Kolskaya* plotted for comparison. The third-octave equivalents are shown in Figure 23.

At frequencies below 1 kHz, the sound levels emitted by the ship are far in excess of that generated by the rig, even in its noisiest “boulder-drilling” phase. With the main engines turned off, the ship is quieter above 400 Hz. With main engines running this cross-over frequency rises to 2 kHz.

In order to measure the far-field levels, the ship would have had to have been positioned *ca.* 500 m from the rig. Applying the spherical spreading equations would thus reduce the received levels from the rig by 53 dB. Cylindrical spreading would drop levels by half this, 26 dB. In both cases the sound levels generated by the rig would be far below the levels generated by the support vessel, even for the strongest tonals seen. We therefore conclude that it is not possible to quantify the far-field response using such a vessel.

At high frequency, the spectra generated by *Kolskaya*'s tugs – the *Atrek*, *Alphonse Letzer* and *Field Express* - during installation has a similar form to that seen from the *Northern Seeker*. Levels below 100 Hz are rather less, reflecting the distance of the vessels from the hydrophone (>200 m) during the rig installation recordings.

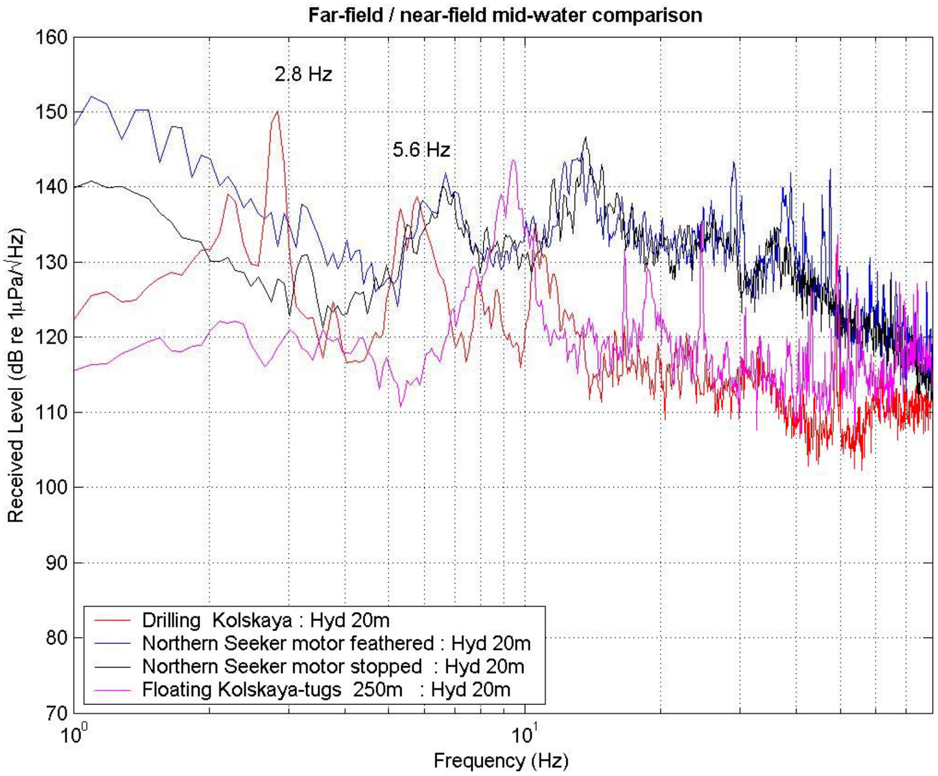

Figure 21: Low frequency plots of the *Northern Seeker* measurements compared to the highest drilling phase levels and levels recorded prior to rig installation, with three tugs present

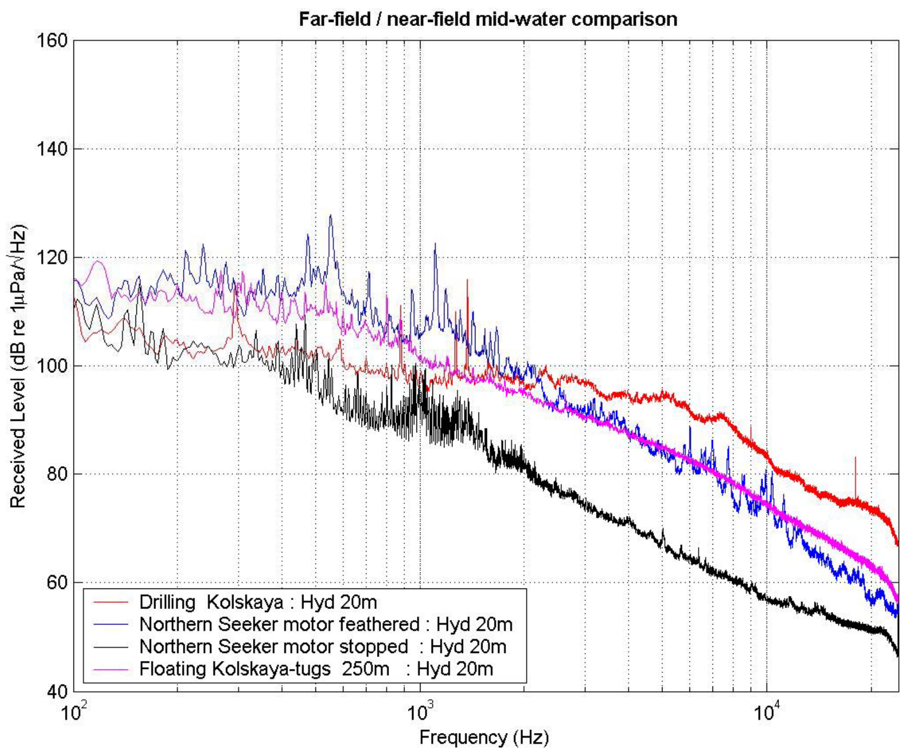

Figure 22: High frequency plots of the *Northern Seeker* measurements compared to the highest drilling phase levels and levels recorded prior to rig installation, with three tugs present

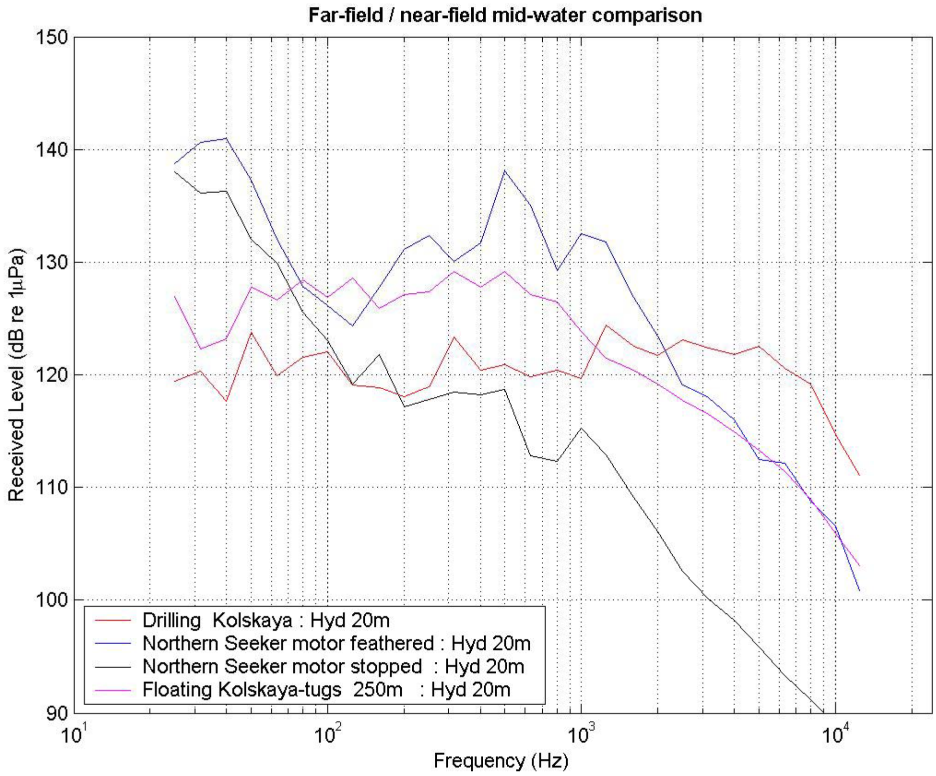

Figure 23: Third octave plots of the *Northern Seeker* measurements, compared to drilling phase levels and levels measured while the tugs were present at the beginning of the rig installation.

3.6 B4-05 porpoise observations

The T-POD recordings produced a small (12d) dataset, which has limited the ability to obtain a coherent picture of the many variables affecting porpoise activity around the drilling rig. Furthermore, all the observations on the B4-05 took place using a waiting-on-weather (WOW) period. It was therefore not possible to compare encounters during varying activity at this location. In the original report (Turner et al. 2005) we undertook very detailed analysis e.g. intensity (ECPM), behaviour (EMCR) and duration (ETPM), but patterns were non-significant presumably because of the short nature of the data set and the long WOW period ; a précis is presented here.

The three T-PODs logged 73 encounters during a total of 33,706 monitoring minutes (23.4 days) – a mean encounter interval of 462 monitoring minutes, or 7.7 hours. The shallow starboard mooring stopped logging on December 23rd due to a hardware fault in the micro-controller. This unit (T-POD 406) was retired from subsequent deployments and replaced with the spare unit (T-POD 409).

Figure 24 displays the timeline of B4-05 deployments, with a broken line at each deployment position indicating the duration of each deployment. The diagram shows all 'cet high' porpoise clicks, with the length of the vertical bar indicating the number of clicks in each train. Figure 24 also shows helicopters on deck and support vessels alongside. No encounters were logged during helicopter activity, though this only totalled 87 minutes over the course of the deployment. Support vessels were alongside for approximately 760 minutes in total (these durations were not accurately logged). One 'Cet Hi porpoise' encounter occurred during this time.

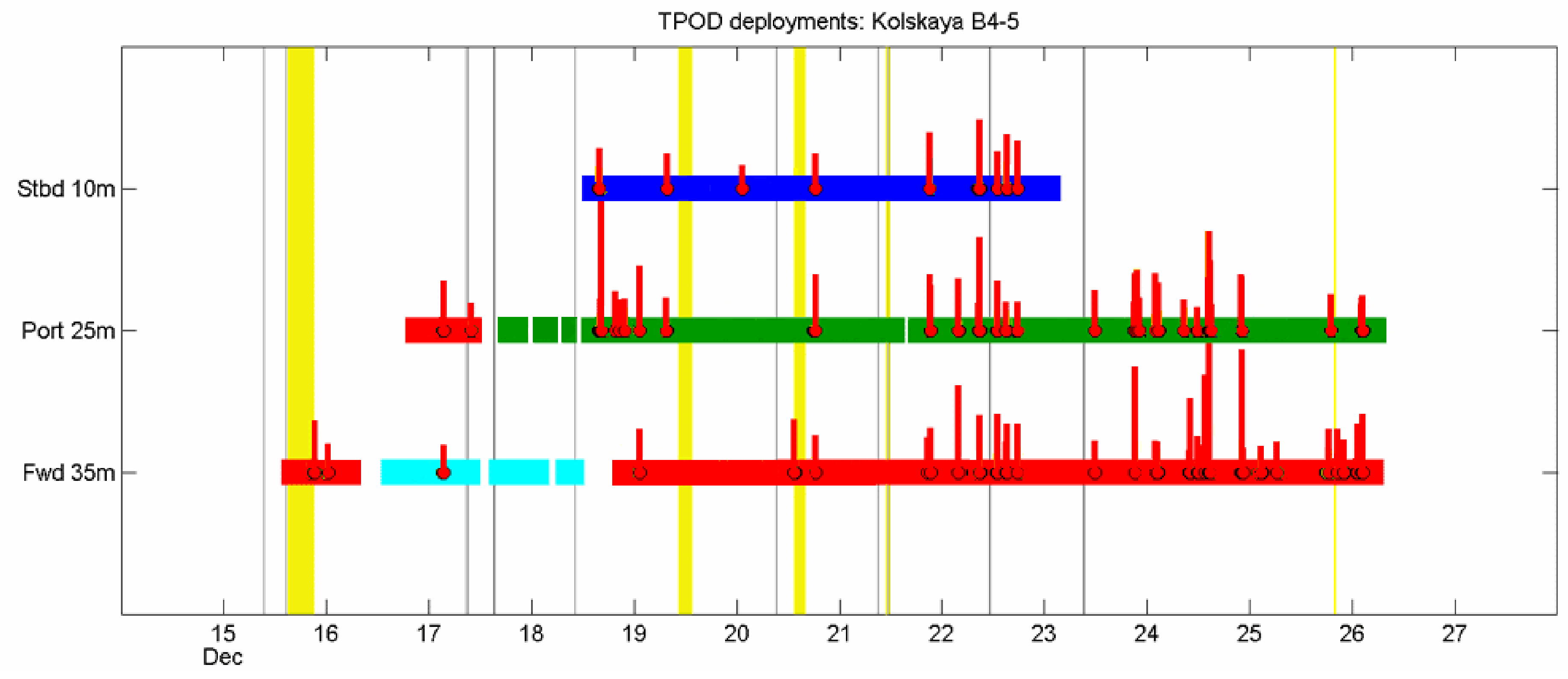

Figure 24: Timeline for T-POD deployments at site B4-05. The coloured horizontal bars show the duration of each deployment, colour-coded by the actual T-POD concerned (blue #406, red #407, green #408 and cyan #409) and indicating the deployment position and depth on the y-axis. The horizontal axis shows the day in December 2004. Circles along the bars indicate that a click train was detected and classified as being generated by a cetacean. The length of the vertical bar arising from the circle is scaled by the number of clicks in that train, and has a maximum value of 200. Red bars indicate a 'high probability porpoise' click train. Vertical yellow lines indicate a support vessel alongside. Vertical grey lines indicate a helicopter on deck.

3.7 B11-04 porpoise observations

Unfortunately, the starboard mooring was lost during the long-term deployment on B11-04 and data were only recovered from its initial, day-long, test. In addition, the hardware fault encountered during the B4-05 deployment (T-POD 406) also occurred during this deployment, this time affecting T-POD 407 which stopped logging five days after being left. The third T-POD (408) functioned correctly for the entire deployment.

The T-PODs logged a total of 126 encounters in 46,675 monitoring minutes (32.4 days) – a mean encounter interval of 370 monitoring minutes (6.16 hours).

Helicopters were on deck for a total of 299 minutes during the deployment. Support vessels were alongside for approximately 1584 minutes. No porpoise encounters were logged during helicopter activity. One encounter was logged while support boats were alongside.

Figure 25 shows the full deployment timeline, as previously. Helicopter and support vessel activity is marked, over a background of broad classes of rig activity. The activity log was divided into "waiting-on-weather", "casing and cementing", "drilling", "BOP" – meaning wellhead activities such as testing preventers etc., and "logging". We additionally mark the windspeed, as recorded in the barge logbook, to indicate the general environmental conditions at the time. Waiting-on-weather was a significant feature during the deployment, and we propose (later) that the extreme nature of the wind - and wave-field may also have affected porpoises adversely. Two periods of relatively intense porpoise activity occurred, first on January 10th, following a sustained Beaufort 12 storm, and again on January 13th/14th, following another high wind and wave period.

The primary interest of this dataset lies in testing whether drilling activities affect porpoise activity. Accordingly, we grouped T-POD data by rig activity and tested for significant differences. Figure 26 shows the mean ±SD of the total activity (ETCC) and the click rate (EMCR) during various activities.

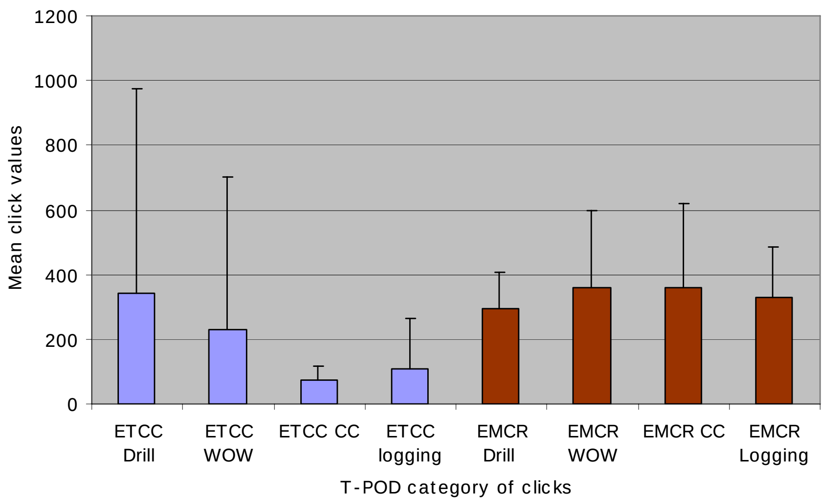

Figure 26: Mean ± SD of the encounter total click counts (ETCC) and the encounter mean click rates (EMCR) grouped by activities: drilling (drill), cementing and casing (CC), waiting on weather (WOW) and logging.

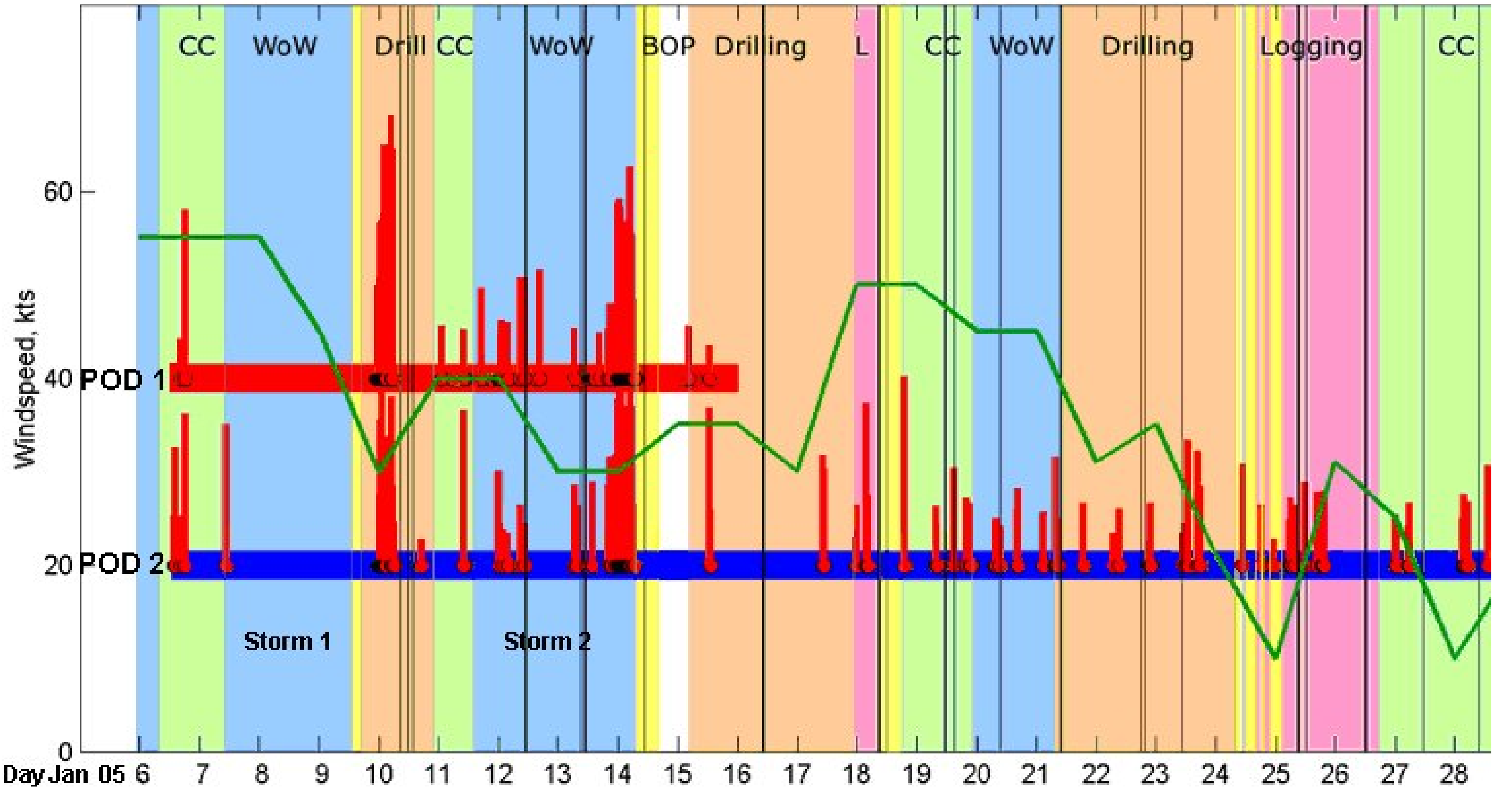

Figure 25: Timeline for T-POD deployments at site B11-04. The coloured horizontal bars show the duration of each deployment, colour-coded by the actual T-POD concerned (blue #408 and red #407. The lost POD #409 is not shown). The horizontal axis shows the day in January 2005. Circles along the bars indicate that a click train was detected and classified as being generated by a porpoise Cet Hi encounter. The length of the vertical bar arising from the circle is scaled by the number of clicks in that train, and has a maximum value of 200. The figure also shows broad classes of activity taking place on the platform – casing and cementing, waiting-on-weather, drilling, wellhead activities (BOP), and logging. Yellow bands indicate that a supply vessel was alongside the platform. Vertical grey lines indicate helicopter activity. The green line indicates the windspeed, in knots, recorded in the barge logbook.

When all the other permutations were tested - *i.e.* WOW *vs*. logging, WOW *vs*. CC, CC *vs*. logging etc., there were no significant differences observed in the ETCC or the EMCR. There were therefore no significant differences in porpoise activity during any of these activities around the rig (Kruskal-Wallis H = 1.543, d.f. = 2, P = 0.461 for ETCC and Kruskal-Wallis H = 0.135, d.f. = 2, P = 0.935 for EMCR). Though not presented here, a similar result was obtained for the encounter intensity (ECPM) - Kruskal-Wallis H = 1.786, P = 0.618), indicating that the encounter duration was also similar across all activities. In short, porpoises produced similar numbers of clicks at similar rates throughout all rig activities.

During the Beaufort 12 waiting-on-weather period there was only one 'high probability porpoise' encounter. When drilling started immediately following the storm, however, there was a significantly higher number of clicks (ETCC mean ± SD = 641 ± 819.26, Mann-Whitney rank sum test: T = 274.5, n_1 =14, n_2 = 15, P = 0.005) and click rate (EMCR mean ± SD = 336.79 ± 57.64, Mann-Whitney rank sum test: T = 281.00, n_1 =14, n_2 = 15, P = 0.002) compared to all other periods when the rig was drilling. However, the intensity of clicks in each encounter (ECPM) was similar throughout all drilling periods (t test, n_1 = 14, n_2 = 14, t = 1.57, P = 0.129, mean ± SD 55.50 ±21.01 and 40.16 ± 29.84 for after the storm and all other drilling periods respectively.

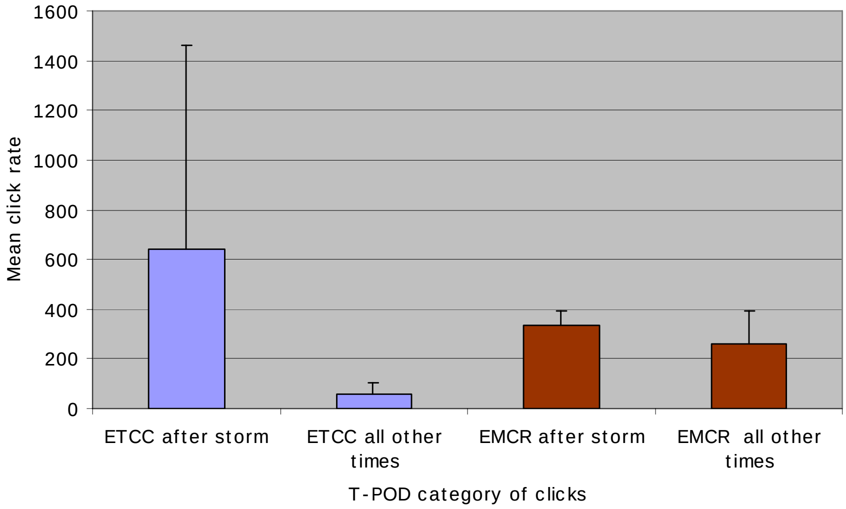

Figure 27: Mean ± SD of the 'high probability porpoise' encounter total click counts (ETCC) and the encounter mean click rates (EMCR) when drilling commenced after the hurricane and at all other drilling times in sector B11-04 only.

This indicates that after the storm, when drilling commenced, there was more porpoise total activity around the rig and the animals were probably feeding at a higher rate than porpoises present during other drilling periods (Figure 27).

3.8 B11-04/B4-05 comparisons

Comparisons between 'waiting-on-weather' periods for B4-05 and B11-04 were performed for total activity (ETCC), behaviour (EMCR) and encounter intensity (ECPM).

There was significantly more total activity (ETCC) in B11-04 than B4-05 (Mann-Whitney rank sum test: T = 4181.00, n_1 = 55, n_2 = 71, P <0.001, mean ± SD 228.15 ± 467.40 and 61 ± 74.53 for B11-04 and B4-05 respectively).

Encounter intensity (ECPM) was also higher at B11-04 than B4-05, as indicated by a Mann-Whitney rank sum test: T = 4092.50, n_1 = 55, n_2 = 71, P < 0.001, mean ± SD 45.36 ± 18.53 and 36.26 ± 22.52 for B11-04 and B4-05 respectively.

There was no significant difference in behaviour (EMCR) between the two sites (Mann-Whitney rank sum test: T = 3754.00, n_1 = 55, n_2 = 71, P = 0.199), indicating that the porpoise feeding rates were similar at both sites.

3.9 A6-A rig and platform activity logs

The platform ceased production for a period of six days when the *Noble Kolskaya* docked onto the side of the platform on 12th/13th August 2005. Production ceased again on 24th and 27th August, 29th August until 11th September, from 5th until 18th October and on 7th and 20th December. At all other times, the platform was producing on one, two or three wells.

Figure 28 illustrates the activities of the A6-A and the *Noble Kolskaya* throughout the study period. Overlaid on Figure 28 is the porpoise activity. From 27th December 2005 until 12th January 2006, porpoise activity levels increased and this was examined later in detail and was attributed to high bouts of probable porpoise feeding activity.

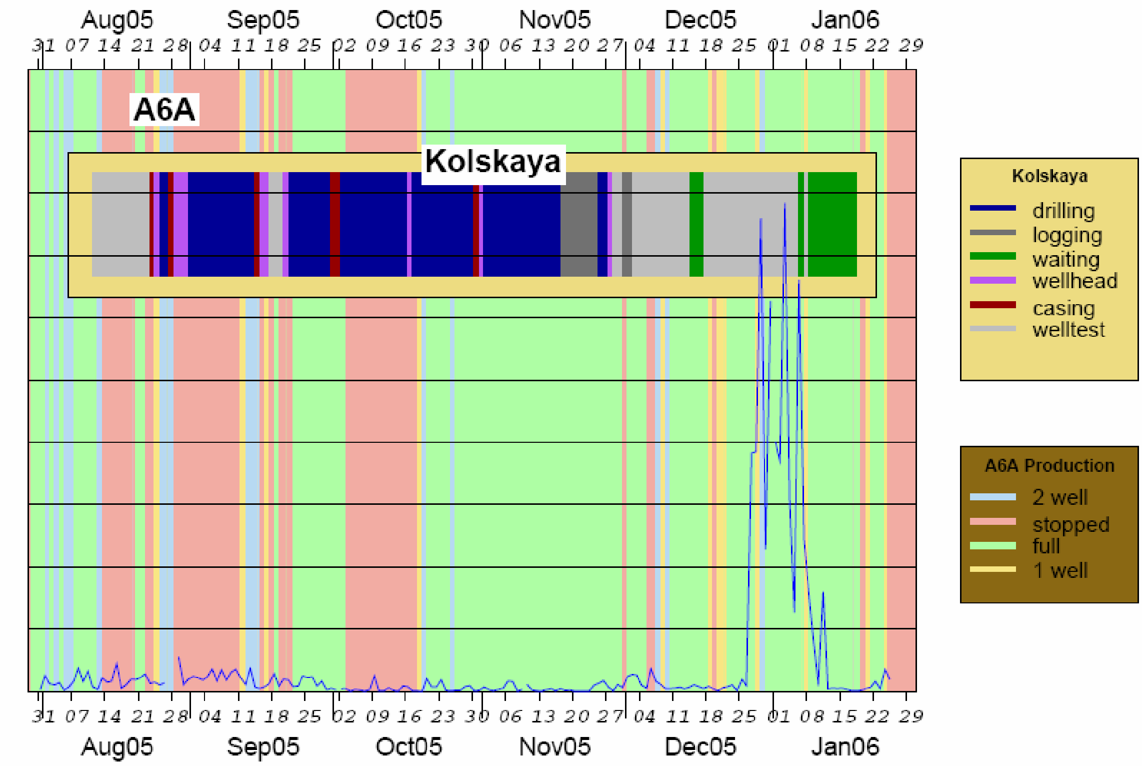

Figure 28: Activity logs of the A6-A gas production platform and the *Noble Kolskaya* drilling rig during the six-month study period. The blue line is porpoise activity measured by one of the deeper T-PODs (407). No scale is necessary, as this is simply a schematic to provide an idea of porpoise levels in relation to platform activity.

Barge helicopter and boat data for the *Noble Kolskaya* were only available in detail between the 13th August 2005 and 8th November 2005. Thus, we did not test to see if there were differences in porpoise activity with boat and helicopter activity.

3.10 A6-A porpoise activity and behaviour analysis

We recorded data from three T-PODs. However, at one point we recorded from four T-PODs, when POD 516 was trapped under the legs for 46 days (31/07/05-15/09/05). At that time, we deployed another T-POD, as a precaution in case POD 516 could not be retrieved. Twenty files were saved totalling 426,999 KB of data. T-PODs recorded continuously for *ca*. 509 T-POD days from 30th July 2005 until 27th January 2006. For the v.3 T-POD, there were 80 days with no porpoise encounters (24.93% of total), so no encounter statistics could be presented on those data. Likewise, of the 175 monitoring days for the v.4 T-POD, there were no porpoise encounters on 73 days, representing 41.478% of the total. A total of 2,388 porpoise encounters were recorded for all T-PODS.

All T-PODs were pooled for depth i.e. 10 m, 25-35 m and 40 m, as we were not investigating the activity of porpoises with respect to depth in the water column. POD 516 (v.4) was always analysed separately from the v.3 pods (406, 407 and 408), but POD 516 has been presented on the same graphs.

We performed the analysis and/or presented graphs on the following porpoise 'Cet hi' indicators:

1. Encounters per day (*presence*)
2. Number of clicks per day (*presence*)
3. Encounter duration (*behaviour*)
4. Minimum Inter click Interval (*behaviour*)

Figures 29 to 31 show the number of average porpoise encounters per day from July until the end of January. Porpoises were recorded on most days. Note: the scales differ to allow for varying porpoise activity levels during each month.

From 14th-23rd August, there were only four porpoise encounters, with a period of up to eight days with no encounters at all. This corresponded exactly to the period of time when the *Noble Kolskaya* docked onto the side of the platform on 13/14th August. Porpoise encounters did not begin to increase again until around 6th September, 23 days later, reaching near pre-docking levels around 12th September. There were also other long periods with no porpoise encounters, such as from 2nd November until 19th November. These periods of reduced or no porpoise activity did not appear to correspond to any particular change in concurrent platform/rig activities.

3.11 A6-A seasonal changes in porpoise activity

For the seasonal analysis of porpoise activity, we analysed the number of clicks per day as an indication of the porpoise *activity*. The total number of 'Cet hi' clicks was separated into six months (August 2005 to January 2006). There were only three monitoring days in July, so these data were added to the August data set. There were 27 monitoring days in January, but all the other data were continuous for the months in between.

Figure 32 shows the total number of porpoise clicks per day over the six-month period. There was a clear seasonal difference in porpoise activity, with the number of clicks per day decreasing towards the end of the summer and autumn, reaching a minimum in October and November, then increasing towards the middle of the winter peaking in December and January. Both T-POD versions showed similar patterns.

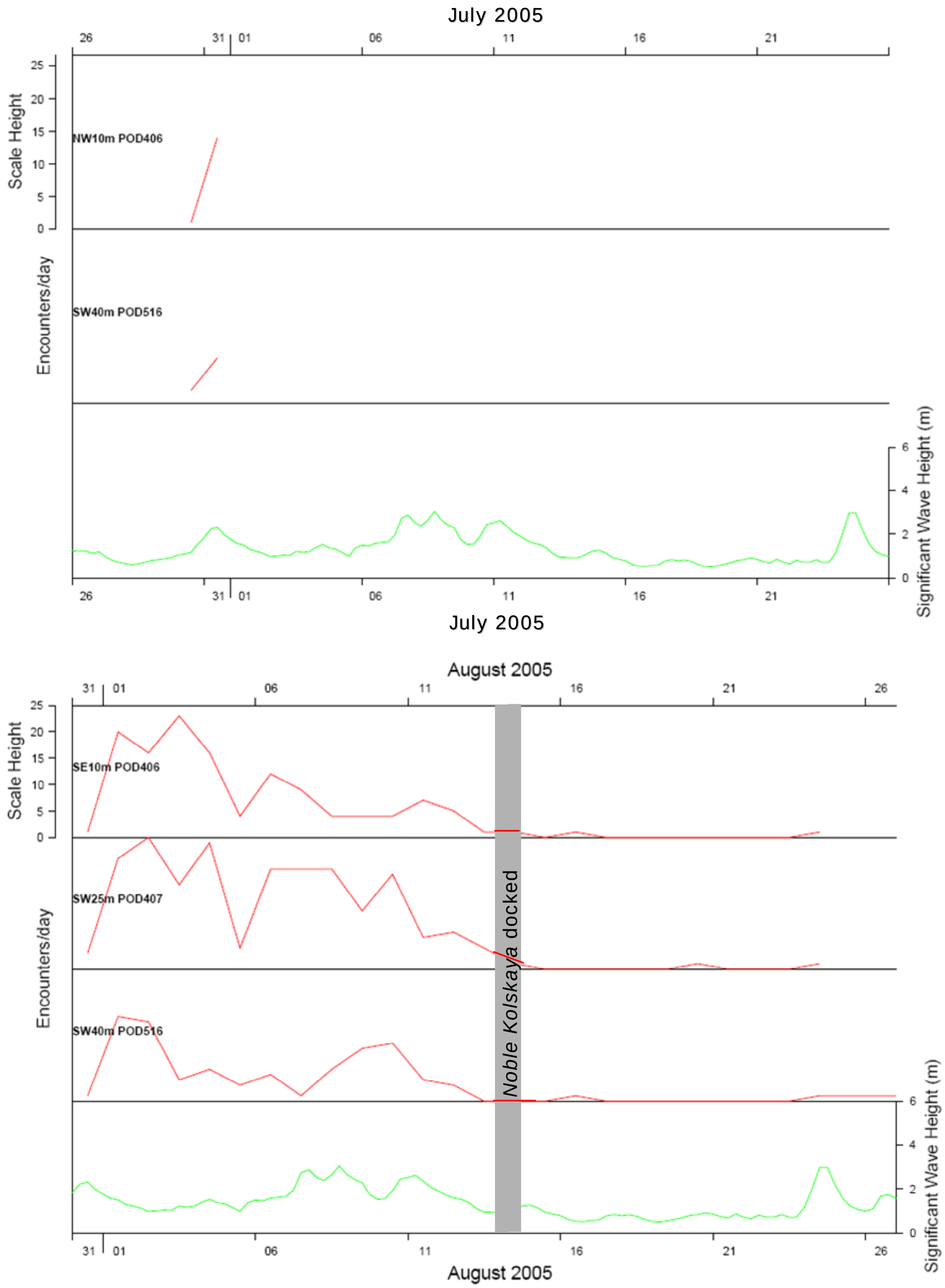

Figure 29: Daily averaged porpoise encounters for July (top) and August (bottom) in 2005. July is truncated because there were only 2 days of sampling. Red lines represent the porpoise activity for each POD (v.3s and the v.4) at the different depths (m). The green line represents significant wave height (m) as given in the ECMWF forecast data. The grey vertical bar indicates when the drilling rig, Noble Kolskaya, docked onto the A6-A production platform.

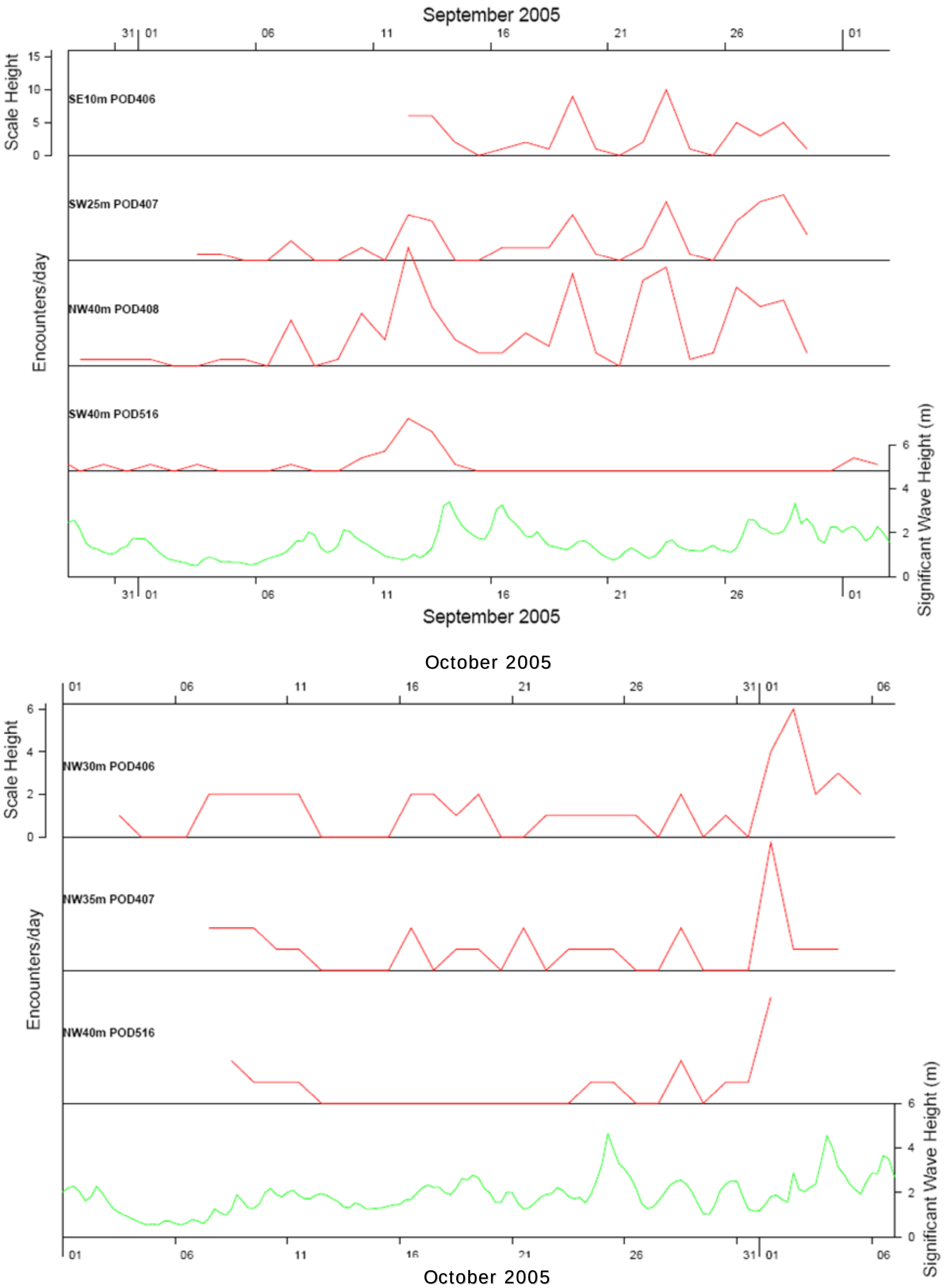

Figure 30: Daily averaged porpoise encounters for September (top) and October (bottom) in 2005. Red lines represent the porpoise activity for each POD (v.3s and the v.4) at the different depths (m). The green line represents the significant wave height (m) as given in the ECMWF forecast data.

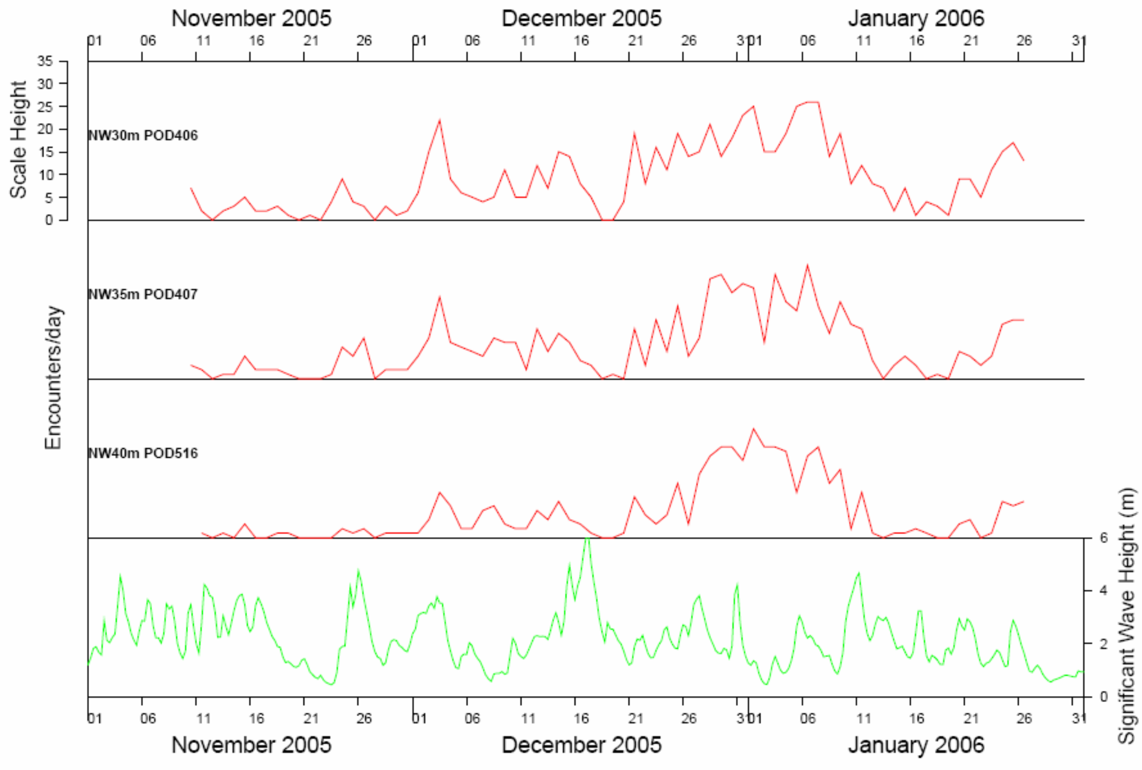

Figure 31: Daily averaged porpoise encounters for November 2005 to January 2006. Red lines represent the porpoise activity for each POD (v.3s and the v.4) at the different depths (m). The green line represents the significant wave height (m) as given in the ECMWF forecast data.

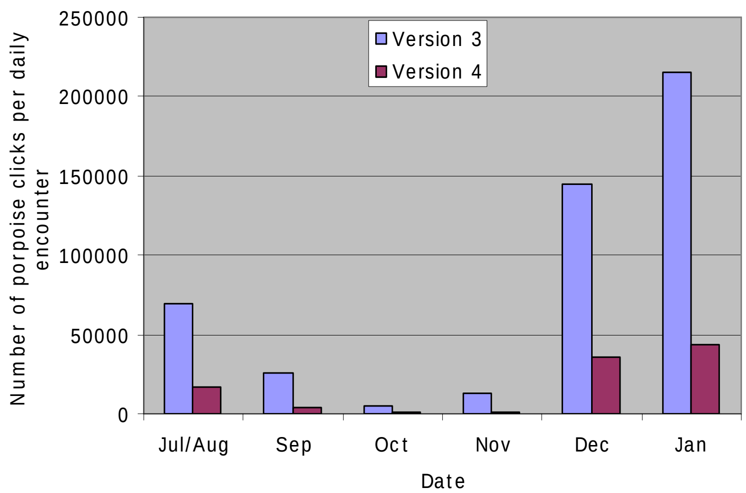

Figure 32: Seasonal porpoise activity expressed as total number of porpoise clicks per daily encounter per month from 2005-2006 for both versions of T-POD.

Kruskal-Wallis One Way Analysis of Variance on Ranks with an All Pairwise Multiple Comparison Procedures (Dunn's Test) was used to test for differences in porpoise clicks per day between months (all tests and permutations not shown). Essentially, there were no significant differences between the months of December and January (P>0.05) or between July and September (P>0.05), when the levels of porpoise activity were similar. However, there were significant differences between the winter months (December and January) and all other months, indicating elevated winter porpoise activity (P < 0.001).

This clear seasonal changes in porpoise activity meant that we could not definitively tease out differences in porpoise activity in relation to the periods of time when the A6-A was isolated (August and again in January) or when joined to the *Noble Kolskaya.* Likewise, this seasonal change complicated matters when testing for significant differences with porpoise activity in relation to platform/rig activity.

3.12 A6-A seasonal changes in porpoise behaviour

There was no real difference in the amount of time a porpoise spent visiting the hydrophone (encounter duration or *behaviour*) between the months (Table 3). However, the proportion of that time spent feeding clearly did change in December.

	median	min	max
July	150	27	1790
August	182	31	1790
September	141	27	1289
October	260.5	84	1445
November	147	35	800
December	178	29	2580
January	180	26	3027

Table 3: Median encounter duration (in minutes) between all months. There were too few samples in October to derive a meaningful median.

3.13 A6-A porpoises activity and weather

Figure 33 plots the average porpoise encounters per day against average significant wave height (averaged for the 00:00, 06:00, 18:00 and 00:00 forecast). Porpoise activity dropped on 14th December 2005 as the wave height steadily increased to above 5 m, after which porpoise activity fell to zero. Once the storm had passed, the activity of porpoises rose to higher levels than previously recorded.

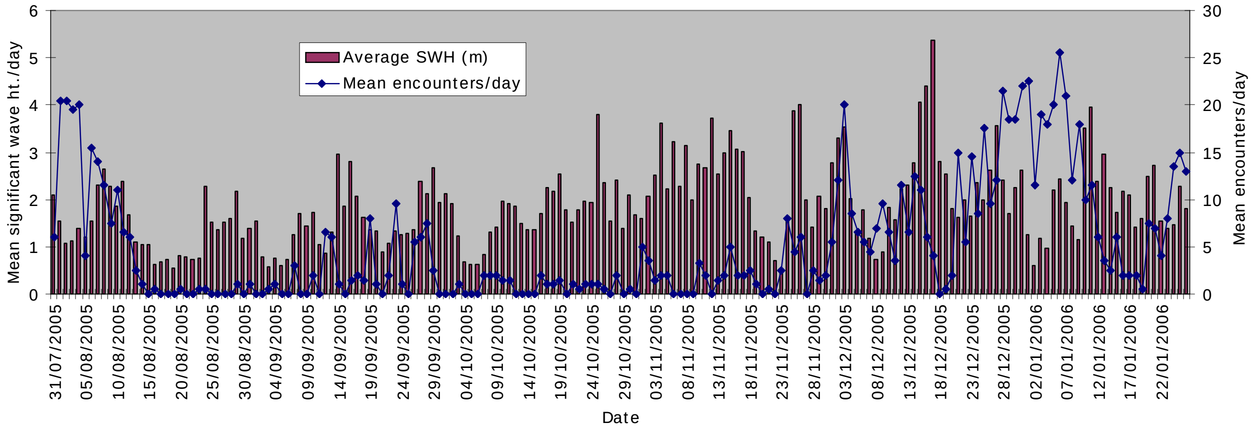

Figure 33: Mean number of porpoise encounters per day in relation to mean significant wave height in metres (averaged from the 00:00, 06:00, 12:00 and 18:00 ECMWF data set).

This increase in porpoise activity ties in with the feeding activity observed when most activity after the storms comprised feeding activity. This was exactly the same pattern observed during the extreme storm event in the B11-04 sector and is a very significant biological observation for this species.

3.14 A6-A activity of porpoises in relation to A6-A and Kolskaya presence

During the study, the A6-A was isolated for a total of 26 days (31st July until 12th/13th August and again from 18th January until 27th January). The remaining 125 days of the study comprised the A6-A/*Noble Kolskaya* complex. We have undertaken analysis to examine possibilities of the porpoises' activity (*presence*) in relation to industrial activity, but we cannot make any definitive assumptions about these results because there was a seasonal difference porpoise activity.

Nonetheless, we tested the following:

1. The before, during and after activity of porpoises for v.3 T-PODs
2. The before, during and after activity of porpoises for v.4 T-POD

Where:
Before = Before the *Noble Kolskaya* docked on the platform
During = A6A/Kolskaya complex
After = After the *Noble Kolskaya* departed from the platform

We then tested the short period of 13 days before the rig docked (31st July – 12th August) and the 12 days after the rig docked (13th August 24th August) to address the following question:

Question: **Did the docking of a rig onto the side of a platform change the *presence / absence* of porpoises foraging around the legs?**

Again, we have not presented the statistical *post hoc* permutations for brevity.

There were too few samples (n = 10) values of Inter-click interval (feeding) data to test for significant difference in porpoise feeding activity in the period before the *Noble Kolskaya* arrived to do any statistically valid comparisons. However, there was a significant difference in the minimum inter-click interval per train 13 days before the *Noble Kolskaya* departed from the platform (Mann-Whitney Rank Sum Test n_1 = 240 , n_2= 143, T = 32159.5, P < 0.001). Minimum inter-click intervals were significantly shorter (median = 3.1) before the rig departed than after the rig departed (median = 15.09), indicating that a greater time was allocated towards feeding before the rig departed than after its departure. However, this result is unclear and might be a result of the reduction in porpoise activity just before the rig departed and immediately after its departure.

Answer:
The answer is multi-fold:

1. Excluding seasonal differences (a large assumption), both T-PODs show that there were no significant differences between the before (August) and after (January) phases, when the A6-A was isolated.
2. Both T-PODs also show that there were no significant differences between the activity of porpoises after the rig docked (during) in comparison to when the rig was alone again in January (after) - but there are not enough 'after' data to make this observation statistically valid.
3. The feeding analysis results are unclear.
4. However, there were significant differences between the activity of porpoises before the rig docked and after the rig docked. Indeed, it is clear that the daily encounters of porpoises did *decrease* after 13th/14th August, when the *Noble Kolskaya* docked onto the platform. Therefore, a quick test to compare the number of porpoise clicks per daily encounter for the 13 days before the rig docked and for the 13 days after the rig docked revealed that there was a highly statistically significant difference between these two periods (v.3 T-PODs: Mann-Whitney Rank Sum Test n_1 = 27, n_2= 25, T = 334.000 , P < 0.001 and v.4 T-POD Mann-Whitney Rank Sum Test n_1 = 14, n_2= 13, T = 96.000, P <0.001). As these data

were taken essentially within a month, the likelihood of seasonal effects was diminished, and we have more confidence in this result.

Clearly, assuming no other factors were influencing the data set, for this platform only, the docking of a rig onto the A6-A had a temporary reduction on the activity of porpoises that recovered after a period.

We were not able to reliably test this hypothesis in the period of time directly after the rig departed the platform, with the period of time when the platform/rig complex existed, entirely because we did not have enough sampling data after the rig left (n = 7d only). However, there was a very clear reduction in porpoise activity prior to the rig's departure and a clear reduction in activity straight after the rig departed. Porpoises had gradually returned to near previous levels seven days after the rig had departed. It is evident that the same pattern of activity was being observed as before the rig docked onto the platform.

3.15 Activity of porpoises in relation to platform and rig activity

The A6-A was isolated for 14 days from 30th July until 12th August. The platform was alone once again for 10 days on 18th January 2006 until 27th January 2006. The platform was producing gas during both these periods of time. We were therefore not able to test for differences in porpoise activity with the production cycles. Neither were we able to test for production/non-production when the rig was docked onto the platform, because of the concurrent rig activities.

There was a strong seasonal effect on porpoise activity, with the encounters of animals increasing in the winter months, so we were not able to tease out any effects of the rig activity on porpoise activity and behaviour over the entire study period. Therefore, we examined industrial activity (drilling, logging, wellhead etc.) effects on a per months basis, but rig activities did not change sufficiently enough during one month to give large enough sample sizes for statistical testing. Clearly, porpoises were present throughout most platform/rig activities. This merits further replicated work.

3.16 A6-A porpoise feeding behaviour

We used the inter-click interval (ICI) as an indicator of *feeding behaviour* in porpoises. Clicks with ICIs of <10 ms were deemed to be an indication of feeding behaviour, and all other clicks as routine search phase, travelling, communicating and navigating etc. behaviour. While this is the standard method of roughly dividing the activity of porpoises into feeding/non-feeding, this is likely to be an over simplification of the circumstances. We are currently examining these data further using more sophisticated algorithms and have a paper in preparation from those results.

Figure 34 displays a histogram showing the proportion of ICIs within trains binned into 2 ms categories for v.3 T-PODs only. It is clear from Figure 34 that there are a large number (46.95%) of clicks below 10 ms, with approximately half (23.16%) of these being below 2 ms.

This peak is very unusual and can mean one of two things:

1. There was a large amount of feeding echolocation taking place around the rig within (approximately) 1.5 m of the harbour porpoises head (allowing for signal return time)
2. Short-duration tonal clicks are being produced from sources other than harbour porpoises.

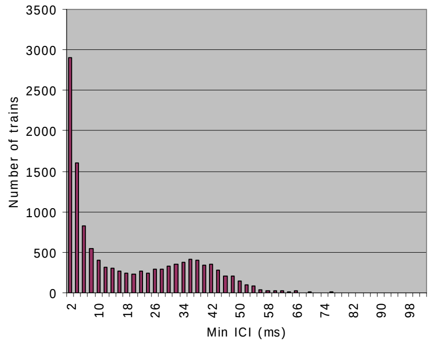

Figure 34: Frequency distributions of minimum inter-click intervals in porpoise trains for the whole data set for the v.4 T-POD only.

Brief Explanation

Speed travels at a speed of 1522 ms^{-1} in seawater with 35 PSU salinity and a standard temperature of 20°C (http://hyperphysics.phy-astr.gsu.edu/hbase/sound/souspe2.html.). During the study, the sea was considerably cooler than 20°C and we have therefore used a reduced and approximate speed of 1500 ms^{-1} in conjunction with the atypical 2 ms feeding buzz clicks to determine the distance between a harbour porpoise's head and its prey:

Speed of sound = 1500 ms^{-1}
= 1500 m in 1 s
= 1500m/1000 in 1 ms
= 1.5m in 1 ms
= 3m in 2 ms

However, the echolocation signal would only travel half of the 3 m distance (from the porpoise to the target and back to the porpoise) until it made contact with the target i.e. 1.5 m.

With reference to No. 2 above, short-duration tonal clicks may also be produced from sources other than harbour porpoises. Indeed, a range of species colonised the T-PODs and mooring wire/ropes over the deployment period. There is the possibility that as the T-PODs became increasingly fowled with time, small crustaceans and other fauna on the case and around the transducer may have produced *false porpoise positives*. In other words, scratching creatures might have been making tonal sounds that mimicked a porpoise clicks which were then falsely classified as 'Cet hi' porpoise clicks by the T-POD algorithm. We therefore decided to test for this possibility before undertaking further analysis on ICIs. To eliminate the possibility of No. 2, we randomly chose the three deployments:

1. SW25m 2005 07 31 POD407n2.pdc (23 days 17 hrs 48 min) Leg 2
2. SW40m 2005 07 31 POD516n2.pdt (45 days 10 hrs 55 min) Leg 3
3. NW30m 2005 11 09 POD406n3.pdt (52 days 10 hrs 42 min)[1] Leg 5

We separated the deployment periods into quarters, thirds or halves (depending on the number of files collected in each deployment), that approximated to the beginning and the end of each deployment. Given that marine fowling increases with time, we proposed the following:

- *If the short duration clicks were attributed to marine creatures 'rasping' on the transducer, the proportion of short duration tonal clicks should also, theoretically, increase towards the end of each deployment.*

[1] We only took 10 days at the beginning and 10 days at the end of this deployment and cannot account for season.

However, further analysis revealed that the proportion of ICI <10m s did not increase at the end of deployments (data not presented here), with the exception of in Leg 5, when there was a significant increase in the number of short duration clicks (<10 ms) – which corresponded to the period following a storm, and were thus, probably hungry porpoises.

We re-consulted the original data files and examined these individual clicks within these trains. The 2 ms clicks were very similar to each other and the ICI was not static. We consulted the manufacturer and he suggested that they might be:

- Unusual pieces of porpoise activity (because they are surrounded by clicks mostly from porpoises); or,
- Multipath delay times (unlikely); or,
- Feeding bouts of porpoises.

We undertook further, detailed manual analysis of the file that generated the high peak in clicks <2 ms to see if multipath was as common in the last few days of the file, when there was increased activity. This is the only feature of the data that can help distinguish loud sounds that have travelled a long way (cetaceans and boat sonars) from small sounds at the transducer surface (fowling organisms).

There were numerous multipath porpoise click trains at the end of the file, so the data were valid. It was therefore highly unlikely that there was a non-cetacean source of loud tonal trains other than boat sonars, and given that boats were at the platform/rig daily, it is clear that they were not the source of the data. It was also unlikely that we had a large surface noise problem because the platform/rig activity was not unusual for that time period. We conclude that the large proportion of clicks below 2 ms were probably attributable to feeding bouts of porpoises.

4. DISCUSSION

4.1 Generated noise levels

The low frequency components – seen both as an increase in mean sound density level within certain frequency bands and the development of tonal components – were the highest recorded received levels observed during the measurements. In the case of the 2.8 Hz tonal, this was observed as a received level of around 140.6 dB re 1μPa ± 1 dB. For an equivalent sound spectral density level of 150 dB re 1μPa/√Hz, this is approximately 25 dB above the upper limit of the prevailing limits of noise taken from the generalised ambient noise spectra (Wenz 1962) for the same frequency.

Numerous other lower level components were observed both during preparation and drilling phases. These were seen both as clearly defined tonals and elevated broadband sound level densities. Strong variations in these levels were observed over relatively short time periods. The strongest mean sound level density levels were observed below 4 Hz. 'Quiet' – i.e. non-boulder-drilling – periods in both pre- and during-drilling phases were around 125 dB re 1μPa/√Hz and were approximately 15-20 dB above the equivalent levels measured during the tank discharge and holding phases. A reduction to <90 dB re 1μPa/√Hz in sound level density was observed in frequencies above 10 kHz and <80 dB re 1μPa/√Hz for frequencies above 80 kHz.

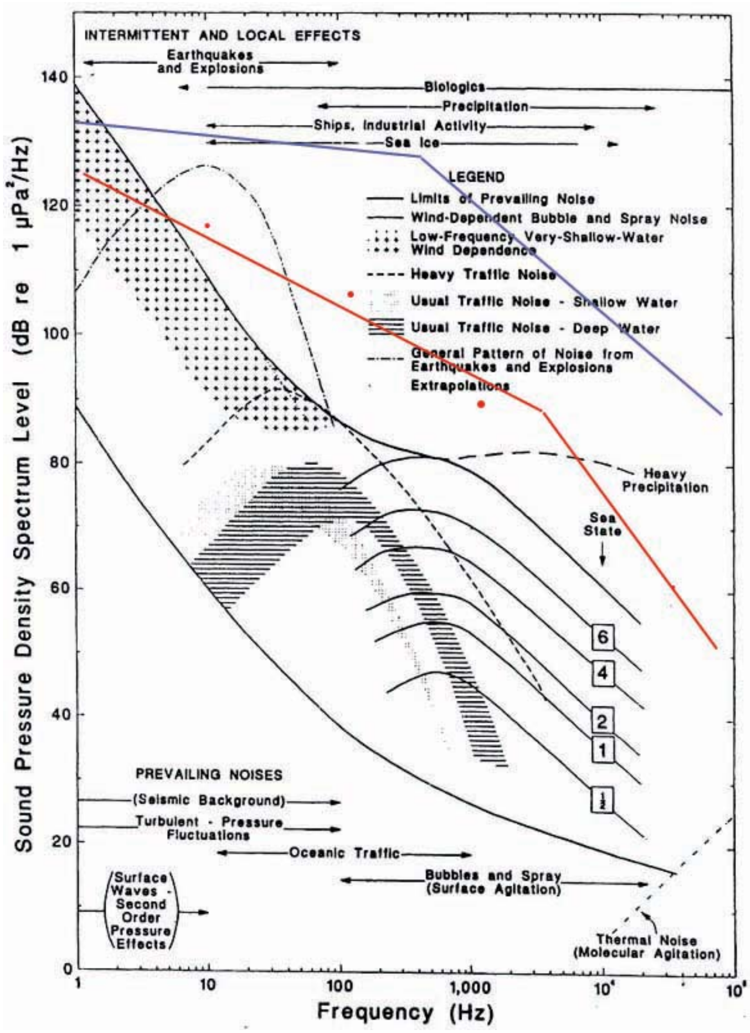

Figure 35: Platform (red) and support vessel (blue) spectrum levels plotted against accepted ambient noise levels in the ocean, adapted from Wenz (1962).

Sound pressure density spectrum levels measured here are generally of the same order as those measured by Gales (1982) for other metal-legged drilling platforms *e.g.* 119-127 dB re 1 µPa at the near-field locations, *c.f.* 125 dB re 1 µPa in this study. Tonal frequencies were limited to similar frequencies of 1.4 kHz (*Noble Kolskaya*) versus 1.2 kHz (Gales 1982). The strongest tones from all metal-legged platforms measured by Gales were at very low frequencies, near 5 Hz, reflecting the generally low rotation rates of the drillstem and its apparently dominant influence in noise generation, at least when drilling through relatively hard formations (such as the boulders in this study).

Figure 35 plots the general form of the measured spectra against published ambient noise levels (Wenz 1962). The red line gives the broadband rig noise, while the blue line shows levels measured with support vessels alongside (during installation). Rig noise levels lie approximately 20 dB above ambient until the ‘knee’ at 8 kHz is reached, with levels dropping rapidly to close to background levels from thereon. Boat noise is considerably higher, lying generally 20 dB above the output from the rig itself.

4.2 Far-field contributions

The site of well B4-05 is located relatively close to major production fields which may contribute to elevated levels of background noise. These sources include the A6-A platform, only 7.5 nm distant, the Rolf, Gorm and Tyra fields (15 nm, 20 nm and 22.5-27.5 nm respectively) and the Valdemar and Roar platforms (20 and 18.5 nm respectively). The Skjold, Halfdan, Dan, Kraka and Regna oil fields are only slightly further from the site. Two gas pipelines run less than 2.5 nm from B4-05, with the Europipe gas pipeline at 4.5 nm range.

Applying a ‘worst-case scenario’ of cylindrical spreading and neglecting absorption losses (these would be rather low at the low frequencies discussed) sound pressure levels from the A6-A platform would be reduced by over 40 dB and those from the 20+ nm fields by more than 46 dB. If generated levels were similar to that measured on the *Noble Kolskaya*, this would drop them well into background ambient noise levels.

4.3 Our noise results in comparison to other studies

Noise emanating from fixed, metal-legged rigs/platforms is generally considered to be relatively low level and at very low frequencies, near 5 Hz (DOI 2004) – entirely consistent with our findings. Gales (1982) measured noise near platforms and man-made islands while drilling or production was occurring. His research presents the only published comprehensive work to date on the characteristics of underwater noise from drilling and production operations in temperate waters (Santa Barbara Channel and Middle Atlantic and Alaska coastal areas study).

From the bottom-founded platform, Gales (1982) concluded that platform noise was so weak that it was nearly undetectable even alongside the platform in sea states greater than three (again, consistent with our far-field findings). However, in that study, source levels could not be calculated because of the near-field nature of the measurements. Although in that study, only stylised spectra were reported, the strongest tones from all four platforms were at very low frequencies, near 5 Hz. Received levels of these tones were 119-127 dB re 1 μPa at the near-field locations. The highest frequency tone was at 1.2 kHz.

Underwater noise from platforms standing on metal legs would be expected to be relatively weak because of the small surface area in contact with the water and the placement of machinery on decks well above the water (Greene and Moore 1995). Gales (1982) also measured from bottom-standing production platforms with steel structures and multiple steel legs. The strongest tones from four production platforms were at very low frequencies, between *ca*. 4.5 Hz and 38 Hz, which were measured at ranges 9-61 m (i.e. near field and therefore not converted to source levels). Two platforms powered by gas turbines produced more tones, with peak sound spectrum levels at 50-200 Hz when measured at ranges of 9-61 m.

These results are generally consistent with expectations. However, more data on noise around these rigs and other types of production platforms and islands are needed before a quantitative analysis of production platforms will be possible (Greene 1995).

A recent study recorded industrial noise in the Shetland-Faroes channel (Swift and Thompson 2000) associated with the BP Foinaven and Schiehallion fields. Frequencies were divided into three bands (1-10 Hz, 10-30 Hz and 30-100 Hz) and the mean and standard deviation noise levels calculated for each. Quoted figures were 120 ± 12, 111 ± 9 and 111 ± 6 dB re $1 \mu Pa/\sqrt{Hz}$, respectively. High recorded noise levels were ascribed largely to FPSO (floating production, storage and offloading vessels) operations (particularly its gas turbines), ship movements in support of operations and rig moves, rather than drilling activities on the platforms themselves, which, again, is consistent with the results presented here.

Vessels are major contributors to the overall background noise in the sea. Vessel sound levels and frequency characteristics underwater are mostly related to vessel size and speed. It follows that larger vessels generally emit more sound than smaller vessels do, and those travelling with a full load, or those pushing or towing a load, are noisier than unladen vessels. Broadband source levels of ships between 55 and 85 m are around 170-180 dB re 1 μPa@1m (Richardson et al. 1995), with most energy below 1 kHz, which, again, is all consistent with the measurements in this study. See Richardson et al (1995) for a review on shipping noise.

4.4 Can porpoises hear the rig?

The auditory sensitivity of the harbour porpoise, *Phocoena phocoena*, was measured by Anderson (1970). This study produced an audiogram between 1 kHz and 150 kHz which was very similar to that produced by Johnson (1966) and showed that harbour porpoises have better hearing at lower frequencies than bottlenosed dolphins.

Kastelein *et al.,* (2002), however more recently measured the underwater hearing sensitivity of a two-year-old harbour porpoise in a pool. Auditory sensitivity was measured by using narrow-band frequency-modulated signals having centre frequencies between 250 Hz and 180 kHz. The resulting audiogram was U-shaped with the range of best hearing defined as 10 dB within maximum sensitivity from 16 kHz to 140 kHz, with a reduced sensitivity around 64 kHz. Maximum sensitivity was about 33 dB *re* 1 μPa between 100 and 140 kHz, and corresponds with the peak frequency of echolocation pulses produced by harbour porpoises at 120–130 kHz. Sensitivity falls about 10 dB per octave below 16 kHz and falls off sharply above 140 kHz. Compared to Anderson's (1970) audiogram of this species, the present audiogram shows less sensitive hearing between 2 kHz and 8 kHz and more sensitive hearing between 16 kHz and 180 kHz. This harbour porpoise has the highest upper-frequency limit of all odontocetes investigated. Another set of audiograms is currently being carried out for this species by Drs. Klaus Lucke and Paul Lepper (K. Lucke and P. A. Lepper *pers. comm.*) using the same animals in the same tank and will be available in the literature in mid 2007.

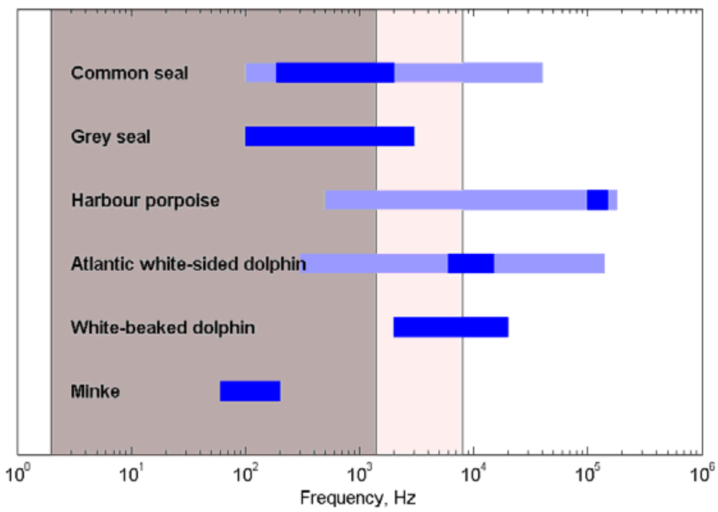

Figure 36: Vocalisation (dark blue) and hearing (where known, light blue) ranges of the generally most common species on the Dogger Bank. Frequencies of highest sound level generated by the platform are shaded dark grey, with less intense output shaded light grey.

The rig drilling activities in this study are thus not expected to mask harbour porpoise echolocation signals. Cetaceans would be likely to display behavioural changes, if any, in response to noise generated by the *Kolskaya*, rather than the sound having any adverse physiological effects. Figure 36, shows the vocalisation range (dark blue) and hearing range (where known, light blue) for common species in the area. The frequencies where sound levels generated by the platform are highest are shaded in dark grey, with the roll-off region to 8 kHz shaded more lightly. Figure 36 demonstrates that all these species could be expected to hear platform operations. Harbour porpoises are the only species whose vocalisations are outside of the frequency range of the loudest generated sounds.

4.5 B4-05 and B11-04 porpoise observations

The porpoise activity at the locations in this study appear to be low in relation to the more coastal regions studied previously, although it is difficult to make direct comparison because other studies used different T-POD versions, settings and sensitivities. In the Shetland Isles, Fisher & Tregenza (2003) logged percentage positive minutes (PPMs) of 3.3 – 4.2% throughout the study, rising to over 20% at the end of the study. Off Denmark, Tougaard et al (2003b) recorded typical PPMs of around 4-7%. Mean encounter durations (TPMs) in the Shetlands were 2-3 minutes, with a maximum of 51 minutes recorded. TPMs in Denmark were typically 8 minutes. The Peak MCR in Shetland was 1041 clicks/second, consistent with feeding activity. Tougaard et al (2003b), however, noted that the encounter duration in January and February, November and December comprised only 15% of their data. So much so, that they actually discarded those data from their report. We are aware that our encounter data are low, and have endeavoured to analyse the results as productively as possible given our data collection window, which was constrained by the rig move dates.

4.5.1 Porpoise acoustic encounters during drilling

We found no significant differences in the activity of harbour porpoises during drilling/non-drilling periods. This was true of all parameters, including the total number of encounters, the encounter duration, encounter intensity and the click rate. The species most likely to be affected by offshore drilling activities are those that have hearing ranges which cover the broadcast sound spectrum and have habitat in the surrounding area. In the case of the Dogger Bank, this would be minke whales (*Balaenoptera acutorostrata*), none of which were observed. However, a minke whale was observed swimming between the legs of the A6-A in a previous trip (photographs confirmed this anecdotal sighting).

However, we advise caution when viewing these results as the small T-POD dataset does not allow complicated multivariate statistical modelling to be performed. It is therefore difficult to separate the various influences on porpoise activity. Longer-term datasets are required to determine how each factor – such as weather in combination with drilling, or ship activity in combination with time of day, or seasonal differences – affects porpoise encounter rates.

No porpoise encounters occurred while helicopters were on deck or approaching/leaving at low altitude. The total duration of such activities was very low (total = 386 minutes), however, and given the low density of porpoises in the area, we would not necessarily expect an encounter to occur in this timeframe. The sample size is too small to allow any statistical testing of avoidance. Gales (1982), however, provided anecdotal information that changes in behaviour – such as a rapid dive or other avoidance reactions – occurred when helicopters were present. There are also a number of papers reviewing this topic (see Richardson et al. 1995 for more details; Richardson and Würsig 1997).

Two porpoise encounters occurred while support vessels were alongside the rig, in a total of 2,344 minutes of this activity. As with helicopter avoidance, this sample size does not allow us to draw any statistically valid conclusions about porpoise avoidance of these vessels. However, harbour porpoises do tend to avoid approaching vessels (Polacheck and Thorpe 1990).

In our study, the rig tender vessels generated higher levels of noise than the drilling, especially when they were using engines to hold position alongside the rig for supply or transfer operations. However, marine mammals are not likely to be significantly impacted by this noise disturbance in the long term. Avoidance behaviour, if any, is likely to be very localised and short-term.

The T-PODs recorded one encounter (duration 1 min, number of clicks = 44) during an ROV deployment. The frequency of the sidescan sonar used by the ROV (Sea Prince, 325 kHz) appears unlikely to disturb the animals, although the effect of their thruster noise is less clear. The T-PODs correctly classified ROV deployments as boat sonars.

4.5.2 Rigs as artificial reefs?

This study has shown that harbour porpoises were present around the *Noble Kolskaya*. Though we have no baseline data on the utilisation of the surrounding waters by harbour porpoises before the rig was emplaced, we suggest that that the rig acts as temporary artificial reef and a potential habitat enhancement feature for this species.

Artificial reefs are man-made structures placed on the sea floor to mimic some of the characteristics of natural reefs (Sayer and Baine 2002). Research has shown that artificial reefs can attract fish and crustaceans (Fowler et al. 1999; Walker et al. 2002) but, to date, there has been little research on the utilisation of reefs by top predators such as porpoises.

When any object is placed into the water column it ultimately attracts fish, which use the legs are a refuge and foraging habitat. A jackup rig is a ‘temporary reef’, present for short-periods of time on one location. The legs are quickly colonised by seaweeds in the sunlit areas (Forteath et al. 1982), tunicates (sea squirts), sea stars (e.g. *Asteria rubens*), bryozoans, mussels (e.g. *Mytilus edulis*), crabs (*Cancer pagurus*), sponges, sea anemones and numerous other species (V. L. G. T. pers. obs.). The exposed position of some rig/platforms results in a high delivery rate of plankton to these habitats, which sustains large numbers of filter-feeding animals (mussels, anemones), and planktivorous fishes (Schroeder and Love 2004). Pelagic fishes aggregate to a variety of offshore structures, and they compose a significant part of the fish community at oil rigs/platforms compared to natural reefs. Elevated numbers of fish, which are easily located and concentrated in one location, might be expected to attract top level predators such as the harbour porpoise.

There are many studies investigating the role of decommissioned rigs as artificial reefs (e.g. Caselle et al. 2002; Love et al. 2001; e.g. Love et al. 2003; Schroeder and Love 2004). Rigs support a great diversity of life (e.g. see Carlisle et al. 1964; e.g. see Shinn 1974; Wolfson et al. 1979). In California, for example, an extensive 'rigs to reefs' programme was introduced in 1998 to use decommissioned rigs/platforms for enhancing local fish populations. In the Gulf of Mexico, 85 obsolete oil rigs/platforms have been converted to artificial reefs since 1986. A flourishing red snapper industry in the Gulf is probably dependent on these sites.

4.5.3 Porpoise energetics

One of the most interesting results of this study is that the total harbour porpoise activity (Encounter Total Click Count, ETCC) and possible feeding rate (Encounter Mean Click Rate, EMCR) significantly increased after the January hurricane at the B11-04 site. The encounters coincided with the onset of drilling after the long waiting-on-weather period. Given that drilling, and indeed all other rig activities, appeared to have no significant effect on porpoise activity overall, we originally postulated that drilling sounds could act as a 'dinner gong' – but we need much more data to support such a theory. Certainly, noises of drilling may be familiar to harbour porpoises and may act as an attractant to animals that know there is a predictable food source around the legs of rigs/platforms. This has been with reference to some acoustic deterrent devices used on nets, such as pingers and fish farm deterrent devices (e.g. Mate and Harvey 1986).

The heightened total click count and click rate following the storm might be best explained in terms of harbour porpoise energetics (see Jepson 2001; Otani et al. 2001 and references therein). Harbour porpoises are very small and consequently have a very high metabolic rate. This, coupled with the porpoise's small size, means it has a relatively large surface area over which to lose heat to the environment, where water temperatures range from 4°C to 16ºC. There is pressure, therefore, on these animals to feed at rates higher than larger cetaceans with lower metabolic rates. Indeed, in harbour porpoises, the food consumption varies between 4% and 9.5% (Kastelein et al. 1997) and 7.5% - 10% body weight daily (Jepson 2001), representing between 8000 and 25000 kJ/day (Kastelein et al. 1997).

Like all other marine mammals, harbour porpoises have blubber to keep them warm. Blubber is the major site of lipid storage and harbour porpoises will preferentially metabolise muscle tissue rather than fat in times of starvation to prevent heat loss to the surrounding water. Studies which have compared the blubber thickness distribution of robust porpoises (killed randomly in commercial fishing operations) with those from animals that died of terminal starvation and washed up on beaches, have provided an opportunity to determine how blubber is used as an energy source in an extreme situation such as a long storm. Starved porpoises have thoracic blubber layers that are reduced by up to 40% compared to robust porpoises of the same age and size class (Koopman 2005).

Preliminary calculations indicate that a starving porpoise could rely on the lipids in its blubber as its sole source of energy for only about a week (Koopman 2005). Waves during the hurricane were up to 15 m in amplitude, making the shallow water areas around the rig dangerous for a harbour porpoise. Porpoises are intelligent animals, however, with excellent spatial awareness. We had routinely recorded them foraging around the reef before the storm and these animals may well have returned there immediately afterwards to feed on a predictable food source.

Furthermore, a predictable food source is extremely important for an animal whose diet is strongly influenced by seasonal variations in food supply, higher energetic costs of pregnancy and lactation (Santos et al. 2001) and in changes in water temperature. Indeed, in harbour porpoises, there is a marked regular seasonal increase in body fat in late autumn and subsequent loss in early April, that correlates with food intake (Jepson 2001). We suggest that rigs are good foraging sites for harbour porpoises, but caution that we do not currently have enough long-term, non-seasonally biased data to confirm this supposition.

4.5.4 Porpoise variation between sectors B4-05 and B11-04

Although baseline data are absent, the variation in click frequency between the two sites may be attributable to either or both seasonal and spatial variation. Seasonal variation is more likely to be the dominant factor as the B4-05 and B11-04 locations have similar oceanographic conditions and were only separated by *c.* 24 nautical miles.

4.6 A6-A porpoise observations

According to Culik (2004): "*The causes of lowered [harbour porpoise] abundance may be diverse, but they are primarily related to human activities…traffic and offshore industries…may be responsible for the decline of the species in the area*".

Clearly this is not the case at the A6-A and in the B4-05/B11-04 sectors. This assumption now needs to be modified and our new findings confirmed by replicated and controlled longer-term studies and put into the peer-reviewed literature and released to the wider scientific community.

4.6.1 Seasonal changes in porpoise activity and behaviour

Porpoises were recorded during all months of the study, but their activity was extremely varied. The significant increase in porpoise activity and feeding activity (expressed as minimum inter-click intervals) over the winter months is a new observation for this species and has not previously been reported. There have been some anecdotal observations suggesting that porpoises move offshore during the winter. For example, the United Nations Environment Programs (Conservation of Migratory species) states "*Some seasonal movements (related to food availability) occur: mostly inshore in summer and offshore in winter*" (for a review see Culik 2004). Encounter duration (the amount of time the porpoises spent visiting a hydrophone) did not vary between months, but the proportion of that time allocated to feeding (minimum inter-click intervals) did. The fact that the porpoises were feeding more heavily in the winter is an indication that this is either a prey-related or energetic (i.e. colder in winter) phenomenon.

Dierderichs et al., (2003) carried out environmental impact study using porpoise detectors off the coastal west island of Sylt in Germany. They found a clear decrease in porpoise activity from August until December 2002, which was confirmed by concurrent aerial porpoise sightings. Henriksen (2004) and Tougaard et al, (2005a) also recorded lower echolocation activity off the Danish coast in the winter months and higher activity in the summer. Porpoises are also observed in higher number in German waters in the summer (Siebert et al. 2006). As expected, these results are exactly the opposite to those obtained in this A6-A study; we found a significant increase in the winter encounters of porpoises as compared to the summer, again an indication that these animals move offshore in the winter. At a recent workshop, S. Brasseur (V. L. G. T. *pers. comm.*) stated that in her study, she had observed significantly more porpoises in the winter onshore, than in the summer. If these findings are scientifically peer-reviewed and supported by future studies in other regions, then it is necessary for further investigation to establish more definitive migration patterns.

Figure 37 compares the coastal data presented from one of Diederich's et al., (2003) T-PODs and the Siebert et al., (2006) study, with one of the pods (POD 516) used in this study. Though the two studies in Figure 37 are not directly comparable (Diederichs used % click frequency, whereas we used mean number of clicks per day, and Siebert's study is based on sightings, strandings etc.), the trend is clear.

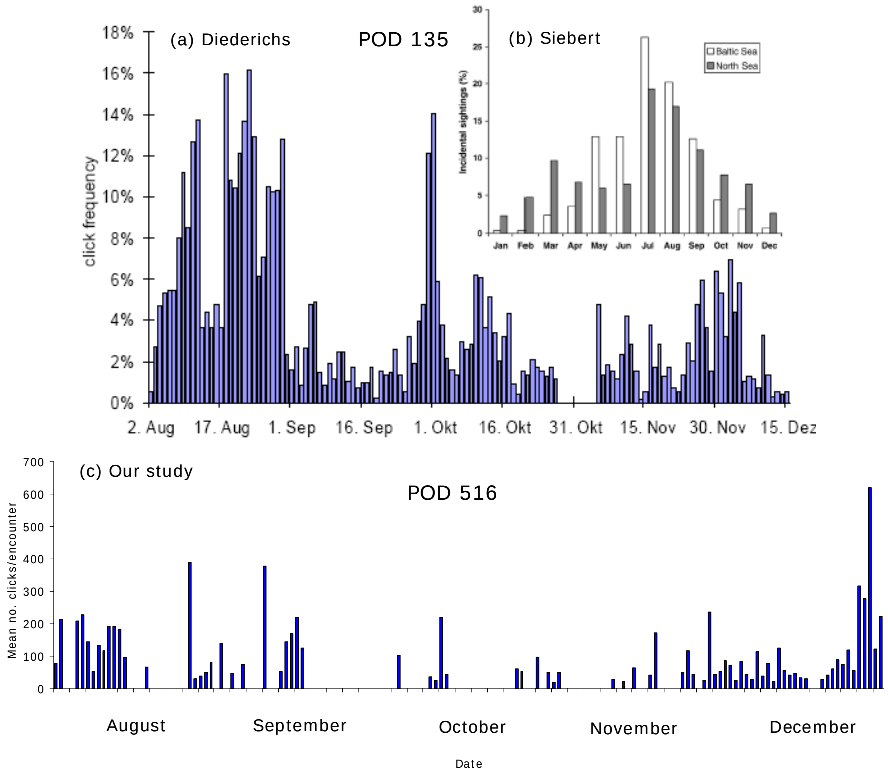

Figure 37: Comparison of the seasonal porpoise activity for one T-POD in (a) Diederichs et al (2003) sightings data from (b) Siebert et al. (2006) study and (c) our study.

In both the Diederichs et al. (2003) graph and the Siebert et al. (2006) graph, there is a trend for porpoise click frequency/sightings to decrease towards the winter months whereas we see an increase in the number of clicks per day towards the end of the winter. Although the years are different (Diederichs work was carried out in 2002 and our study in 2005), we believe that this is the first semi-quantitative indication that porpoises may be either moving offshore during the winter, or possibly using the platforms as a stop-off point on migration routes. This hypothesis, however, requires rigorous scientific testing, further work and comparison with other studies. If this hypothesis is correct, then platform/rigs may be even more important foraging grounds for this species than we had previously anticipated. Furthermore, platform/rigs may also be important feeding areas for these animals in the winter months, when food might be expected to be scarcer and the animals' energy requirements in higher demand because of colder water temperatures. We strongly recommend that this work be taken further to investigate this occurrence within the same season on the same dates. We feel that in order to quantifiably confirm this observation, concurrent shore-based surveys and offshore surveys need to be carried out.

In 2002, S. Koschinski (quoted in Culik 2004) summarised the following:

1) There might be a tendency of porpoises from the Kattegat to migrate into the North Sea during winter months;
2) A proportion of animals may stay in the western Baltic during the winter or even in the Baltic Proper;
3) There might be a difference in migratory tendency between putative sub-populations; and,
4) Migration patterns might depend on winter severity.

The fourth point is supported by Forney (1999), who investigated trends in the abundance of harbour porpoise in central and northern California for the period 1986-95. Porpoise sighting rates were analysed in relation to area, sea state, cloud cover, year and sea surface temperature anomaly (SSTa). The result indicated a significant, non-linear effect of sea surface temperature on porpoise sighting rates, with no significant year effect once SSTa was included.

These results suggest that harbour porpoises may exhibit inter-annual movement in and out of the study area in relation to changing oceanographic conditions (Culik 2004).

In the isolated Black Sea, there is no evidence of Interaction with Atlantic populations. According to an anecdotal 1930's account quoted in Culik (2004): "*harbour porpoises arrived along the Crimean coast of the Black Sea in large numbers in October-November, when the Black Sea sprat began to migrate; the same situation was observed in March-April when the Azov sprat began to migrate".*

Clearly, seasonal migration in this species is a complicated issue and can be related to prey movement, locating suitable calving grounds (see Thomsen et al. 2006 for further information), weather, oceanographic conditions and even ice movements (Gaskin et al. 1993).

4.7 Porpoises and weather

The A6-A results showed a similar trend to B11-04 data; it is clear that in the Dogger bank region, in the close vicinity of platforms/rigs, porpoise activity decreases during periods of heavy weather. Figure 38 shows a comparison of the A6-A and the B11-04 data. Wind speed has been converted to knots for direct comparison. At the B11-04 (top diagram, Figure 36), when wind speeds were *ca.* 55 kts (28.294 ms^{-1}, Beaufort 10) porpoise activity began to fall (there is a lag) to zero levels in the waiting on weather period (Storm 1). After the waiting on weather period, when the wind speed dropped to *ca.* 30 kts (15.433 ms^{-1} Beaufort 7), the porpoise activity rose again to levels higher than before. This pattern was also observed, though attenuated, in the second storm period, when wind speed rose to *ca.* 40 kts (20.578 ms^{-1} Beaufort 8), with a corresponding drop in porpoise activity, until the wind speed had dropped, once again, to *ca.* 30 kts (15.433 ms^{-1} Beaufort 7). Clearly, a similar pattern is being observed at lesser wind speeds at the A6-A. This event also tied in with significantly increased levels of feeding activity (ICI < 10 ms) at both the B11-04[2] and the A6-A following all storm events. The only difference between the two data sets is that at the B11-04, the increased levels of activity and feeding coincided with the onset of drilling, and we had proposed that drilling might act as a '*dinner-gong*' to porpoises. However, the A6-A data suggests that this is probably not the case, as the activities associated with the periods of reduced wind speed were completion and well testing, and no drilling occurred.

We feel that the observation of significantly increased levels of feeding activity after a storm is probably the most important finding of the report and is the first semi-quantified observation of this species during storms at sea.

There are four possible explanations for this observation:

1. The porpoises cease to vocalise during periods of heavy weather;
2. The T-PODs did not record during periods of heavy weather;
3. Animals moved out of the area during heavy weather (possibly trying to find deeper/calmer water); and
4. Animals moved out of range from the T-POD during periods of heavy weather.

[2] Note: at the B11-04, we did not use the inter-click interval as an indication of feeding activity. We used encounter mean click counts, but the pattern was still similar.

Firstly, we have no way of determining whether porpoises were silent during the storm event other than comparing our acoustic observations with visual observations carried out at the same time. However, harbour porpoises are not seen in anything more than a Beaufort 2 (see Teilmann 2003; see Thompson and White 2004 for factors influencing porpoise sightings). Their small size, barely visible blow and undemonstrative surface behaviour make them among the most difficult species to detect visually. Visual observations during storms, therefore, are extremely unlikely unless the animals leapt clear of the water (an uncharacteristic behaviour for this species). Underwater, the turbulence and sediment suspension would probably be too great for camera observations. We therefore cannot conclusively answer our first explanation.

Secondly, with regards to the T-POD performance, we examined the raw data files in train by train in great detail and were satisfied that the T-PODS were working adequately in periods of heavy weather.

Third and fourthly, the only other plausible explanation is that the animals moved away from the rig/platform structure or tried to find deeper/calmer water or that they moved out of the T-POD range (*ca.* 300 m) during periods of heavy weather.

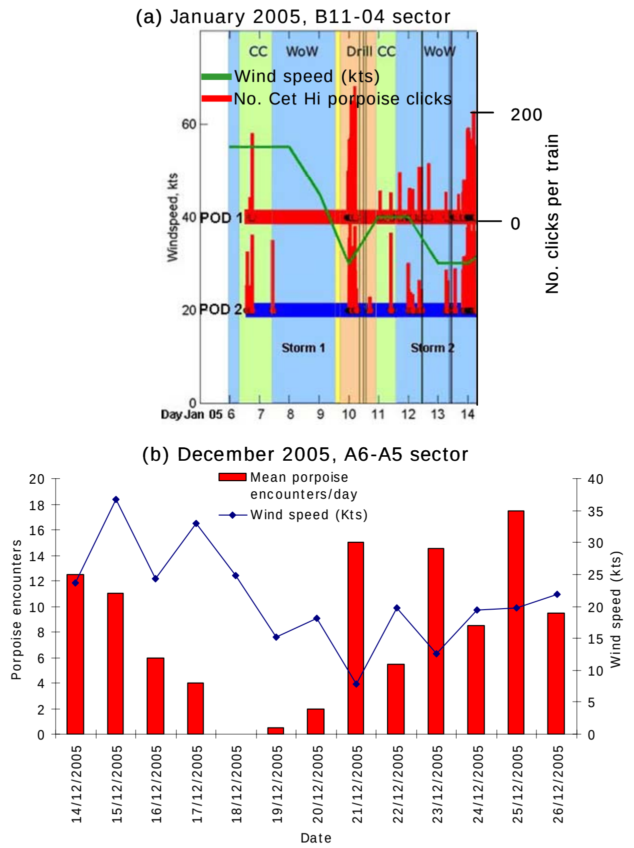

Figure 38: Figure (a) shows the porpoise number of clicks per encounter vs. wind speed during two storm events in January 2005 off the B11-04 site. WoW = waiting on weather, Drill = drilling, CC = cementing and casing. Peaks in porpoise activity are up to 200 clicks per encounter. Figure (b) shows porpoise encounters vs. wind speed during a storm event in December 2005 at the nearby A6-A gas production platform.

4.7.1 Revision of the 'dinner gong' hypothesis

In light of the new A6-A data, we revised our 'dinner gong' hypothesis and believe that it is more likely that porpoise activity in storms is related to physical disturbances in the water column. We estimated the water column properties based on the 08/01/05 most extreme wind, wave and swell data from the B11-04 results (Turner at al., 2005). Our calculations indicated that during the storm, conditions would have been extremely unsuitable for a porpoise to remain in such shallow water close to the rig. At that time, we anticipate that wave-induced currents, rather than turbulent motions, may have been the greater hazard to a porpoise. Turbulence would probably have been an order of magnitude (factor of 10) less, except, perhaps, near rig/platform legs, where eddies may have been shed or close to large waves in the process of breaking. Tide at the time was estimated to be *ca.* 0.26 ms^{-1}, so mean currents at the surface (when the tide augments wind drift, and wind and tide are roughly aligned) would have been *ca.* 1.5 ms^{-1} near the surface and 0.4 ms^{-1} near the seabed. These currents would have reinforced the wave-induced currents. Extreme periodic wave-induced flows (and periodic horizontal displacements of non-swimming particles*) were estimated to be about 6.6 ms^{-1} (15 m*) at the surface and 0.9 ms^{-1} (2 m*) near the seabed and there would have been substantial sediment in suspension at the time. More importantly, in those conditions, bubble clouds generated by breaking waves would have been likely to reach a mean depth of about 25 m (some going much deeper) in the observed winds of 30 ms^{-1}, significantly reducing acoustic range at frequencies of 100 kHz. This would have made it impossible to detect the height of the sea surface from porpoise sonar operating at such frequencies on the seabed.

4.7.2. Porpoises in storms

We assume that porpoises either moved out of the area during periods of heavy weather, or moved out of T-POD range.

With the exception of limited observations of naturally marked individuals, all information on harbour porpoise movements has come from telemetry studies (Read 1999; Read and Gaskin 1985) but there are no observations of these animals in storms. Porpoises are extremely mobile and are capable of covering large distances in relatively short periods (Read and Westgate 1997). The mean daily distance travelled by eight porpoises equipped with satellite-linked transmitters in the Bay of Fundy (N. E. USA), for example, varied between 14 km and 58 km (Read and Westgate 1997). Tagged individuals made rapid point-to-point excursions lasting from hours to days that were interspersed with longer periods of residency in restricted areas (Read and Westgate 1997). It is entirely feasible, therefore, that porpoise can move quickly out of stormy weather.

A porpoise can swim at speeds ranging 0.5 - 4.2 ms^{-1}, but their mean swimming speed is about 0.76 - 0.91 ms^{-1} (Otani et al. 2001). If we take the upper end of the average, then 0.91 ms^{-1} translates as 3.276 km hr^{-1} and a distance of 78.624 km in 24 hours. However, if we take the maximum speed, then 4.2 ms^{-1} translates as 15.12 Km hr^{-1} (an unsustainable swimming speed) and a distance of 362.88km in 24 hours. Hurricanes routinely travel at speeds of 22.5 - 28.9 Km hr^{-1}, which is faster than a porpoise's maximum swimming speed (15.12 Km hr^{-1}).

Figure 39 plots the storm tracks from the B11-04 extreme storm event from 8th –10th January 2005. It is clear that the storm started in the Dogger Bank area and spread out in all directions, deepening ENE of the A6-A platform by 12:00 noon of the same day.

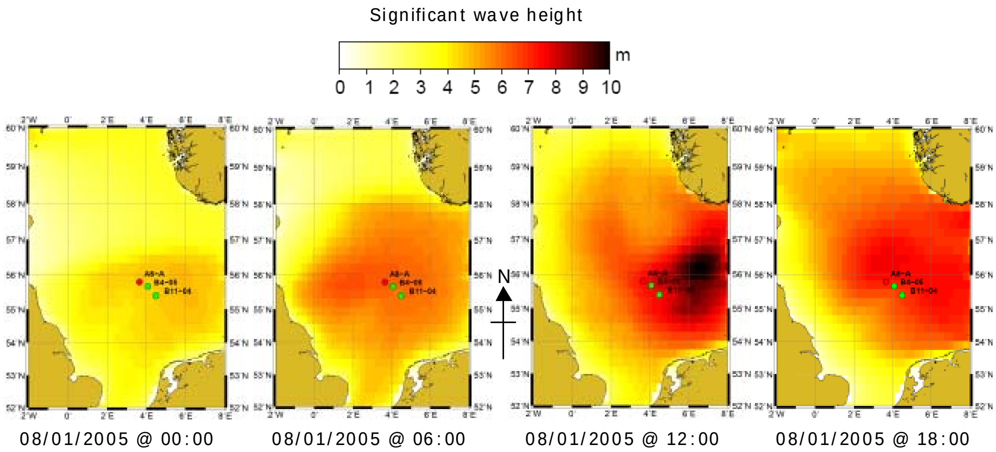

Figure 39: Storm plot of significant wave height during extreme weather event at B11-04. Data from Turner et al. (2005) study. Map projection: Mercator.

Given that one minute of a degree = one nautical mile, which is = 1.852 km, then one degree = 111.12 km. If we are conservative and assume that each meridian of longitude is actually one nautical mile (neglecting the fact that parallels of latitude are the typical reference), when it is actually less as we move North of the equator, we can then calculate the following:

1. For a porpoise to leave the A6-A area, it would need to travel in a SW direction to find calmer water.
2. An animal would therefore need to swim 2° East in longitude.

3. Each degree has 60 minutes, therefore 2 x 60 x 1,852m = 222,240m.
4. Each kilometre is 1000m, therefore 222,240m/1000 = 222.24 km.

A porpoise would have had to swim 224.24 km in 24 hours to avoid the storm. Given that their average swimming distance based on the above rough estimates is around 80km/day, this is not feasible. Furthermore, it is currently not known if porpoises are able to determine storm direction, though it is likely that they are able to derive some of this information from surface wind wave direction.

The water around the Dogger Bank region (and the North Sea in general) is very shallow, and the A6-A was positioned at the deeper end of this scale (*ca.* 48m). It is plausible that animals still try and find even deeper and/or calmer water, but it may be that the animals just move away from the platform/rig to avoid collision with the legs. It could be suggested that the open sea is a safer region during a heavy storm; there are anecdotal reports of higher rates of marine mammals stranding during such storms. Furthermore, telemetry studies have shown that in north America, porpoises that moved out of the Bay of Fundy into the Gulf of Maine did so following the 92 m isobath (depth contour), which may represent an important movement corridor (Read and Westgate 1997). Depth might also, therefore, be an important factor.

4.8 Porpoise spatial mapping

The observation that porpoise fast click (or feeding) activity (inter-click intervals < 10 ms) and their activity in general increased after storms is consistent with our previous observations of these animals around the rig in the B11-04 sector. We assume that porpoises have an excellent spatial map of the good feeding sites in their environment. Harbour porpoises (Verfuß et al. 2005) and finless porpoises, *Neophocaena phocaenoides*, (Akamatsu et al. 2005) are certainly able to use their echolocation for spatial orientation and navigation. Indeed, Schnitzler et al. (2003) postulated that echolocation in bats, for example, evolved primarily for orientation in space or navigation and that the transition to prey acquisition followed later. We assume the same transition for echolocating cetaceans.

Navigation can be defined as *the ability of animals to find, learn and return to specific places* (Trullier et al. 1997). Schnitzler et al. (2003) went further and defined three categories of navigation: small – middle – and large-scale navigation. Small-scale navigation involves the animal's process of moving around in the immediate vicinity, with the animal's target being within its range of perception. Middle-scale navigation comprises the ability to follow routes to goals beyond the perceptual range but within the home range of an animal. Routes are characterised by sequences of places to which animals react with recognition-triggered responses (Trullier et al. 1997). A certain landmark or constellation of landmarks (e.g. an oil field) defines each place or conspicuous objects that serve as guides (e.g. platforms/rigs or even the recognised acoustic noise signature from such installations). Large-scale navigation encompasses movements in unfamiliar areas, for example during migration or homing, which is defined as guided or directed movements homeward or to a destination (Verfuß et al. 2005). If we accept the use of landmarks by odontocetes, then at long distances, the animals might be expected to lock onto larger objects (such as a platform) as potential foraging areas, and subsequently detect prey after arrival at the platform/rig. We therefore assume that porpoises exhibit *middle-scale navigation* and can relocate a platform/rig effectively after extreme storm events or during seasonal migrations (*large-scale navigation*). For a review on biosonar behaviour in porpoises see (Akamatsu et al. 1992; Akamatsu et al. 1995; Akamatsu et al. 2005; Au 1999; Goodson and Sturtivant 1996; Kastelein et al. 2000; Kastelein et al. 1999; Kastelein et al. 1995; Kastelein et al. 2005; Møhl and Andersen 1973; Teilmann et al. 2002; Thomsen et al. 2005a; Verboom and Kastelein 1995, 1997; Verfuß et al. 2005).

Optimal foraging theory assumes that that porpoises in the area are distributed across habitats in proportion to food availability and that animals remain near a prey patch (a rig surrounded by fish) until it become energetically profitable to move on to the next patch (Stephens and

Krebs 1986)[3]. Many large predators use vast areas of the ocean, but typically concentrate their activities in smaller, localised areas for periods of time (Sloan et al. 2005). Some marine mammals, such as gray whales, *Eschrictius robustus* (Rice and Wolman 1971), blue whales, *Balaenoptera musculus* (Mate et al. 1999), humpback whales, *Megaptera novaeangliae* (Best et al. 1998) and elephant seals, *Mirounga angustirostris* (Stewart and Delong 1995), undertake long annual migrations, but return seasonally to forage in localised areas. This leads back to our interpretation of navigational scale. Migration can be interpreted as the result of foraging decisions made at meso (10's to 100's of km) and fine scale (1-10 km). On a meso-scale, we assume porpoises were originally foraging around the rig as part of a general seasonal offshore movement in the winter. On a micro-scale, assuming the animals moved out of the areas during heavy storms (and were not silent), the animals might simply have returned to the platform/rig after the storm to feed.

We also return to our previous assumptions about porpoise energetics. Porpoises are small cetaceans with limited body fat, and a relatively high metabolic rate for a cetacean. They have a large surface area over which to lose heat to the environment. The increase in inter-click intervals <10 ms following the storm is also best explained in terms of harbour porpoise energetics (for more details refer to Jepson 2001; for more details refer to Otani et al. 2001 and references therein). There is therefore pressure on these animals to feed at rates higher than larger cetaceans with lower metabolic rates. The small size of harbour porpoises do not enable them to carry large energy stores (Koopman 1994), so their patterns of movement are likely to be related strongly to the distribution of their prey. We assume that following a storm event, when foraging conditions were predicted to be sub-optimal, hungry porpoises returned to a foraging site that was known to be rich in prey species such as a rig which may be acting as an artificial reef attracting fish (Caselle et al. 2002).

Finally, the rigs might have induced currents between the legs porpoises are known to prefer feeding in currents which may expose more benthic fauna that attract the prey of porpoises.

4.9 General porpoise activity: comparison with other studies

Porpoise encounters per day ranged from 1-26 over the season, with most encounters observed in December. Again, although direct comparisons with other studies is difficult, for the reasons intimated earlier, Table 4, gives a summary of general porpoise statistics for coastal studies. Each worker used different 'porpoise' units, but we have converted our units where possible.

Allowing for differing data analysis techniques between studies, different T-POD settings and pooling of seasonal data, overall porpoise activity around the platforms/rigs was generally lower than that in coastal areas. However, when a porpoise visited the hydrophone (an encounter), the numbers of clicks that it produced during this encounter was similar to those produced in coastal studies. It is clear that the echolocation from offshore porpoises is similar to recordings from animals in coastal regions.

[3] Foraging theory is another factor that we have not accounted for. Presumably, platform and rig locations are well known to foraging porpoises and therefore the fitness consequences of choosing a rig location may also depend on the number of other individuals present (i.e. fitness consequences are density-dependent).

Study location	Author (s)	Porpoise statistics	Our results*
B4-05/B11-04 sites	Turner et al., (2005)	Mean = 4 encounters / 24 hrs	Mean = 5.458 encounters/24 hrs
Yell sound, Hamna voe, Shetland islands, Scotland	(Fisher and Tregenza 2003)	Mean? Porpoise encounter duration = 310 min	Mean = 244.163 min**
Yell sound, stingray barge (impact area), Shetland islands, Scotland	(Fisher and Tregenza 2003)	Mean? = Porpoise encounter duration = 8 min	Mean = 244.163 min
Hornsreef wind farm, Denmark – impact area	(Tougaard et al. 2003a)	Mean = 1 encounter /1-2 hours	mean = 0.227 encounters /hr
Bloody Bay, sound of Mull, Scotland	(Carlström 2005)	Median Day encounter rates/hr = 0.35, night = 1.03	Median = 0.083/h
Nysted wind farm, Denmark	(Henriksen et al. 2004)	707 monitoring days (41% with no encounters)	333 monitoring days (24.93% with no encounters)
Nysted wind farm, Denmark	(Henriksen et al. 2004)	40 clicks/minute	0.983/minute
Nysted wind farm, Denmark	(Henriksen et al. 2004; Tougaard et al. 2005a)	Clicks/encounter (intensity) = *ca.* 100-150	140.636 clicks/encounter

Table 4: Comparison of A6-A data to those collected in other studies. *version 3 T-PODs, pooled for all months, medians and ranges presented where means not applicable. **This statistic is only meaningful when presented per month, or per activity.

4.10 Change of porpoise encounters after docking of the *Noble Kolskaya*

The observation that the patterns in porpoise activity changed significantly when the drilling rig *Noble Kolskaya* docked onto the side of the platform, and again when the rig departed, was very interesting. We do not have any measurements of platform/rig noise during this period, and these events have not been recorded by us previously. We can therefore only assume that the ongoing activities at that time were unsuitable for porpoise foraging.

During the rig docking procedure several tugboats were connected, which helped manoeuvre the rig into position. At that time, there would have been engine, thruster, and propeller cavitation noise. Activities such as jacking up, preloading, skidding out the cantilever, erecting scaffolding, installing vent lines, tender boat offloading, and realigning the derrick over the centre of the well would have created an array of noise spectra. Again when the rig left the platform, noise levels might be predicted to have been relatively high. When the rig was awaiting a departure weather window, the tugboats Zeus and Remo arrived. The rig jacked down to 3 m draft, the deep well pumps were disconnected, the rig jacked down again to 2 m draft and an integrity test was performed. The tugs Zeus and Remo were then connected to the rig, the legs were pulled and the rig moved off location, leaving the 500m zone at 20:00 hrs. It is conceivable therefore, that porpoises avoided the area during these procedures, to return when noise levels had returned to normal.

It is evident, however, that that the benefits of the platform/rig being present at the site vastly outweigh the 20 or so days when the platform/rig was probably not 'attractive' to porpoises. Porpoises returned consistently to the site to forage after the rig docking/departure event, so this finding was not considered to be a matter of concern. It might be argued that if a hole had not been drilled in the first place, then the porpoises might not be present. However, we caution that we currently have inadequate 'before and after' data and while we can predict that porpoises are attracted to platform/rigs, we still cannot conclusively state this fact unless we have 'before and after' data and replicated control data. This is a crucial requirement to ensure that the study stands up to scientific rigour.

Finally, there might have been one more benefit of the *Noble Kolskaya* docking onto the side of the platform. Rigs are well known for their reef-forming species assemblage associations. The *Noble Kolskaya* is likely to have bought a new recruitment of prey or food of prey species to the site, and larvae were likely to be more abundant (supply-side ecology). Anecdotally, we noticed a faster rate of fowling on T-PODs when the *Noble Kolskaya* was present than when the A6-A was alone. Perhaps of more conclusive evidence was the observation that the T-PODs at the southern end of the A6-A (where the *Noble Kolskaya* was docked) were considerably more fowled than the T-PODs moored at the northern end of the A6-A. However, the purpose of this study was not to ascertain the extent of fowling and it would be necessary to design such a study to account for seasonality. Larger installation complexes might therefore be predicted to attract more fish and provide more feeding opportunities for porpoises than smaller installations. Again, when referring to optimal foraging theory, larger installations may also influence density-dependent factors.

4.11 Porpoise activity in relation to industrial activity

We did not observe any changes in the activity of porpoise in relation to platform and rig operations other than the docking and undocking procedures. However, we did not have enough samples to definitively tease out the effects of the platform alone and the platform/rig complex. Superimposed on this was the finding that animal activity differed with season, whereas platform/rig scheduled activities did not. For example, we did not know whether the animal numbers were lower in the summer because they were mostly shore-based or whether it was because the animals were perturbed by platform/rig activities. With a six-month data set on one installation, the number of inferences on porpoise behaviour is limited. The only way to answer this conclusively is to gather more samples, from several installations, and use advanced multivariate statistics to tease out any effects, accounting for season.

4.12 Porpoise behaviour

At all times, porpoises were presumed to be actively feeding around the platform/rig. The proportion of click pulses with minimum inter-click intervals of <10 ms was 46.95% of the total. The vast proportion of these faster rate clicks was observed after the storm event in December, supporting our suppositions about hungry porpoises after storms.

4.13 Implications of studies

These studies have generated several very interesting results on harbour porpoise activity and feeding behaviour in relation to rig operations. However, the short-term nature of the studies (the B4-05 and B11-04 were designed solely for mitigation purposes) do not permit scientifically robust conclusions to be drawn when attempting to answer the prime questions: *are porpoises attracted to installations* and *what are the long-term benefits/costs (if any) of installations to porpoise?* Confirmation of these results with baseline studies and further, longer-term, replicated and controlled studies would both positively enhance EIAs for such operations and provide results of great general scientific interest.

5. ACKNOWLEDGEMENTS

Appin Scientific Limited wishes to thank the following organisations for recognising the scientific importance in the findings and subsequently commissioning a further study: B4-05 and B11-04 Studies – German North Sea Consortium composed of Wintershall AG (Member and Operator), EWE, Mærsk and RWE Dea; A6-A Study – Wintershall AG (Operator), A6-A5 Consortium composed of BEB, EWE and RWE Dea. These projects would not have been possible without the additional co-operation, assistance and enthusiasm, of these organisations.

We would like to also thank the crew of the *Noble Kolskaya* and to the ROV crew for looking for the lost T-POD. Many thanks to Niels Torgau for providing extra technical information on request, and to both Niels and Christian Busch for enthusiastically supporting the project within Wintershall AG and rallying for project support. We would also like to thank the crew of the A6-A platform, in particular, Joost Wichers, for his retrieval of our 'lost POD 516' and Dirk Koolhaas for his photography. Thanks also to Dr. Nick Tregenza for all his invaluable help throughout the study and for being available at all hours of the night during the optimisation phase of the project. A plethora of thanks to Professor Steve Thorpe FRS for his advice on the weather analysis section and for his comments on the pending manuscript.

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