Carbon Trust

Offshore Renewables Joint Industry Programme (ORJIP) Project 4, Phase 2

Understanding the Effectiveness of Acoustic Deterrent Devices on Minke Whale (*Balaenoptera acutorostrata*), a low frequency cetacean.

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Understanding the Effectiveness of Acoustic Deterrent Devices (ADDs) on Minke Whale (*Balaenoptera acutorostrata*), a Low Frequency Cetacean .

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List of Abbreviations and Units

Abbreviation/ Unit	Definition
µPa	microPascal
ADD	Acoustic Deterrent Device
AHD	Acoustic Harassment Device
AIS	Automatic Identification System
ALARP	As Low As Reasonably Practical
ANOVA	Analysis of Variance
CCTV	Closed Circuit Television
CEE	Controlled Exposure Experiment
dB	decibel
ESW	Effective Strip Width
FFT	Fast Fourier Transform
GIS	Geographical Information System
GPS	Global Positioning System
HD	High-definition
Hz	Hertz
IBI	Inter-Blow Interval
IMCA	International Marine Contractors Association
ISI	Inter-Sequence Interval
JNCC	Joint Nature Conservation Committee
kHz	kilohertz
km	Kilometre
kmh^{-1}	Kilometres per hour
LF	Low frequency
m	Metre
ms^{-1}	Metres per second
MCA	Maritime and Coastguard Agency
MCR	Marine Conservation Research Limited
MMO	Marine Mammal Observer
ms	millisecond
MW	Megawatt
NOAA	National Oceanic and Atmospheric Administration
ORJIP	Offshore Renewables Joint Industry Programme
OWA	Offshore Wind Accelerator
OWF	Offshore wind farm
PAM	Passive Acoustic Monitoring
pk (or 0-pk)	Peak (or zero to peak)
pk-pk	Peak to peak
PTS	Permanent Threshold Shift
rms	root mean square
SD	Standard Deviation

SEL	Sound Exposure Level
SNCBs	Statutory Nature Conservation Bodies
SOTW	Song Of The Whale
SPL	Sound Pressure Level
SPSS	Statistical Package for the Social Sciences
SST	Sea Surface Temperature
STW	Scottish Territorial Waters
TTS	Temporary Threshold Shift
UHF	Ultra High Frequency
UTC	Coordinated Universal Time
VRT	Video Range Tracking

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Executive Summary

Increasing scale and complexity of offshore wind farms (OWF) and on-going concern for European Protected Species (EPS) has led to interest in identifying alternative mitigation strategies to commonly used visual observation and acoustic detection methods for marine mammals. Acoustic Deterrent Devices (ADDs) have been identified as a potentially effective tool for a number of small cetacean species, but research has been lacking for some other key species that occur within prospective OWF sites.

A controlled exposure experiment (CEE) was designed and implemented to test the efficacy of the Lofitech ADD as a potential mitigation tool for the minke whale during piling operations. During August and September 2016, visual tracking of minke whales was undertaken in Faxaflói Bay, Iceland by a team of researchers on the R.V. Song of the Whale. When a focal animal had been identified and tracked for at least 30 minutes, the ADD was deployed at a distance of 1,000 m in order to expose the animal to the ADD signal. The behaviour of the focal animal was tracked during a control, treatment and post-treatment phase in order to understand the potential reactions to the ADD signal. Biological parameters such as inter-sequence interval, inter-blow interval, net swim speed, and measures of path predictability were recorded and later analysed to examine the behaviour in detail. In addition, the variable 'away speed' was derived in order to determine both the directionality and the longevity of any effect on the behaviour of the focal animal.

The ADD itself was fully characterised in the field. The unit deployed was found to have a source root mean square (rms) sound pressure level of 198 dB re 1 µPa re 1m, for a fundamental frequency of 14.6 kHz. The pulse length had an average of 752 ms. As noted in the literature, variability among individual units is expected.

A total of 46 minke whales were successfully tracked. Of these, 15 included successful deployments of the ADD. The focal animal moved away from the ADD deployment site in all cases. A significant increase in net swim speed during the treatment phase was observed, with whales increasing their speed by an average of 7.4 kmh^{-1}. The away speed variable showed a significant increase in speed during the second half of the treatment phase, indicating that animals both increase their speed and the directness of their path in relation to exposure to the ADD signal.

The results highlight that the Lofitech ADD is effective at evoking a deterrence response in minke whales, suggesting that such devices could be effective at reducing any potential for injurious effects from exposure to subsea noise generated during pile-driving activity at OWF sites.

1 Introduction

1.1 ORJIP

1.1.1 The Offshore Renewables Joint Industry Programme ("ORJIP") was established in 2013, as a standalone programme, building on the success of the Offshore Wind Accelerator (OWA). Managed by the Carbon Trust, the remit of ORJIP is to bring together industry, regulators, statutory nature conservation bodies (SNCBs) and academics to work together with an overarching objective of creating scientific evidence to reduce offshore wind farm consenting risks. ORJIP projects are funded by a number of offshore wind developers with an interest in the UK offshore wind market.

1.1.2 A priority consenting risk to the offshore wind farm (OWF) industry is the potential effects of subsea noise (primarily produced during pile-driving) on marine mammal receptors. To address this risk ORJIP proposed a project to develop mitigation solutions on behalf of offshore wind developers.

1.1.3 For Phase 1 of the project ORJIP commissioned a desktop review and provided a set of advisory services regarding Acoustic Deterrent Device (ADD) use and improvements to standard mitigation measures currently used in the UK during pile-driving. Phase 1 of this project has been completed and the results are available online[1]. A summary of the key findings of Phase 1 of the ADD project is provided below (Section 1.2).

1.1.4 The present study constitutes Phase 2 of ORJIP and the focus here is to use field-based evidence to review the effectiveness of ADDs as a mitigation tool for reducing the risk of injury to minke whale from pile-driving and provide further recommendations to inform the industry. This study has been undertaken by RPS Energy Limited in collaboration with Marine Conservation Research Limited (MCR).

1.2 Background

1.2.1 Phase 1 of ORJIP researched the effectiveness of ADDs as a practical multi-species solution to mitigation for injury during pile-driving at offshore wind farms. Most evidence for the effectiveness of ADDs comes from studies of harbour porpoise (a high-frequency cetacean) and seals, with little evidence available on the effectiveness of these devices to mitigate for injury to mid- and low-frequency cetaceans. Phase 2 of ORJIP will therefore build on the findings of this work to investigate the applicability of ADDs to minke whale, a low-frequency cetacean.

1.2.2 Phase 1 of ORJIP reviewed and made recommendations about current and future marine mammal mitigation practice in relation to Round 3 and Scottish Territorial Waters (STW) offshore wind farm (OWF) developments. As Rounds 1 and 2 OWF sites were developed, marine mammal mitigation moved from the adoption of the Joint Nature Conservation Committee (JNCC) *Guidelines for minimising the acoustic disturbance to marine mammals from seismic surveys* (JNCC, 2004 and 2010a), to a similar but dedicated protocol; the *Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise* (JNCC, 2010b). The central mitigation methods used by this protocol are visual and acoustic monitoring by Marine Mammal Observers (MMOs) and Passive Acoustic Monitoring (PAM), followed by initiation of a soft-start to piling with delays to piling implemented due to any proximity of marine mammals within the mitigation zone.

[1] https://www.carbontrust.com/client-services/technology/innovation/offshore-renewables-joint-industry-programme-orjip/

1.2.3 There is considerable uncertainty regarding the effectiveness of these 'standard' mitigation methods in relation to OWF developments (Parsons *et al.,* 2009; Wright and Cosentino, 2015). The effectiveness of MMOs is heavily dependent on weather and associated sighting conditions, and even under good conditions, sighting rate decreases with sighting distance (Barlow *et al*., 2001). This is particularly important for smaller species such as the harbour porpoise (*Phocoena phocoena*) for which detection rates can be very low, and for which there is significant decline in detection rate with increasing sea state (Embling *et al*., 2010; Leaper *et al.*, 2015). For example, data from visual boat-based surveys in the Hornsea Zone found that the Effective Strip Width (ESW) for harbour porpoise decreased from 343 m in Beaufort sea state 1 to 281 m in sea state 2 and the equivalent detection probability (g(0)) decreased from 0.576 to 0.224 (SMart Wind, 2013). Deep diving species are also difficult to monitor: Barlow and Gisiner (2006) suggest that the probability of observers sighting a beaked whale drops rapidly in sub-optimal survey conditions, and for mitigation monitoring can be as low as 2% (or lower if the observer is inexperienced) for whales directly on the trackline.

1.2.4 Reliable detection using PAM systems can also be problematic and Wright and Cosentino (2015) provide a summary of the issues that arise in using PAM for mitigation. One issue is that animals not vocalising will remain undetected. Another problem is the ability to pinpoint the distance of the animals from the centre of the mitigation zone as both the range of accuracy of the system (e.g. may be ± 300 m) and the directionality of the vocalisation in relation to the hydrophone can influence the distance estimation. As with visual observers, there is also potential for inexperience of the operators to influence the reliability of detection for a non-automated system. Finally, the distance over which detections are possible may not be sufficient to cover the whole mitigation zone. Harbour porpoises, for example, can be reliably detected by PAM within a few hundred metres, though that can be dependent on the orientation of the animal in relation to the hydrophone. This is considerably less than the 'standard' 500 m mitigation zone recommended in the JNCC guidelines (JNCC, 2010b). PAM is less effective with some other species, particularly those utilising low frequencies to vocalise due to poor signal to noise ratio in the lower frequencies exacerbated by operational sounds during construction.

1.2.5 In addition to uncertainties with sighting and detection, there are significant costs, logistical, and health and safety issues related to the long-term deployment of teams of personnel into the operational environment of an OWF installation. The Phase 1 report looked in detail at these issues and found that in terms of costs, the use of MMOs and PAM personnel and equipment can cost between 1% and 5.5% of the installation vessel cost per pile, depending upon whether those personnel and equipment are based on the installation vessel or on a separate support vessel (Herschel *et al*., 2013). Depending upon whether an MMO, or an existing member of the vessel crew is used for ADD deployment, the cost as a percentage of the installation vessel cost per pile is likely to fall to less than 1% (Herschel *et al*., 2013). Health and safety is a key priority for the offshore industry as a whole. Companies are responsible for protecting their workers and the public from the consequences of their activities, as per the Health and Safety at Work Act of 1974 (HSE, 2001). Central to this is the concept of the reduction of risk to levels that are *as low as reasonably practical* or 'ALARP' (RenewableUK, 2014). Crew changes during projects involve inherent risks, whether by crew vessel or helicopter, as well as the additional risks associated with personnel on-board and the tasks required of them such as PAM equipment deployment and recovery. The reduction of personnel on projects is a straightforward way of reducing overall exposure hours during operations and therefore the overall risk to ALARP levels (Herschel *et al*., 2013).

1.2.6 Round 3 and STW OWF development sees projects being developed and proposed on a much larger scale than the previous two rounds. With larger turbines being manufactured, bigger scale wind farms, and the potential for multiple piling vessels operating concurrently and multiple phases of piling over many years, the amount of noise that could be introduced into the marine environment from piling is likely to increase substantially. Environmental Impact Assessments (EIAs) for proposed OWFs consider both the spatial and temporal scale of subsea noise arising from piling. The average size of turbines installed at the 408 European offshore wind farms connected to the grid by 2014 was 3.7 MW (EWEA, 2015); the Siemens SWT 3.6 MW turbine being the most popular turbine installed in UK waters (www.thecrownestate.co.uk). This size of turbine could typically be installed using a ~2,000 kJ hammer energy e.g. Lincs Offshore Wind Farm (Centrica Energy, 2007). However, the progress of developing larger turbines has been rapid and the new generation turbines are more than double the 3.6 MW average power output for 2014 and nearly 18 times larger than the earlier turbines installed approximately 25 years ago (Figure 1.1). In 2016 DONG energy installed the first 8 MW offshore turbines the Burbo Bank Extension (DONG Energy, 2013). The associated hammer energy required to install these larger turbines needs to be substantially greater, (e.g. a 3,500 kJ hammer was used for the Burbo Extension piled foundation installation) and therefore the radius over which injury could occur in marine mammals has also increased.

Figure 1.1: Diagrammatic representation of the progress in development of increasingly larger turbines for use in offshore wind farms. Source: humberbusiness.com).

1.2.7 With this in mind, it is clear that the draft guidelines may fall short of allowing reliable detection over the potentially larger distances required to ensure that the risk of injury is minimised, or indeed even over the minimum 500 m distance recommended (JNCC, 2010b). ORJIP Phase 1 highlighted that ADDs could offer a practical solution to mitigation as the use of such devices could displace marine mammals out of the zone of potential injury and therefore mitigation could move away from the traditional approach of using MMOs and PAM. However, further evidence is required to support the use of ADDs as an effective alternative, particularly in relation to low-frequency (and mid-frequency) cetaceans. In particular, there is uncertainty as to the effectiveness of this device in a multispecies environment and the effect ranges over which ADDs will deter the target animals. The next section provides an overview of ADDs and their current application to marine mammal mitigation.

1.3 Acoustic deterrents and marine mammals

1.3.1 Acoustic deterrents have been employed for many years as a practical solution in the aquaculture industry to deterring marine mammals, specifically seals, from fish farms. The deterrents used in fish farms are usually termed acoustic harassment devices (AHDs), seal 'scarers', or 'scrammers'. Although originally developed in the late 70s and early 80s as relatively low power units, due to the problem of habitation to these devices by seals (Anderson and Hawkins, 1978), the technology was developed to produce higher amplitude sounds that would be painful to seals and may therefore have far field effects at deterring animals.

1.3.2 The effectiveness of AHDs in aquaculture has led to wider applications of acoustic devices such as the use of 'pingers' in reducing bycatch of marine mammals, particularly from static fishing nets (Kraus *et al.*, 1997; Trippel *et al.*, 1999; Barlow and Cameron, 2003; Dawson *et al.*, 2013). Pingers are generally classified as low power output devices that alert marine mammals to the presence of the static fishing gear, however, they can also be effective at deterring animals from the vicinity of the nets, albeit over relatively small distances (Koschinski and Culik, 1997; Laake *et al.*, 1998; Kastelein *et al.,* 2001; Hardy *et al.,* 2012).

1.3.3 Although there are different terms for acoustic deterrents, the generic term used in this report is Acoustic Deterrent Device (ADD) and refers to a high power output device that can deter animals from a specific area (Box 1).

Box 1. Terminology of acoustic deterrents

The different terminology for acoustic deterrents can be confusing and the ORJIP Phase 1 report therefore provided a detailed description of the different terms and their historic application (Appendix E in Herschel *et al.*, 2013). Herschel *et al*. (2013) suggest that for clarity, the generic term, which refers to any device that can be deploy to deter animals from a specific area using acoustic signals, is an **Acoustic Deterrent Device (ADD)**. Although evidence from field studies have suggested that pingers may be effective at deterring some marine mammal species from an area, due to the lower intensity of these devices, and the potential habituation shown by seals at fish farms (Jacobs and Terhune, 2002) and by harbour porpoise (Cox *et al.*, 2001), these devices have not been considered further under the generic term ADD.

1.3.4 Although ADDs were developed to mitigate against economic damage to fish farms from seal predation, it was observed that secondary effects occurred on harbour porpoise with exclusion over larger ranges than seen for seals (Johnston, 2002; Olesiuk *et al.*, 2002). Whilst this raises concerns in relation to unwanted habitat exclusion for harbour porpoise in the vicinity of fish farms there is a potential benefit in terms of their potential to deter animals from subsea noise injury zones produced during offshore pile-driving. Thus, ADDs have been proposed as a potential mitigation solution for the offshore renewable industry (Gordon *et al.,* 2007). Gordon *et al.* (2007) developed a cumulative noise exposure model to explore the ranges at which animals needed to be moved in order to reduce the risk of injury. Although the results were not conclusive (due to sensitivity to factors such as propagation conditions and uncertainties as to animal reactions to aversive sounds), the study highlighted that the risk of injury to marine mammal hearing from pile-driving could be greatly reduced if animals were to move out of an area before piling started. Consequently the JNCC guidelines recommended consideration of the careful use of ADDs in the protocol for minimising the risk of injury to marine mammals from piling noise (JNCC, 2010b) and as a 'tentative' mitigation solution for the protection of marine European Protected Species from injury and disturbance (JNCC, 2010c).

1.3.5 The Phase 1 ORJIP report (Herschel *et al.*, 2013) highlighted that in order for ADDs to be effective they would need to evoke a response of 6 or 7 on the Southall *et al.* (2007) behavioural response severity score. This is because the response score of 6 is the lowest score which includes a fleeing response. Although this is higher than the JNCC recommended benchmark of 5 for a significant behavioural response (indicating a sustained and chronic disruption of behaviour) of a cetacean European Protected Species (EPS) (JNCC, 2010c) the purpose of ADD deployment is to achieve sufficient displacement from an area adjacent to pile driving activity and thus avoid potential injury. Therefore this higher score is justified.

1.3.6 Previous studies that have looked at how effective ADDs are at displacing marine mammals have only focussed on seals and harbour porpoise. For the six shortlisted ADDs highlighted as having the potential to provide a multispecies solution in the Phase 1 ORJIP study – Airmar dB plus II, Lofitech, Ace Aquatec Seal Scrammer, Terecos, Genuswave, and Seamarco FaunaGuard – it was apparent that the only evidence came from field and captive trials of harbour porpoise, grey seal and harbour seal, with no information available for mid frequency cetaceans (e.g. bottlenose dolphin) or low frequency cetaceans (e.g. minke whale) (see Table 3.4 in Herschel *et al.,* 2013). In addition, some of these devices did not appear to be effective across all species they were tested on. For example, whilst the Airmar dB plus II was effective at deterring harbour porpoise over a maximum range of 3.5 km (Olesiuk *et al.*, 2012) the efficacy of this device on harbour and grey seals was less apparent, with no observable response in some cases (Jacobs and Terhune, 2002). Similarly, the Terecos deterred harbour porpoise out to a range of 1 km but there was no range determined for captive harbour seals or grey seals (Götz and Janik, 2010). For other devices, such as the Ace Aquatec Seal Scrammer there was only information on harbour and grey seals from captive and field trials. In the field trials the deterrence range was estimated as approximate 60 m (although this was only for displacement of 50% of the animals) (Götz and Janik, 2010). Based on sound propagation Kastelein estimated a potential effect range of the Ace Aquatec Seal Scrammer on harbour porpoise of 0.2 to 1.2 km although this was not tested (Kastelein *et al.*, 2010). A full review of the efficacy of these devices was provided for ORJIP Phase 1 (Sparling *et al*., 2015; Herschel *et al.,* 2013).

1.3.7 The Lofitech ADD has been frequently used in recent studies as an effective multispecies device. Brandt *et al.* (2013a) conducted field trials of a Lofitech ADD on harbour porpoise in Inner Danish waters and found that the device successfully deterred animals 99% of the time out to a distance of 1.9 km (translating to a received sound level of ≥122 dB re 1µPa (rms)) and 50% of the time out to 2.1 to 2.4 km (119 to 121 dB re 1µPa (rms)). Brandt *et al.* (2013a) note, however, that transmission loss is high for this study site and that the deterrence distances elsewhere may be higher due to differences in seabed characteristics (e.g. coarser substrate at North Sea sites may lead to greater propagation ranges) (Brandt *et al.*, 2013b). Gordon *et al.* (2015) tested the Lofitech ADD on UHF tagged harbour seals in Scotland (Kyle Rhea and Moray Firth) at ranges of ~500 to 1,500 m. They found that animals typically responded to the Lofitech ADD out to a distance of 1,000 m, with the minimum range at which no response was observed recorded as 998 m. The percentage response decreased with increasing distance from the ADD source with 100% response out to 1,000 m and thereafter a steady decline was seen with the most distant group recorded at 4.1 km showing a 20% response (Gordon *et al.*, 2015). Notably, a "response" in this study was not always a directed movement away from the sound source as it depended on their activity and direction of travel at the time of the ADD activation. The minimum approach distance to the ADD was 473 m and animals did appear to change course to avoid the sound. Overall, the study found an increase in distance travelled between surfacings and an increase in net swim speeds during ADD activation.

1.3.8 Kastelein *et al.* (2015a, 2015b) conducted exposure experiments on harbour porpoise and harbour seal in captivity to broadcast recordings of the Lofitech ADD at different SPLs over 30 minute durations. The behavioural response study showed no significant response during trials, although it was noted that the recording used in this study produced source levels lower than the actual Lofitech device. Comparison of these results from the studies described above which were conducted in the field highlights that animal responses in a captive environment are very different to those observed in the wild and therefore inferences from captive experiments must be treated with caution.

1.4 Sensitivity of minke whale to subsea noise

1.4.1 Cetaceans have largely evolved to rely on sound as a primary sense for vital functions. Unlike the odontocetes (toothed whales) there is no dedicated echolocation mechanism in mysticetes (baleen whales), which includes the species minke whale, although there are some physical similarities in that both suborders have evolved to incorporate fatty tissues into their auditory systems for aquatic sound reception. Although the fats have different lipid profiles in mysticetes compared to odontocetes, they function in similar ways by reducing the sound speed compared to surrounding tissue and may therefore help to focus the sound towards the ears (Yamato *et al.,* 2014).

1.4.2 Mysticetes primarily hear and communicate with potential mates and conspecifics within the low frequency (LF) range of ~10 Hz to 30 kHz which can propagate many kilometres underwater (Urick, 1983). The sensitivities of marine mammals to different frequency sounds are illustrated by audiograms. The information from which audiogram data are derived for the hearing group 'LF cetaceans' (i.e. minke whale) is limited, with no direct measures for auditory thresholds made for any species within the LF cetacean group (NMFS, 2016). A range of audibility for LF cetaceans has therefore been established from observed vocalisation frequencies and reactions to playbacks of sound (Tyack and Clark, 2000) and from anatomical measurements of the auditory system (e.g. Houser *et al.*, 2001; Parks *et al.*, 2007; Tubelli *et al.*, 2012; and Cranford and Krysl, 2015). The upper and lower limits of the most sensitive hearing range (range over which animals are likely to be most sensitive to sounds) for LF cetaceans is given as 0.2 to 19 kHz in the latest guidelines from NOAA (NMFS, 2016) and the derived audiogram for LF cetaceans is present in Figure 1.2.

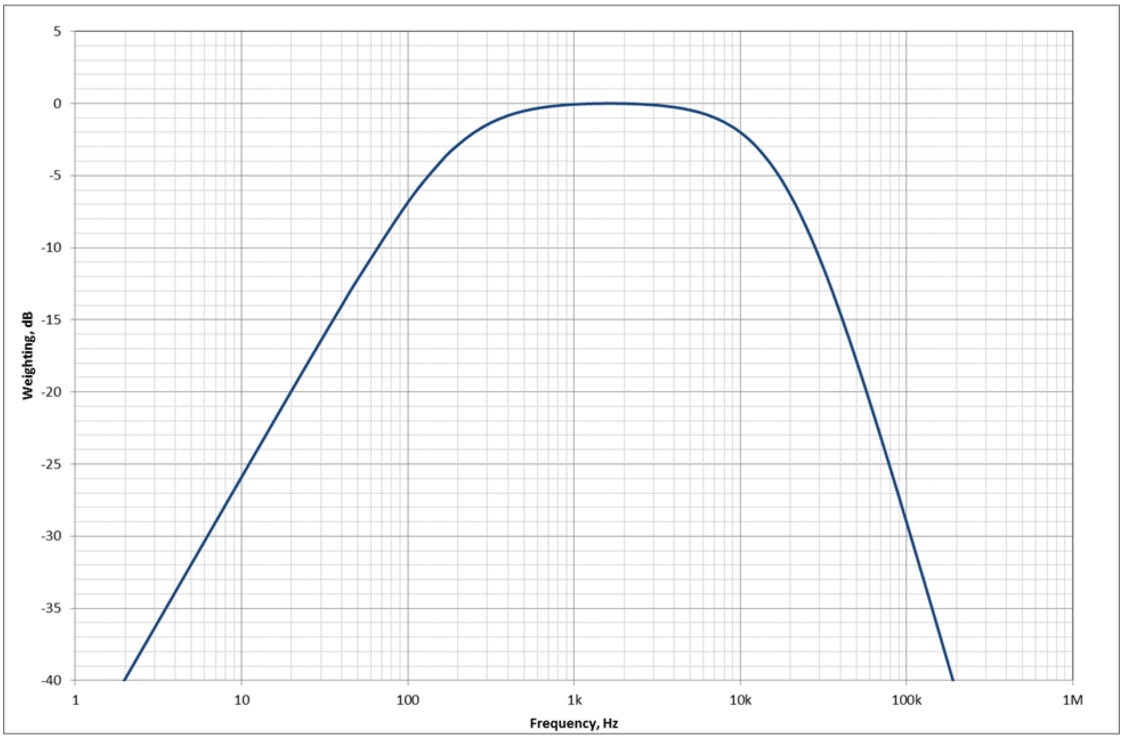

Figure 1.2: Audiogram weighting function for low-frequency cetaceans, including minke whale (NMFS, 2016).

1.4.3 An audiogram can be used to understand whether any animal is likely to hear a particular sound based on the measured hearing capabilities of the species. Hearing threshold audiograms represent the lowest levels of detectable sound (Richardson *et al.,* 1995). The ability to discriminate between sounds of different frequencies and intensities depends on the ability of the receptor to hear the sounds above background levels. Additionally, hearing thresholds are likely to vary between individuals of different age, gender and health status (Richardson *et al.*, 1995).

1.4.4 In the subsea environment, where background ambient noise levels can be high, masking can occur where a receptor is unable to detect a sound, even if the sound is above the absolute hearing threshold (Richardson *et al.,* 1995). Thus the success of an ADD will depend on the signal being detectable above ambient noise levels, including additional man-made noises that contribute to the baseline soundscape, at an appropriate level to elicit a deterrence response. This is not, however, a simple effect to predict because it is possible that marine mammals may be able to detect discrete tones at much lower levels than the broadband masking noise level. This is because the character of the sound differs significantly from other masking sounds (Wenz, 1962).

1.5 Aim and objectives

1.5.1 The aim of this study, as stated in the RfQ is to understand the effectiveness of a chosen ADD device on minke whales (a low frequency cetacean species). Specific objectives of the study are as follows:

- Undertake field testing to test the effectiveness of the chosen ADD system in displacing minke whales;
- Review the findings of the exposure tests in terms of the effectiveness of the ADD and how suitable they are as a method to mitigate injury to minke whales, with particular reference to subsea noise from piling as a potential source of injury; and
- Provide recommendations on the use of ADDs in the offshore wind farm industry to inform government guidance on mitigating injury to marine mammals.

1.5.2 As identified during Stage 1 of Phase 2, the desired range of deterrence for ADDs in order for them to be considered effective should be a minimum of 500 m, the minimum mitigation zone applied to construction piling operations (JNCC, 2010b). Further, the effectiveness of ADDs should be at least equal to or better than the current practice of utilising MMOs and PAM (Sparling *et al*., 2015).

2 Methods

2.1 Study area

2.1.1 The location for this study was Faxaflói Bay, southwest Iceland, shown in Figure 2.1. Faxaflói Bay is a relatively shallow bay measuring 50 km long and 90 km wide and covering an area of approximately 5,000 km^2. Water depths range between 35 and 50 m, with an average depth of 38 m. In this respect, the site is in keeping with the general character of Round 3 offshore wind farm sites. Faxaflói Bay was one of the recommended sites for this study within the Phase 2, Stage 1 report (Sparling *et al*., 2015).

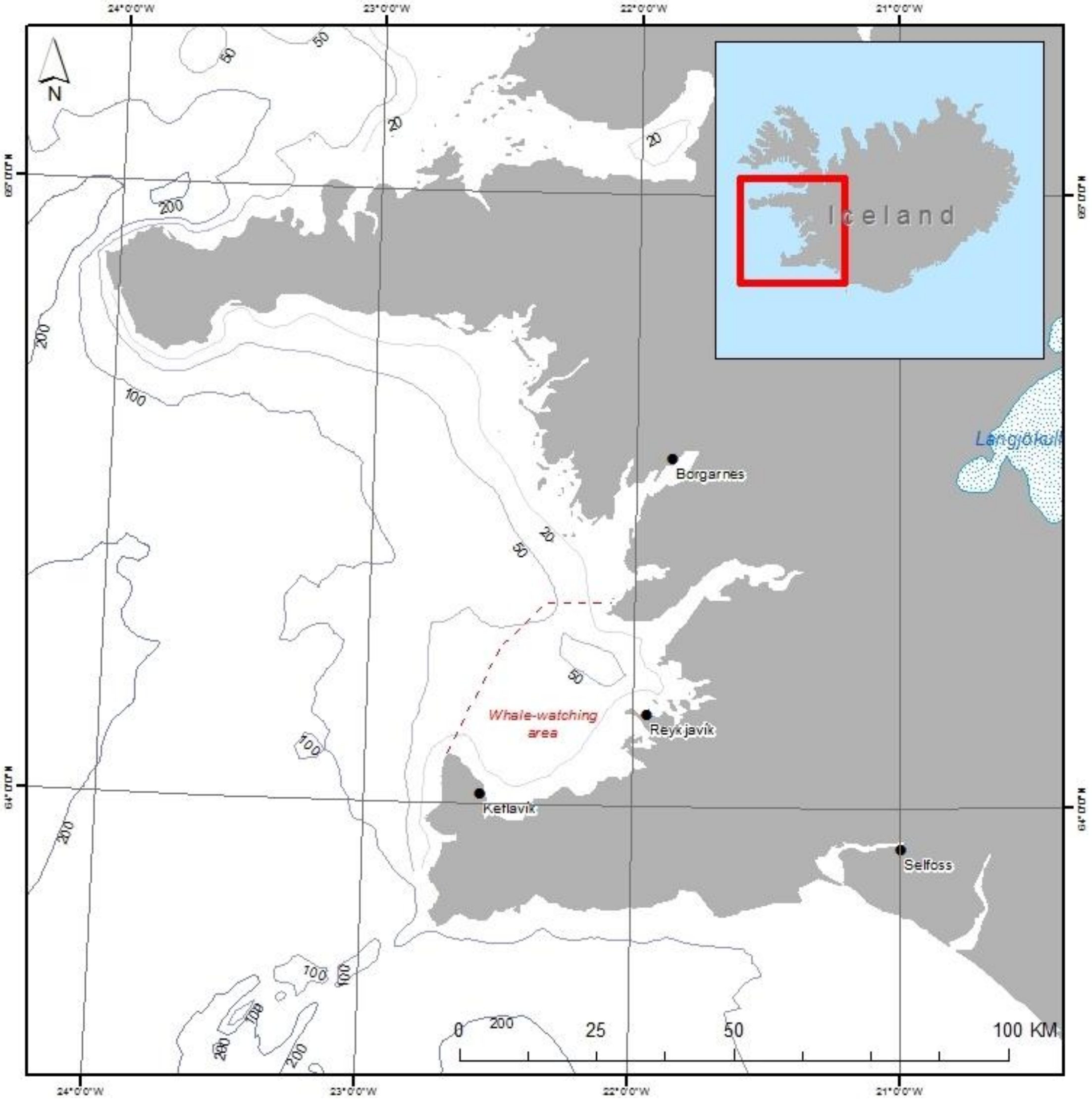

Figure 2.1: Map of the study area (red inset area) - Faxaflói Bay, Iceland.

2.1.2 Faxaflói Bay is a popular location for whale and dolphin watching benefitting from the regular occurrence of several marine mammal species, including common minke whale *Balaenoptera acutorostrata*, the target species for this study (Bertulli *et al*., 2015). Faxaflói Bay is a summer feeding ground for minke whales and there is predictable seasonal occurrence close to the shore in relatively high numbers.

2.2 ADD selection

Introduction

2.2.1 As discussed previously (Section 1.3) the ORJIP Phase 1 report identified and reviewed six ADD units that were either commercially available or under development at the time of writing. Those devices were:

- Ace Aquatec MMD
- Airmar dB plus II
- Lofitech
- Terecos
- GenusWave
- Seamarco FaunaGuard

2.2.2 These devices were highlighted as having acoustic characteristics in the hearing ranges of UK species of interest in relation to Round 3 OWF sites, have a demonstrable track record within the literature as resulting in aversive responses among UK species of interest, and be available for commercial application (Herschel *et al*., 2013). The devices were reviewed further within the ORJIP Phase 2 Stage 1 report, which listed the devices by Ace Aquatec, Seamarco and Lofitech as the best options from both procurement and operations perspectives. The Lofitech ADD was noted as not having a bespoke model for the OWF market, though was also noted as the device which had been subject to the most independent scrutiny in terms of potential mitigation capability (Sparling *et al*., 2016). For this reason, the Lofitech ADD was highlighted as the 'frontrunner' in terms of potential trials within the ORJIP Phase 2, Stage 2 Request for Proposals and therefore selected for use within this study.

Previous use of Lofitech for mitigation

2.2.3 The Lofitech ADD is a 'seal scarer'; a device developed specifically for deterring seals from aquaculture sites in order to reduce depredation on fish and the resultant economic impact. The effectiveness of these devices for that purpose has been examined on a number of occasions (Table 2.1). Such studies have noted the potential for these to devices to result in incidental impact upon cetaceans when used in an aquaculture context, leading to the use of these more widely as a deterrent during pile-driving operations as a mitigation tool. The effectiveness of these devices as a mitigation tool has therefore warranted further investigation. Table 2.1 summarises the studies where the Lofitech ADD has been deployed and what the results of those deployments were in relation to the 'target' species.

Table 2.1: Summary of studies undertaken using the Lofitech ADD

Author	Species	Summary of results
Gordon *et al*. 2015	Harbour seal	Responses (mostly seen as movement away from source) recorded up to 3,122 m 100% response out to ~1,000 m
Harris *et al*. 2014	Grey and harbour seal	Significant reduction in seal sightings within 80 m of Lofitech ADD. Sightings beyond 80 m not analysed.
Brandt *et al*. 2013a	Harbour porpoise	Clear reduction in harbour porpoise sighting rate within 1 km of Lofitech ADD. Immediate disappearance at exposure ranges of 300 to 1,100 m.

Author	Species	Summary of results
Brandt *et al*., 2013b	Harbour porpoise	Significant deterrence effect up to 7.5 km away. Number of detections within 750 m of C-PODs decreased by 52-95% of the value before ADD activation.
Götz & Janik, 2010	Grey and harbour seal	60 m deterrence range for seals in the wild. Greatest range of four commercial systems used in comparison, equal with that of Ace-Aquatec.
Fjälling *et al*. 2006	Grey seal	Reduced predation at fish traps

Technical specifications

2.2.4 The Lofitech ADD system (Figure 2.2, below) comprises a control unit containing a pulse generator and amplifier, linked to a transducer via a 25 m cable (as standard). The unit is powered by a 12V battery. A system specification sheet is available in Lofitech ADD specification sheet (Appendix A).

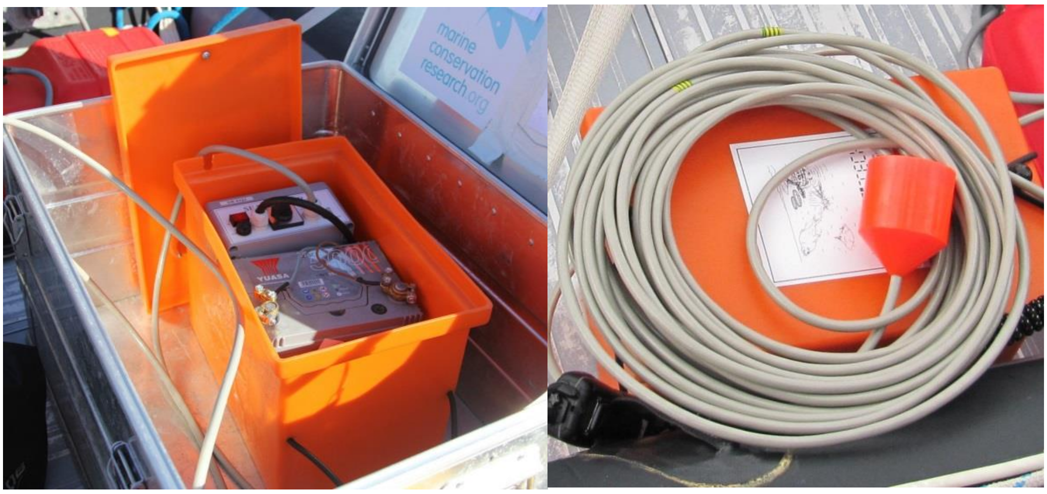

Figure 2.2: Lofitech ADD unit, showing the pulse generator and power source in weatherproof housing (left) and transducer head (right).

2.2.5 The system has a nominal sound pressure level output of 191 dB re 1 µPa re 1 m, producing patterns of signals between 10 and 20 kHz. The metric for the sound pressure level (i.e. rms, 0 to peak, peak to peak) has not been defined by the manufacturer.

2.2.6 Previous studies have shown the unit to produce pulses of around 500 ms duration, with variable length pauses between pulses (Brandt *et al*., 2013; Fjälling *et al*., 2006). A summary of source characteristics following measurements taken as part of this project are summarised later in Section 24.

2.2.7 The frequency of the Lofitech falls within the range of hearing of low frequency cetaceans based on theoretical audiogram data, and therefore was considered appropriate to use in this study (see Figure C.2 in Appendix C).

2.3 Fieldwork

Research vessels

2.3.1 The research vessel utilised throughout the field period was the R/V *Song of the Whale* (SOTW). SOTW was purpose built for cetacean research and designed to be extremely quiet even when under power in order to cause minimum disturbance to animals and to maximise effectiveness of passive acoustic surveys (Figure 2.3). A full vessel specification is available in R/V *Song of the Whale* specification (Appendix B). The secondary vessel was a 4.2 m Zodiac® rigid inflatable, used for deployment of the ADD transducer (Figure 2.4).

Figure 2.3: R/V Song of the Whale

Figure 2.4: rigid inflatable tender used for ADD deployments

Subsea noise field methods

2.3.2 Field measurements were conducted in order to characterise the Lofitech ADD source and the propagation of sound away from the device in Faxaflói Bay.

2.3.3 A calibrated hydrophone was deployed from R.V. *Song of the Whale* and the ADD was deployed from the Zodiac tender (Figure 2.4). The Zodiac was stationed at various distances from the research vessel and hydrophone depending on the test being performed, with measurements conducted with the Zodiac at distances of approximately 200 m, 500 m, 1,000 m, 1,500 m and 2,000 m from the hydrophone.

2.3.4 The distance between the two vessels was measured using a range finder and tracked for future analysis using GPS, with the two vessels' positions being constantly logged throughout the survey period.

2.3.5 The measurements were carried out using a calibrated Reson TC 4040 hydrophone connected to a Reson EC6067 charge conditioning amplifier which was connected to a Sinus Apollo data acquisition system (with 80 kHz bandwidth). Analysis was undertaken using a laptop computer loaded with Samurai analysis software.

2.3.6 The post-processing involved selecting the time limits of an individual pulse, then using Fast Fourier Transform (FFT) analysis to create an FFT plot in the frequency domain. Analysis was performed to determine the rms, SEL and 0-Peak parameters and sonograms showing time history were also generated.

2.3.7 Full details of the measurement methodology, equipment and analysis procedures can be found in Appendix C - Subsea Noise Modelling.

Minke whale visual observations

Visual search effort

2.3.8 Visual searching was conducted during daylight hours and in sea states <4, i.e. in conditions when minke whales could be detected and studied. Although video tracking techniques generally require sea states of 3 or less, attempting to find focal animals in slightly higher sea states allows tracking effort to commence as soon as conditions ameliorate. When the weather conditions were appropriate, the primary vessel commenced searching tracks in the study area soon after dawn (0600 hrs) and continued until around 2000 hrs, in order to make use of the long daylight hours. The logging software 'Logger' (www.marinconservationresearch.org) was running at all times to record environmental and sightings data, and automatically derived data streams including GPS information, AIS signals and feeds from the vessel's instruments (e.g. sea-surface temperature and wind speed).

2.3.9 The vessel followed pre-determined searching tracks designed for the study area using an equally spaced zigzag design. The choice of which of these searching tracks to use was determined on a daily basis using all available data including historic patterns of whale distribution, previous sightings from the primary vessel and information from other sources (e.g. reports from whale-watching vessels). The survey effort was conducted at speeds of between 5 and 10 knots (speed over ground).

2.3.10 Visual searching was conducted by two dedicated observers from an elevated observation platform (eye height of 5.4 m). One observer scanned the sector from 0-90 degrees and the other from 270-360 degrees; 7x50 binoculars with internal compass and reticles were used to confirm details of sightings. When a sighting was made of a marine mammal the observer reported the details to another team member acting as a dedicated data recorder. The data recorder saved all the information to the survey database using the Logger software. The aim was to record sighting time, species, distance, relative bearing, relative heading, number of animals, cue and behaviour for all animals observed. In the field, relative bearing was estimated using angle boards mounted on the either side of the observation platform and distances estimated by eye.

2.3.11 All times recorded on paper forms or entered into computers in the field were recorded in Coordinated Universal Time (UTC). All computer times and instrument times (cameras, video, clipboard watches, etc.) were also set to UTC. In addition to noting details of all sightings, the data recorder also documented any changes in environmental information (every hour or whenever local conditions change significantly) and survey effort. A watch rotation system was put in place whereby observers were on watch for one hour, before spending an hour as the data recorder, and then observing for another hour on the opposite side of the observation platform.

Video range tracking

Principles of Video Range Tracking

2.3.12 Tracking small-scale movements of whales requires measurements of range and bearing from the observation platform in addition to data on the location of the platform. Data on the location of the primary vessel was recorded automatically every second. A combined video-binocular Video Range Tracking (VRT) system was used to derive the required information on range and bearing to focal animals (Leaper and Gordon, 2001). The video system enabled an archived verbal commentary to be made documenting information about the whales' behaviour, field conditions and the sequential activities of the research team. The basic principle behind the tracking system is that the absolute position of the primary vessel is known from the GPS and relative positions of the other objects such as whales from ranges and bearings. As accurate timing is critical to this analysis, the GPS clock is the reference by which all watches and clocks in video cameras are set. Range from the video camera is derived by measuring the angle between the whale and the horizon from a known height. Measuring angles from a video relies on first having calibrated the focal length of the lens, and this focal length not being changed without subsequent calibration. There were times when there appeared to be no horizon because there was land in the way; this was not a problem if the bearing to the focal animal was known as well as the distance to the land post-survey.

Procedures for Video Range Tracking

2.3.13 When a minke whale was sighted, it was then tracked using VRT techniques until either it was deemed to have been lost or could be confused with another individual. This ensured that an accurate plot of the whale's movements in relation to the primary vessel could be generated. Locations of the secondary vessel were logged using a GPS unit. Additionally, the secondary vessel carried an AIS transponder and this signal, along with all other vessels transmitting AIS signals (e.g. fishing vessels or larger ships), was automatically logged using a Pamguard module. Additionally, the data recorder routinely entered sightings of vessels without an AIS transponder into the survey database with distance/bearing estimates and any other information (e.g. vessel type) when within 2000 m. Given that the absolute position of the primary vessel will be known every second from GPS, the relative positions of whales (by recording ranges and bearings) and the ADD deployment (from GPS/AIS) can be compared.

2.3.14 When a minke whale was observed in the study site, a subjective decision was made to assess if it was appropriate to track the animal. This decision included consideration of daylight hours and prevailing weather conditions. For example, at least two hours of daylight were to be available. If VRT was deemed appropriate, an observer would be situated at each side of the elevated observation platform with a set of VRT equipment comprising a pair of 7x50 binoculars and a small HD video camera (with a three second pre-record buffer) mounted on a monopod (Figure 2.5). On the first sighting of a whale during each surfacing sequence, the observers would press record while aiming the binoculars at the animal, ensuring that both the target animal and the horizon/shoreline are in frame. Ideally, the pre-record buffer would capture the exact moment of this surfacing. A running commentary by the observers was recorded to video in order to log the reticule/bearing readings from the binoculars, the direction of travel of the whale, the number of animals and type of surfacing (e.g. flat surfacing, arched surfacing, lunge, fast swim). This information was collected for each surfacing event with the video left on constant record while the whale is at or close to the surface. If weather conditions were unsuitable for VRT (e.g. rain or poor visibility), surfacing times were recorded manually.

Figure 2.5: Video Range Tracking equipment

2.3.15 Using the observer's eye height above sea level, the radial distance was calculated to the animal from video frames using measurements of the angle of dip from the horizon to the whale. As magnetic compasses may be influenced by electro-magnetic fields from deck instruments and the steel structure of the vessel, an alternative technique to derive accurate bearing information was incorporated in the field protocol. Downward facing CCTV cameras mounted above the observation platform were used to capture images of the observers as they direct their binoculars towards the focal animal. From a line running along the top of each binocular, accurate angles to the animal, relative to the boat could be calculated (Figure 2.6).

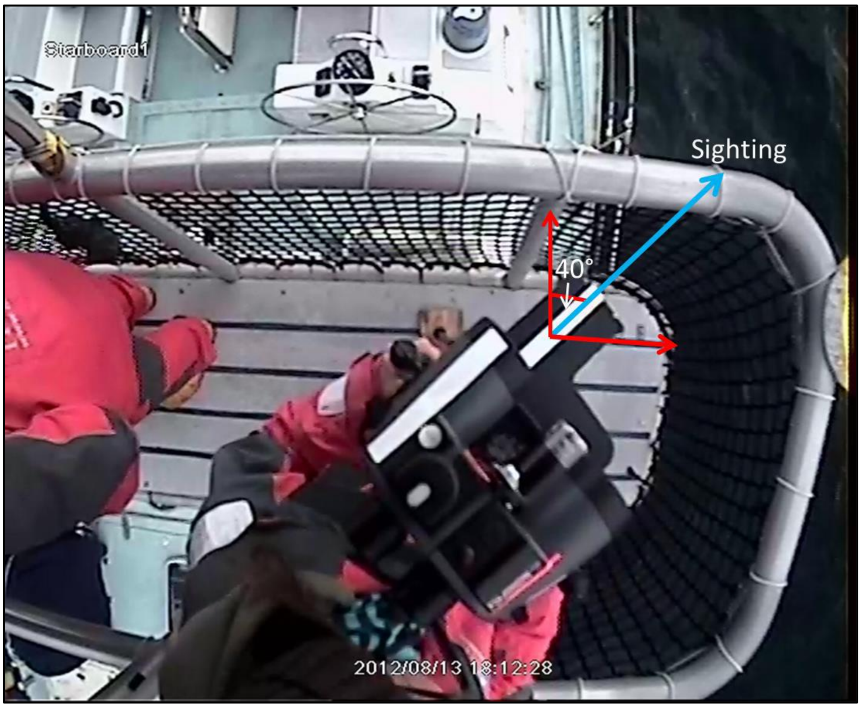

Figure 2.6: CCTV image from a starboard camera showing the orientation of an observer's binoculars in relation to the primary vessel

2.3.16 When conducting a focal follow all observed surfacings of minke whales within 2,000 m were recorded even if these were not believed to be of the focal animal. As many surfacing events as possible were recorded on video to measure surfacing locations. Continuous recording of the whales' activities, in particular, locations and timings of surfacings was carried out by both observers. Although the observers measured ranges (from binocular reticles) and bearings (from binocular compasses) to whales, the VRT outputs were used to derive accurate ranges post-process. Accurate bearings were also calculated post-survey using the information from the CCTV system monitoring the orientation of the observers' binoculars. Each relative bearing from the primary vessel was converted to a true bearing using the vessel's true heading provided by the feed from a Simrad HS70 GPS Compass (recorded in real-time to the Logger software).

Controlled exposure experiments (CEEs)

2.3.17 After tracking a focal whale for at least 30 minutes, attempts were made to deploy the secondary vessel and to expose the focal animal to the ADD signal. This took place in a sequential approach for each focal animal, with steps 1 to 4 below ideally completed to derive a single trial including a control. As habituation was explicitly not a concern for the scope of this study, repeat trials using the same focal whale were not required. Additionally, repeat exposures to the same minke whale may cause escalating behavioural responses, and thus were avoided to reduce the likelihood of measuring the response of sensitised whales.

2.3.18 VRT took place continuously throughout all of the following steps and only ceased at step 4:

1) **Pre-exposure phase:** an animal identified in the appropriate conditions for a focal follow was tracked for a period of 30 minutes.

2) **Control Phase:** following a successful 30 minute tracking period, the secondary vessel was deployed and positioned itself at the required distance ahead of the focal animal's vector of travel, travelling slowly in a wide arc to minimise the potential for disturbance and cutting its engine once in place. If the animal did not engage in directed movement the aim was to manoeuvre the ADD source to within the required distance. To provide some measure of the potential of the secondary vessel to influence the focal whale's behaviour, the first time the

secondary vessel was brought into position, the ADD was not deployed. The approximate distance between the focal whale and the secondary vessel was estimated in real-time using the AIS feed from the secondary vessel and/or range-finder binoculars. When the focal animal was deemed to be within the correct distance of the secondary vessel, a 15 minute 'non-deployment' (control) took place, whereby the secondary vessel remained motionless and the primary vessel continued to track the focal animal.

3) **Treatment phase:** after the 15 minute control phase, the secondary vessel would reposition itself as described in Step 2 to ensure the focal animal was at the correct distance away from the ADD source. When the secondary vessel was in place for the second time, and at least 15 minutes has passed since the previous (non-deployment) phase, the ADD device was deployed in to the water and activated. The team on the primary vessel continued to track the whale and after 15 minutes, the trial was considered complete and the ADD deactivated and retrieved.

4) **Post-treatment phase:** after the last trial, the focal animal was tracked by the team on the primary vessel for an additional 30 minutes where possible, in order to provide information on post-exposure behaviour. Once the focal animal was lost or 30 minutes has elapsed, the primary vessel would slowly move away from the focal animal and reunite with the secondary vessel. When at least 1,000 m clear of the focal animal, the searching pattern would be recommenced in order to find another focal animal/group providing the weather conditions and availability of daylight were conducive.

2.3.19 These steps are summarised in Figure 2.7. Originally the plan had been to add an additional step where the treatment phase was in two parts: one with the ADD activated and the other with the ADD deactivated with the observers unaware of which state the ADD was in during observation. This was to ensure that there was an objective recording of the movement of the whale without any pre-conceived idea of what to expect. However, in practice this was difficult to achieve as there was a limited time over which tracking of each focal whale was possible and therefore this step had to be removed to ensure successful tracking over as many focal whales as possible.

2.3.20 The stand-off distance for the secondary vessel and therefore deployment range of the ADD was increased from 500 m to 1,000 m on 21st August, having completed three trials at this approximate distance. The reactions seen during early trials were so extreme as to result in the loss of the focal animal, meaning that not all steps in the protocol could be followed, including the 30 minute post-deployment monitoring.

2.3.21 Trials were not attempted if alternative potential sources of disturbance, such as shipping, were within (or likely to be within) 2,000 m. Tracking efforts continued if another vessel came within 2,000 m during a trial; however, trials of this nature were treated separately during analysis and efforts made to characterise the focal animal's behaviour in response to both the ADD and the approaching vessel(s).

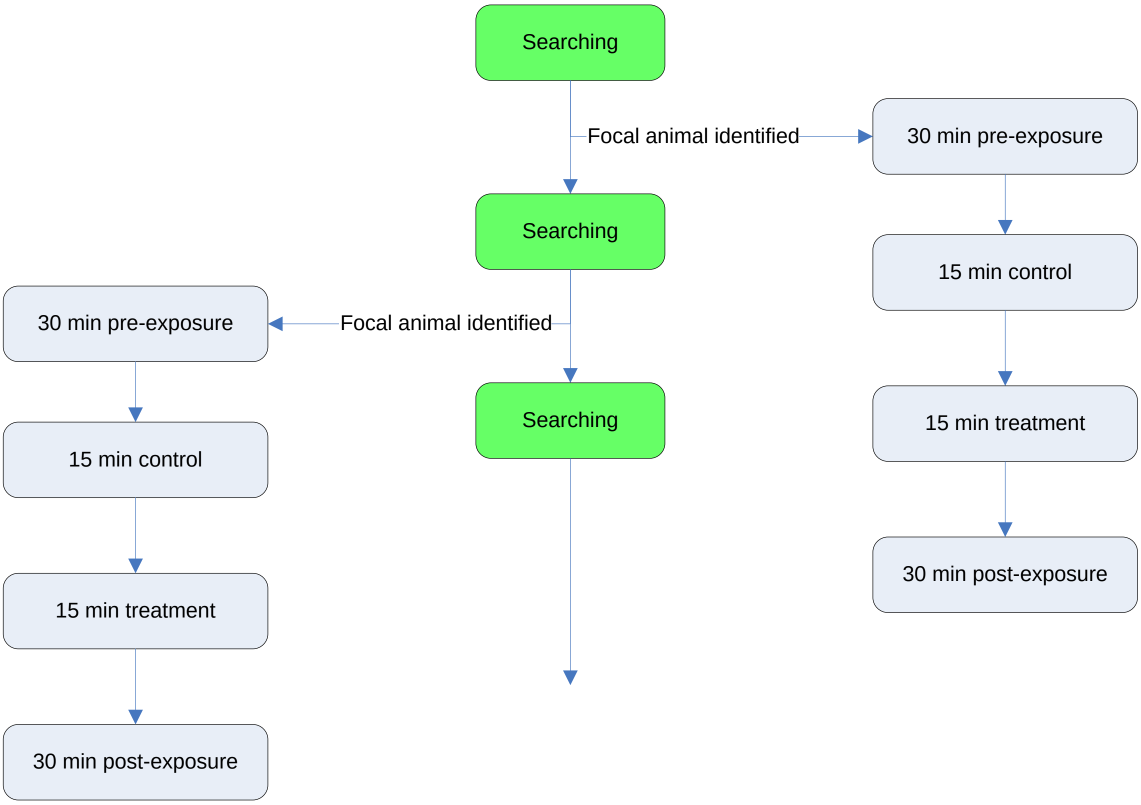

Figure 2.7: Summarised protocol for focal follow and CEE activities

2.4 Subsea noise modelling

Noise propagation model

2.4.1 The water in Faxaflói Bay is mainly 35 to 37 m deep and in the inner and coastal parts of Faxaflói Bay water depths are around 40 to 50 m deep (Rasmussen *et al.*, 2013). The seabed substrate is predominantly sand or basalt (Rasmussen & Miller, 2002). The use of a simplified empirical modelling is therefore considered to be a valid approach for the specific conditions in which the tests were undertaken. It is worth noting that these water depths are similar to the round three and STW offshore wind farm sites, but consideration will need be given to potential differences in propagation due to effects such as temperature gradients, seabed type and scattering if applying these results to other sites.

2.4.2 The generalised model for underwater noise propagation typically assumes geometrical spreading of sound energy either as a cylindrical wave, as a spherical wave or somewhere in between. Rather than simply fit a curve to the measured data, a frequency dependent curve was therefore derived based on a combination of best fit to data and standard acoustic theory. The curve fitting exercise was undertaken in order to determine how sound spread away from the sound source in Faxaflói Bay during the trials. This exercise took both the geometrical spreading of energy and molecular absorption of energy in the water into account. The line of best fit was judged by using the values which resulted in the best correlation between the measured data and calculated value as indicated by the R^2 correlation coefficient.

2.4.3 Using the propagation model derived above, it was then possible to calculate the source level. Further analysis was also carried out using semi-empirical models in order to validate the derived source level and coefficients of propagation and absorption. Full details of the methods are presented in Appendix C along with further explanation and justification for the chosen methodology. It is recommended that a more complex modelling approach be considered on a site by site basis if the findings from this study (in terms of range of effect) are to be directly applied to other sites.

Exploring the potential to induce injury

2.4.4 In order to investigate the potential for the Lofitech ADD to cause injury to a marine mammal during deployment, a further noise modelling exercise was undertaken to model the sound exposure of minke whales to sound emitted by the device and to compare this against thresholds for permanent and temporary threshold shift contained in NOAA guidelines (National Marine Fisheries Service, 2016). For cumulative SEL dose, three scenarios were modelled in which an individual was assumed to be at starting distances of 500 m, 100 m, and 25 m from the ADD at the start of activation.

Table 2.2: PTS and TTS thresholds recommended by NOAA assessing the potential for auditory injury to arise in minke whale exposed to an ADD.

Noise metric	PTS	TTS	Note
Peak sound pressure (dB re 1μPa)	219	213	Single pulse threshold for peak sound pressure level
Sound exposure level (dB re $1\mu Pa^2s$)	199	179	Pure tone noise with no rapid rise time and therefore thresholds are for exposure to continuous rather than impulsive noise.
Root mean square (dB re 1μPa)	n/a	n/a	n/a

2.4.5 Sound propagation away from the ADD was modelled using the propagation coefficients derived previously (described in Section 0). The cumulative SEL of a minke whale swimming away from an ADD was the calculated assuming a conservative swim speed of 2.5 ms^{-1} and an average pulse rate of 0.5 pulses per second. Cruising swim speeds of minke whale have been shown to be 3.25 ms^{-1} (Blix and Folkow, 1995; Cooper *et al*., 2008) but the more conservative swim speed of 2.5 ms^{-1} used in this assessment allows some headroom to account for the potential that the animal might not swim directly away from the source, could change direction or does not maintain a fast swim speed over a prolonged period. The modelling assumed 30 minutes of activation which reflects the likely activation time for marine mammal mitigation for offshore piling.

2.5 Data analyses

Mapping whale tracks and responses to ADD

2.5.1 For each focal whale tracked during the CEEs a map was produced in GIS to show the whale's position at each step of the CEE. The maps show the position of each whale, as recorded by the field team during each surfacing event, and mapped spatially with a vector representing the line of travel between each consecutive point. Tracks were colour coded according to which phase of the CEE each surfacing fell within.

2.5.2 A summary of the responses of all tracked focal whales was plotted graphically to illustrate the distance of focal animals from the ADD deployment site over the treatment phase (15 minute ADD activation and during the post-treatment phase when the boat continued to monitor whales after the device was deactivated.

2.5.3 Bar and line graphs were also produced to summarise the response of whales during each phase of the CEE. Responses were measured using a number of biological parameters described below.

Estimating biological parameters

2.5.4 A number of biological parameters were derived from each track using the information collected during a focal follow. The biological parameters are described below.

Dive time: Inter-sequence interval (ISI) and Inter-blow interval (IBI)

2.5.5 The typical foraging behaviour of minke whales in this study and a previous study conducted in Faxaflói (unpublished MCR data from 2012) involves a long dive of 2 to 6 minutes, followed by a sequence of 4 to 6 shorter dives, nearer the surface, lasting 10-40 seconds each. To capture this inherent variation in dive profile, the first measure of dive time (ISI) only considered the longer dives, whilst the second measure (IBI) only considered the shorter dives.

2.5.6 The ISI is calculated as the time (in seconds) between the last blow from the short dive sequence to the first blow of the next short dive sequence.

2.5.7 The IBI is calculated as the time (in seconds) between blows at the surface during a short dive sequence.

Net swim speed

2.5.8 The net swim speed (metres per second) of each whale was obtained for each surfacing by dividing the distance covered between successive surfacings by the time elapsed. Thus net 'swim speed' is really a measure of the net movement between successive surfacings (which could be quite convoluted) and therefore provides a minimum measure of the speed at which whales swim between surfacings. Net swim speed was calculated for all surfacings of each focal whale but the mean net value (sum of all the distances divided by sum of all the times) was taken across all surfacings to give this biological parameter.

Path predictability: directness and deviation indices

2.5.9 The directness index is one measure of path predictability; the other measure being the deviation index (Williams *et al.*, 2002). The directness index measures path predictability on the scale of a tracking session. It was generated by dividing the distance between end-points of a path by the cumulative surface distance covered by all dives. The directness index can be thought of as the ratio of the diameter of a path to its perimeter. The resulting ratio was then scaled to 100 such that the parameter can range from 0 (a circular path) to 100 (a straight line) (Figure 2.8).

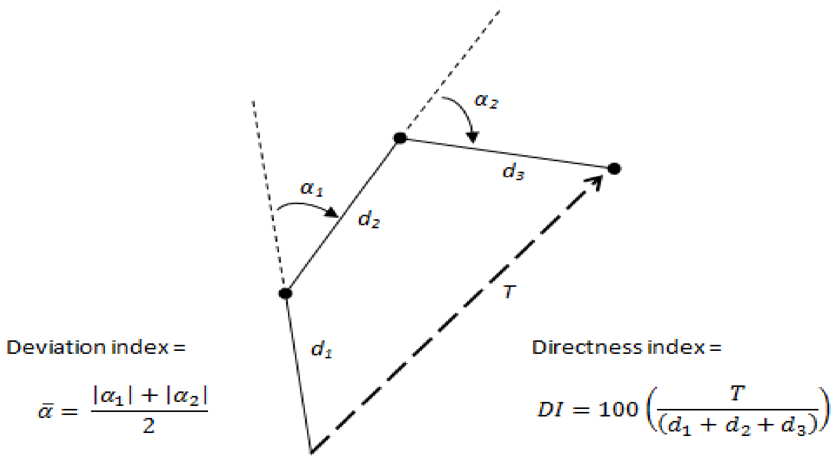

Figure 2.8: A sample swimming path with four surfacings (●) and three dives (d_i), showing two measures of path predictability: deviation and directness. The deviation index is the mean of all angles between observed dives and the straight-line paths predicted (…) by preceding dives. The directness index is the ratio of the track diameter (T) to its perimeter (from Williams et al., 2002).

2.5.10 The deviation index is a second measure of path predictability and was based upon the changes in the whale's course (angle between observations) from one surfacing to the next and can therefore be considered as an inverse measure of a path's smoothness (Figure 2.8). For each surfacing in a track, the angle between the path taken by a dive and the straight-line path predicted by the dive before was calculated (Williams *et al.,* 2002). The deviation index is the mean of the absolute value of each of these discrepancies, in degrees, during the entire track. A low deviation index indicates a smooth path, while a high deviation index indicates an erratic path. Indices of directness and deviation are calculated for each track.

2.5.11 A track that shows high deviation and high directness is described as erratic but directional, whereas a track with low deviation and low directness is smooth but non- directional.

Environmental parameters

2.5.12 Information on environmental parameters was collected in the field concurrently during the tracking of focal whales. Where possible, measurements were taken as soon as the ADD was activated. The following table describes the parameters measured (Table 2.3).

Table 2.3: Environmental parameters recorded during the CEE.

Environmental parameter	Description
Day	A sequential number representing study day, with day 1 being 11/08/16 and day 24 being 03/09/16
Time	Time of day in decimal hours, e.g. 9:30 AM = 9.5 and 8.15 PM = 20.25
Latitude and longitude	Position of the whale in decimal degrees
Depth	Water depth in metres measured using GEBCO (General Bathymetric Chart of the Oceans)
Slope	Maximum change in depth for each GIS cell in relation to its neighbour, calculated as a percentage change
Distance of ADD	The distance between the ADD deployment site and the last surfacing of the whale prior to activation of the ADD
Wind speed	Measured from a masthead instrument aboard the survey vessel in kmh^{-1}
SST	Sea Surface Temperature measured from a hull-mounted sensor on the survey vessel in centigrade
Encounter rate	Encounter rate for each survey day measured as the number of individual minke whales encountered while survey effort was 'searching' (i.e. not when tracking whales or moving to/from port) divided by kilometres of search effort

Comparing the phases of the CEE

2.5.13 The biological parameters were estimated for each focal whale over the different phases of the CEE (pre-treatment, control, treatment and post-treatment). Box plots were produced to illustrate the mean and inter-quartile range for each biological parameter (dependent variable) for all focal whales successfully tracked.

2.5.14 A repeated measures multivariate ANOVA was carried out to test the difference between the phases of the CEE where H_0 is that there is no difference between the different phases. In a doubly multivariate repeated measures design, the dependent variables represent measurements of more than one variable for the different levels of the within-subjects factors.

2.5.15 Although most of the dependent variables were normally distributed at all levels of the independent variable (i.e. for each treatment type), two were positively skewed. Thus, inter-blow interval (IBI) was log-transformed and inter-sequence interval (ISI) was reciprocal-transformed to improve assumptions of normality. A Kolmogorov-Smirnov test of normality (with Lilliefors significance correction) was subsequently carried out for each dependant variable within each of the four phases and the resulting test found that there was no significant difference from a normal distribution and therefore the ANOVA could be performed on this basis.

Away-speed

2.5.16 The five dependent variables used to characterise whale behaviour (IBI, ISI, net swim speed, deviation index and directness index) are scalar variables that describe the magnitude of a response but not its direction relative to the location of the ADD. Therefore, the away-speed parameter was derived as a measure of the directionality and longevity of an effect on whale behaviour from the deployment of an ADD. As this parameter could only be calculated relative to the position of the ADD following activation, the resulting values were produced for the treatment and post-treatment phases only.

2.5.17 Away-speed, a vector variable describing a whale's net speed of travel (in kmh^{-1}) away from the ADD, was estimated as follows (and shown graphically in Figure 2.9):

$$Away\ speed = \frac{(\text{Distance between blow}_n \text{and ADD}) - (\text{Distance between blow}_0 \text{ and ADD})}{\text{Time elapsed between blow}_0 \text{and blow}_n}$$

Where blow_0 is the last blow observed immediately prior to ADD activation and blow_n is the blow that is being measured in each case.

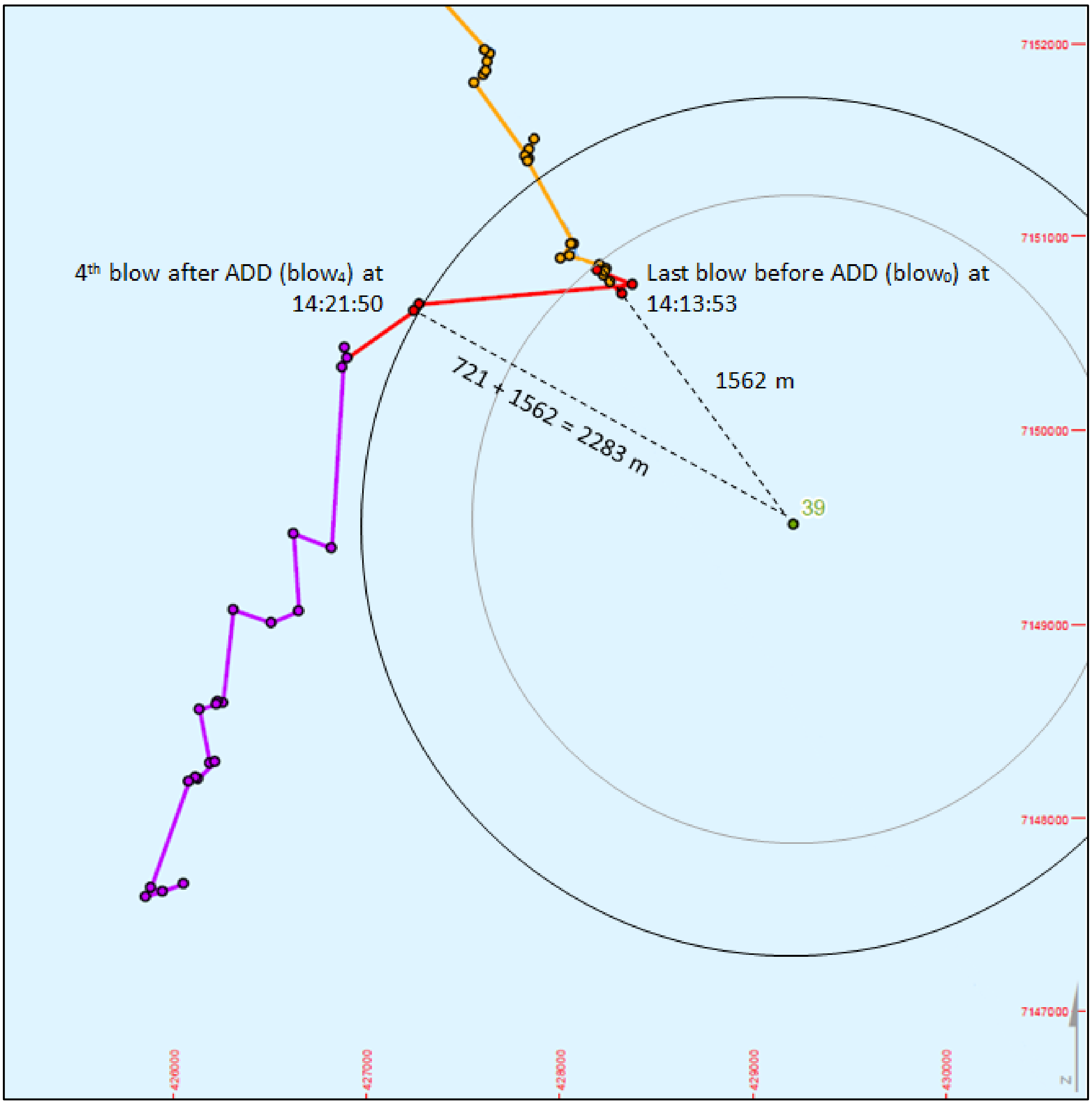

Figure 2.9: Illustration of the calculation of away-speed relative to the ADD deployment location. The track of the focal whale is denoted by the orange (control phase), red (treatment phase) and purple (post-treatment phase) lines. The number '39' denotes the location of the ADD for the CEE on the focal whale labelled 'sighting 39'.

2.5.18 The figure above illustrates how away-speed was calculated relative to blow 4; and the calculation is as follows:

$$Away - speed \;=\; \frac{2283 - 1562}{14{:}\,21{:}\,50 - 14{:}\,13{:}\,53} = \frac{0.721\;km}{0.1325\;hours} \;=\; 5.44\;kmh^{-1}$$

2.5.19 For each focal whale, away-speed was calculated for each surfacing event relative to the ADD i.e. Δ distance (blow 0 to ADD) and (blow 1 to ADD); Δ distance (blow 0 to ADD) and (blow 2 to ADD); and so on, until all blows recorded during the treatment and post-treatment phases had been used to estimate away-speeds. A representative away-speed could then be summarised for each whale by calculating the mean value for the different phases e.g. treatment and post-treatment.

2.5.20 Note that if away-speed was positive, the whale was considered to be moving away from the ADD at a given net speed, whilst if away-speed was negative, the whale was considered to be moving toward the ADD deployment site.

Effect of ADD on away-speed during treatment and post-treatment phases

2.5.21 The difference in away-speed between the treatment and post-treatment phases were investigated using a paired samples *t*-test. The paired samples *t*-test assumes that observations are not independent of one another since the test is on the same focal whale during different phases of the CEE. The null hypothesis is that there is no difference in away-speed between the treatment and post-treatment phase.

2.5.22 To delve into more detail, the difference in away-speed of focal whales was also investigated in the first half of the treatment phase (T1) compared to the second half of the treatment phase (T2). In this way, greater resolution could be provided on the point at which acceleration away from the ADD, if any, began. Mean values for T1 and T2 were estimated for each focal whale by averaging the away-speed across the first 50% of surfacing (blows) and the second 50% of surfacings. Again a paired samples *t*-test was performed to look for significant difference between T1 and T2.

Multiple regression model

2.5.23 A backward stepwise multiple regression model was run in SPSS to look for environmental covariates that may explain any variability in average away-speed during the treatment phase for the focal whales. This analysis assumes that the data are normally distributed and there is no collinearity between independent variables. The test of multicollinearity showed that longitude and day were both correlated with a number of other variables and therefore these parameters were removed from the model. Once this was done, the collinearity was resolved for the remaining parameters as demonstrated by variance inflation factors (VIF) of less than 10[2].

2.5.24 The independent parameters entered into the first step of the multiple regression model were therefore: time, latitude, depth, slope, distance from ADD, wind speed, SST and encounter rate.

Relationship between received sound levels and biological parameters

2.5.25 Analysis was conducted in order to explore the relationship between the various biological parameters and received sound pressure levels. However, in general it was found that there were insufficient data to derive any statistically significant relationships between received sound levels and such parameters. This was compounded by the fact that the vast majority of exposure experiments were carried out at similar ranges between the ADD and mammal, meaning that the majority of data collected were for very similar received sound levels.

[2] A rule of thumb is that if VIF>10 then multicollinearity is high.

3 Results

3.1 Subsea noise

ADD source characterisation

3.1.1 The Lofitech ADD was found to have a source sound pressure level of approximately 198 dB re 1 µPa (rms) re 1 m in this study. However, field measurements using the devices in other studies have determined different source levels, for example 193 dB re 1 µPa (rms) re 1 m (Gordon *et al*. 2015) and 197 dB re 1 µPa (rms) re 1 m (Brandt *et al*. 2012; Brandt *et al*. 2013). These values are slightly higher than specified by the manufacturer, although the metric of the source level (e.g. rms, 0-pk, pk-pk) was not stated in the manufacturer's specification (see Appendix A).

3.1.2 The fundamental source frequency was determined to be 14.6 kHz with lower level harmonics at 29.2 kHz, 43.6 kHz and 72.8 kHz. Presumably there will also be higher order harmonics which were beyond the 80 kHz bandwidth of the measurement system, although the harmonics were all found to be at a significantly lower level than the fundamental frequency and it is therefore unlikely that these higher harmonics will be significant in terms of assessing the effects of sound emitted by the device.

3.1.3 Pulse length was found to be generally quite consistent across all measurements with an average pulse length of 752 ms^{-1}. The source characteristics are summarised in Table 3.1.

Table 3.1: Lofitech ADD source characteristics.

Parameter	Source level re 1 m	Unit	Standard deviation	Fundamental frequency, kHz
SEL	197	dB re 1 µPa²s	2.0	14.6
RMS sound pressure level	198	dB re 1 µPa (rms)	1.9	14.6
Peak sound pressure level	204	dB re 1 µPa (pk)	2.3	14.6

3.1.4 The frequency dependent curve that was derived was based on a combination of best fit to measured data and consideration of standard acoustic theory (i.e. empirical modelling), and was represented by the simplified algorithm:

Received Level = S + N log R + αR

where S is the source level (re 1 m), R is the distance from source to receiver (m), N is a coefficient of geometrical divergence and α is a coefficient of molecular absorption.

3.1.5 The sound propagation coefficients derived for N (-19) and *α* (-0.004) in the model resulted in a propagation curve for the main source frequency of 14.6 kHz of:

RMS sound pressure level = 198 – 19 log R – 0.004 x R (dB re 1 µPa)

3.1.6 This is illustrated graphically (Figure 3.1) and validated with further analysis using other semi-empirical sound propagation models in order to confirm the derived source level (Appendix C). The graph here presents the sound pressure levels as rms as this is the metric most commonly used for assessment of behavioural effects and therefore allows comparison with other studies, however, a similar relationship is also be seen if peak pressure or single pulse SEL are plotted using their corresponding source levels.

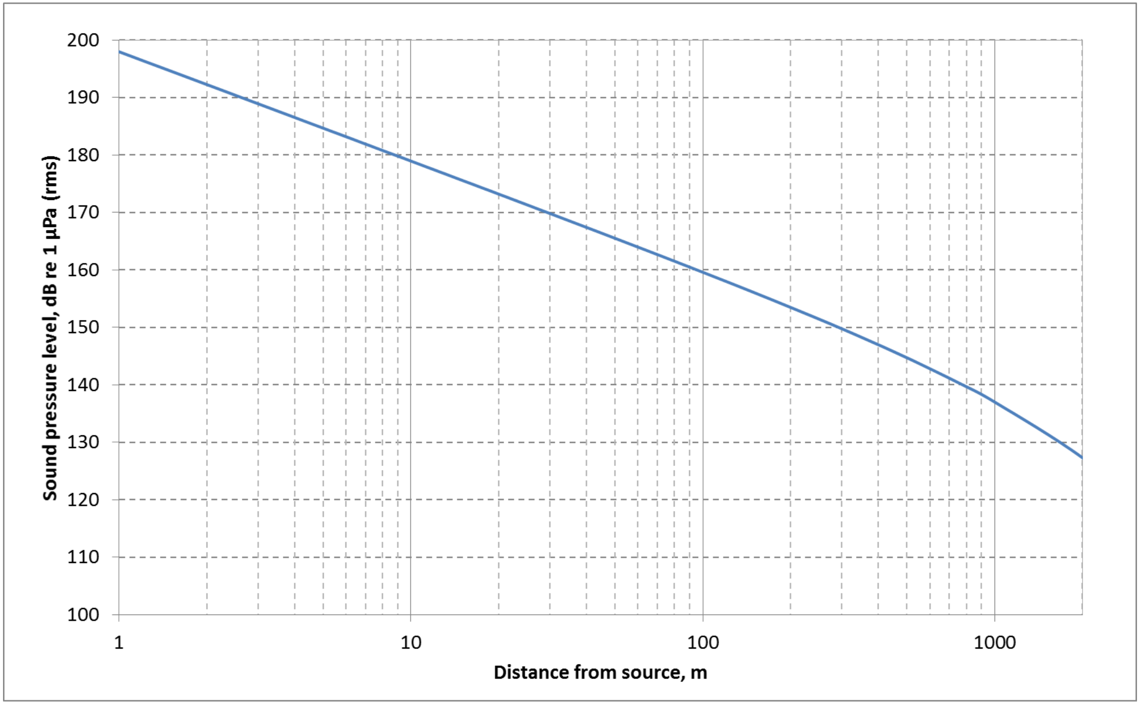

Figure 3.1: RMS sound propagation curve for Lofitech ADD in Faxaflói Bay.

3.1.7 There was an approximately inverse square decrease in sound pressure level (rms) at increasing distance from the ADD source for the fundamental source frequency (14.6 kHz) at ranges close to the source. This is shown in (Figure 3.1) which is presented using a logarithmic scale. The graph also shows that molecular absorption and scattering of sound energy becomes increasingly important at ranges further from the ADD (approximately > 1 km). This is because molecular absorption of energy follows an approximately linear relationship (i.e. a fixed dB per meter) as opposed to an inverse square relationship.

3.1.8 There was little observable difference in the sound pressure levels recorded over three depths (10 m, 20 m and 30 m) at each distance measured by the hydrophone (Table C.1 in Appendix C). For example, the values of sound pressure level measured as rms, averaged across depths and at distances from the ADD, were derived from Table C.1 in Appendix C as:

- 154.7 ± 1.0 dB re. 1µPa (rms) @ ~200 m
- 142.8 ± 1.9 dB re. 1µPa (rms) @ ~600 m
- 136.1 ± 1.6 dB re. 1µPa (rms) @ ~1,000 m
- 126.9 dB re. 1µPa (rms) @ 1,508 m
- 124.3 dB re. 1µPa (rms) @ 2107 m

3.1.9 Note that for the last two distances, the sound pressure levels were only measured at one depth (30 m). Table C.1 in Appendix C also presents the results of the measured sound pressure levels at harmonic frequencies (29.2, 43.6, and 72.8 kHz) and illustrates that the measured levels are lower compared to the fundamental source frequency.

PTS and TTS thresholds for minke whale

3.1.10 The source peak sound pressure level was measured as 204 dB re 1 μPa re 1 m which is below the thresholds of 219 dB re 1 μPa (pk) for permanent threshold shift (PTS) and 213 dB re 1 μPa (pk) for temporary threshold shift. It is therefore highly unlikely, based on current NOAA guidelines (National Marine Fisheries Service, 2016), that the Lofitech ADD could result in instantaneous injury due to peak pressure.

3.1.11 The potential for injurious effects to occur was also explored using cumulative SEL, as a much more precautionary approach. Since ADD noise does not fall within the NOAA classification of impulsive noise (Table 2.2), the thresholds for cumulative dose were 199 dB re 1 μPa^2s for PTS and 179 dB re 1 μPa^2s for TTS. For three cumulative dose scenarios modelled (starting distances of 500 m, 100 m, and 25 m from the ADD) the noise modelled predicted that even for the scenario where the whale was as close as 25 m from the ADD, there was no exceedance of the PTS or TTS thresholds for minke whale (Figures C.2, C.3 and C.4 in Appendix C - Subsea Noise Modelling).

3.2 Minke whale visual observations

Search effort

3.2.1 Field work was conducted between August 10th and September 18th. A total of 2,800 km (310 hours) survey effort was carried out. During that time, 246 minke whales were sighted (shown in Figure 3.2 below). Of those, 46 focal whales were tracked. A total of 23 tracks were greater than 30 minutes duration. Focal follows that included successful ADD deployment were carried out on 15 occasions.

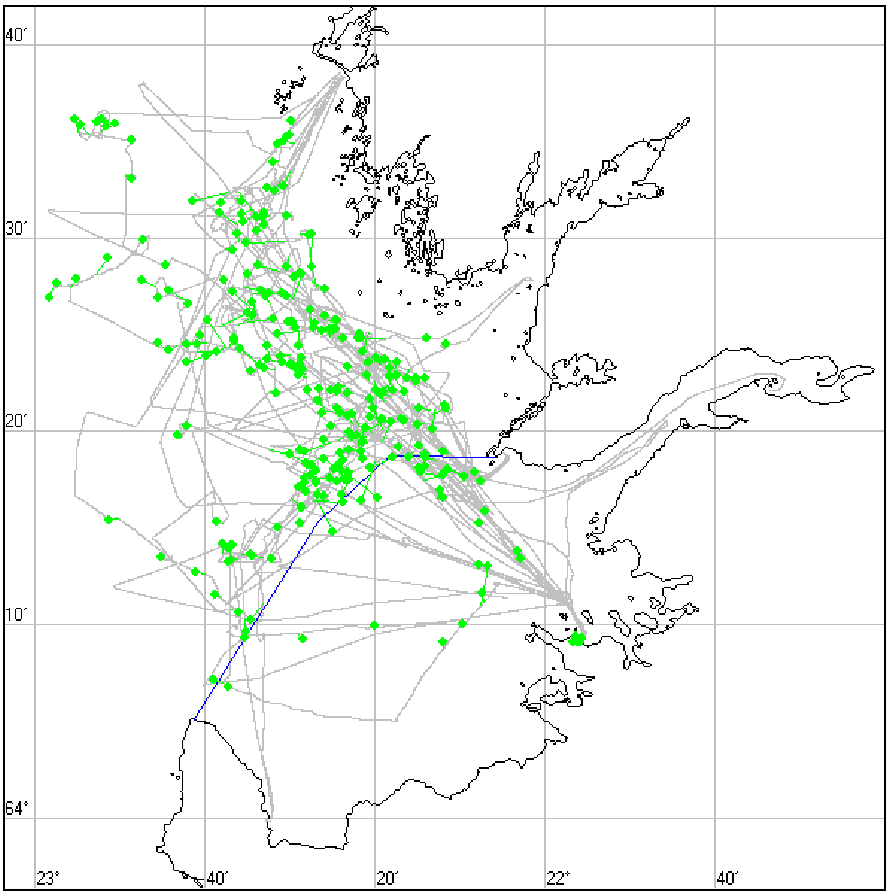

Figure 3.2: Distribution of minke whale sightings within Faxaflói Bay during study period. Blue line denotes the limit of the whale watching area.

Whale response

Response maps

3.2.2 In all fifteen deployments, the focal animal moved away from the ADD deployment site following activation of the unit (Figure 3.3). An illustration of a tracked whale during the CEE is provided in Figure 3.4. These tracking maps were produced for each focal whale (Response Maps). Most focal whales tracked displayed a clear and sustained movement away from the ADD deployment site (Figure 3.3). However, two focal whales (whales 35 and 40) exhibited a net movement back toward the deployment site some minutes after the cessation of the ADD playback suggesting possible recovery after 10 to 15 minutes in these cases.

3.2.3 The initial ADD deployment protocol of activating the device at 500 m resulted in strong reactions from the focal animals (see Figure 3.3). In each case the animal moved away quickly, making it difficult to undertake post-deployment tracking in some instances. For example, Focal whales numbered 2, 10, 16, and 19 were exposed to ADD playback at 500 m, and disappeared rapidly (Figure 3.3). Subsequent to modification of the protocol and activation of the ADD at 1,000 m, post-deployment tracking became possible, allowing a more complete picture of focal animal behaviour to be gained.

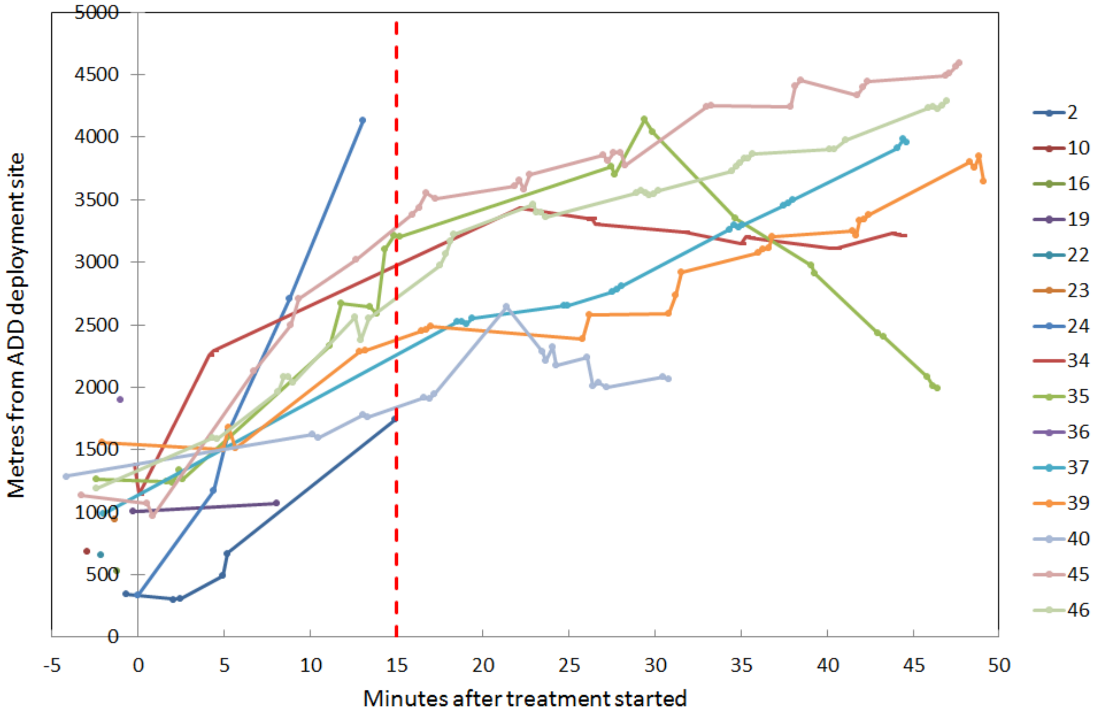

Figure 3.3: Graph illustrating the distance of focal whales from the ADD deployment site during treatment and post treatment phases of the CEE. The red dashed line indicates the end of the treatment phase. Note for some whales exposed to the ADD at 500 m, a single dot is marked on the graph indicating that these animals disappeared too quickly to be tracked over the full CEE.

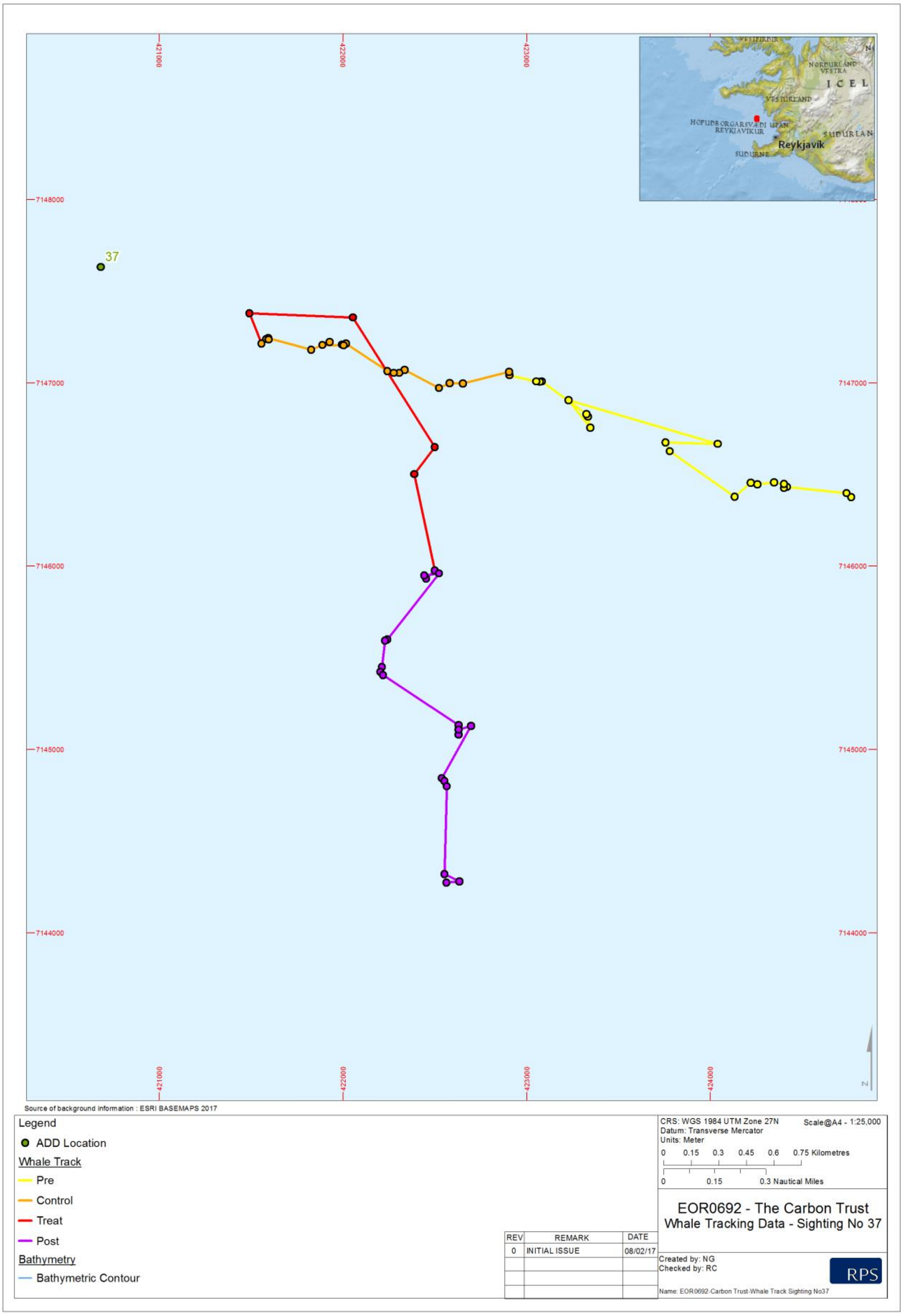

Figure 3.4: Trackline plot for whale 37 showing all four CEE phases, demonstrating the clear movement away from the ADD deployment site (denoted by the green point, labelled '37').

3.3 Data analyses

Summary data for biological parameters

3.3.1 For most focal whales there was little discernible change in the ISI over the course of the experiment, although, on average, there was a slight increase in ISI over the treatment and post-treatment phases (Figure 3.5). Focal whales 19 and 22 were exceptions to this, both exhibiting a more dramatic increase in ISI during the treatment phase, and in the case of whale 19, also during the post-treatment phase (Figure 3.6).

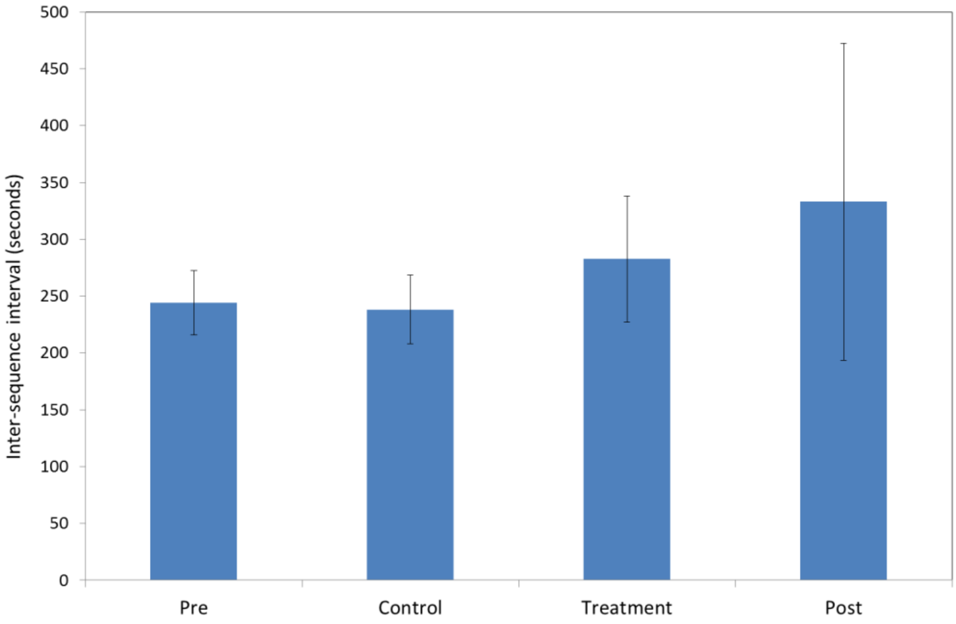

Figure 3.5: Bar graph showing Inter Sequence Interval (ISI) for the whole treatment group. Error bars are 95% Confidence Intervals.

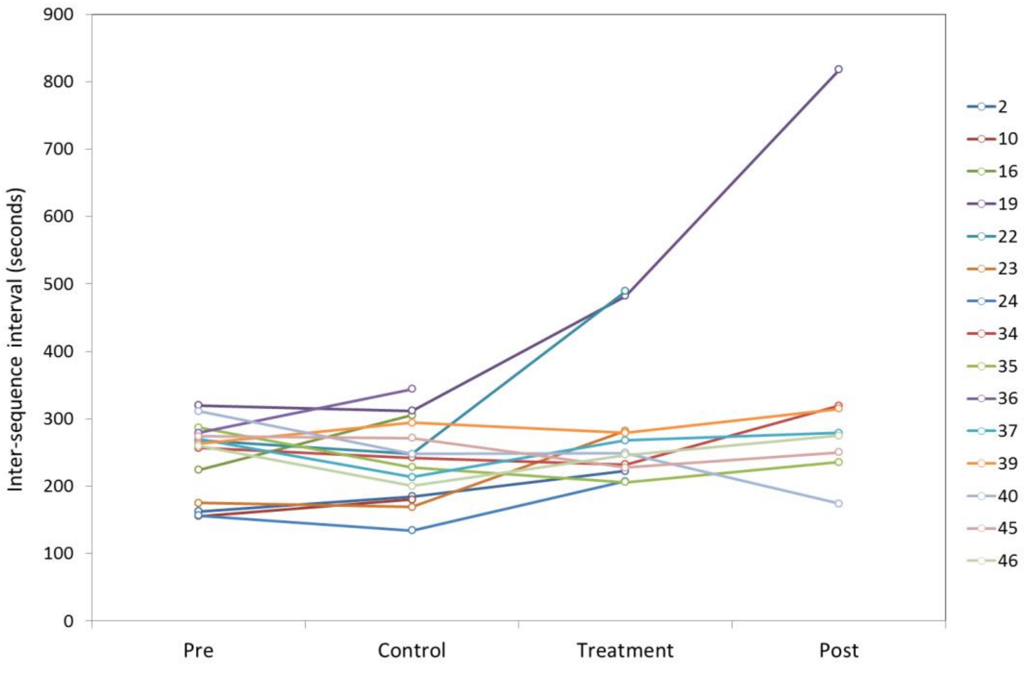

Figure 3.6: Mean Inter Sequence Interval (ISI) for each focal whale tracked during the different phases of the CEE.

3.3.2 The mean IBI of focal whales showed an increase during the treatment phase and appeared to return to baseline levels during the post-treatment phase (Figure 3.8) The increase in mean IBI may be driven by the more extreme reaction of a subset of focal whales, whilst other individuals showed no apparent changes in IBI during the treatment phase (Figure 3.8).

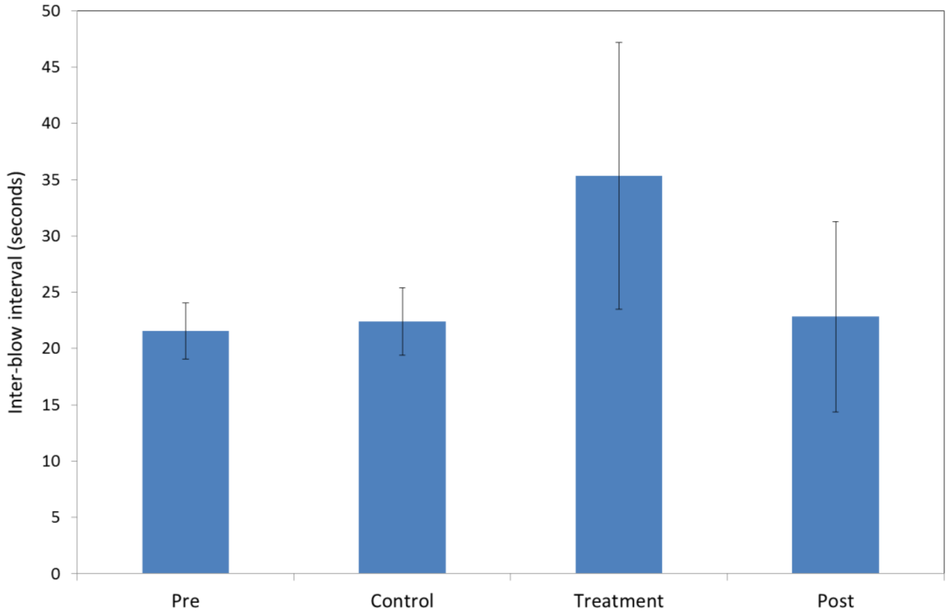

Figure 3.7: Bar graph showing Inter Blow Interval (IBI) for the whole treatment group. Error bars are 95% Confidence Intervals.

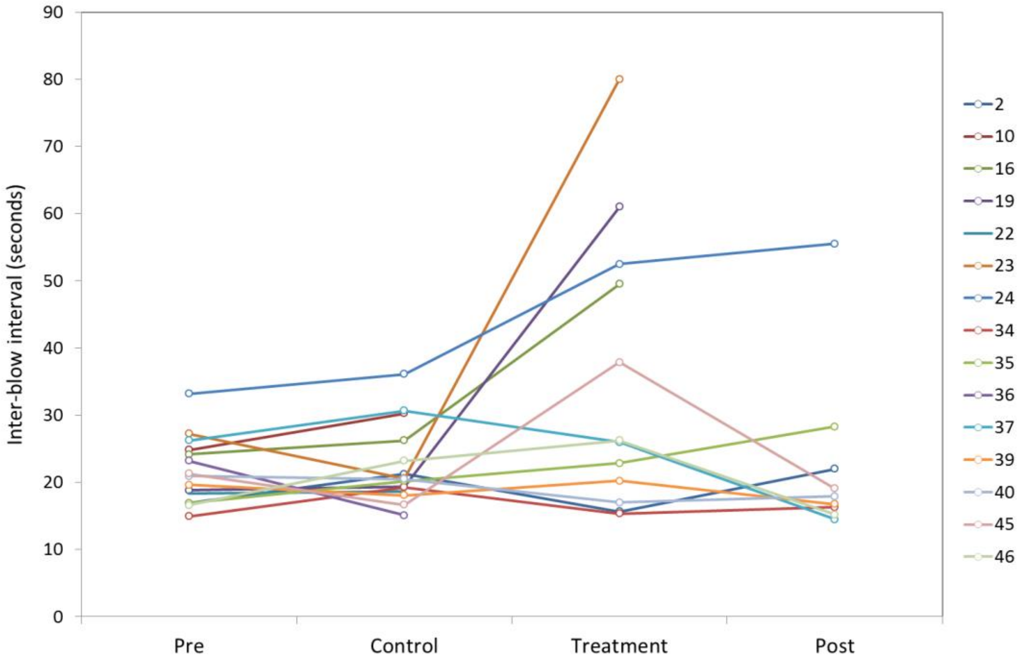

Figure 3.8: Mean Inter Blow Interval (IBI) for each focal whale tracked during the different phases of the CEE.

3.3.3 A marked increase in mean net swim speed (i.e. net movement between points) was observed across all focal whales, with the greatest difference between the control and treatment phases (Figure 3.9). All focal whales showed similar responses in mean net swim speed during the CEE (Figure 3.10).

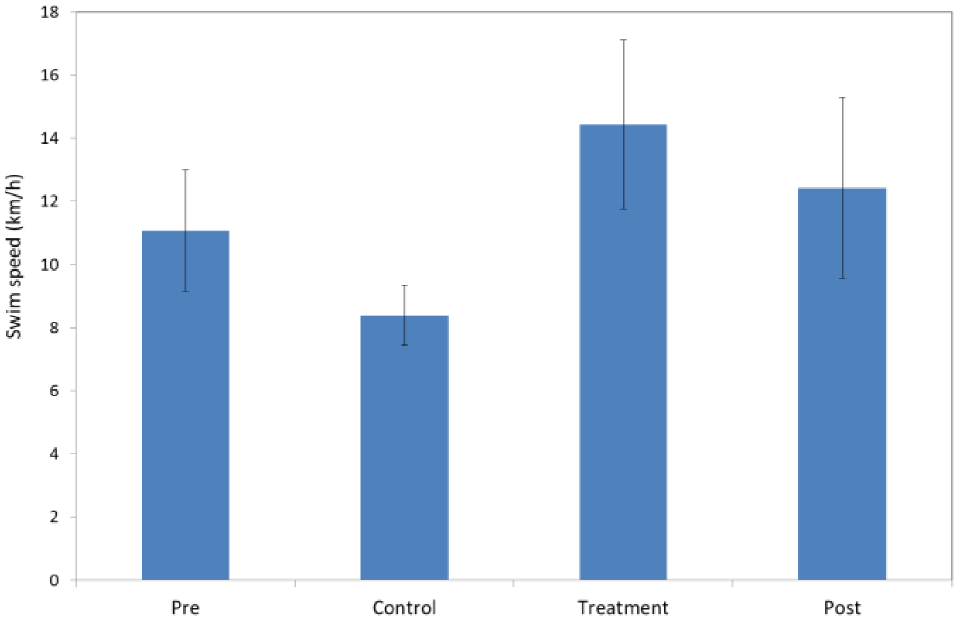

Figure 3.9: Bar graph showing net swim speed (kmh^{-1}) for the whole treatment group. Error bars are 95% Confidence Intervals.

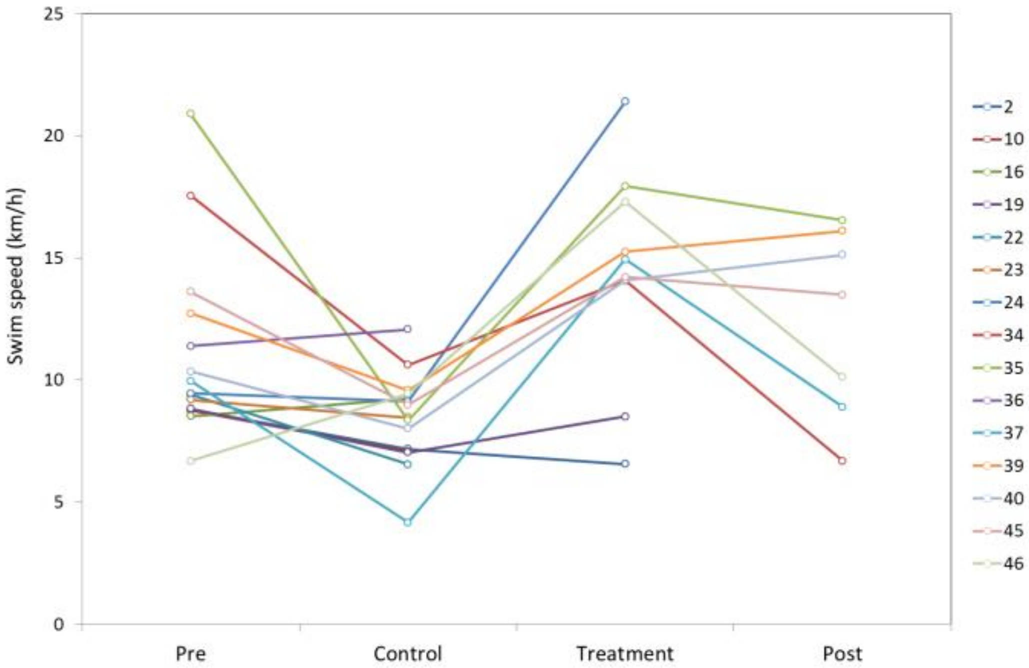

Figure 3.10: Mean net swim speed (kmh^{-1}) for each focal whale tracked during the different phases of the CEE.

3.3.4 The mean deviation index did not appear to vary much across the different phases of the CEE (Figure 3.11). During the treatment phase, however, there was notable variation in the deviation indices of different focal whales, with some individuals show more erratic behaviour (high deviation index) compared to others (Figure 3.12).

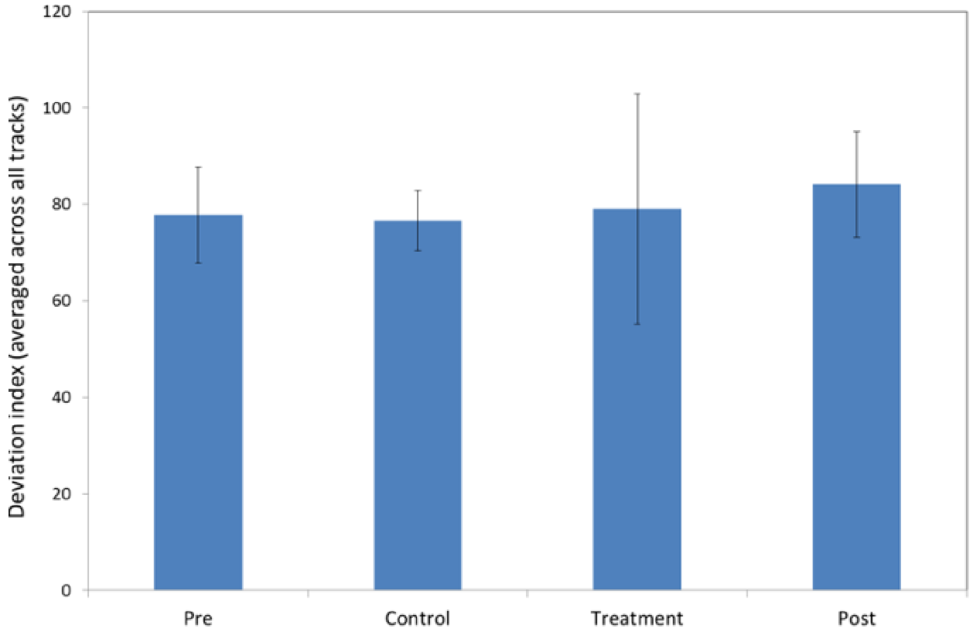

Figure 3.11: Bar graph showing deviation index for the whole treatment group. Error bars are 95% Confidence Intervals.

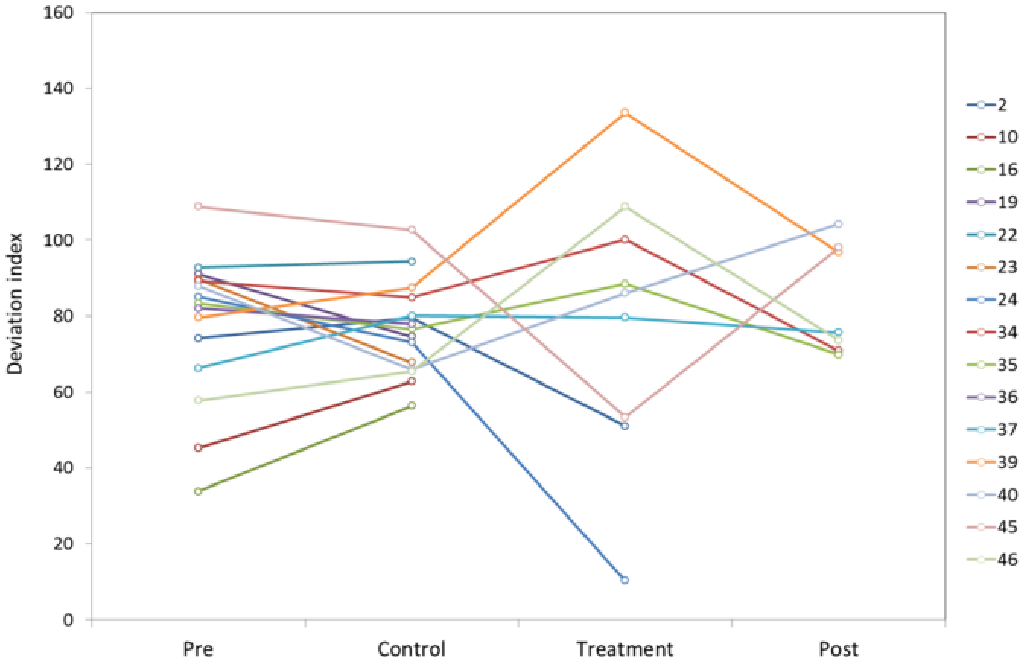

Figure 3.12: Mean deviation index for each focal whale tracked during the different phases of the CEE.

3.3.5 In contrast to the deviation index, there was a notable increase in the directness index of focal whales during the treatment phase suggesting directed movement (in all cases away) from the ADD source (Figure 3.13). Notably, there was also a small variation in the deviation index between individual whales suggesting that this was a consistent response across all focal whales. This result was fairly consistent across all focal whales, with only a few instances where the directness decreased from the control phase to the treatment phase (Figure 3.14).

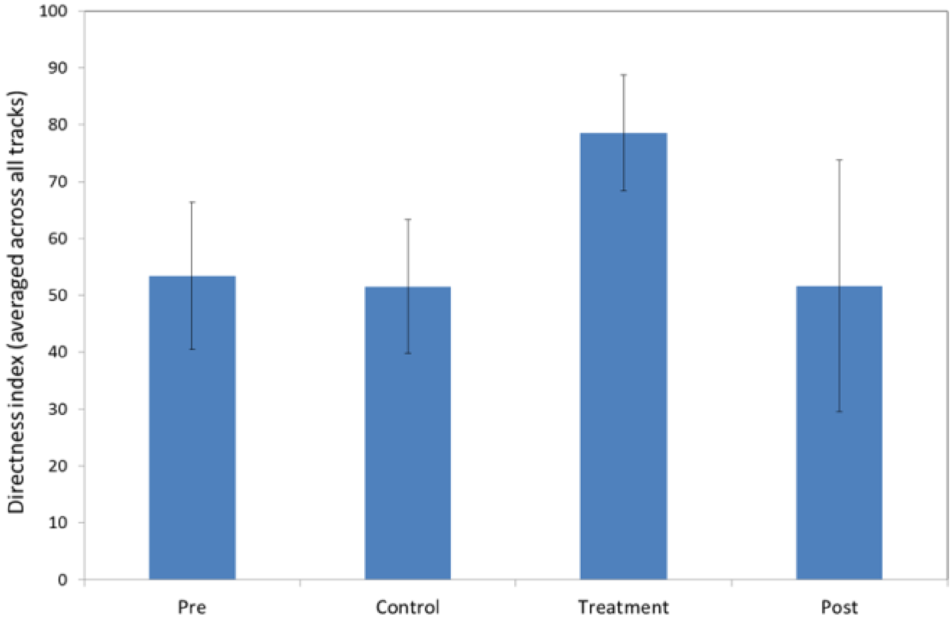

Figure 3.13: Bar graph showing directness index for the whole treatment group. Error bars are 95% Confidence Intervals.

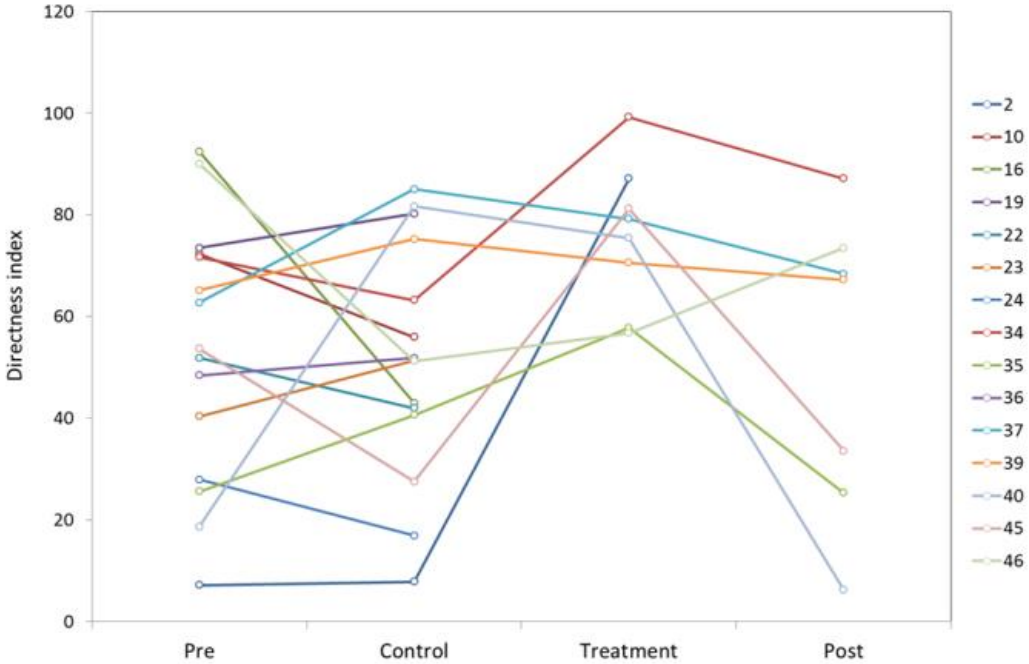

Figure 3.14: Mean directness index for each focal whale tracked during the different phases of the CEE.

Variation in biological parameters over the phases of the CEE

3.3.6 Box and whisker plots showing the mean and interquartile range for each of the biological parameters estimated during the CEEs summarise the responses of the focal whales across the different phases of the CEE (Figure 3.15). The plots show very little difference between the pre-exposure and control phases. The only difference here was that the secondary vessel had not been deployed and manoeuvred into position for the pre-exposure phase and therefore comparison between pre- and control will only highlight any effect of the secondary vessel. For this reason the pre-exposure phase was omitted from ANOVA. Post-treatment was also omitted from the ANOVA since not all whales were successfully tracked during this time and therefore including this phase would mean decreasing the number of subjects that could be included in the analysis. Summary statistics for five biological parameters measured during the control and treatment phases are provided below (Table 3.2).

Table 3.2: Descriptive statistics for the five dependant variables analysed in the ANOVA.

Variable	Mean	Std.Dev	Minimum	Maximum	N
IBI (control) (s)	22.4	5.9	15.1	36.1	15
IBI (treatment) (s)	35.4	21.0	15.3	80.0	12
ISI (control) (s)	238.2	59.5	134.0	344.1	15
ISI (treatment) (s)	282.6	98.1	206.0	489.0	12
Speed (control) (kmh^{-1})	8.4	1.9	4.2	12.1	15
Speed (treatment) (kmh^{-1})	15.1	4.7	6.6	21.4	10
Deviation index (control)	76.6	12.4	56.3	102.7	15
Deviation index (treatment)	79.0	36.5	10.2	133.6	9
Directness index (control)	51.6	23.2	7.8	85.1	15
Directness index (treatment)	78.6	15.6	56.7	99.8	9

3.3.7 Results of the repeated measures ANOVA for within-subjects effects found a significant difference in whale behaviour between the control and treatment phases (Global $F_{5,4} = 8.74$, $p = 0.028$). Subsequent univariate tests for within-subjects effects showed that the variables representing speed and directness index varied significantly between control and treatment tracks (Table 3.3). Estimates of partial ETA squared suggest nearly 81% of the variability in whale speed is due to the independent variable (i.e. treatment type).

Table 3.3: Univariate tests for within-subjects effects in the repeated measures ANOVA.

Variable	Type II SS	Df	F	Sig.	Partial Eta squared
IBI	0.002	1	0.165	0.695	0.020
ISI	0.294	1	0.728	0.418	0.083
Speed (kmh^{-1})	246.4	1	33.216	0.000	0.806
Deviation index	1.027	1	0.001	0.971	0.000
Directness index	3695.1	1	5.701	0.044	0.416

3.3.8 There were some outliers in the dataset (show in Figure 3.15). The outliers often relate to the small sample size and the variation in behaviour from one whale to another. The only extreme outlier (more than three times the inter-quartile range) in the dataset was an estimate of mean inter-blow interval during a ‘post’ track (shown as focal whale 24 in the boxplot; Figure 3.15). As it is likely that outliers in this study may represent genuine individual variation, removal of outliers was not considered an appropriate action. When comparing ‘control’ and ‘treatment’ tracks, however, the extreme outlier mentioned above is not an issue.

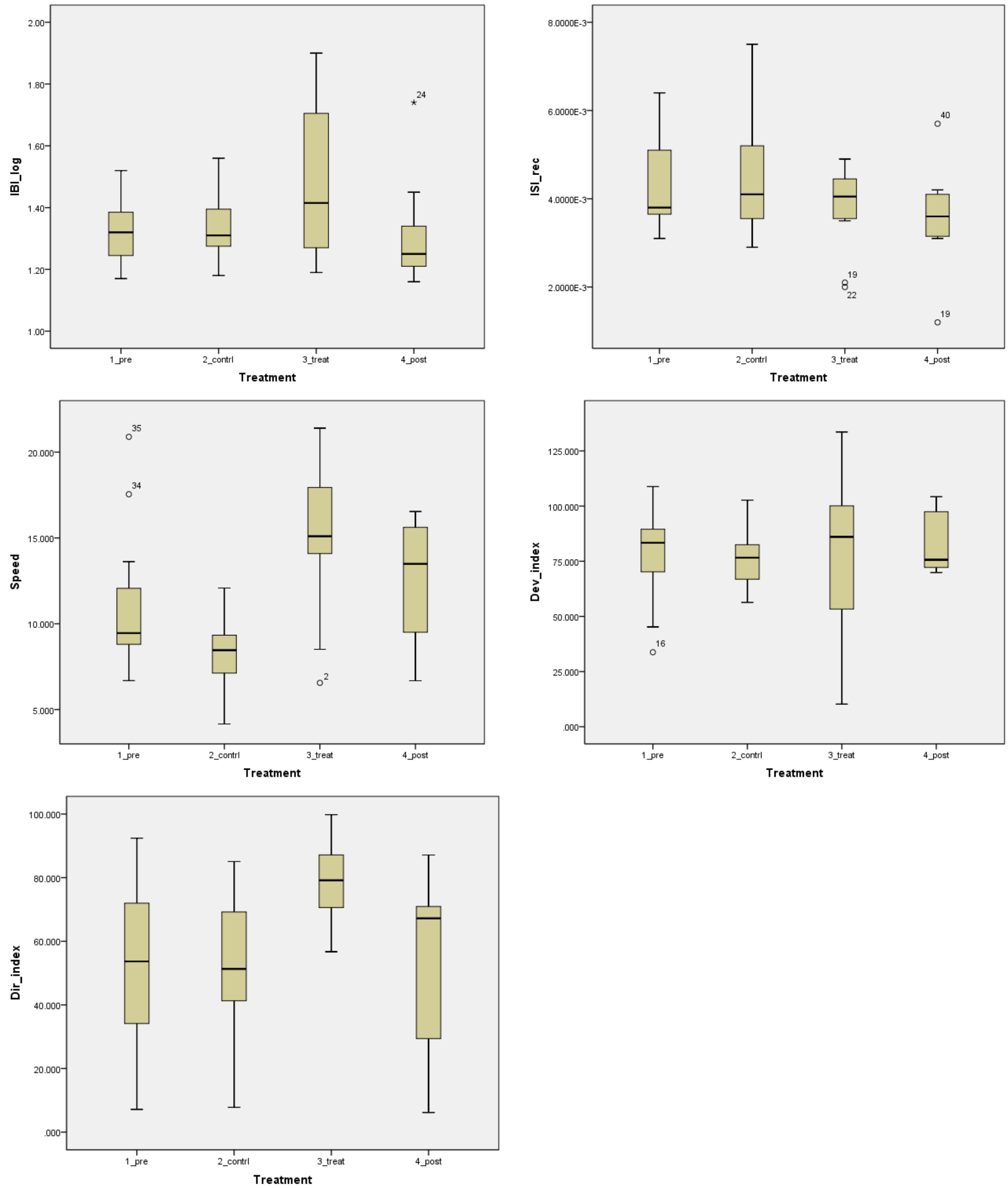

Figure 3.15: Boxplots of all levels of the independent variable (treatment type) for the five dependent variables. Outliers (more than 1.5 times the inter-quartile range) are represented by circles along with the relevant case number; extreme outliers (more than three times the inter-quartile range) are represented by asterisks.

3.3.9 These results of the repeated measures ANOVA suggest significant differences between the control and treatment phases but not the exact nature of these differences. Therefore, *post-hoc* pairwise comparisons were calculated with Bonferroni corrections to identify the changes that were occurring in the tracked whales' behaviour. For the highly significant difference found in the net speed of travel, whales were, on average, increasing their net swim speeds by 7.4 kmh^{-1} when exposed to the ADD treatment (Table 3.4). Similarly, the mean directness index increased by 28, suggesting that the path of the whales' travel became straighter (less circular) when exposed to the ADD (Table 3.4).

Table 3.4: Post-hoc pairwise comparisons between control and treatment tracks for each of the dependent variables (significance estimates with a Bonferroni correction.

Variable	Mean difference (control – treatment)	Std Error	Sig.	95% CI (lower bound)	95% CI (upper bound)
IBI	0.951	1.135	0.695	0.711	1.271
ISI	-3.906	3.333	0.418	-1.057	2.299
Speed (kmh^{-1})	-7.400	1.284	0.000	-10.361	-4.439
Deviation index	0.478	12.909	0.971	-29.289	30.245
Directness index	-28.656	12.002	0.044	-56.311	-0.980

Away-speed

3.3.10 When comparing the net swimming speeds of whales in the repeated measures ANOVA (Section 0), speed was found to increase significantly between the control and treatment phases after the activation of the ADD. For net away-speed only the treatment and post-treatment phases could be compared and a small increase in away-speed going from the treatment to the post-treatment phases of the CEE was found (mean difference = -0.11, SD = 1.28) (Figure 3.16). The repeated measure *t*-test found that this difference was not significant $t(6) = -0.236$, p = 0.822 (Table 3.5).

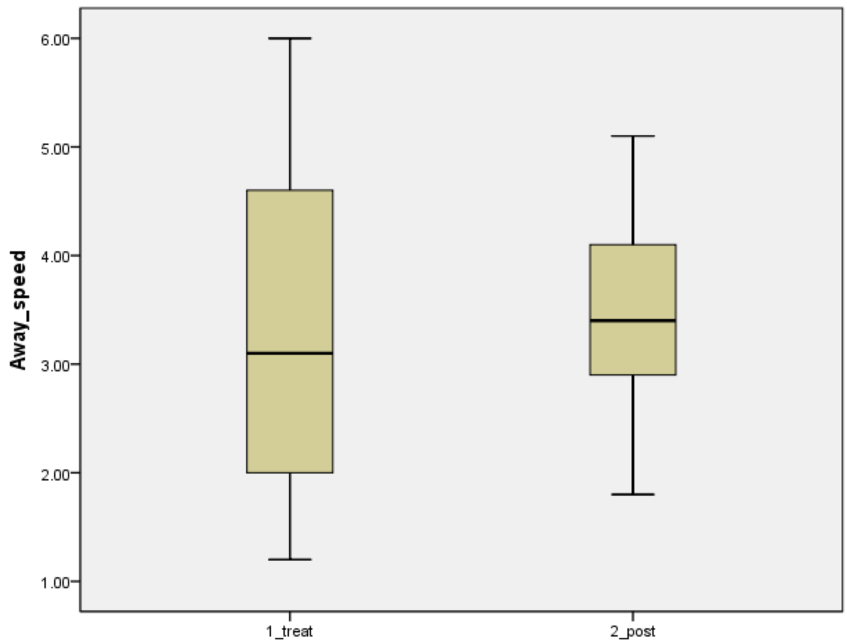

Figure 3.16: Box plot showing mean and inter-quartile range for net away-speed (kmh^{-1}) estimated for all tracked focal whales during the treatment and post-treatment phases of the CEE.

Table 3.5: Repeated measures t-test for the difference in away-speed (kmh^{-1}) between treatment and post-treatment phases.

Paired test	Mean difference	S.D.	S.E.	95% CI (lower)	95% CI (upper)	t	df	Signif. (2-tailed)
Treatment vs post-treatment	-0.11	1.28	0.49	-1.30	1.07	-0.236	6	0.822

3.3.11 A plot of net away-speed against time elapsed suggested that the most pronounced changes in away-speed occurred during the 15 minute treatment phase (Figure 3.17). Therefore an additional comparison of away-speeds was made by comparing the first half of values measured during the treatment phase (T1) with the second half of values within this same phase (T2).

3.3.12 A summary of the net away-speeds recorded during treatment, control and T1 and T2 is provided in the following table (Table 3.6).

Table 3.6: Descriptive statistics for net away-speed (kmh^{-1}) measured during each tracking phase.

Tracking phase	Mean	S.D.	Minimum	Maximum	N
Treatment	3.4	1.8	1.2	6.0	7
Post-treatment	3.5	1.1	1.8	5.1	7
T1	2.8	4.1	0.0	13.1	9
T2	6.4	5.0	1.7	16.8	9

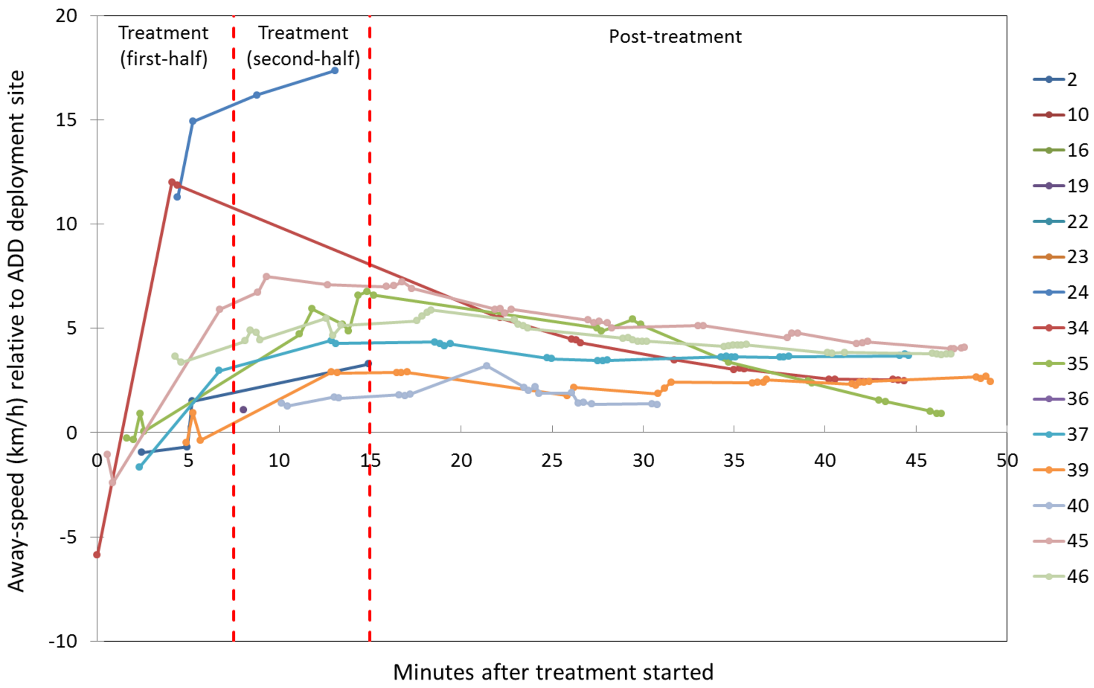

Figure 3.17: Variation in the vector net away-speed (kmh^{-1}) over time during the treatment and post-treatment phases of the CEE for the different focal whales. The two halves of the treatment phase (T1 and T2) are denoted by the red dotted lines.

3.3.13 There were only two notable outliers in the dataset, caused by elevated away-speeds measured from the track of whale 24 during the treatment phase (Figure 3.18). As it is likely that outliers in this study may represent genuine individual variation, removal of outliers was not considered an appropriate action. When making the overall comparison between the treatment and post-treatment tracks, however, these outliers were not problematic.

3.3.14 The repeated measures *t*-test found that away-speeds were significantly higher (on average, 3.53 ± 2.53 kmh^{-1} faster) in the second half of the treatment phase compared to the first half ($t(8) = -4.19$, p = 0.003) (Table 3.7). This suggests that there is an 'acceleration phase' away from the ADD once it has been activated and that whales typically accelerated away from an active ADD during the treatment phase before reaching a steady away-speed of 6.4 kmh^{-1}.

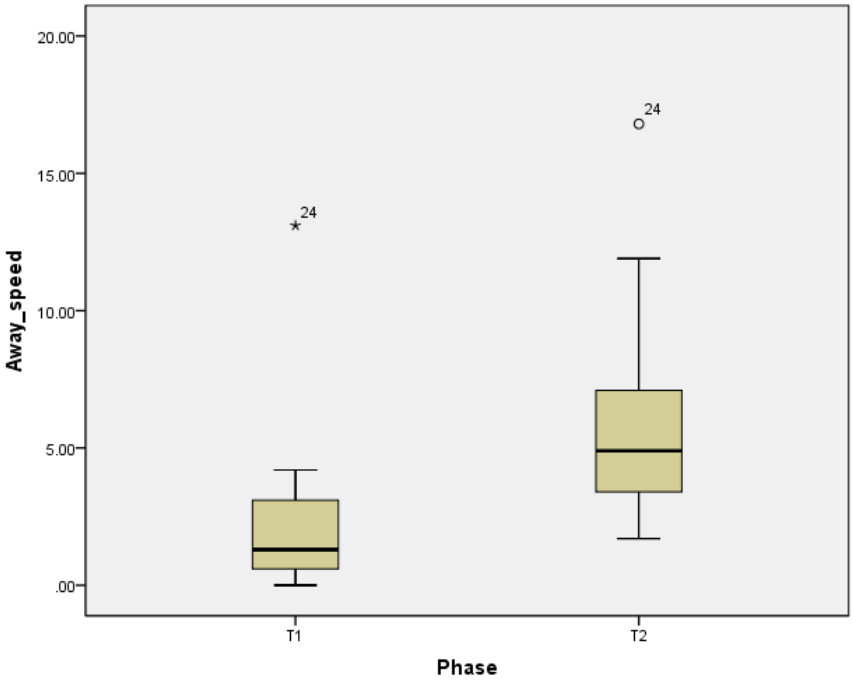

Figure 3.18: Box plot of away-speed (kmh^{-1}) measured during the first and second halves of the treatment phase (T1 and T2 respectively). An extreme outlier (more than 3 times the inter-quartile range) in T1 is represented by an asterisk; an additional outlier (more than 1.5 times the inter-quartile range) in T2 is represented by a circle along. Both outliers are derived from the track of focal whale 24.

Table 3.7: Repeated measures t-tests for the difference in away-speed (kmh^{-1}) between the first half (T1) and second half (T2) of the treatment phase.

Paired test	Mean difference	S.D.	S.E.	95% CI (lower)	95% CI (upper)	t	df	Signif. (2-tailed)
T1 vs T2	-3.53	2.53	0.84	-5.48	-1.59	-4.190	8	0.003

3.3.15 The backwards stepwise multiple regression model looking at the effect of environmental parameters on average away-speed during the treatment phase found that the best predictors were: time, distance to the ADD, depth and slope ($F_{4,5} = 17.394$, $p = 0.008$). This was the 4th model in stepwise sequence, the previous three having dropped latitude, SST, and wind speed respectively. The final model (model 4) explained 98.2% of the variance (R^2) in away-speed in whales (Table 3.8).

Table 3.8; Results of multiple linear regression for the final model

Model	R	R^2	Adjusted R^2	Std. Error of the estimate	Dubin-Watson
4	0.991	0.982	0.901	1.302	2.458

3.3.16 All the coefficients, with the exception of slope, were significant in the final model, indicating that slope is a less important feature in explaining away-speed, however, since the standardised coefficient is large for slope (0.385) it is still considered to be relatively important in the overall model.

3.3.17 Standardised coefficients and the associated significance levels suggest that distance from the ADD is one of the best predictors of away-speed (Table 3.9). The unstandardised coefficient shows that for every 100 m closer to the ADD deployment site there is a 0.89 kmh^{-1} increase in away-speed, assuming all other variables are held constant. Encounter rate also ranks high in the model, although the change in away-speed is very small, such that for an increase in encounter rate of 1 animal for every 10 km of search effort the away-speed increases by 0.9 kmh^{-1}, when holding all other variables constant (Table 3.9).

3.3.18 The multiple regression model also found that away-speed decreased with increasing: i) depth (for every 1 m increase in depth a decrease of 0.10 kmh^{-1}); ii) slope (for every % increase in slope a decrease of 2.78 kmh^{-1}); and iii) time of day (for every hour later in the day a decrease of 0.86 kmh^{-1}) (Table 3.9).

Table 3.9: Coefficients in the multiple linear regression for the final model.

	Unstandardised coefficients		Standardised coefficients			Collinearity statistics	
Model	B	Std. error	Beta	t	Sig.	Tolerance	VIF
(Constant)	30.851	4.096		7.532	0.002		
Time	-0.857	0.185	-0.518	-4.625	0.010	0.875	1.143
Depth	-0.101	0.027	-0.422	-3.758	0.020	0.871	1.148
Slope	-2.780	1.163	-0.385	-2.391	0.075	0.423	2.364
Distance from ADD	-0.008	0.002	-0.816	-5.387	0.006	0.479	2.088
Encounter rate	0.089	0.019	0.523	4.785	0.009	0.920	1.087

Relationships between received ADD sound levels and biological parameters

3.3.19 As discussed previously, there was limited ability to undertake detailed analysis of the relationship between received sound pressure levels and biological response parameters. This is because:

- There were a limited number of treatment experiments; and
- The treatment experiments were generally started with a similar range between the ADD and mammal, meaning that animals were exposed to similar sound levels during each test.

3.3.20 The above factors mean that most tests were conducted with maximum sound pressure levels in the range 130 to 140 dB re 1 µPa (rms) (according to the noise propagation model) with only one animal being treated at a lower level and one at a higher level. Figure 3.19 shows a comparison between the received sound pressure level and percentage change in directness index. Whilst this does show an apparent increased reaction at higher SPL, this is based on limited data and some caution should be exercised in interpreting these results.

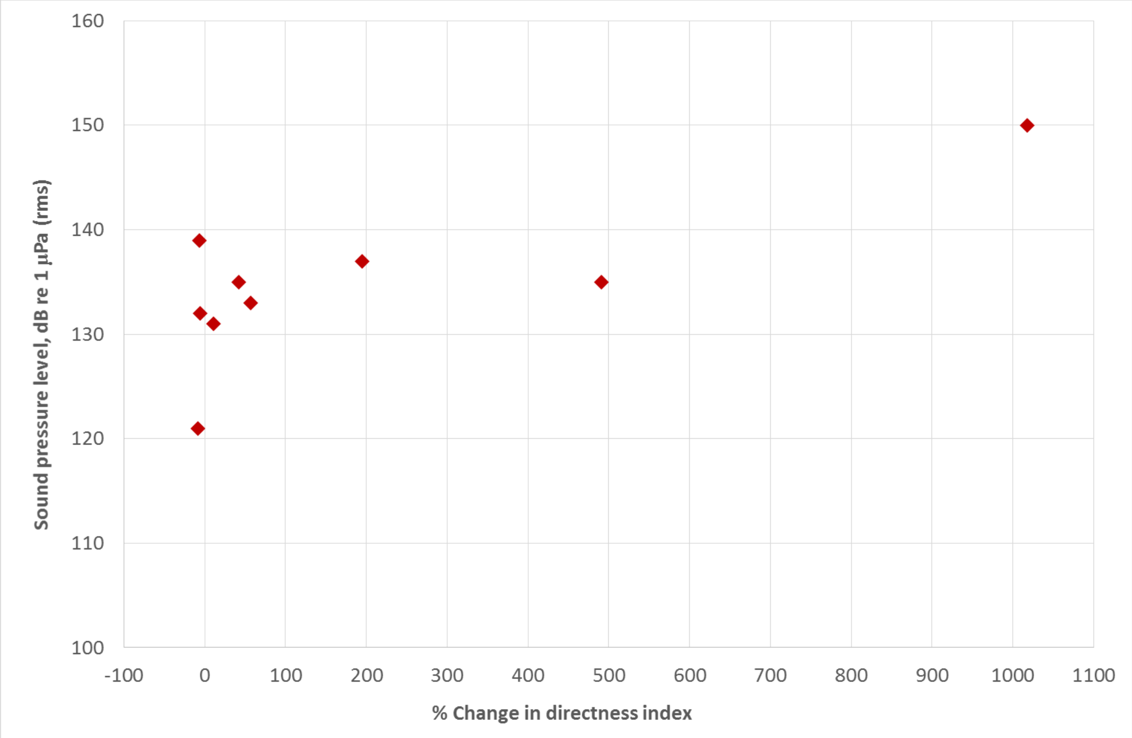

Figure 3.19: Plot of percentage change in directness index vs. maximum estimated rms sound pressure level to which animal was exposed during the test.

4 Discussion

4.1 Effectiveness of the Lofitech ADD on deterring minke whale

Invoking a deterrence response

4.1.1 Central to the idea of 'effectiveness' of the ADD, is the ability to deter animals from proximity to piling that may result in injury. The objective within this study was to examine whether this could be achieved over a minimum of a 500 m mitigation zone, typically utilised during construction projects following the JNCC guidelines (JNCC, 2010b and 2010c). A given ADD unit may have capability beyond this range, but in order to be considered fit for purpose, that range must be kept clear prior to the onset of the noise-producing activity (e.g. pile-driving). The results presented here demonstrate that the Lofitech ADD modifies the behaviour of free-ranging minke whales at both 500 m and 1,000 m. In this Controlled Exposure Experiment (CEE), the tracked minke whales demonstrated a significant increase in net swim speed, and a significant increase in the directness of their movement during the treatment phase of the CEE (i.e whilst the ADD was activated).

4.1.2 Of all the biological parameters measured, the greatest effect of the ADD deployment appeared to be on net swim-speed and directness. There was a marked increase in net swim speed during the treatment phase with focal whales increasing their net speed by 7.4 kmh^{-1} compared to the control phase. The mean net swim speed decreased after treatment but was still, on average, higher compared to the control phase. Summary statistics showed that the mean net swim speed for the treatment phase was 15.1 ± 4.7 kmh^{-1}. This is faster than the assumed fleeing speed of minke whales currently used in many acoustic models for pile-driving, which is a conservative 1.5 ms^{-1} (= 5.4 kmh^{-1}) based on Otani *et al.* (2000). It is also faster than other commonly cited swim speeds for minke whale such as 3.25 ms^{-1} (=11.7 kmh^{-1}) based on the work by Blix and Folkow (1995) or 4.5 knots (=7.4 kmh^{-1}) following Stern (1992). These results suggest that the conservative assumptions used in acoustic models should be re-visited as knowledge on swim speeds is improved, although noting that a certain level of precaution is still necessary since acoustic models commonly assume that animals maintain a constant directional movement, fleeing perpendicular to the noise source, which may not be case. Thus, it is important to take account of both swim speed and directionality.

4.1.3 It is therefore encouraging that there was also found to be a significant increase in directness for minke whales exposed to the ADD during the treatment phase. On average the directness index increased by 28, with the mean value estimated during the treatment phase as 78.6 ± 15.6. Scored out of a possible 100, this demonstrates that the focal whales exposed to the ADD were responding with directed movements away from the ADD.

4.1.4 Furthermore, estimates of net "away-speed" (a measure of net speed and distance from the ADD source) indicated that whales consistently moved away from the site of the ADD deployment, and had significantly higher net speeds during the second half of the treatment phase. This suggests that the focal whales continued to increase their speed when exposed to the sound of an ADD playback, up to a speed that they then maintain while swimming in a direct line that reduces their exposure to the aversive sound.

4.1.5 Further assessment of the away-speed response of the focal whales found that a number of environmental parameters were able to significantly explain an increase or decrease in away-speed. Distance to the ADD was the most significant of these predictors and the results suggests that whales are responding more strongly the closer they are to the deployment site (i.e. their away-speed increases with decreasing distance to the ADD). It was hypothesised that this was most likely due to the higher sound levels received at closer range, however, the small number of data points for whales exposed to the ADD at closer ranges meant that this was difficult to statistically validate.

4.1.6 Depth and slope also influence how a whale may respond to the ADD. As both depth and slope increased so the net away-speed of whales was found to decrease. It is possible that this could be due to the increasing depth leading to more rapid decay of sound due to propagation over distance. In other words, the larger distance between the bounding layers of the surface and bottom provides a greater volume over which the sound energy can "spread". However, it is likely that this effect would be minor over the distances concerned. It is also possible that this could be a behavioural effect either due to natural response to the changes in the animals surrounding environment i.e. if animals move deeper naturally in response to an increase in depth the distance travelled in a horizontal plane could reduce, or that a flight response results in the animal deliberately moving to deeper water.

Effectiveness of ADD in the context of background noise

4.1.7 The vast majority of research relating to both physiological effects and behavioural disturbance due to noise on marine species is based on determining the absolute noise level for the onset of that effect. As a result, methods and criteria for assessing the effects of noise on marine mammals and fish tend to be based on the absolute criteria, as opposed to the difference between the ambient noise level and the specific sound being assessed (e.g. Southall *et al*., 2007).

4.1.8 It is important to note that there is a paucity of scientific understanding regarding how various species distinguish anthropogenic sound relative to masking noise. An animal's perception of sound is likely to depend on numerous factors including the hearing integration time, the character of the sound and hearing sensitivity. It is not known, for example, to what extent marine mammals can detect tones of lower magnitude than the background masking noise or how they distinguish time varying sound. Therefore, it is necessary to exercise considerable caution if attempting any comparison between the ADD source noise and the masking ambient noise level. For example, it does not follow that because the sound pressure level due to the source being considered is below the numeric value of the ambient noise level that this means that marine mammals cannot detect that sound. This is particularly true where the background noise is dominated by sound which is outside the animal's range of best hearing acuity.

4.1.9 Generalised ambient noise spectra attributable to various noise sources (Wenz 1962) are shown in Figure 4.1.

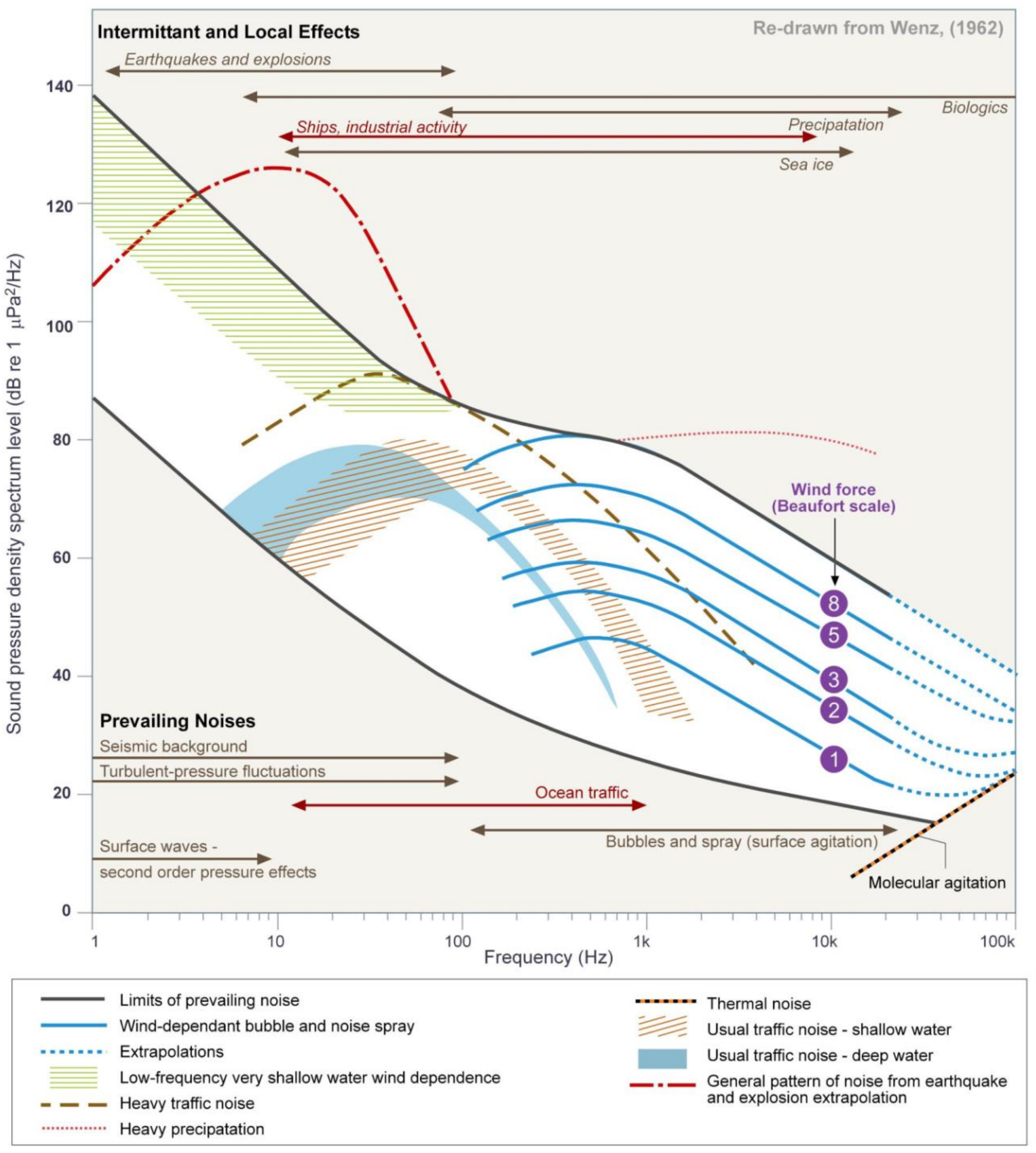

Figure 4.1: Generalised ambient noise spectra attributable to various noise sources (Wenz 1962).

4.1.10 It can be seen that noise levels are generally dominated by sources of a low frequency character. Whilst it is possible that higher wind and rain noise could increase the masking level in the region of the ADD frequency it is unlikely that, for example, noise from vessels would produce any significant sound energy in the same frequency region as the ADD. Consequently, it is considered unlikely that higher ambient noise conditions on wind farm sites would significantly affect the effectiveness of ADDs as a mitigation measure, subject to the limitations discussed above relating to paucity of data on marine mammal sound perception.

Biological effects of ADD use

4.1.11 Originally intended for use in the fish farm industry, ADDs were designed to emit unpleasant sounds in the sensitive range of hearing of seals, but with no intention to have any biological significance to seals. Given the consequent success of such devices to deter other species, and potential applications to other industries, it was necessary to explore, in this study, whether there is potentially any biological significance for minke whale in employing ADDs as mitigation devices.

4.1.12 To this end the study investigated whether ADDs, through exposure to peak pressure levels or through cumulative sound exposure, can lead to PTS or TTS in minke whale. Both peak pressure and cumulative dose were found to be lower than the NOAA thresholds at which the onset of PTS and TTS could occur. Even based on the more precautionary cumulative approach – assuming a starting distance of 25 m, a conservative estimate for swim speed of 2.5 ms^{-1} and an ADD deployment duration of 30 minutes – the cumulative noise model found that there was no realistic potential for inducing any kind of auditory damage. It was also found that auditory damage was unlikely to occur even for much lengthier deployments such as 1 or 2 hours of ADD use. This is because the main exposure occurs during the first few tens of pulses upon start-up, with the exposure due to each pulse reducing as the animal swims away.

4.1.13 Having established that injurious effects are not predicted to occur, the fundamental question that needs to be asked is whether the introduction of ADD use as a mitigation measure significantly increases the risk of disturbance (compared to piling or piling and soft start only) and then whether the benefits outweigh any such increase in disturbance. Disturbance has the potential to cause detrimental biological effects on marine mammals, including reduced feeding, cessation of vocalisations, interruption of breeding behaviour, startle responses and displacement from key habitats. These in turn may lead to physiological effects which may then affect marine mammal populations e.g. increase in mortality or decrease in fecundity.

4.1.14 The use of ADDs as a mitigation method relies on the premise that marine mammals will be disturbed enough to leave the area on hearing the ADD signal. It is therefore relevant to consider potential disturbance from using ADD and whether this represents an acceptable balance between the "unwanted side effects" and benefits.

4.1.15 Previous studies have determined that marine mammal disturbance occurs within tens of kilometres of impact piling activities. Consequently, the starting point for comparison is one where potential disturbance, leading to likely avoidance, is already likely to occur. Given, that the source sound pressure level due to ADD use is significantly lower than those produced during impact piling, it is considered likely that the zone of disturbance due to the piling itself will be significantly larger than that due to the use of ADDs. Consequently, the primary effect of introducing ADDs is that there is a slightly longer period when disturbance occurs compared to piling alone. Driving a pile is likely to take several hours at a time, and therefore it is considered unlikely that any additional period of disturbance due to ADD deployment would be significant.

4.1.16 Injury is considered to be a more severe impact than disturbance because disturbance is likely to be temporary. Consequently, on balance, it is generally concluded that the benefits in terms of reducing the likelihood of injury far outweigh the slight increase in time over which disturbance may occur. On a project-specific basis, however, the effects of disturbance, including any arising from deployment of ADDs, must be investigated, particularly in respect of EPS legislation, under which it is an offence to deliberately disturb wild animals of an EPS.

Deriving a severity scale for minke whale

4.1.17 To assess and quantify any adverse behavioural effects of noise exposure, a metric for the impact such changes might have on critical biological parameters such as growth, survival, and reproduction is required. The severity scale of Southall *et al*. (2007) was designed to provide some analytical basis for assessing biological significance using the best available evidence from scientific literature. Establishing a severity score is meant to differentiate between minor and/or brief responses (0–3), those that could affect foraging, reproduction or survival (4–6), and those (7–9) that could be considered likely to affect vital rates (Appendix E – Southall *et al.* (2007) Behavioural Response Severity Score Table). Although developing severity scales in this way is inherently constrained by our limited understanding of the effects of external influences on free-ranging marine mammals, it does provide a rudimentary framework for assessing the relative biological importance of behavioural responses.

4.1.18 Williams *et al*. (2014) derived a number of response variables similar to those used in the ADD study from a study of killer whale behaviour in response to vessel traffic. In that study, minor, moderate and extensive changes in any given variable were defined as follows:

- No change: 0–10% (response score 0);
- Minor change: 10–20% (response score 2-3);
- Moderate change: 20–50% (response score 3-4); and
- Extensive change: >50% (response score 5).

4.1.19 For the purposes of this study, the same classification scheme was used for the variables relating to net swim speed, dive profile (IBI & ISI) and path predictability (deviation and direction indices). In addition, the away-speed variable was used to provide evidence of both moderate and extensive avoidance as summarised in Table 4.1.

Table 4.1: Severity scale used in this study (following Southall et al., 2007 and Williams et al., 2014).

Response score	% change in given variable(s)	Corresponding behaviours
0	0 – 10 (any variable)	No change in any response variables
1	10 – 20 (deviation or directness)	Brief orientation response
2	10 – 20 (IBI or ISI)	Minor change in dive profile
	10 – 20 (deviation or directness)	Multiple orientation behaviours
3	10 – 20 (speed, deviation or directness)	Minor change in locomotion speed, direction and/or deviation
	20 – 50 (IBI or ISI)	Moderate change in dive profile
4	20 – 50 (IBI, ISI, speed, deviation or directness)	Moderate change in locomotion speed, direction, deviation and/or dive profile
5	>50 (IBI, ISI, speed, deviation or directness)	Extensive change in locomotion speed, direction, deviation and/or dive profile
6	As for response score 5 plus 10 – 50 (away-speed)	Minor or moderate avoidance
7	As for response score 5 plus >50 (away-speed)	Severe and/or sustained avoidance

4.1.20 The parameters measured from each focal whale are summarised in Table 4.2. Estimates of inter-blow interval, inter-sequence interval, net swim speed, deviation index and directness index could be made from all tracking sessions; estimates of away-speed could only be made for the treatment and post-treatment phases. These variables were used to derive a severity score for each focal whale following the criteria in Table 4.1; these are summarised in Table 4.2. Following Southall *et al*. (2007), only a single response needs to be observed to derive the corresponding score (i.e. not all behavioural responses need be observed). If multiple responses were observed, the one with the highest score was used to derive the severity score.

4.1.21 Of the 15 tracks analysed, severity scores could be derived for 13 focal whales. For six of the animals successfully tracked at the start of the study, there was no away-speed recorded and this has an effect on the final severity score. This is because the away-speed score is the deciding factor for increasing the severity score from a 5 to a 6 or 7. Thus, it is important to note that for animals without an away-speed recorded, the final score represents a minimum value only. Indeed, if the tracking graphs are examined for these first six tracked whales (Response Maps), it can be seen that all focal whales successfully tracked during the treatment phase (i.e. #2, 19, 24) elicited an avoidance response, so on this basis the severity score for tracked focal whales should be 6 or 7 according to the definitions. Other focal whales listed in Table 4.3 without an away-speed were those that were lost during the control phase. It is possible that these whales also exhibited avoidance responses. As these whales were tracked in almost optimal environmental conditions (i.e. low sea states with good visibility), it is more likely that the whales were lost due to sudden changes in behaviour (such as rapidly leaving the area) than an alternative explanation that the observers were unable to see them even though they had remained in the area.

4.1.22 Of the animals where an away-speed was recorded (#34, 35, 37, 39, 40. 45 and 46) two of the tracks (#37 and 39) showed sustained avoidance, expressed in a continued increase in away-speed throughout the post-treatment phase; these tracks were classified with a severity score of 7. Another two focal whales (#35 and 40) showed minor or moderate avoidance, characterised by a slightly lower percentage change in away-speed. The remaining three successfully tracked animals during the treatment phase (#34, 45 and 46) all scored a 5 on the severity scale. Examining the tracking maps (Response Maps), it can be seen that whales #34, 45 and 46 initially moved directly away from the ADD in an avoidance response but then during post-treatment, changed direction to move perpendicular to the direction of travel away from the ADD. Note that if we were to use the away-speed calculated as the difference between the first and second half of the treatment phases (T1 and T2), the % change would be greater and therefore lead to an increase in the severity scores from 5 or 6 up to a score of 7.

Table 4.2: Summary of behavioural variables measured; IBI = inter-blow interval, ISI = inter-sequence interval, speed = net swim speed, dev_ind = deviation index, dir_ind = directness index and away = away-speed. Where available, the upper value represents the average; the lower value represents the standard deviation (- denotes an estimate made from a single measurement for which no standard deviation is available).

	Pre-treatment					**Control**					**Treatment**						**Post-treatment**					
Whale ID	IBI	ISI	Speed	Dev_ind	Dir_ind	IBI	ISI	Speed	Dev_ind	Dir_ind	IBI	ISI	Speed	Dev_ind	Dir_ind	Away	IBI	ISI	Speed	Dev_ind	Dir_ind	Away
2	16.9	162.2	8.8	74.2	7.1	21.3	184.6	7.2	79.5	7.8	15.7	222.5	6.6	51.0	87.1	1.7	22.0					
	11.4	45.4	7.2			13.0	110.0	5.9			7.5	82.2	3.2			2.7	17.0					
10	24.8	155.5	8.8	45.2	72.3	30.3	180.3	7.1	62.8	56.0												
	18.6	33.9	6.5			24.9	55.0	4.3														
16	24.2	223.8	8.5	33.8	92.4	26.3	305.3	9.2	56.3	43.0	49.5											
	11.1	24.8	4.3			15.1	114.8	7.6			31.8											
19	18.8	319.7	8.8	91.1	73.5	19.3	311.7	7.0	74.6	80.2	61.0	482.0	8.5			1.1		818.0				
	6.4	106.6	7.1			5.4	112.2	4.1			-	-	-			-		-				
22	18.4	267.7	9.4	92.8	51.9	18.7	247.6	6.5	94.4	42.0		489.0										
	10.8	65.6	13.1			13.2	22.4	5.1				-										
23	27.2	175.1	9.2	89.7	40.4	20.6	169.1	8.5	67.8	51.3	80.0	282.0										
	16.8	46.0	5.4			12.9	52.4	5.1			-	-										
24	33.2	156.3	9.5	85.1	27.9	36.1	134.0	9.1	73.0	16.9	52.5	207.3	21.4	10.2	99.8	14.9	55.5					
	22.9	34.6	7.1			26.3	29.1	7.9			25.9	60.6	9.0			2.6	3.5					
34	15.0	256.7	17.5	89.3	71.6	19.3	242.0	10.6	84.9	63.2	15.3	232.0	14.1	100.1	99.2	6.0	16.3	319.1	6.7	70.8	87.1	3.4
	4.3	35.9	14.9			17.3	54.0	6.9			2.9	-	0.1			10.3	1.8	203.3	3.9			1.0
35	16.9	287.0	20.9	83.4	25.6	20.2	227.9	8.3	76.6	40.6	22.9	206.0	17.9	88.5	57.8	3.1	28.3	235.7	16.5	69.9	25.3	3.4
	5.0	22.0	15.7			5.9	53.6	8.4			9.4	117.5	15.5			2.9	23.0	127.2	10.3			2.2
36	23.2	279.0	11.4	82.0	48.4	15.1	344.1	12.1	77.9	51.8												
	15.4	118.4	9.3			3.5	55.0	7.9														
37	26.2	269.6	10.0	66.2	62.7	30.7	213.3	4.2	80.1	85.1	26.0	268.0	14.9	79.6	79.2	2.5	14.5	278.7	8.9	75.7	68.4	3.7
	21.5	116.6	10.1			18.1	62.8	2.1			13.6	71.6	17.9			2.9	2.4	103.1	5.6			0.3
39	19.6	263.0	12.7	79.6	65.1	18.0	294.0	9.6	87.5	75.2	20.2	278.7	15.3	133.6	70.6	1.2	16.8	314.7	16.1	96.8	67.2	2.4
	7.7	47.3	9.5			5.2	74.4	6.5			3.8	134.4	13.2			1.7	3.4	106.6	12.8			0.3
40	21.0	311.3	10.4	88.0	18.6	20.5	247.6	8.0	65.9	81.7	17.0	249.3	14.1	86.0	75.5	1.5	17.9	174.2	15.1	104.2	6.2	1.8
	7.9	36.9	8.2			4.8	43.6	5.0			1.7	119.1	9.3			0.2	4.8	55.7	12.9			0.5
45	21.3	273.7	13.6	108.8	53.7	16.7	271.4	9.0	102.7	27.5	37.9	227.5	14.2	53.3	81.2	4.7	19.0	250.2	13.5	98.1	33.5	5.1
	7.5	52.6	12.8	62.1		6.9	61.2	8.8			27.9	78.6	9.7			4.0	5.3	28.6	9.2			0.9
46	16.6	259.8	6.7	57.8	90.0	23.2	200.5	9.4	65.3	51.2	26.2	246.3	17.3	108.9	56.7	4.5	15.2	275.0	10.1	73.6	73.5	4.5
	2.2	59.7	3.5			10.7	101.2	5.7			19.0	123.0	11.7			0.7	1.9	24.4	5.8			0.7
Global mean	21.5	244.0	11.1	77.8	53.4	22.4	238.2	8.4	76.6	51.6	35.4	282.5	14.4	79.0	78.6		22.8	333.2	12.4	84.2	51.6	

Table 4.3: Percentage change in estimates of behavioural variables between the control and treatment phases (except for away-speed which is derived by comparison of the first half of the treatment with the second half of the treatment phase). For all variables except away-speed, only the absolute values were considered (i.e. either an increase or decrease of 26% in inter-blow interval would be considered a moderate change of 20-50%); for away-speed, a decrease was considered to represent no change and thus not constitute an avoidance reaction. Subsequent severity scores are derived following the rationale of Table 4.1.

% Change	Whale ID														
Control - treatment	2	10	16	19	22	23	24	34	35	36	37	39	40	45	46
IBI	-26		89	216		289	45	-20	13		-15	12	-17	127	13
ISI	21			55	97	67	55	-4	-10		26	-5	1	-16	23
Speed	-9			21			134	33	115		259	59	76	58	83
Deviation index	-36						-86	18	16		-1	53	31	-48	67
Directness index	1018						491	57	42		-7	-6	-8	195	11
Away-speed								-44	11		50	108	26	8	-1
Min. severity score	**5**		**5**	**5**	**5**	**5**	**5**	**5**	**6**		**7**	**7**	**6**	**5**	**5**

Implications for other low frequency cetaceans

4.1.23 It is notable that the fundamental frequency of the Lofitech ADD is outside the theoretical range of best hearing sensitivity of minke whales (Figure 1.2), although within their hypothesised hearing range. The results of this study confirm that minke whales can hear and do respond to sounds at this frequency (c. 15 kHz) which challenges whether their hearing sensitivity is better than hypothesised by Ketten and Mountain (2011) at this frequency.

4.1.24 There is a paucity of data relating to low frequency cetacean hearing in general, with available audiometric data being derived theoretically rather than measured. Thus, for example, the hearing weighting functions in the NOAA guidelines are derived based on a combination of available theoretical studies (Houser, Helweg, and Moore 2001; Cranford and Krysl 2015) and further theoretical predictions.

4.1.25 Given the scarcity of audiometric data, it is difficult to make any firm conclusions about possible implications for other low frequency cetaceans. However, by looking at the composite audiogram curves presented in Figure 4.2, it is clear that the fundamental frequency of c. 15 kHz is within the hearing range of all of the hearing groups. Clearly, further research needs to be carried out on individual species in order to confirm its effectiveness as a deterrent device for species other than minke whale. However, the fact that the frequency used is potentially audible to a wide range of marine mammals could theoretically mean that the Lofitech device could have a deterrent effect on a wide range of species.

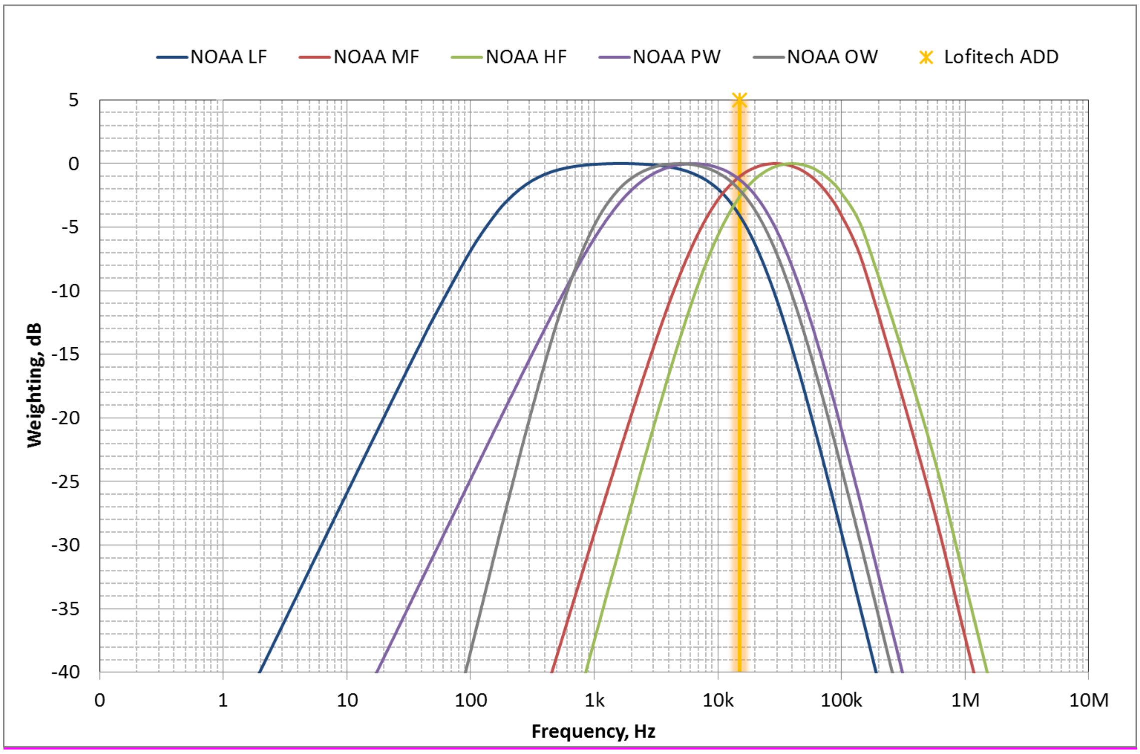

Figure 4.2: Comparison of NOAA (2016) hearing weighting curves and Lofitech ADD fundamental frequency. Key: LF – Low Frequency cetaceans, MF – Mid Frequency cetaceans, HF- High Frequency cetaceans, PW – Pinnipeds in Water, OW – Otariids (and other non-phocid marine carnivores) in Water.

4.2 Recommendations on the use of ADD in the offshore wind industry

4.2.1 These results suggest that ADD can be used as an effective mitigation measure for minke whale for the offshore wind farm industry to reduce the potential for injurious effects from piling. Based on the results of this study a number of recommendations can be made when considering the application of ADDs as a mitigation tool.

Type of ADD device

4.2.2 The device tested in this study was the Lofitech ADD and together with the results from other field trials (see section 1.3), it can be considered to be a successful multi-species mitigation tool for minke whale, harbour porpoise, harbour seal and grey seal. Whilst the frequency components that the Lofitech device emits are outside the theoretical range of best hearing sensitivity of minke whale, this study demonstrated that all of the focal whales responded to the received sound levels during ADD activation. Therefore, the results demonstrate that, if deployed, the Lofitech device could be used effectively to deter minke whales over ranges that would reduce the risk of exposure to harmful noise sources, such as piling at offshore wind farms. A range of other ADD devices also have acoustic characteristics in the hearing ranges of UK species of interest and have a proven track record at deterrence (primarily with harbour porpoise, harbour seal and grey seal). It is recommended, therefore, that further information is collated (particularly where there is field evidence available), to allow a range of devices to be signed off as potentially appropriate for multi-species mitigation.

4.2.3 In the final Stage One Phase Two ORJIP report Sparling *et al,* (2015) outline the factors influencing the suitability of an ADD device for use during pile driving at offshore wind farms. In addition, the report provides a review of the various devices that are currently available and assesses each of these against the required criteria that influence a successful ADD deployment. For each OWF project, guidance should be sought on the appropriate ADD unit to apply depending on the focal species.

Duration of activation

4.2.4 Given that the response of minke whales to the ADD was in some cases a prolonged avoidance, it is recommended that in each case the duration of exposure to ADDs should be tailored specifically to the project requirements. The duration of activation should be determined to ensure sufficient time for all marine mammals to flee the injury zone (estimated by project-specific modelling) whilst avoiding an extended period of activation to ensure additional disturbance is minimised. Hershel *et al.* (2015) recommended that the ADD is deployed to ensure marine mammals flee twice the length of the injury zone. The swim speed assumed should be based on the best available evidence from scientific studies of the relevant species. Where limited evidence is available, a precautionary approach should be applied, as is typical in most subsea noise models. Such precaution is necessary to allow for non-directional fleeing of an animal away from the noise source. In general, subsea noise models assume a swim speed of 1.5 ms^{-1} for most cetaceans and pinnipeds based on a study of harbour porpoise (Otani *et al.,* 2000). For minke whale, the swim speed typically used in subsea noise models is often 3.25 ms^{-1} based on Blix and Folkow (1995), however, the swimming speed of minke whale could be revisited in light of results from this study or other more recent work on minke whale.

Mitigation personnel and equipment

4.2.5 It is recommended that due consideration be given to the size and composition of the mitigation team deployed during construction projects, depending upon the scope of mitigation required following the consenting process. The recommendations provided below are for the ADD component of a mitigation plan only, and do not provide detail on any additional mitigation or how the ADD mitigation would be integrated into other mitigation that may be required as a licence condition.

4.2.6 The equipment is simple to use, but it is recommended to ensure a crew member (where permissible), or a dedicated MMO/PAM Operator is both familiar with the equipment and available for its deployment and operation where necessary. A single individual would be sufficient, unless additional visual and/or acoustic monitoring using traditional methods is required on a given project. However, for 24 hour operations, two personnel would be required. An important aspect of any ADD usage is whether it has been effective. While effective deterrence has been demonstrated experimentally, no guarantee can be provided that all animals will have moved beyond the mitigation zone in the given deployment timeframe. Consideration to should be given to visual and acoustic monitoring in tandom with ADD deployment to confirm that the mitigation zone is clear of animals in order to either commence operations or enact any necessary delay.

4.2.7 No equipment failure was experienced during the fieldwork for this project. However, the conditions for deployment were deliberately benign in order to ensure accurate behavioural data collection. The deployment of the ADD from a rigid inflatable vessel was straightforward and not representative of the varying conditions that may be experienced during construction projects. It is anticipated that the standard cable length of the transducer (25 m) may not be enough for all projects, depending upon the deployment location best suited to the equipment, and so Lofitech and any of their contemporaries producing similar devices will need to be able to provide alternative cable lengths. As the use of an ADD may be central to the mitigation of a project, back-up equipment is recommended, in case of loss or failure.

Communications protocol

4.2.8 It is recommended that a formal communications protocol be prepared for all projects in order to make clear where the mitigation personnel and equipment factor into the commencement of piling. This should identify those personnel dedicated to the deployment of the ADD, the interaction with any MMO/PAM Operator present, and to whom they report in order to ensure that the time between the cessation of the ADD signal is swiftly followed by the onset of piling. As with traditional MMO/ PAM fieldwork, it is recommended that the personnel responsible for ADD deployment keep accurate records of deployment times and conditions in order to prepare suitable daily, weekly and end of project summary reports.

5 Conclusions

5.1.1 The objective of this study was to determine whether ADDs can be considered an effective mitigation tool to deter minke whales, a low-frequency cetacean, from potential injury zones prior to the onset of piling at offshore wind farms. Key findings from this study are highlighted below:

- ADDs are effective at invoking a deterrence response in minke whale without the risk of inducing injurious effects even if deployed over longer durations (1-2 hours);
- Measured biological parameters showed that minke whales are responsive to ADD activation, for example by increasing their net speed and directness away from the source and maintaining this even after the ADD has been deactivated;
- When compared to the Southall *et al.* (2007) severity scale, the response of minke whales to ADDs is considered to score 5, 6 or 7, representing a minor avoidance up to a sustained avoidance;
- Subject to a limited understanding of how marine mammals perceive sound, it is considered unlikely that higher ambient noise conditions on wind farm sites would significantly affect the effectiveness of ADDs as a mitigation measure; and
- Used as a tool for mitigating for injurious effects from pile-driving activity, the additional duration of ADD deployment (in the context of the duration of pile-driving) is not considered likely to induce temporary or permanent hearing damage, nor result in any long-term behavioural effect;

5.1.2 Based on these findings, the report has made a number of recommendations for the use of ADDs as a mitigation tool, as required under project-specific licence conditions. The recommendations discuss the type of ADD to be used, duration of deployment, personnel and equipment requirements and the communication protocol.

5.2 Future Research

5.2.1 This study has focussed on the effect of ADDs on minke whale, as a low-frequency cetacean and adds to current scientific understanding of the effectiveness of such devices in a multi-species environment. Further work is, however, required to gathering empirical evidence with respect to the potential efficacy of using ADD to deter other low-frequency cetaceans over the predicted injury ranges. In addition, field studies are required to investigate the efficacy of using ADDs to deter mid-frequency cetaceans over injury ranges.

5.2.2 The device used in this study was the Lofitech, however, there are a range of other devices on the market, and under development that may to be effective at deterring marine mammals from injury zones. Consideration should therefore be given to investigating the potential effectiveness of alternative ADD units for a suite of marine mammal species.

5.2.3 Finally, it is important that the results of future research initiatives, either carried out at a site-specific level, or as part of a strategic work programme, are shared among the offshore wind farm community to inform future projects and the industry as a whole.

6 References

Anderson, S. and Hawkins, A.D. (1978) Scaring seals by sound. Mammal Review. 8: 19-24.

Barlow, J. and Cameron, G.A. (2003). Field experiments show that acoustic pingers reduce marine mammal bycatch in the California drift gill net fishery. Mar. Mammal Sci. 19(2): 265–83Gotz, T. & Janik, V.M., 2010. Aversiveness of sound in phocid seals: psychophysiological factors, learning processes and motivation. Journal of Experimental Biology, 213, 1536-1548

Barlow, J., Gisiner, R. (2006). Mitigating, monitoring and assessing the effects of anthropogenic sound on beaked whales. Journal of Cetacean Research and Management 7, 239–249

Blix, A. S. and Folkow, L. P. (1995). Daily energy expenditure in free living minke whales. Acta Physiol. Scand., 153:61-66.

Brandt, M.J., Höschle, C., Diederichs, A., Betke, K., Matuschek, R., Nehls, G., (2013a). Seal scarers as a tool to deter harbour porpoises from offshore construction sites. Mar. Ecol. Prog. Ser. 475, 291–302. http://dx.doi.org/10.3354/meps10100.

Brandt, M.J., Höschle, C., Diederichs, A., Betke, K., Matuschek, R., Witte, S., Nehls, G., (2013b). Far-reaching effects of a seal scarer on harbour porpoises, *Phocoena phocoena*. Aquat. Cons. Mar. Freshw. Ecosyst. 23(2), 222–232. http://dx.doi.org/10.1002/aqc.2311.

Centrica Energy (2007) Lincs Offshore Wind Farm Environmental Statement. January 2007.

Cooper, Lisa Noelle, Nils Sedano, Stig Johansson, Bryan May, Joey D. Brown, Casey M. Holliday, Brian W. Kot, and Frank E. Fish. 2008. "Hydrodynamic Performance of the Minke Whale (Balaenoptera Acutorostrata) Flipper." Journal of Experimental Biology 211 (12): 1859–67.

Cox, T. M., Read, A. J., Solow, A. R., and Tregenza, N. (2001). Will harbour porpoises (*Phocoena phocoena*) habituate to pingers?, Journal of Cetacean Research And Management 3: 81-86

DONG Energy (2013) Burbo Extension Environmental Statement. March 2013.

Dawson, S.M., Northridge, S., Waples, D., Read, A.J. (2013) To ping or not to ping: the use of active acoustic devices in mitigating interactions between small cetaceans and gillnets. Endangered Species Research 19: 201 – 221

Embling, C.B., Gillibrand, P.A., Gordon, J., Shrimpton, J., Stevick, P.T., and Hammond, P.S. (2010) Using habitat models to identify suitable sites for marine protected areas for harbour porpoises (*Phocoena phocoena*). Biological Conservation 143: 267 – 279.

EWEA (European Wind Energy Association), (2015). The European offshore wind industry – key trends and statistics 2014. January 2015.

Gordon, J., Blight, C., Bryant, E., & Thompson, D. (2015). Tests of Acoustic Signals for Aversive Sound Mitigation with Common Seals. Sea Mammal Research Unit report to Scottish Government.

Hardy, T., Williams, R., Caslake, R., Tregenza, N. (2012) An investigation of acoustic deterrent devices to reduce cetacean bycatch in an inshore set net fishery. J. Cetacean. Res. Manage. 12(1): 85 – 90.

Herschel, A., Stephenson, S., Sparling, C., Sams, C., & Monnington, J. (2013). ORJIP Project 4, Phase 1: Use of deterrent devices and improvements to standard mitigation during piling. Report submitted to the Offshore Renewables Joint Industry Programme.

HSE (2001). Reducing risks, protecting people, HSE's decision making process. Crown copyright 2001.

*et al*Jacobs, S.R., Terhune, J.M., (2002). The effectiveness of acoustic harassment devices in the Bay of Fundy, Canada: seal reactions and a noise exposure model. Aquatic Mammals, 28,147-158

JNCC (2010a) JNCC guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys. August 2010.

JNCC (2010b) Statutory nature conservation agency protocol for minimising the risk of injury to marine mammals from piling noise. August 2010.

JNCC (2010c) The protection of marine European Protected Species from injury and disturbance. Guidance for the marine area in England and Wales and the UK offshore marine area. June 2010.

JNCC (2004) Guidelines for minimizing acoustic disturbance to marine mammals from seismic surveys. Joint Nature Conservation Committee, Peterborough. http://www.jncc.gov.uk/pdf/Seismic_survey_guidelines_200404.pdf

Johnston D.W. (2002) The effect of acoustic harassment devices on harbour porpoises (*Phocoena phocoena*) in the Bay of Fundy, Canada. Biol. Conserv. 108: 113-118.

Kastelein, R. A., Hoek, L., Gransier, R., de Jong, C. A., Terhune, J. M., & Jennings, N. (2015a). Hearing thresholds of a harbor porpoise (*Phocoena phocoena*) for playbacks of seal scarer signals, and effects of the signals on behavior. Hydrobiologia, 756:75-88. 2962

Kastelein, R. A., Helder-Hoek, L., Gransier, R., Terhune, J. M., Jennings, N., & de Jong, C. A. (2015b). Hearing thresholds of harbor seals (*Phoca vitulina*) for playbacks of seal scarer signals, and effects of the signals on behavior. Hydrobiologia, 756:89-103

Kastelein, R.A., Hoek, L., Jennings, N., de Jong, C.A.F., Terhune, J.M., & Dieleman, M., (2010). Acoustic Mitigation Devices (AMDs) to deter marine mammals from pile driving areas at sea: audibility & behavioural response of a harbour porpoise & harbour seals. In COWRIE Ref: SEAMAMD- 09, Technical Report 31st July 2010. ISBN 978-0-9565843-7-3.68

Kastelein, R. A., de Haan, D., Vaughan, N., Staal, C., and Schooneman, N. M. (2001). The influence of three acoustic alarms on the behaviour of harbour porpoises (*Phocoena phocoena*) in a floating pen, Marine Environmental Research 52: 351-371

Koschinski, S., and Culik, B. M. (1997). Deterring harbour porpoises (*Phocoena phocoena*) from gillnets: observed reactions to passive reflectors and pingers, Reports of the International Whaling Commission 47, 659-668

Kraus, S.D., Read, A.J., Solow, A., Baldwin, K., Spradlin, T., Anderson, E. and Williamson, J. (1997). Acoustic alarms reduce porpoise mortality. Nature 388: 525

Laake *et al.*, 1998 Laake, J. L., Rugh, D., and Baraff, L. (1998). Observations of harbour porpoise in the vicinity of acoustic alarms on a set gill net, (US Department of Commerce, NOAA Technical Memorandum, NMFS AFSC 84:), p. 40

Leaper, R. and Gordon, J. (2001). Application of photogrammetric methods for locating and tracking cetacean movements at sea. Journal of Cetacean Research and Management 3, 131-141.

Olesiuk, P.F., Nichol, L.M., Sowden, M.J., & Ford, J.K.B., (2002). Effect of the sound generated by an acoustic harassment device on the relative abundance and distribution of harbor porpoises (*Phocoena phocoena*) in Retreat Passage, British Columbia. Marine Mammal Science, 18, 843-862

Otani, S., Naito, Y., Kato, A. and Kawamura, A. (2000) Diving behaviour and swimming speed for free-ranging harbour porpoise, *Phoceana phocena*. Marine Mammal Science, l6(4), pp. 811-814.

Parsons, E.C.M., Dolman, S.J., Jasny, M., Rose, N.A., Simmonds, M.P., Wright, A.J. (2009) A critique of the UK's JNCC seismic survey guidelines for minimising acoustic disturbance to marine mammals: Best Practice? Marine Pollution Bulletin 58: 643 – 651.

Rasmussen, M (2014) The whaling versus whale-watching debate. In: Higham, J., Bejder, L. & Williams, R. eds. *Whale-watching; sustainable tourism and ecological management*. Cambridge University Press, pp. 81-94.

Rasmussen, M. H., & Miller, L. A. (2002). Whistles and clicks from white-beaked dolphins, Lagenorhynchus albirostris, recorded in Faxaflói Bay, Iceland.Aquatic Mammals, 28(1), 78-89.

Rasmussen, M. H., Akamatsu, T., Teilmann, J., Vikingsson, G., & Miller, L. A. (2013). Biosonar, diving and movements of two tagged white-beaked dolphin in Icelandic waters. Deep Sea Research Part II: Topical Studies in Oceanography, 88, 97-105.

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene Jr, C.R., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A., Tyack, P.L., (2007). Marine mammal noise-exposure criteria: initial scientific recommendations. Aquatic Mammals. 33, 411–521.

Sparling, C., Sams, C., Stephenson, S., Joy, R., Wood, J., Gordon, J., Thompson, D., Plunkett, R., Miller, B. & Gotz, T. 2015. The use of acoustic deterrents for the mitigation of injury to marine mammals during pile driving for offshore wind farm construction. ORJIP Project 4, Stage One of Phase Two. SMRUC-TCT-2015-006, Submitted to The Carbon Trust, 19 October 2015 (unpublished).

Stern, SJ. 1992. Surfacing rates and surfacing patterns of minke whales (*Balaenoptera acutorostrara*) off Central California, and the probability of a whale surfacing within visual range. Rep. Int. Whal. Commn. 42: 379-385.

Trippel, E.A., Strong, M.B., Terhune, J.M. and Conway, J.D. (1999). Mitigation of harbour porpoise (*Phocoena phocoena*) by-catch in the gillnet fishery in the lower Bay of Fundy. Can. J. Fish. Aquat. Sci. 56:113–23.

Urick, Robert J. (1983), Principles of Underwater Sound, 3rd Edition. New York. McGraw-Hill.

Wenz, G.M. (1962) Acoustic Ambient Noise in the Ocean: Spectra and Sources. The Journal of the Acoustical Society of America 34 (12), 1936 - 1956.

Wright, A.J., and Cosentino, A.M. (2015) JNCC guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys: We can do better. Marine Pollution Bulletin.

Yamato, M., Koopman, H., Niemeyer, M., Ketten, D. (2014) Characterisation of lipids in adipose depots with minke and fin whale ears: comparison with "acoustic fats" of toothed whales. Marine Mammal Science 30: 1549-1563.

Appendix A - Lofitech ADD specification sheet

LoFITECH

Seiche
Marine Acoustic Solutions

PRODUCT DATASHEET

ACOUSTIC DETERRENT DEVICE

DESCRIPTION

The Lofitech Acoustic Deterrent Device (ADD) is the most effective solution to deter marine mammals. Warning away seals, porpoises and dolphins ensures the animals' wellbeing and enables commercial operations to continue.

The device is simple to install and operate. It can be conducted by on-site employees with full support and guidance from our experts.

The system consists of a control unit and a transducer. The control unit contains a pulse generator and an amplifier to transmit random bursts of audio frequency signals to the transducer – this is then converted into intense sound.

The ADD transmits 191dB/µPa/m at an optimal frequency (between 10 and 20kHz) for deterring marine mammals.

APPLICATIONS

- Fish farm stock protection
- Fisheries catch protection
- Mitigation during:
  - pile-driving
  - UXO removal
  - oil and gas operations

SPECIFICATIONS
Sound pressure: approx. 191dB/µPa/m
Frequency: between 10 and 20kHz
Waterproof self-contained unit: 60cm x 30cm x 40cm
Range: 500m radius from source – can be tailored to project requirements.
Transducer cable length: 25m
Auto-Marine 12V battery with 90-120Ah
Recharge intervals (120Ah batteries): approx. 3 - 4 days
Power consumption: approx. 0.4A/12V

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Appendix B - R/V *Song of the Whale* specification

Registered Owner: Marine Conservation Research International

British Registered number: 908938

Port of Registry: London, UK

The vessel is fully equipped with the normal communications and navigation equipment found on board a modern vessel (GPS, AIS, SSB & VHF radio and INMARSAT voice and data terminal).

Song of the Whale was designed and built in compliance with Lloyd's Register Rules and Regulations for the Classification of Special Service Craft.

Class notation	100A1 SSC Workboat Mono G5
MCA Category	0 (unrestricted)
Length	21.53 m
Beam	5.6 m
Draft	3 m
Air Draft	33 m
Registered Tonnage	51.58 tonnes
Engine	Yanmar 6LYA-STP 370 hp
Gearbox	Twin Disc MG-5061A 2.47:1 (5HV-571)
Propeller	5 blade fixed 27 x 17 RH APS SKEW100
Generator 1	Onan 9 kW
Generator 2	Whispertech Whispergen 1 kW
AC power	230V AC is provided for research electronics via two pure sine wave inverters, ensuring a clean uninterrupted supply
Fuel Capacity	3300 L
Water Capacity	1200L (100 L/hr Seafresh Watermaker)
Sail Area	267 sq m
Operating speed under power	cruising 6.5 kts, maximum 9.5 kts

Appendix C - Subsea Noise Modelling

Glossary of Terms used in Subsea Noise Modelling Report

Term	Definition
dB	deciBel, dB re 1 µPa for sound pressure level or dB re 1 µPa^{2}s for sound exposure level.
ADD	Acoustic deterrent device
ORJIP	Offshore Renewables Joint Industry Project
NOAA	National Oceanic and Atmospheric Administration - American scientific agency within the United States Department of Commerce
FFT	Fast Fourier Transform – used to analyse data in the frequency domain rather than time domain.
NMFS	Abbreviation for National Marine Fisheries Service.
pk	Abbreviation for peak (also zero-to-peak or 0-pk).
pk-pk	Abbreviation for peak-to-peak.
R^2	Correlation coefficient showing the significance of the relationship between two variables.
RMS sound pressure level	The root mean square sound pressure level of the sound, averaged over a specified time interval.
SPL	Abbreviation for sound pressure level.
SEL	Abbreviation for sound exposure level.
Standard Deviation	A quantity expressing by how much the members of a data set differ from the average value for the data set.
Upper quartile	The value which lies mid-way between the maximum value of the data set and the median value of a data set. Sometimes reported as the 75th percentile.

C.1 Introduction

This appendix presents the results of the acoustic characterisation exercise undertaken in Faxaflói Bay for the Lofitech Seal Scarer Acoustic Deterrent Device (ADD).

C.2 Acoustic Concepts and Terminology

C.2.1 Sound travels through the water as vibrations of the fluid particles in a series of pressure waves. The waves comprise a series of alternating compressions (positive pressure variations) and rarefactions (negative pressure fluctuations). Because sound consists of variations in pressure, the unit for measuring sound is usually referenced to a unit of pressure, the Pascal (Pa). The unit usually used to describe sound is the decibel (dB) and, in the case of underwater sound, the reference unit is taken as 1 µPa, whereas airborne sound is usually referenced to a pressure of 20 µPa. To convert from a sound pressure level referenced to 20 µPa to one referenced to 1 µPa, a factor of 20 log (20/1) i.e. 26 dB has to be added to the former quantity. Thus 60 dB re 20 µPa is the same as 86 dB re 1 µPa, although differences in sound speed and densities mean that the difference in sound intensity is much more than this from air to water. All underwater sound pressure levels in this report are described in dB re 1 µPa. In water the strength of a sound source is usually described by its sound pressure level in dB re 1 µPa, referenced back to a representative distance of 1 m from an assumed (infinitesimally small) point source. This allows calculation of sound levels in the far-field.

C.2.2 There are several descriptors used to characterise a sound wave. The difference between the lowest pressure variation (rarefaction) and the highest pressure variation (compression) is the peak to peak (or pk-pk) sound pressure level. The difference between the highest variation (either positive or negative) and the mean pressure is called the peak pressure level. Root mean square (rms) sound pressure level is used as a description of the average amplitude of the variations in pressure over a specific time window. These descriptions are show graphically in Figure C.1.

C.2.3 The rms sound pressure level (SPL) is defined as follows:

$$SPL_{rms} = 10log_{10}\left(\frac{1}{T}\int_{0}^{T}\left(\frac{p^2}{p_{ref}^2}\right)dt\right)$$

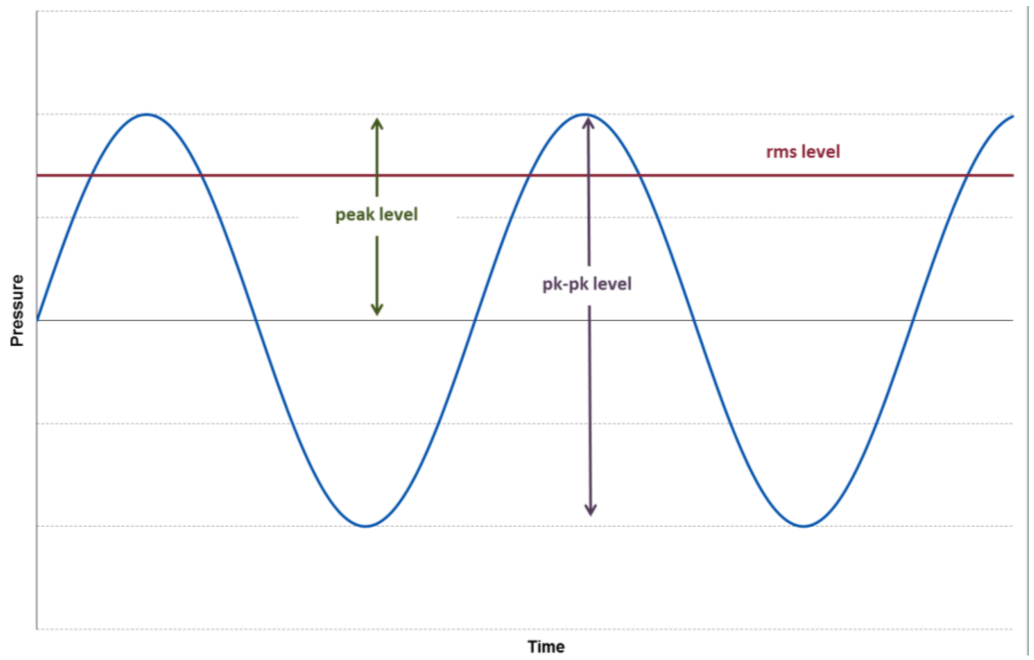


Figure C.1: Graphical representation of acoustic wave descriptors.

C.2.4 Another useful measure of sound used in underwater acoustics is the Sound Exposure Level, or SEL. This descriptor is used as a measure of the total sound energy of an event or a number of events (e.g. over the course of a day) and is normalised to one second. This allows the total acoustic energy contained in events lasting a different amount of time to be compared on a like for like basis. The SEL is defined as follows:

$$SEL = 10log_{10}\left(\int_0^T \left(\frac{p^2(t)}{p_{ref}^2 t_{ref}}\right) dt\right)$$

C.2.5 The frequency, or pitch, of the sound is the rate at which these oscillations occur and is measured in cycles per second, or Hertz (Hz). When sound is measured in a way which approximates to how a human would perceive it using an A-weighting filter on a sound level meter, the resulting level is described in values of dBA. However, the hearing faculty of marine mammals is not the same as humans, with marine mammals hearing over a wider range of frequencies and with a different sensitivity. It is therefore important to understand how an animal's hearing varies over the entire frequency range in order to assess the effects of sound on marine mammals. Consequently, use can be made of frequency weighting scales to determine the level of the sound in comparison with the auditory response of the animal concerned.

C.2.6 No measured data exist for the audiogram of minke whales. However, a theoretical normalised and inverted audiogram for a Minke whale (adapted from Ketten and Mountain 2011; Tubelli *et al*. 2012) is shown in Figure C.2 compared against the NOAA (2016) hearing weighting function for low frequency cetaceans. Based on theoretical assumptions, it is conjectured that the fundamental frequency of the Lofitech ADD (c. 15 kHz) sits outside the most sensitive region of hearing for minke whales, but nevertheless within their range of hearing.

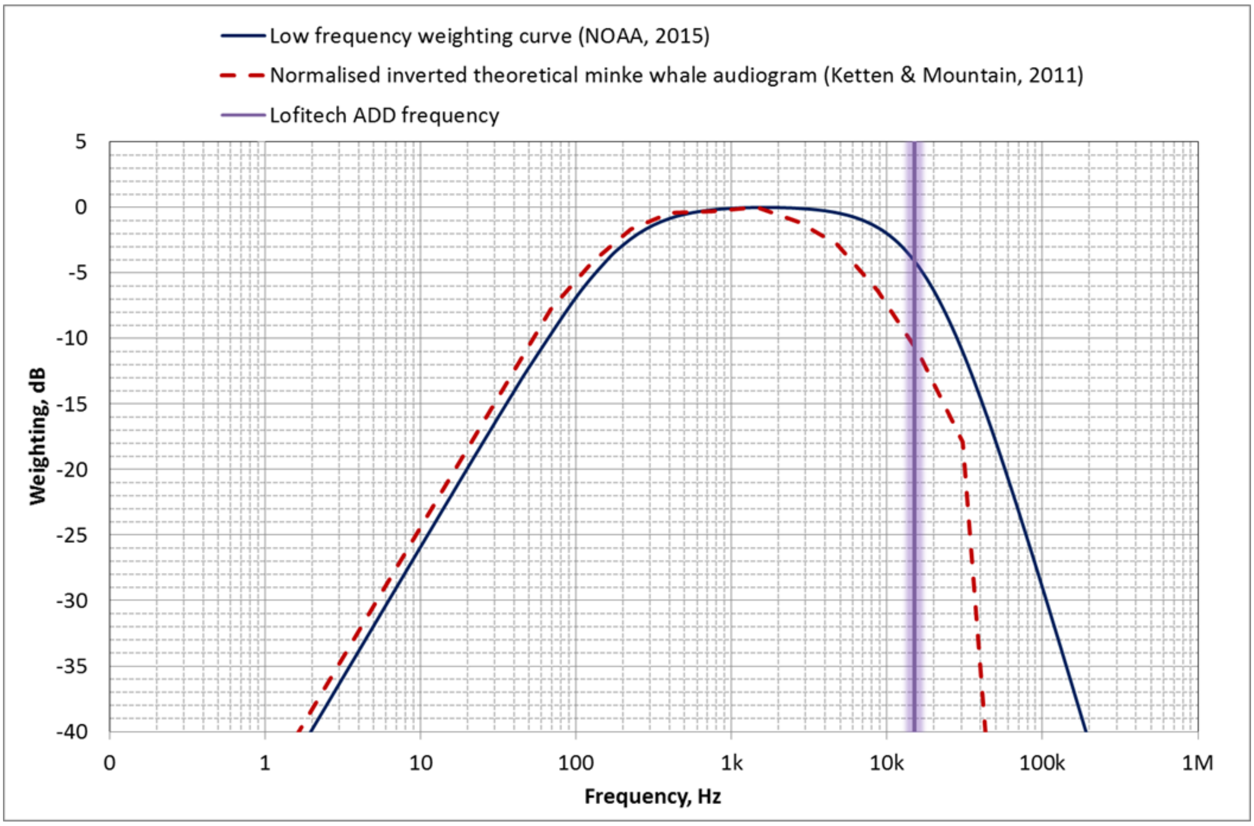


Figure C.2: Comparison between minke whale audiogram and NOAA hearing weighting function.

C.3 Methodology

Monitoring Locations

C.3.1 Measurements were undertaken in two locations. During the earlier part of the day, some initial measurements were undertaken in Hvalfjordur (during poor weather) to test the acoustic set-up (and to provide a backup in case measurements in Faxaflói Bay should not be possible in the case that the weather did not improve).

C.3.2 However, once the wind and sea state had calmed down to an acceptable level for measurements, measurements were undertaken in Faxaflói Bay itself in the area where the majority of Minke Whale trials using the ADD had occurred. Consequently, only the measurements in the Bay are included in the subsequent analysis due to their direct applicability in terms of location and weather conditions to the ADD trials themselves. The bathymetry in the Fjord was very different to the Bay area and so propagation could differ significantly and the weather and sea state were not ideal during the Hvalfjordur measurements.

Deployment

C.3.3 The measurement equipment was deployed from R.V. *Song of the Whale*, a purpose-built 21 m research vessel. The vessel is steel-hulled, with outriggers for towing hydrophone arrays, an 11 m high crow's nest and an elevated A-frame which provides a 5 m eye-height for visual surveying and a dedicated computer/communications room for acoustic detection and data logging.

C.3.4 The ADD was deployed from a Zodiac GRII tender, which was launched from R.V. *Song of the Whale* (see Figure C.3). The Zodiac was stationed at various distances from the research vessel and hydrophone depending on the test being performed, with measurements conducted with the Zodiac at distances of approximately 200 m, 500 m, 1,000 m, 1,500 m and 2,000 m from the hydrophone.

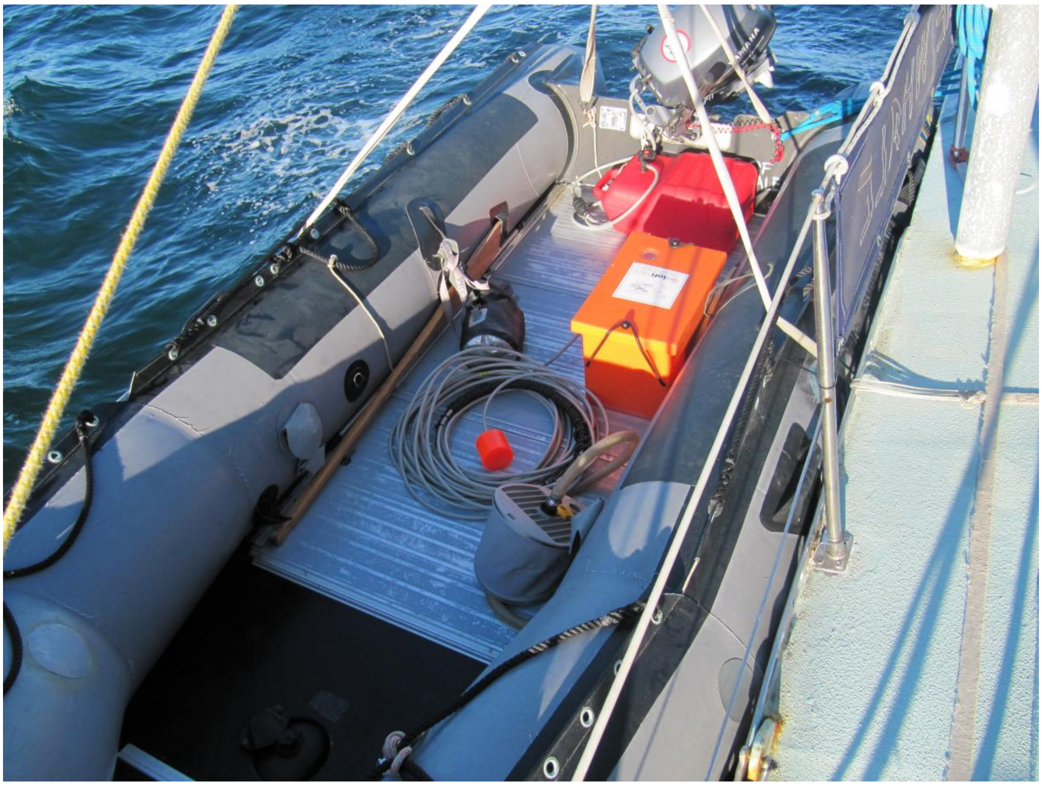


Figure C.3: Photo showing ADD in Zodiac launch.

C.3.5 The distance between the two vessels was measured using a range finder and tracked for future analysis using GPS, with the two vessels' positions being constantly logged throughout the survey period. Meteorological conditions were also logged throughout the survey including wind speed, wind direction, sea surface temperature, sea state and swell.

Instrumentation

C.3.6 Measurements were carried out using a calibrated Reson TC 4040 hydrophone. In addition, a calibration check was performed on the measurement system prior to and after deployment using a Brüel and Kjær 4223 pistonphone.

C.3.7 The instrumentation used for the survey was as follows:

- Reson TC 4040 hydrophone;
- Reson EC6067 charge conditioning amplifier;
- Sinus Apollo data acquisition system (with 80 kHz bandwidth option);
- Laptop computer with Samurai analysis software (see Figure C.4).

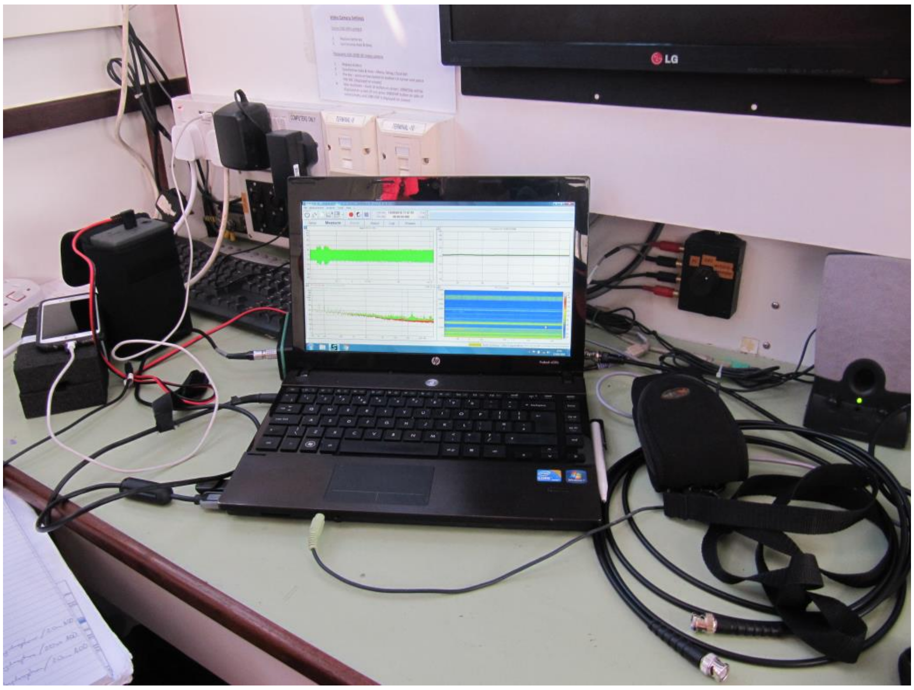


Figure C.4: Photo showing laptop computer with Samurai analysis software

C.3.8 The hydrophone was weighted using lead weighted anchor line and was deployed over the side of R.V. *Song of the Whale* at various hydrophone depths (10 m, 20 m and 30 m). The conditioned signal was recorded directly into the laptop hard drive using the Samurai application for later analysis.

Analysis Procedure

C.3.9 For each of the measurements, a "clean" section of measurement was identified for further analysis of nominally 30 second duration. Within each of the sections, there were consistently fifteen pulses. Each of the fifteen pulses within each of the thirty second measurement periods was post-processed using Samurai analysis software.

C.3.10 The post-processing involved selecting the time limits of an individual pulse, then using Fast Fourier Transform (FFT) analysis with a Hanning window (Harris 1978) to create an FFT plot in the frequency domain. The FFT analysis was performed using 25601 lines over the 80 kHz bandwidth, resulting in a bin width of 3.125 Hz. The sample rate was 204.8 kHz.

C.3.11 The plots of interest were the rms, SEL and 0-Peak. Sonograms showing time history were also generated.

C.3.12 Through objective assessment, a primary frequency and 3 harmonic frequencies were identified as the frequencies to analyse in order to characterise the source.

C.3.13 From the plots for each pulse, the rms, SEL and Zero-Peak levels were extracted from the four frequencies of interest based on an analysis bandwidth of 200 Hz (i.e. 100 Hz either side of the frequency of interest). By utilising an effective bin width of 200 Hz, this ensured that all of the energy within the frequency band of interest was included in the analysis. Peak pressure levels were measured using the peak detection function of the analysis software after applying high-pass and low-pass filtering at 100 Hz either side of the analysis frequency.

C.3.14 For measurements taken at larger distances from the ADD (i.e. distances of approximately 1,000 m or more) the three harmonic frequencies were at or below the noise floor and became more difficult to extract from the analysis. Consequently, it was not possible to present measured levels for these frequencies for some of the measurements.

ADD Measurement Results

C.3.15 A summary of peak and rms sound pressure levels and SELs measured at the various distances and water depths is shown in Table C.1.

C.3.16 More detailed results are presented in Annex A of this report as follows:

- Table A1: Summary of pulse magnitude for fundamental frequency and harmonics (based on arithmetic average of individual pulse data);
- Table A2: Pulse spectrograms and FFT plots;
- Table A3: Individual pulse sound levels (at fundamental frequency); and
- Table A4: Individual pulse lengths.

Table C.1: Summary of measured ADD signal levels at hydrophone location (arithmetic average of all pulses measured).

Distance from ADD to Hydro-phone, m	ADD Depth, m	Hydro-phone Depth, m	0-Peak, dB re 1 µPa				SEL, dB re 1 µPa²s				rms (T90) , dB re 1 µPa				Average Pulse Length, s
			14.6 kHz	*29.2 kHz*	*43.6 kHz*	*72.8 kHz*	*14.6 kHz*	*29.2 kHz*	*43.6 kHz*	*72.8 kHz*	*14.6 kHz*	*29.2 kHz*	*43.6 kHz*	*72.8 kHz*	
193	20	30	159.7	114.2	114.5	110.6	152.7	107.0	107.7	103.6	153.8	108.2	108.8	104.8	0.77
200	20	20	161.2	115.1	117.8	117.5	154.6	108.7	111.6	111.4	155.8	109.9	112.7	112.6	0.76
198	20	10	161.1	113.9	116.6	115.3	153.6	106.7	109.5	108.8	154.6	107.7	110.5	109.8	0.80
570	20	10	150.0	105.2	99.0	93.0	143.3	98.6	92.3	86.9	144.6	100.0	93.6	88.2	0.74
560	20	20	146.3	98.6	95.8	91.5	139.3	92.2	89.6	85.6	140.9	93.9	91.3	87.3	0.69
556	20	30	148.9	103.0	97.8	92.2	141.9	96.0	91.1	86.4	142.9	97.0	92.1	87.4	0.80
996	20	30	141.3	93.0	90.3	87.4	134.2	86.6	83.9	81.4	135.7	88.2	85.5	83.0	0.70
980	20	20	140.6	N/A	N/A	N/A	133.1	N/A	N/A	N/A	134.8	N/A	N/A	N/A	0.67
986	20	10	143.1	N/A	N/A	N/A	136.3	N/A	N/A	N/A	137.9	N/A	N/A	N/A	0.70
1508	20	30	131.8	N/A	N/A	N/A	124.2	N/A	N/A	N/A	126.9	N/A	N/A	N/A	0.54
2107	20	30	128.8	N/A	N/A	N/A	121.8	N/A	N/A	N/A	124.3	N/A	N/A	N/A	0.55

C.4 Discussion

Source Characteristics

C.4.1 Manufacturer's literature pertaining to the Lofitech ADD states that the source sound pressure level is approximately 191 dB re 1 µPa referenced to 1 m, although it does not specify whether this is rms or peak sound pressure level. It states that the source frequency is between 10 and 20 kHz. However, field measurements using the devices in other studies have determined different source levels, for example 193 dB re 1 µPa (rms) referenced to 1 m (Gordon *et al*. 2015) and 197 dB re 1 µPa (rms) reference to 1 m (Brandt *et al*. 2012; Brandt *et al*. 2013).

C.4.2 The source frequencies were determined to be as follows:

- 14.6 kHz (fundamental frequency);
- 29.2 kHz (first harmonic);
- 43.6 kHz (second order harmonic)
- 72.8 kHz (third order harmonic)

C.4.3 Pulse length was found to be generally quite consistent across all measurements (600 – 800 ms). The average pulse length was 752 ms with a standard deviation of 79 ms (based on measurements at 200 m). This is longer than the pulse length of approximately 500 ms reported in previous studies.

C.4.4 The source characteristics are summarised in Table C.2.

Table C.2: Lofitech ADD source characteristics.

Parameter	Source level re 1 m	Unit	Standard deviation	Fundamental frequency, kHz
SEL	197	dB re 1 µPa^{2}s	2.0	14.6
RMS sound pressure level	198	dB re 1 µPa (rms)	1.9	14.6
Peak sound pressure level	204	dB re 1 µPa (pk)	2.3	14.6

Validation of Propagation Coefficients

C.4.5 Rather than simply fit a curve to the measured data, a frequency dependent curve has been derived based on a combination of best fit to data and standard acoustic theory. This is based on the simplified algorithm:

$$Received\ Level = S + N \log R + \alpha R$$

where S is the level re 1 m from the source (assuming an infinitesimally small point source), R is the distance from source to receiver (m), N is a coefficient of geometrical divergence and α is a coefficient of absorption.

C.4.6 The reason for using this algorithm (as opposed to say a simple N log R algorithm) is that inspection of the measured data showed a much higher attenuation rate at larger distances from the source. It was therefore considered important to ensure that effects such as scattering and molecular absorption were accounted for in the analysis.

C.4.7 The generalised model for underwater noise propagation typically assumes a value for N nominally between 10 (which models geometrical spreading of sound energy as a cylindrical wave) and 20 (which models sound energy spreading out from a source as a spherical wave). Spherical spreading (20 log R) represents the case where sound propagates from a source of sound uniformly in all directions. However, due to the bounding influence of the water surface and sea floor, sound propagation may act more like cylindrical spreading (10 log R) at distances further away from the source. Both assumptions are very basic approximations of spreading loss but can be very useful for estimating sound levels at relatively close distances between source and receiver and in relatively simple situations without requiring much more complex calculations.

C.4.8 The water in Faxaflói Bay is approximately 35 to 37 m deep and in the inner and coastal parts of Faxaflói Bay water depths are around 40 to 50 m deep (Rasmussen *et al.*, 2013). The seabed substrate is predominantly sand or basalt (Rasmussen & Miller, 2002). The use of the simplified empirical modelling is therefore considered to be a valid approach for the specific conditions in which the tests were undertaken.

C.4.9 The exact value of the propagation coefficient for mid-range distances from the source requires empirical derivation. A two-stage approach was used to determine the sound propagation coefficients. In the first stage, data from distances of up to approximately 500 m were used to determine the range of possible N values, with the final value being determined by the N value which results in the line of best fit between the data. In the second stage, using the N value calculated in the first stage, the value for the "absorption coefficient", α, was determined by varying its value and selecting the value which resulted in the best correlation between the measured and calculated value as indicated by the R^2 correlation coefficient.

C.4.10 As described previously, use of the N value alone did not adequately describe attenuation at greater distances from the ADD. It is considered likely that this was due to effects due to scattering from the water surface and basalt bottom. In the case of this empirically derived "absorption coefficient", the value for α is therefore an empirical estimate of effects such as molecular absorption of sound energy as well as other effects such as scattering.

C.4.11 The results of the first stage of the analysis which derives values for the propagation coefficient, determined a value of N = -19, which was deemed to be the best match with the measured data.

C.4.12 The results of the second stage of the analysis determined an absorption coefficient of α = 0.004 dB/m, which was deemed to be the best match with the measured data.

C.4.13 It is clear that there is a significant change in propagation curve at distances greater than 1 km from the source. (The theoretical value for molecular absorption at the fundamental frequency is 0.0022 dB/m.) It is thought likely that this could be due to excess attenuation due to both molecular absorption combined with scattering from the sea surface and basalt on the bottom.

C.4.14 Using the propagation coefficients derived above, it is then possible to calculate the source level which was determined to be 198 dB re 1 µPa (rms).

C.4.15 This results in a propagation curve for the main source frequency of 14.6 kHz of:

RMS sound pressure level = 198 – 19 log R – 0.004 x R *(dB re 1 µPa)*

C.4.16 The plots of the original data and trend lines are shown in Figure C.5.

C.4.17 Further analysis using the Marsh-Schulkin semi-empirical sound propagation model (Schulkin and Mercer 1985; Marsh and Schulkin 1962) was also carried out in order to confirm the derived source level. This analysis also found a source sound pressure level of 198 dB re 1 µPa (rms).

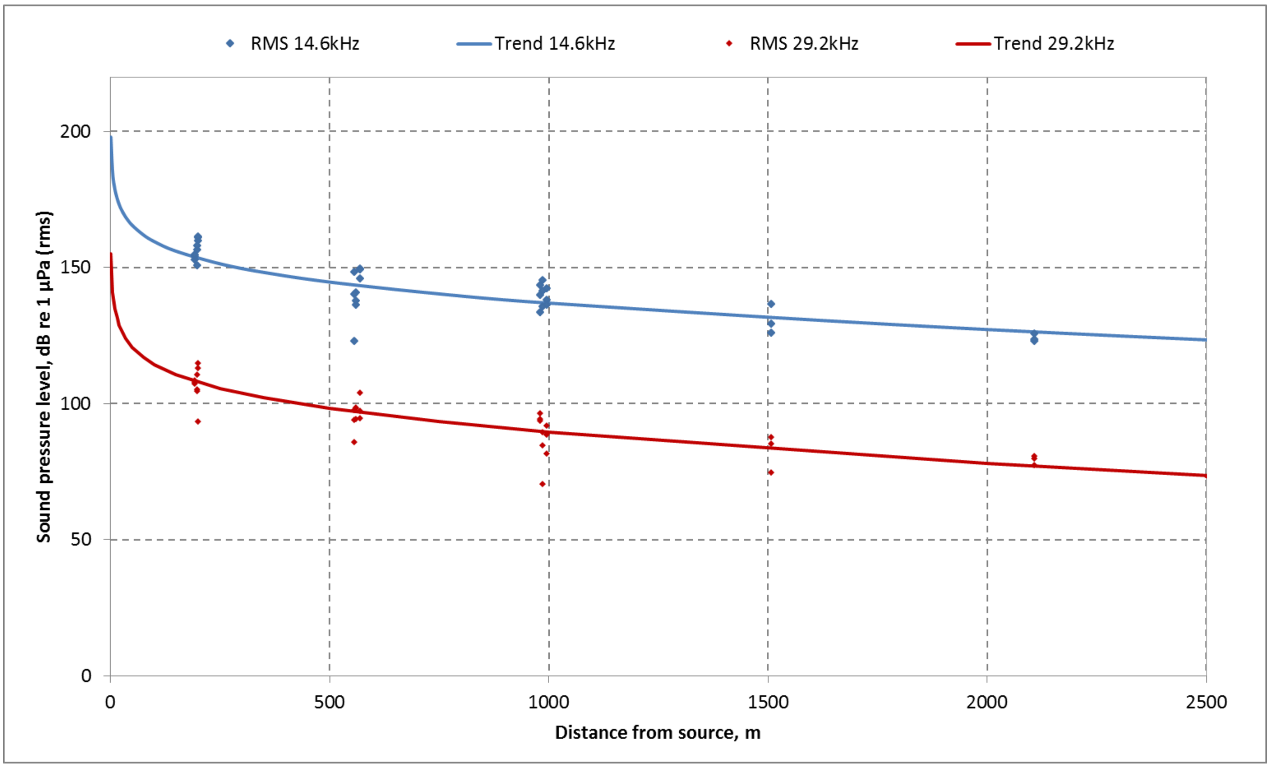


Figure C.5: Plot of measured rms sound pressure levels and trend line

Consideration of Potential for Injury due to Exposure to ADD Sound

C.4.18 Phase dependant time domain metrics such as peak pressure can have relatively large variations over short distances or environmental time variations (for example waves) due to constructive and destructive interference of multipath arrivals. Consequently, there is typically much higher variation in empirically measured data compared to metrics such as rms or SEL. An estimate of the peak source sound pressure level was determined based on an analysis of the measured peak sound pressure levels which were found to be an average of 5.9 dB higher than the rms sound pressure level at 200 m from the ADD. The source peak sound pressure level was therefore estimated to be 204 dB re 1 μPa re 1 m.

C.4.19 It is worth noting that the difference between the peak pressure level and the rms (T90) sound pressure level is higher than would be derived by theoretical consideration of a waveform (a 3 dB difference would be expected for a pure sine wave). Investigations showed that this deviation from the theoretical correction was due to variations in the intensity of sound in each pulse over the pulse length. In other words, the sound level produced by the ADD varies with time, as can be seen by inspecting the time histories in Table A1.

C.4.20 The estimated source peak sound pressure level of 204 dB re 1 μPa re 1 m is below the thresholds of 219 dB re 1 μPa (pk) for permanent threshold shift (PTS) and 213 dB re 1 μPa (pk) for temporary threshold shift. It is therefore highly unlikely that the Lofitech ADD could result in instantaneous injury due to peak pressure.

C.4.21 The cumulative SEL of a minke whale swimming away from an ADD has also been modelled. The modelling assumes a conservative swim speed of 2.5 ms^{-1} and an average pulse rate of 0.5 pulses per second. Cruising swim speeds of minke whale have been shown to be 3.25 ms^{-1} (Cooper *et al.,* 2008; Blix and Folkow, 1995) but a very conservative swim speed of 2.5 ms^{-1} was used in this assessment to allow additional headroom to account for the potential that the animal might not swim directly away from the source, could change direction or does not maintain a fast swim speed over a prolonged period.

C.4.22 The modelling assumes 30 minutes of activation. Further modelling was also undertaken to investigate the effect of activating the ADD for longer periods of time (e.g. 1 hour, 2 hours etc.) but it was found that the cumulative SEL of a swimming animal did not increase significantly for these longer deployment times. This is because the main exposure occurs during the first tens of "pulses" emitted by the device as the animal first starts to swim away, particularly for starting ranges close to the ADD.

C.4.23 It should be noted that the sound exposure calculations are based on a set of simplistic assumptions and that the real world is more complex. Therefore, a range of worst-case assumptions have been used in carrying out the exposure modelling and it is considered that this represents and precautionary assessment. The SEL calculations presented in this study do not take any breaks in ADD activity into account. Furthermore, the SEL criteria described in the NOAA guidelines assume that the animal does not recover hearing between each pulse of sound. This over-estimate is, however, considered to be small because the majority of sound energy to which an animal is exposed occurs when it is at the closest distance to the source, with subsequent exposure at greater ranges making an insignificant contribution to the overall exposure. The relatively slow swim speed of 2.5 m/s is also a precautionary assumption and it is likely that swim speeds will be faster during ADD activation, resulting in lower cumulative SELs than presented here.

C.4.24 The source characterisation of the ADD has shown that the sound produced is characterised by intermittent short periods containing pure tones, but not by rapid rise times or high peak pressure levels. In other words, the sound is not classified as impulsive according to NOAA guidelines[3]. Consequently the PTS threshold is 199 dB re 1 μPa^2s and the TTS threshold is 179 dB re 1 μPa^2s.

C.4.25 The cumulative SELs for three different starting ranges (500 m, 100 m and 25 m from the ADD) are presented in the following figures (Figure C.6 to Figure C.8). The calculations are based on the simplified propagation algorithm coefficients ($N = -19$ and $\alpha = 0.004$ dB/m) derived previously. The graphs show the energy received as a single pulse at each distance from the ADD and also the cumulative dose, which essentially is a sum of each single dose exposure up to a given point. Therefore, as the animal moves further away from the ADD the single pulse energy decreases and the cumulative dose increases until eventually it flattens off. Notably, closer to ADD the initial reduction in single pulse SEL is greater as the animal doubles the distance far quicker (i.e. going from 25 m to 50 m would result in a similar overall reduction in SEL as going from 500 m to 1,000 m). Therefore, closer to the source there is less impact of additional noise on the cumulative SEL because most of the impact occurs at close distances to the ADD. This is illustrated by comparing the cumulative dose curves for an animal starting at 25 m and an animal starting at 500 m: the curve flattens off more rapidly for the animals starting at 25 m (Figure C.6 and Figure C.8).

[3] According to NOAA guidelines impulsive sounds are typically transient, brief (less than 1 second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay (ANSI 1986; NIOSH 1998; ANSI 2005). Non-impulsive sounds can be broadband, narrowband or tonal, brief or prolonged, continuous or intermittent and typically do not have a high peak sound pressure with rapid rise/decay time that impulsive sounds do (ANSI 1995; NIOSH 1998).

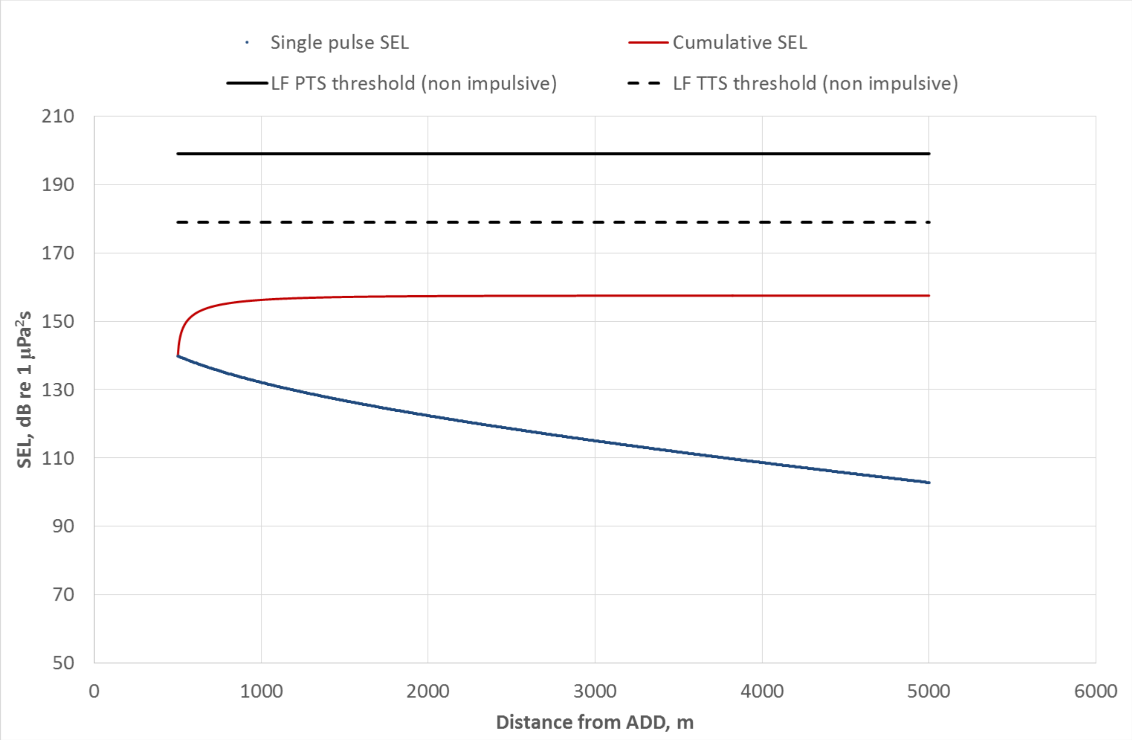


Figure C.6: SEL modelling results for minke whale swimming away from ADD at 2.5 m/s with a starting position of 500 m from the ADD

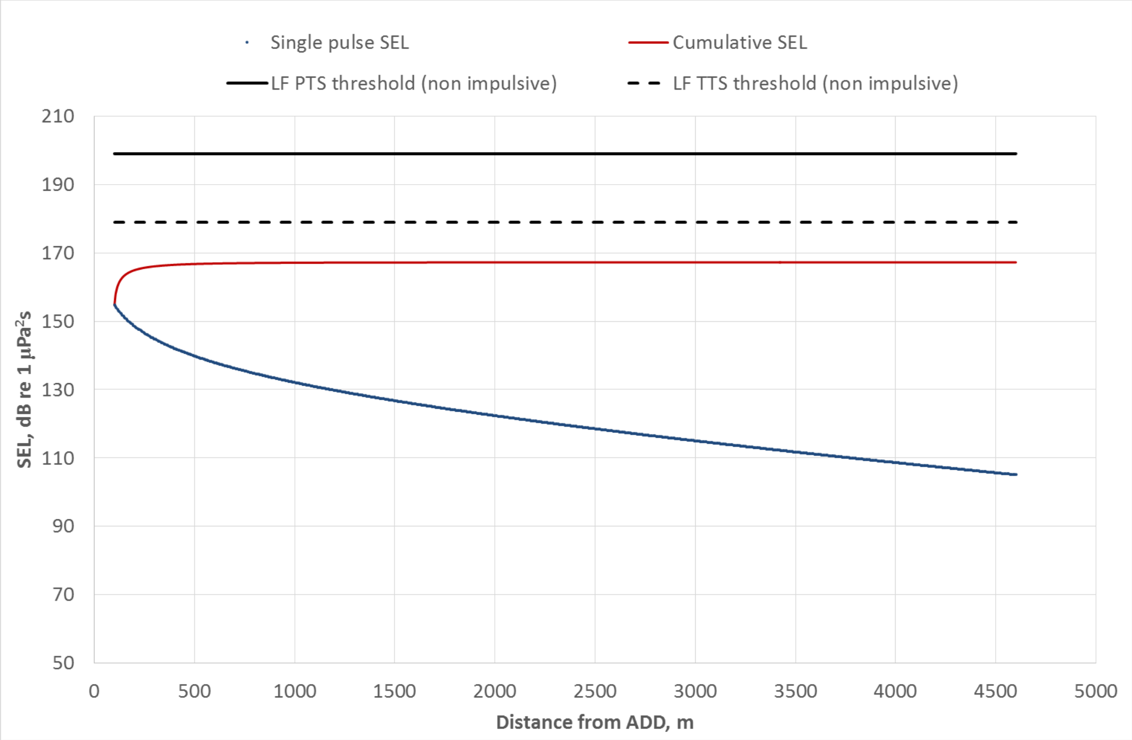


Figure C.7: SEL modelling results for minke whale swimming away from ADD at 2.5 m/s with a starting position of 100 m from the ADD

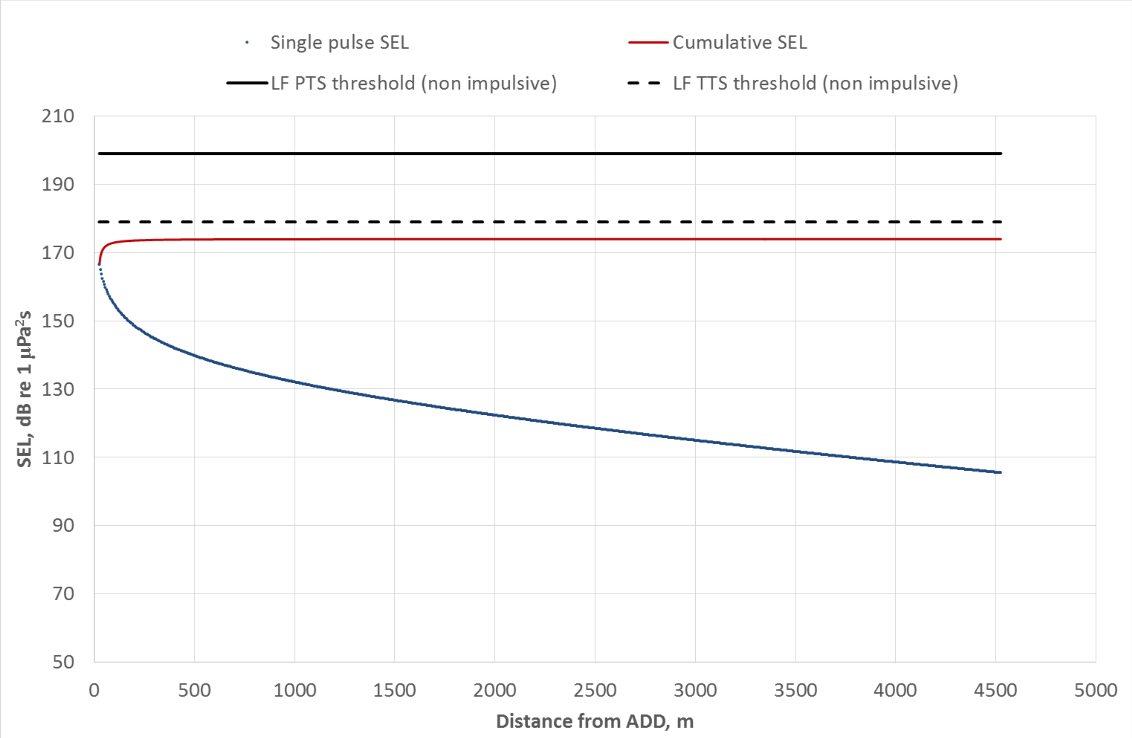


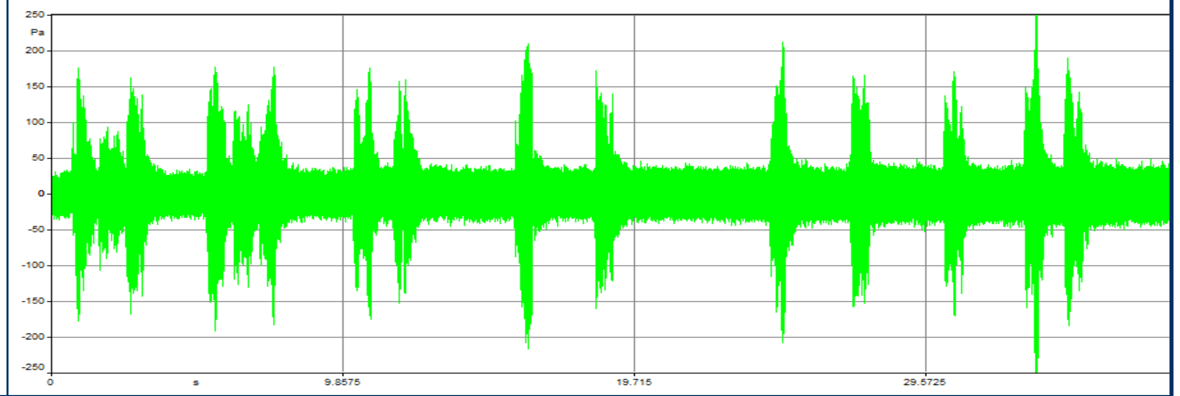
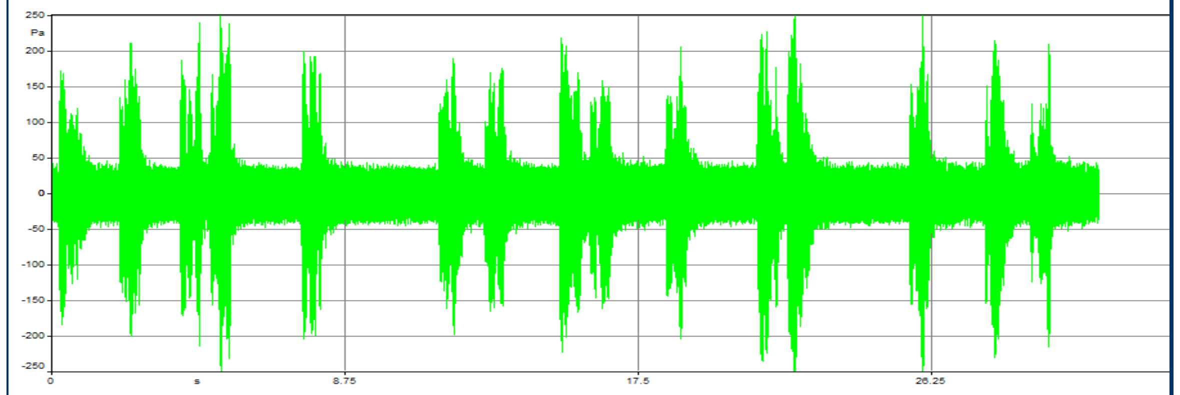
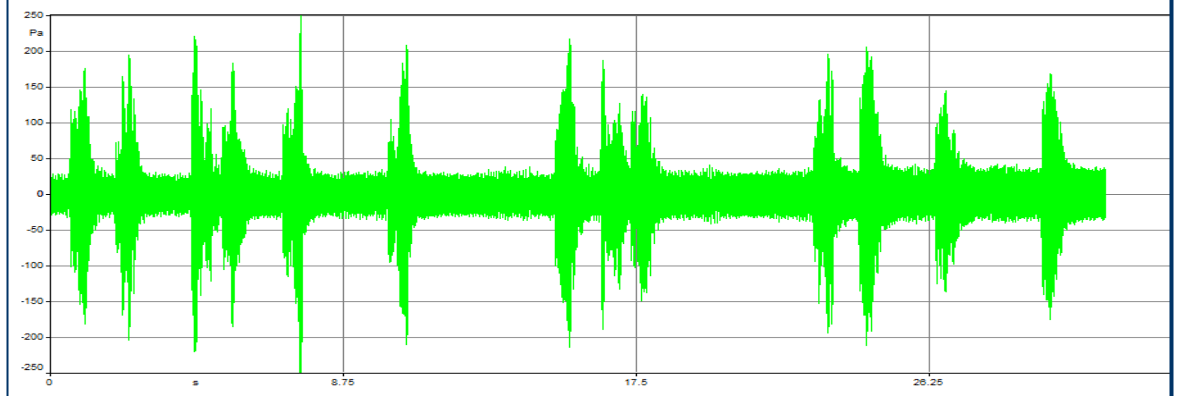
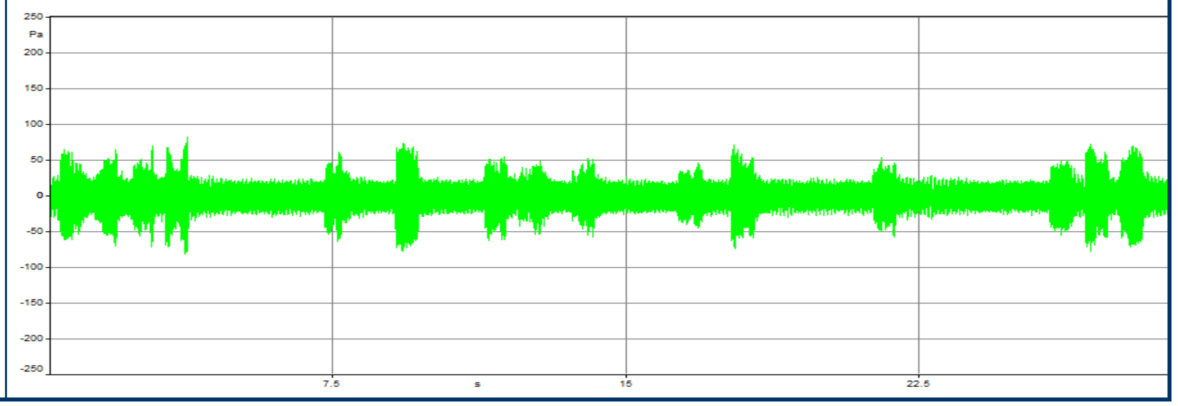
Figure C.8: SEL modelling results for minke whale swimming away from ADD at 2.5 m/s with a starting position of 25 m from the ADD

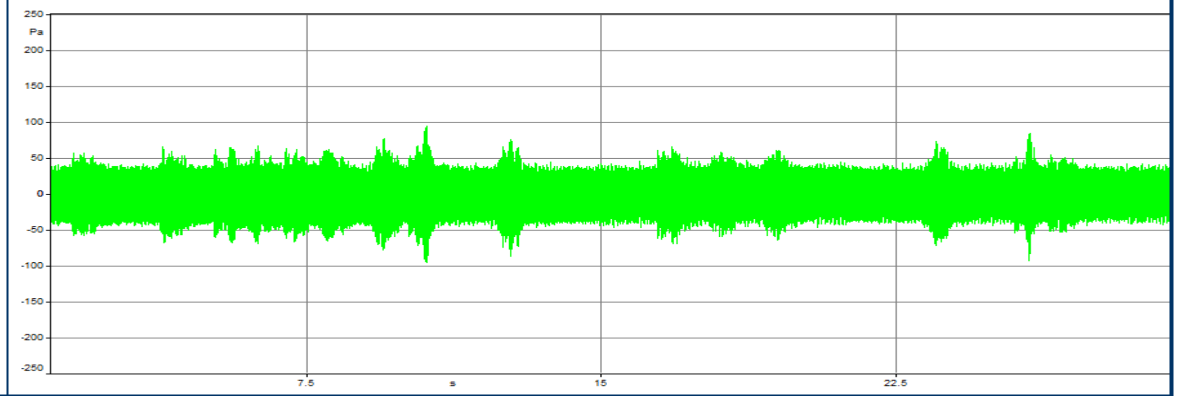
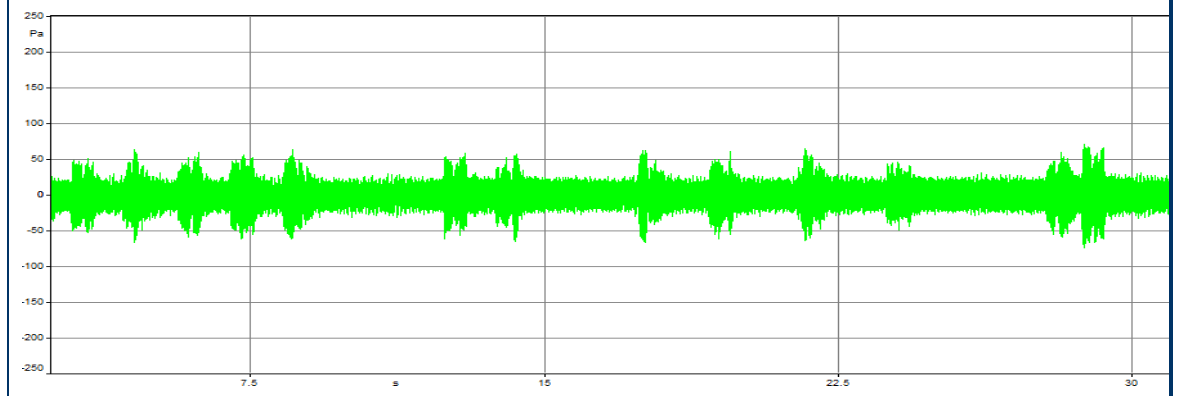
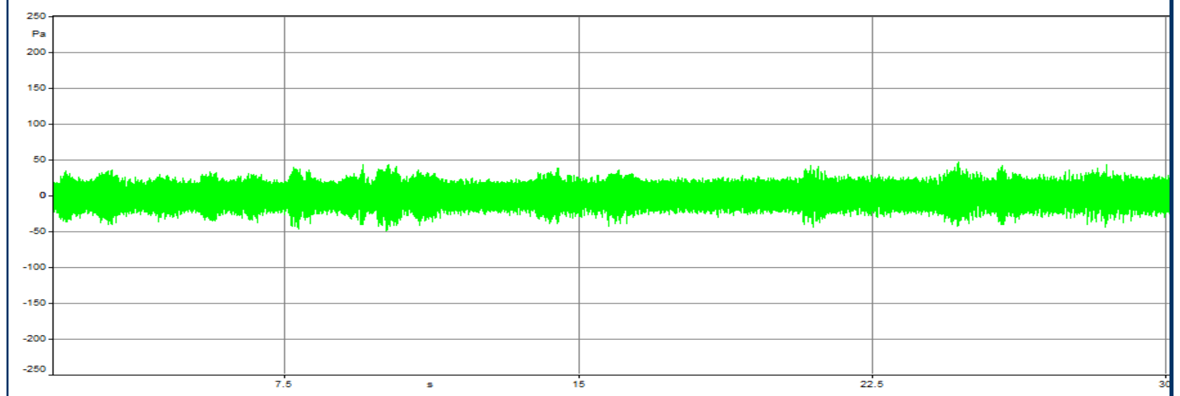
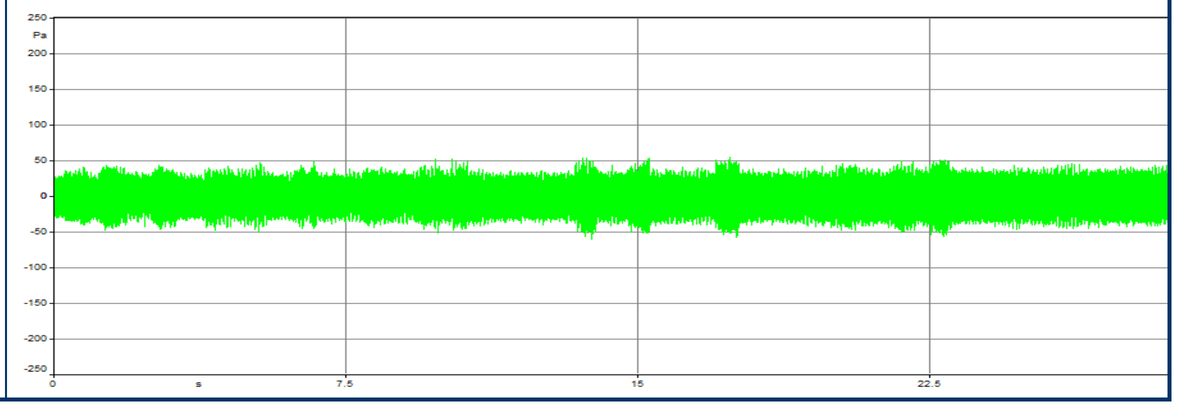
It can be clearly seen that the PTS and TTS thresholds for LF cetaceans are not exceeded for any of the scenarios modelled. Further modelling has shown that TTS threshold would only be exceeded for start distances of less than 10 m from the ADD and the PTS threshold would not be exceeded even if the mammal started immediately adjacent to the ADD. In any case, it is highly unlikely that a mammal would be in the immediate vicinity of the ADD on start-up and it is consequently highly unlikely that either PTS or TTS would occur.

It is theoretically possible that the temporary (but not permanent) threshold shift could occur at extremely short ranges (i.e. less than 10 m from the source at start-up). This scenario, however, is thought to be extremely unlikely and can therefore be effectively discounted.

Annex A: Detailed Measurement Results

Table A1: Summary of pulse magnitude for fundamental frequency and harmonics (based on arithmetic average of individual pulse data)

Time	Distance from ADD, m	Hydro-phone Depth, m	Peak, dB re 1 µPa				SEL, dB re 1 µPa²s				rms (T90) , dB re 1 µPa				Time History Graph
			14.6 kHz	*29.2 kHz*	*43.6 kHz*	*72.8 kHz*	*14.6 kHz*	*29.2 kHz*	*43.6 kHz*	*72.8 kHz*	*14.6 kHz*	*29.2 kHz*	*43.6 kHz*	*72.8 kHz*	
16:50	193	30	159.7	114.2	114.5	110.6	152.7	107.0	107.7	103.6	153.8	108.2	108.8	104.8	
16:53	200	20	161.2	115.1	117.8	117.5	154.6	108.7	111.6	111.4	155.8	109.9	112.7	112.6	
16:56	198	10	161.1	113.9	116.6	115.3	153.6	106.7	109.5	108.8	154.6	107.7	110.5	109.8	
17:04	570	10	150.0	105.2	99.0	93.0	143.3	98.6	92.3	86.9	144.6	100.0	93.6	88.2	

Time	Distance from ADD, m	Hydro-phone Depth, m	Peak, dB re 1 µPa				SEL, dB re 1 µPa²s				rms (T90) , dB re 1 µPa				Time History Graph
			14.6 kHz	*29.2 kHz*	*43.6 kHz*	*72.8 kHz*	*14.6 kHz*	*29.2 kHz*	*43.6 kHz*	*72.8 kHz*	*14.6 kHz*	*29.2 kHz*	*43.6 kHz*	*72.8 kHz*	
17:07	560	20	146.3	98.6	95.8	91.5	139.3	92.2	89.6	85.6	140.9	93.9	91.3	87.3	
17:14	556	30	148.9	103.0	97.8	92.2	141.9	96.0	91.1	86.4	142.9	97.0	92.1	87.4	
17:23	996	30	141.3	93.0	90.3	87.4	134.2	86.6	83.9	81.4	135.7	88.2	85.5	83.0	
17:27	980	20	140.6	N/A	N/A	N/A	133.1	N/A	N/A	N/A	134.8	N/A	N/A	N/A	

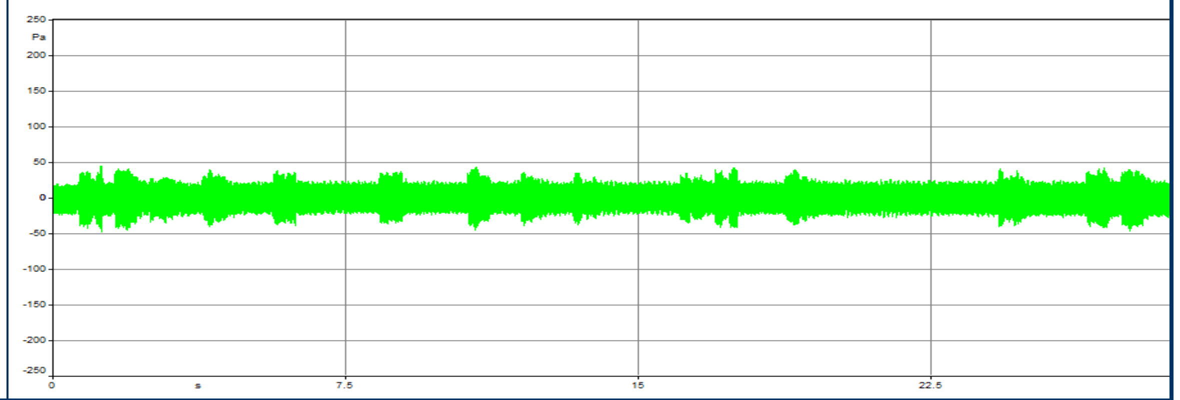
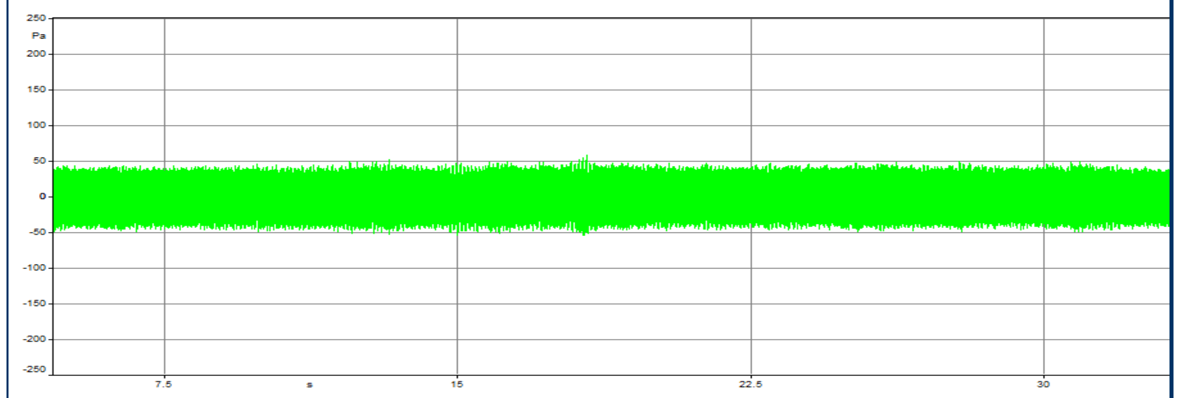
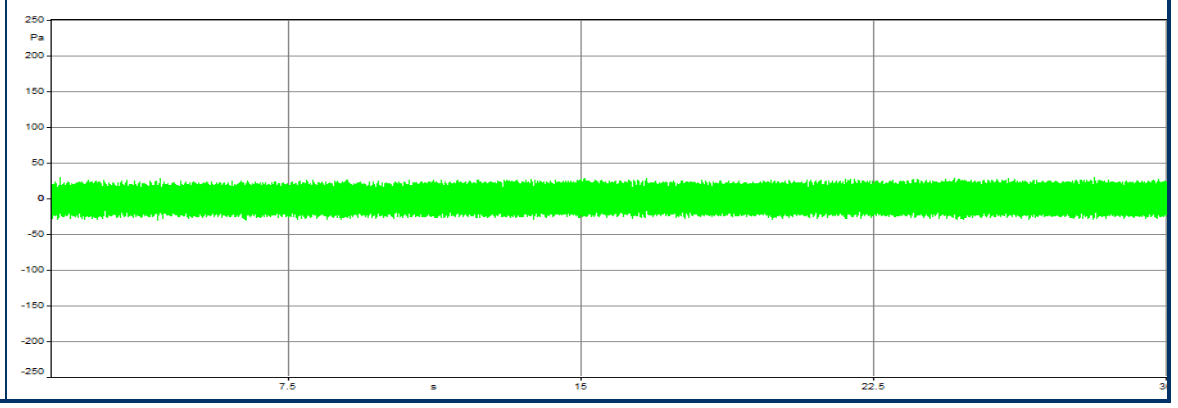
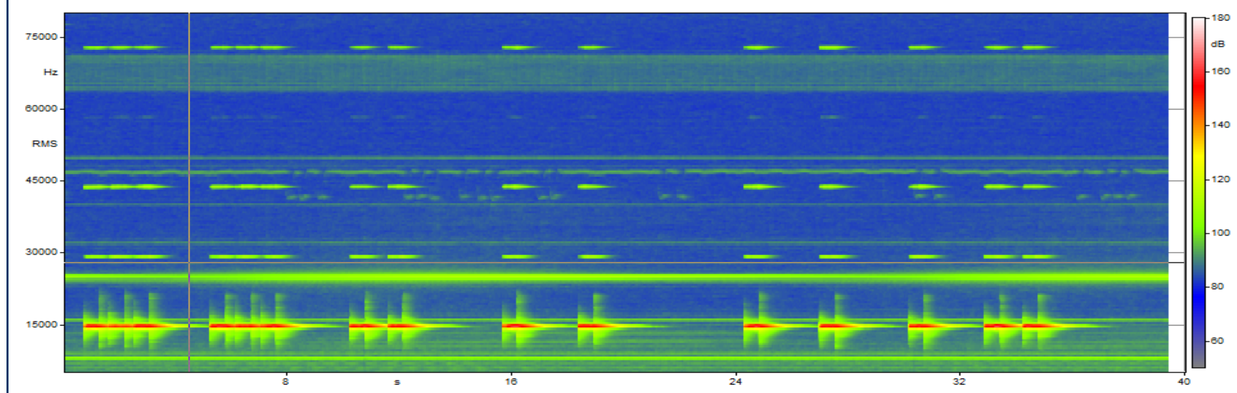
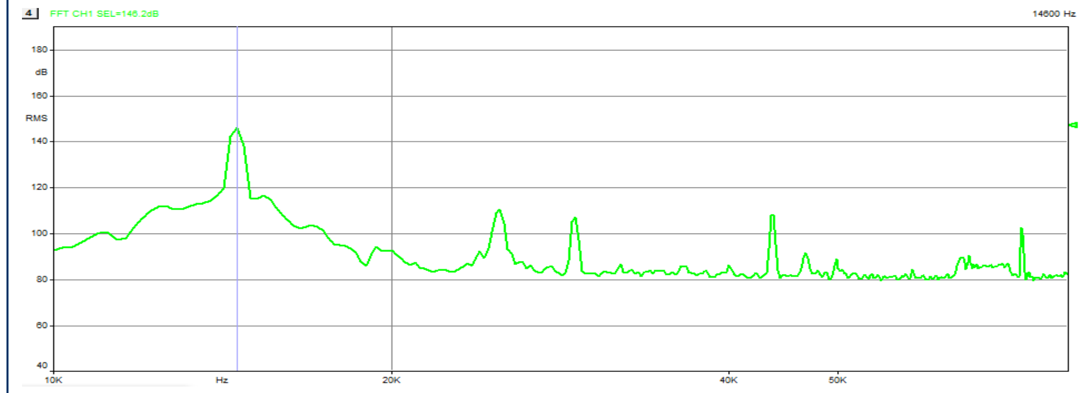
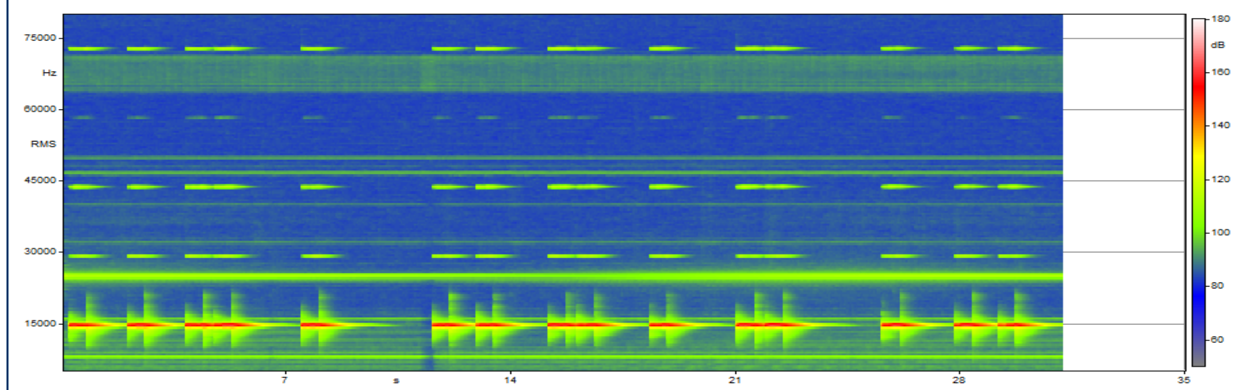
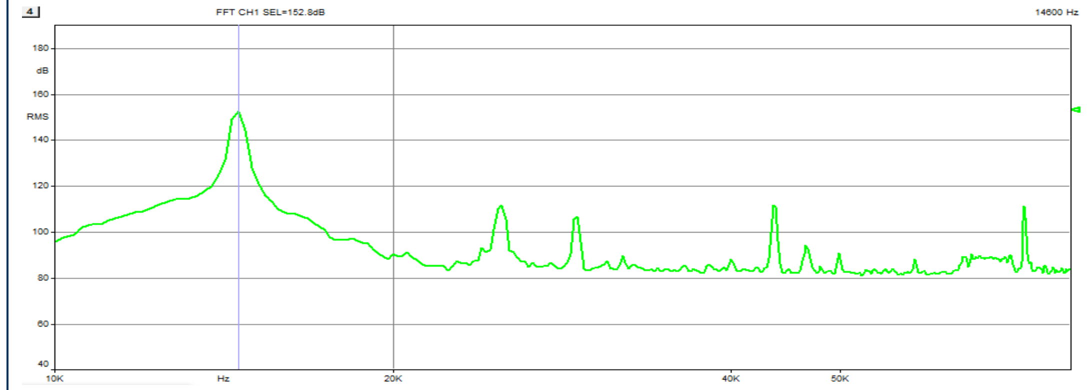
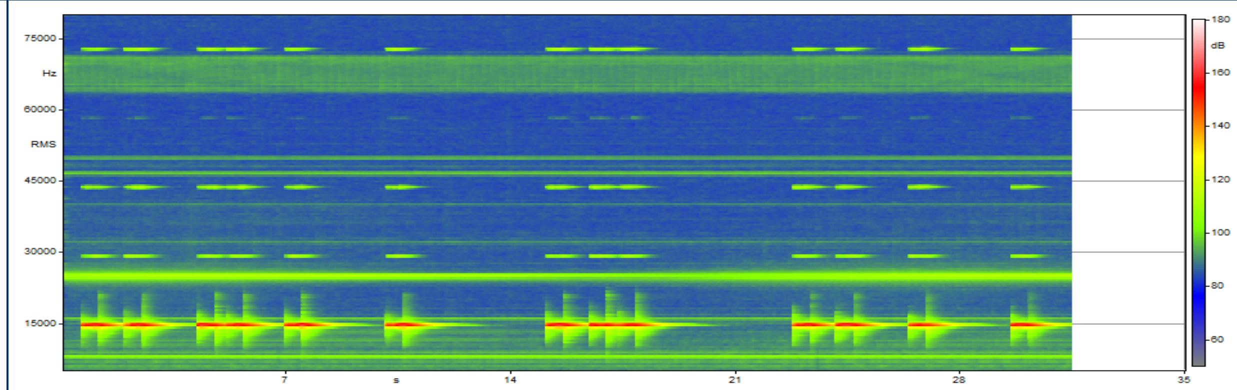
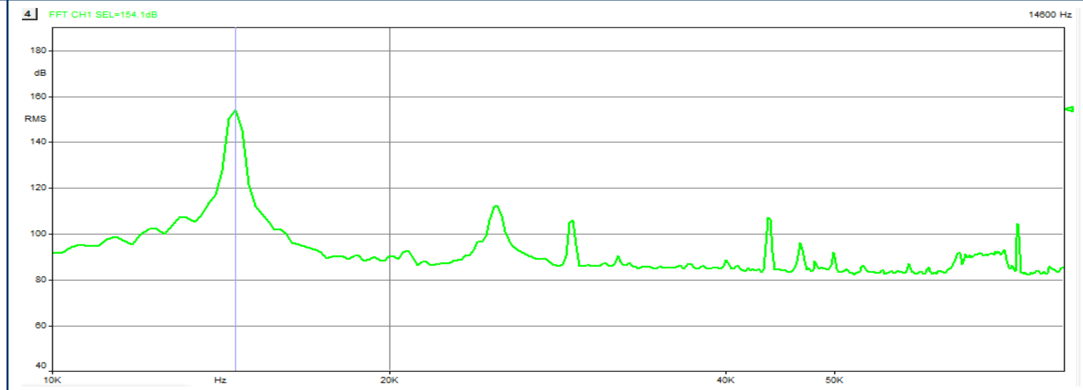
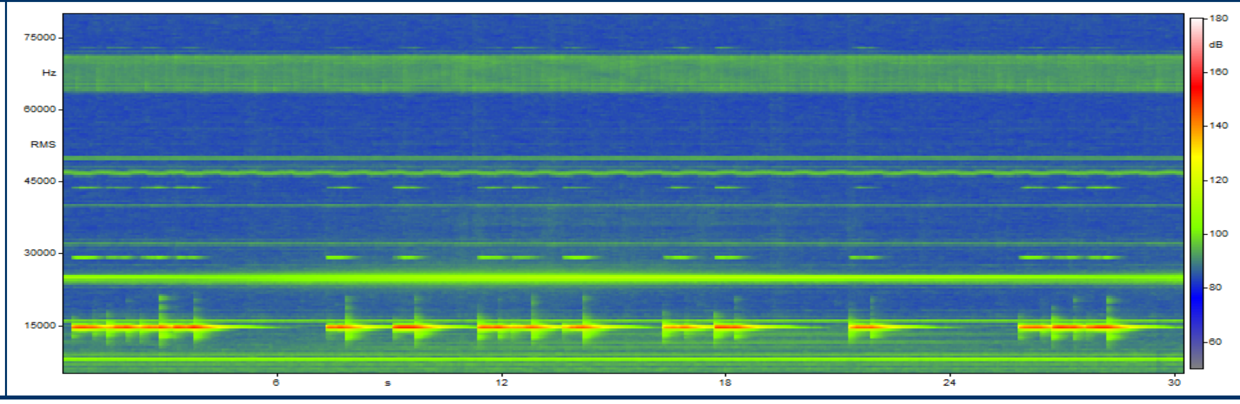
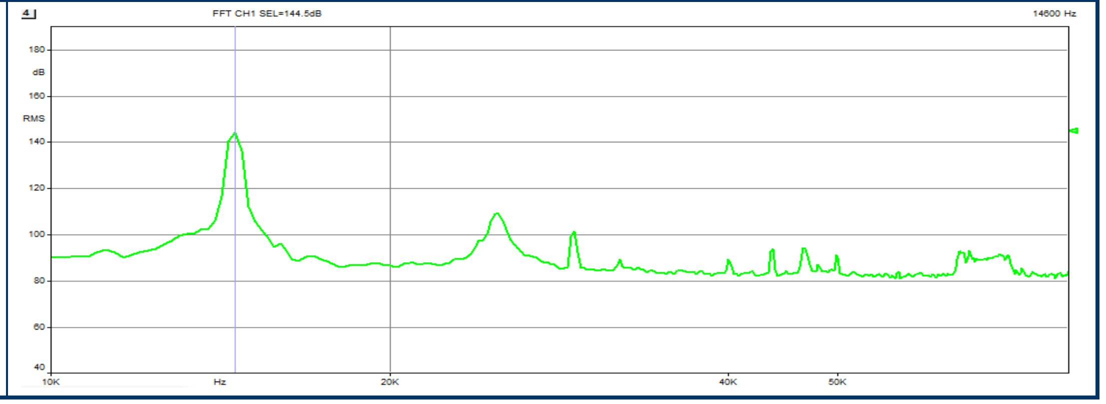
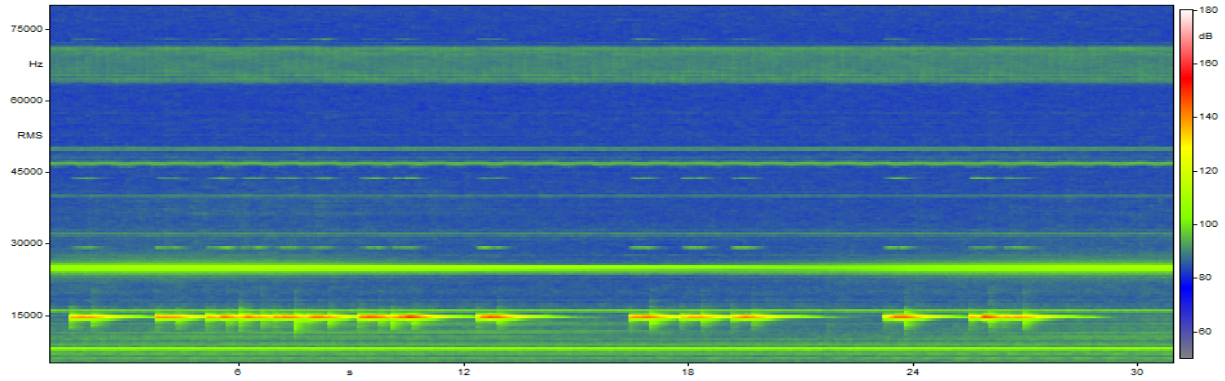
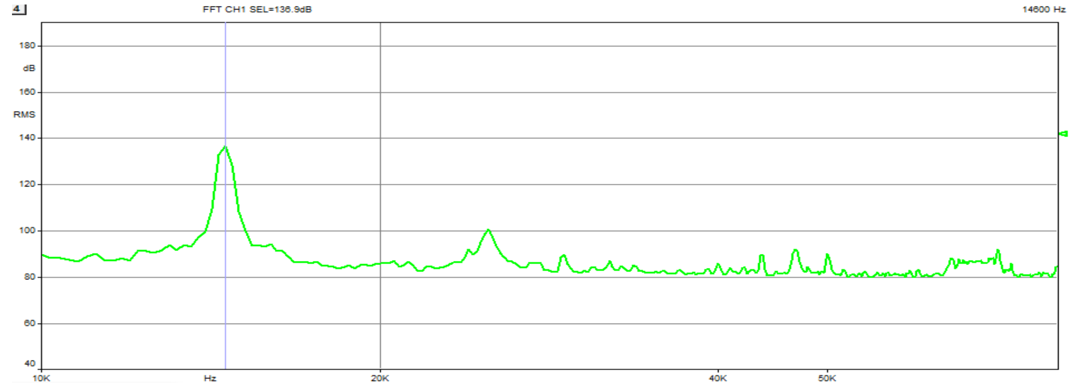
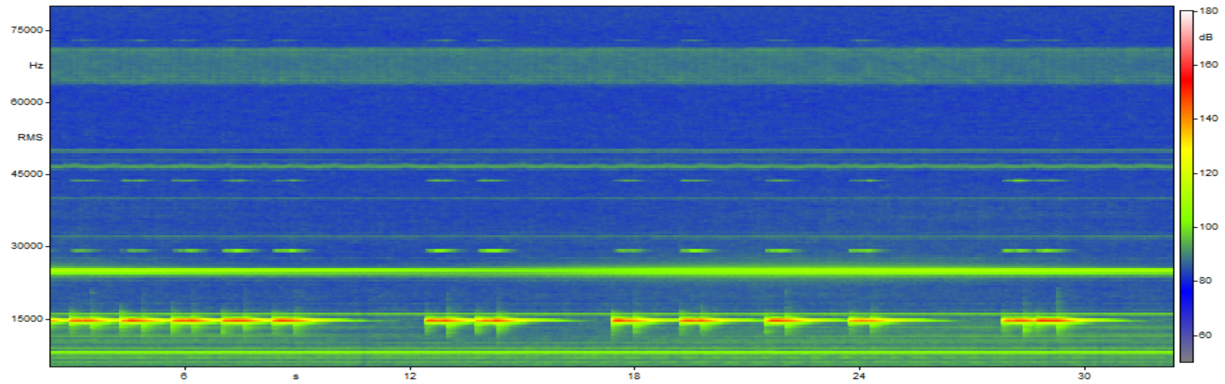
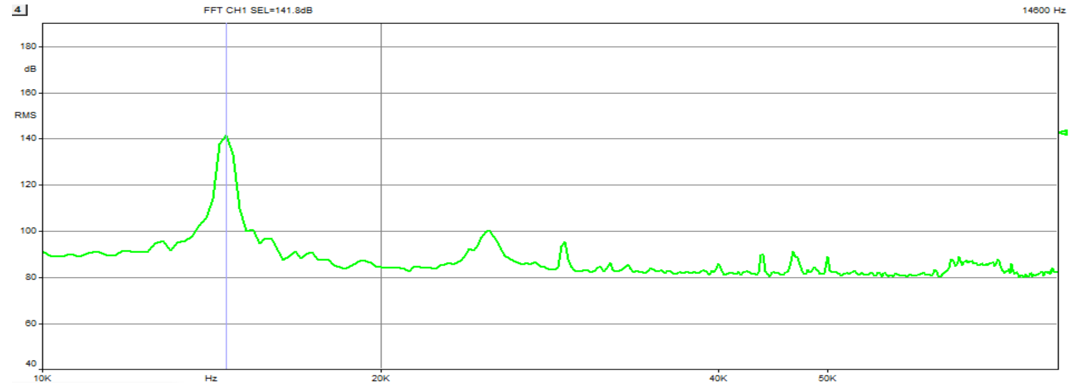
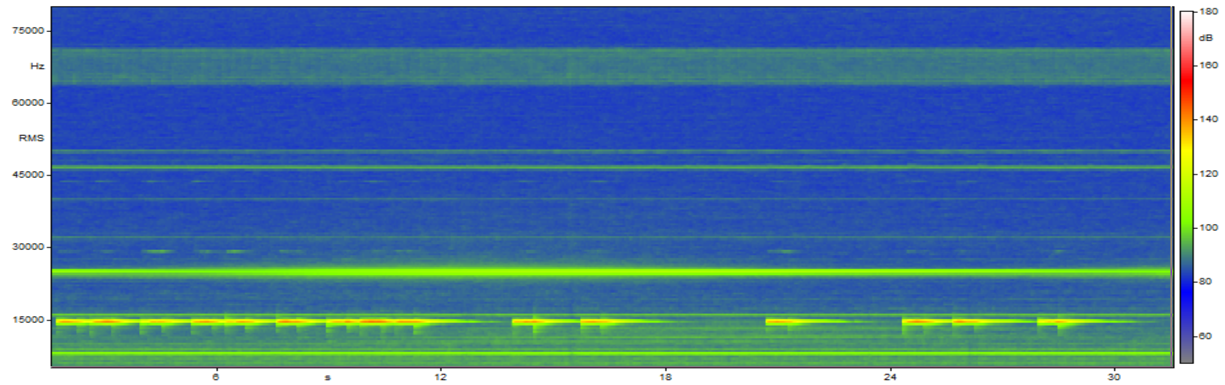
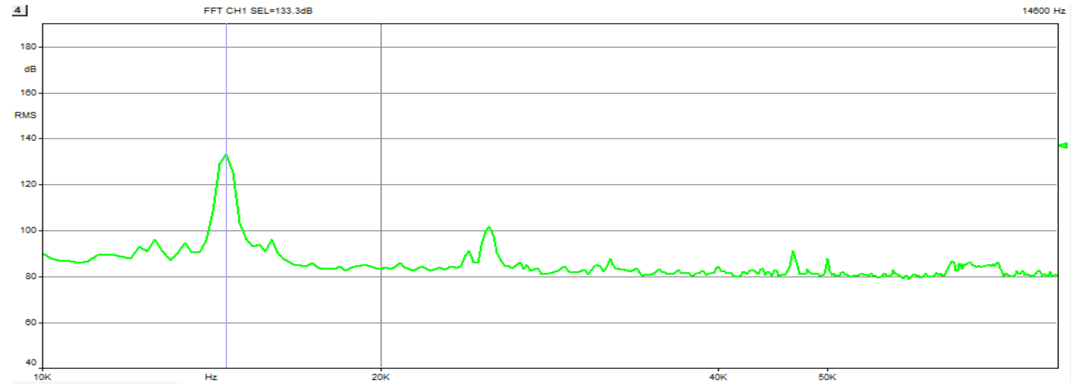
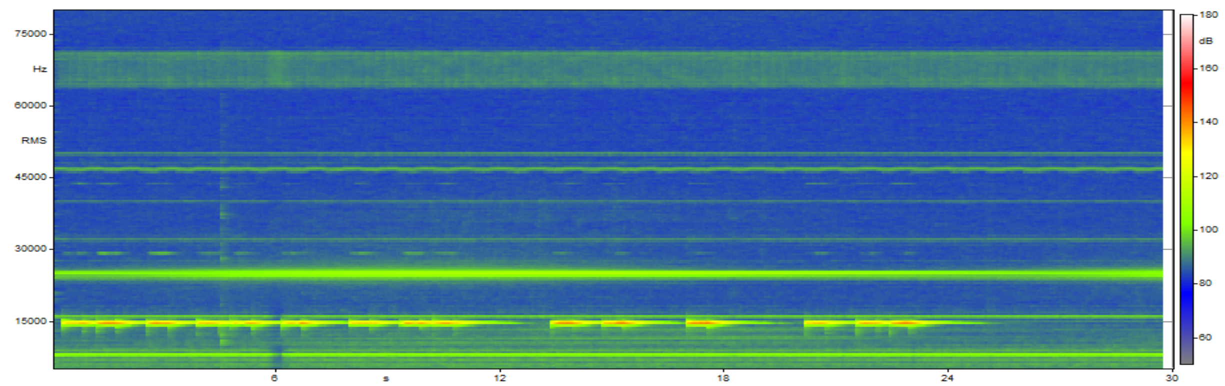
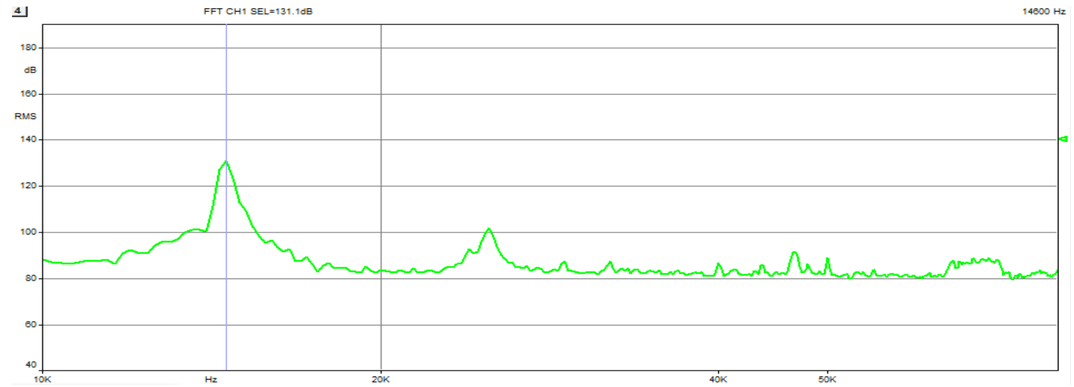
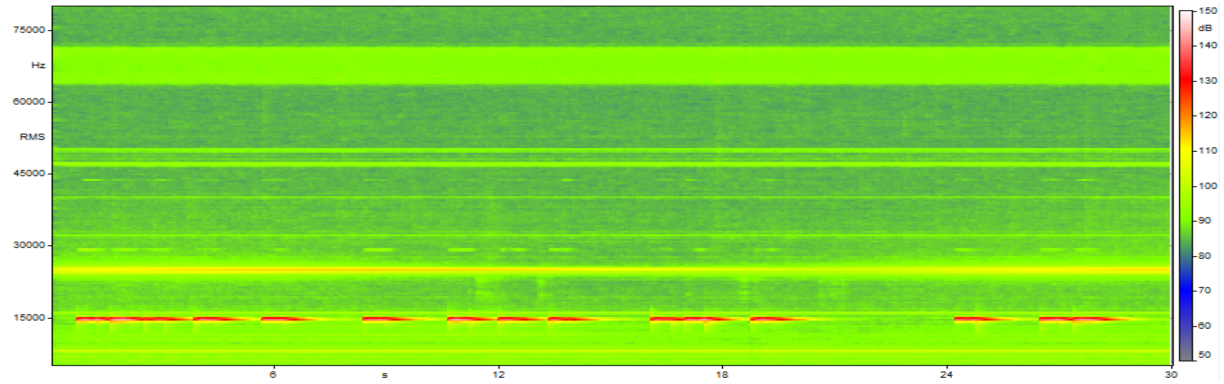
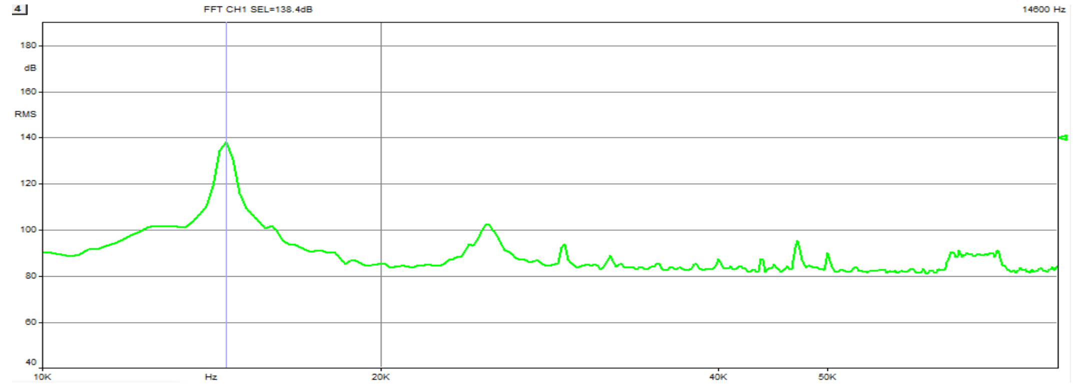
Time	Distance from ADD, m	Hydro-phone Depth, m	Peak, dB re 1 µPa				SEL, dB re 1 µPa²s				rms (T90) , dB re 1 µPa				Time History Graph
			14.6 kHz	*29.2 kHz*	*43.6 kHz*	*72.8 kHz*	*14.6 kHz*	*29.2 kHz*	*43.6 kHz*	*72.8 kHz*	*14.6 kHz*	*29.2 kHz*	*43.6 kHz*	*72.8 kHz*	
17:32	986	10	143.1	N/A	N/A	N/A	136.3	N/A	N/A	N/A	137.9	N/A	N/A	N/A	
17:42	1508	30	131.8	N/A	N/A	N/A	124.2	N/A	N/A	N/A	126.9	N/A	N/A	N/A	
17:59	2107	30	128.8	N/A	N/A	N/A	121.8	N/A	N/A	N/A	124.3	N/A	N/A	N/A	

Table A2: Pulse spectrograms and FFT plots

Time	Distance from ADD, m	Hydro-phone Depth, m	Spectrogram Graph	SEL FFT of typical Pulse (a single example plot from the data)
16:50	193	30		
16:53	200	20		
16:56	198	10		
17:04	570	10		

Time	Distance from ADD, m	Hydro-phone Depth, m	Spectrogram Graph	SEL FFT of typical Pulse (a single example plot from the data)
17:07	560	20		
17:14	556	30		
17:23	996	30		
17:27	980	20		

<table>
<tr><th>Time</th><th>Distance from ADD, m</th><th>Hydro-phone Depth, m</th><th>Spectrogram Graph</th><th>SEL FFT of typical Pulse (a single example plot from the data)</th></tr>
<tr><td>17:32</td><td>986</td><td>10</td><td>
</td><td>
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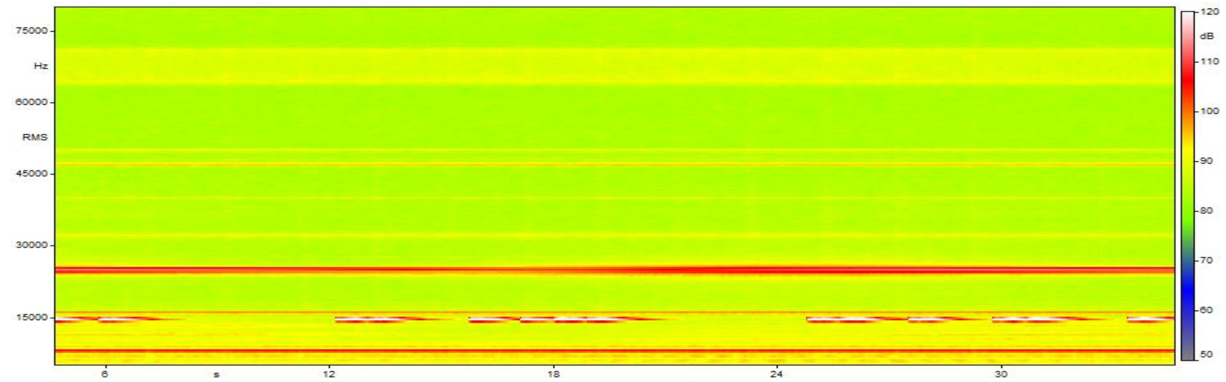
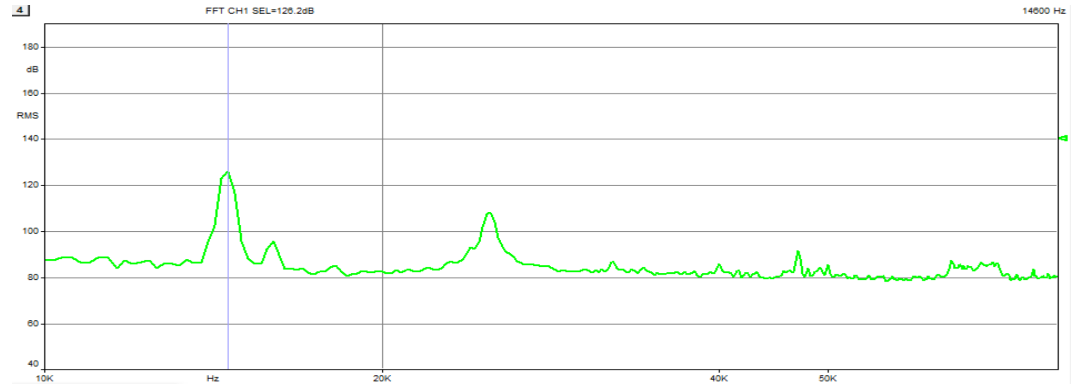
<tr><td>17:42</td><td>1508</td><td>30</td><td>
</td><td>
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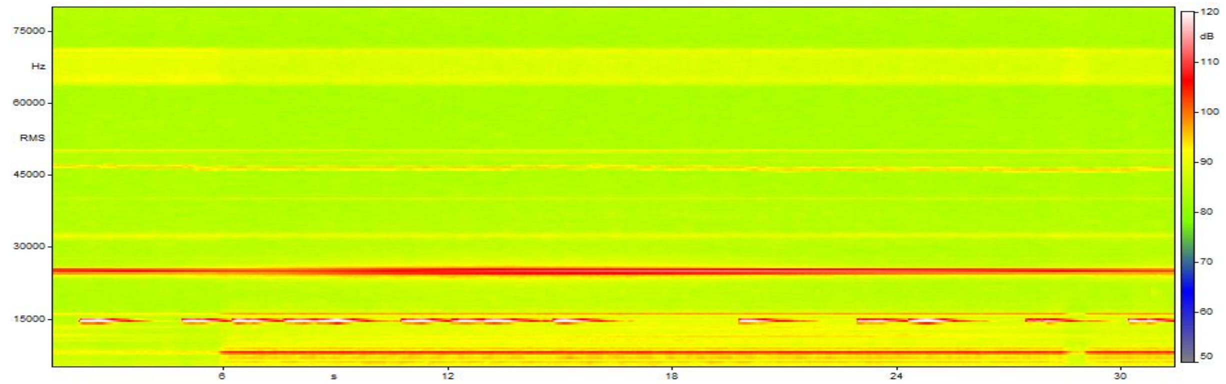
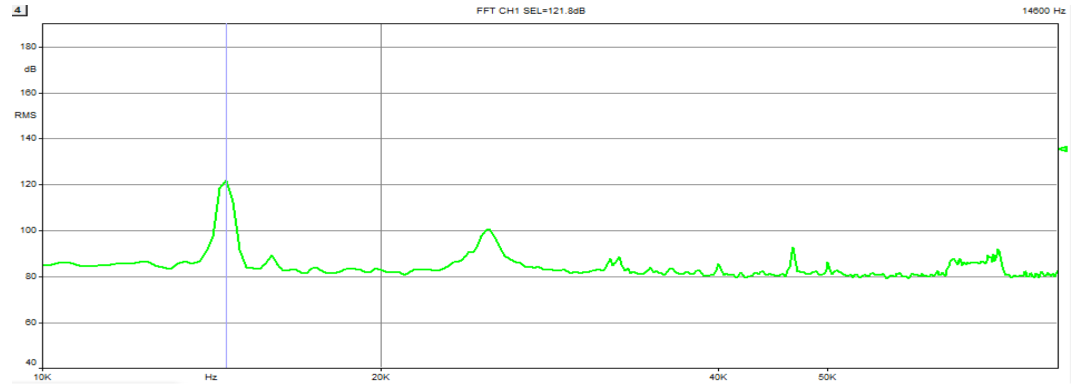
<tr><td>17:59</td><td>2107</td><td>30</td><td>
</td><td>
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Table A3: Individual pulse sound levels (at fundamental frequency)

Measurement Time	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	Pulse 6	Pulse 7	Pulse 8	Pulse 9	Pulse 10	Pulse 11	Pulse 12	Pulse 13	Pulse 14	Pulse 15	Arithmetic Average	Log Average	St. Dev	Min	Max	Range
Zero – peak, dB re 1 Pa																					
16:50	159.9	153.1	159.7	160.1	156.6	160.5	160.5	157.8	163.1	158.7	162.0	159.3	159.5	164.3	160.6	159.7	159.9	2.6	153.1	163.1	10.0
16:53	160.0	161.7	160.9	163.4	162.3	160.3	159.9	162.0	159.5	161.0	162.8	164.5	155.6	162.9	160.6	161.2	161.6	2.1	155.6	164.5	8.9
16:56	161.5	161.4	163.1	160.5	163.9	162.5	163.2	160.5	158.9	161.0	162.6	160.6	160.6	159.8	156.6	161.1	161.5	1.9	156.6	163.9	7.3
17:04	150.8	150.6	149.4	152.9	149.6	153.8	149.4	147.6	148.1	145.8	151.1	147.4	148.2	152.3	152.5	150.0	150.5	2.3	145.8	153.8	8.0
17:07	143.1	143.6	146.5	146.0	145.0	146.3	149.1	152.3	149.7	146.4	141.8	145.5	147.7	145.8	145.7	146.3	147.1	2.6	141.8	152.3	10.5
17:14	149.4	148.1	147.4	149.9	148.9	149.1	150.2	148.0	148.8	150.6	148.3	149.9	144.4	148.3	151.6	148.9	149.1	1.7	144.4	151.6	7.2
17:23	140.7	143.2	137.4	139.5	139.6	143.7	141.9	145.5	141.4	141.4	140.4	140.0	143.6	142.3	139.3	141.3	141.8	2.1	137.4	145.5	8.1
17:27	137.6	142.9	141.5	137.4	138.0	140.8	138.6	139.4	139.7	143.2	144.0	144.3	137.9	140.0	143.8	140.6	141.3	2.5	137.4	144.3	6.9
17:32	144.8	146.1	139.0	143.1	142.2	144.0	145.4	141.0	142.2	140.6	144.9	143.1	142.1	144.1	144.6	143.1	143.5	2.0	139.0	146.1	7.1
17:42	133.0	132.5	128.1	132.0	133.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	131.8	132.1	2.1	128.1	133.2	5.1
17:59	129.2	124.0	131.0	129.4	130.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	128.8	129.3	2.8	124.0	131.0	7.0
SEL, dB re 1 Pa^2s																					
16:50	152.5	146.2	153.4	154.4	150.6	152.6	152.9	151.2	155.7	152.6	153.7	153.3	152.2	155.4	153.5	152.7	152.9	2.3	146.2	155.7	9.5
16:53	152.8	154.8	154.3	156.6	156.0	153.6	153.5	155.8	153.1	154.1	155.9	157.0	155.5	155.6	150.9	154.6	154.9	1.7	150.9	157.0	6.1
16:56	154.1	153.6	154.9	152.4	154.8	154.2	155.8	152.7	152.2	153.3	156.0	153.8	153.8	153.1	149.8	153.6	153.9	1.5	149.8	156.0	6.2
17:04	144.5	142.5	141.4	146.3	142.6	147.7	143.3	140.4	140.6	139.4	145.0	141.5	142.5	145.7	146.0	143.3	144.0	2.5	139.4	147.7	8.3
17:07	136.9	137.3	138.5	137.6	138.6	139.3	141.9	143.4	141.3	140.2	135.5	137.5	140.0	140.2	140.9	139.3	139.8	2.1	135.5	143.4	7.9
17:14	141.8	140.8	141.1	141.5	142.3	143.0	143.1	142.2	140.9	142.7	142.0	142.7	138.2	141.4	145.4	141.9	142.2	1.5	138.2	145.4	7.2
17:23	133.3	135.5	130.9	134.3	132.2	136.5	132.4	139.2	135.5	134.6	134.2	133.3	135.7	134.1	130.8	134.2	134.7	2.2	130.8	139.2	8.4
17:27	131.1	135.8	134.5	130.6	130.5	130.7	131.9	132.2	132.7	135.7	135.7	137.0	130.4	132.3	136.0	133.1	133.8	2.4	130.4	137.0	6.6
17:32	138.4	139.8	132.5	136.3	136.0	137.7	137.9	134.2	133.9	133.5	137.2	135.7	135.5	137.8	138.4	136.3	136.8	2.1	132.5	139.8	7.3
17:42	126.2	124.5	120.1	124.8	125.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	124.2	124.7	2.4	120.1	126.2	6.1
17:59	121.8	120.2	122.4	121.6	122.8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	121.8	121.8	1.0	120.2	122.8	2.6
Rms T90, dB re 1 Pa																					
16:50	153.6	148.0	155.0	155.1	152.4	154.0	154.3	152.0	156.3	153.4	154.8	154.1	152.8	157.2	154.2	153.8	154.0	2.1	148.0	156.3	8.3
16:53	153.7	156.1	155.9	158.0	157.4	154.4	154.4	156.7	154.2	155.4	157.2	157.9	156.8	156.5	152.7	155.8	156.1	1.6	152.7	158.0	5.3
16:56	155.0	154.2	155.7	153.7	155.6	155.1	156.7	153.9	152.9	154.4	156.7	155.0	155.0	154.2	150.9	154.6	154.8	1.5	150.9	156.7	5.8
17:04	146.1	144.1	143.2	147.2	143.7	150.2	144.4	141.5	141.9	140.1	146.5	142.8	143.4	147.2	147.2	144.6	145.4	2.7	140.1	150.2	10.1
17:07	139.1	138.9	139.9	139.4	140.8	140.7	142.0	145.0	143.7	141.5	137.5	139.0	142.0	142.0	142.7	140.9	141.4	2.0	137.5	145.0	7.5
17:14	143.2	141.8	142.6	142.2	143.3	144.1	144.4	143.0	142.0	143.3	142.9	142.9	138.8	142.7	146.0	142.9	143.1	1.5	138.8	146.0	7.2
17:23	135.5	136.7	132.0	136.1	133.9	137.5	134.6	141.2	136.7	135.7	135.6	135.5	136.9	136.1	132.2	135.7	136.3	2.2	132.0	141.2	9.2
17:27	132.7	137.4	136.5	132.0	131.7	132.9	133.4	133.6	134.0	138.2	137.4	139.2	132.4	132.3	138.0	134.8	135.6	2.7	131.7	139.2	7.5
17:32	139.5	140.7	133.6	137.8	138.5	139.3	140.1	135.8	135.9	134.8	139.6	136.7	137.1	139.4	140.0	137.9	138.4	2.2	133.6	140.7	7.1
17:42	128.9	127.1	123.5	126.9	128.3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	126.9	127.3	2.1	123.5	128.9	5.4
17:59	124.3	122.9	125.0	124.3	125.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	124.3	124.4	0.9	122.9	125.2	2.3

Table A4: Individual pulse lengths

Measurement Time	Pulse Length, s															Arithmetic Average	Standard Deviation	Min	Max	Range
	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	Pulse 6	Pulse 7	Pulse 8	Pulse 9	Pulse 10	Pulse 11	Pulse 12	Pulse 13	Pulse 14	Pulse 15					
16:50	0.78	0.66	0.69	0.84	0.66	0.72	0.72	0.84	0.87	0.84	0.78	0.84	0.87	0.66	0.84	0.77	0.08	0.66	0.87	0.21
16:53	0.81	0.75	0.69	0.72	0.72	0.81	0.81	0.81	0.78	0.75	0.75	0.81	0.75	0.81	0.66	0.76	0.05	0.66	0.81	0.15
16:56	0.81	0.87	0.84	0.75	0.84	0.81	0.81	0.75	0.84	0.78	0.84	0.75	0.75	0.78	0.78	0.80	0.04	0.75	0.87	0.12
17:04	0.69	0.69	0.66	0.81	0.78	0.57	0.78	0.78	0.75	0.84	0.72	0.75	0.81	0.72	0.75	0.74	0.07	0.57	0.84	0.27
17:07	0.60	0.69	0.72	0.66	0.60	0.72	0.99	0.69	0.57	0.75	0.63	0.72	0.63	0.66	0.66	0.69	0.10	0.57	0.99	0.42
17:14	0.72	0.78	0.72	0.84	0.81	0.78	0.75	0.84	0.69	0.87	0.81	0.96	0.87	0.75	0.87	0.80	0.07	0.69	0.96	0.27
17:23	0.60	0.75	0.78	0.66	0.69	0.78	0.60	0.63	0.75	0.78	0.72	0.60	0.75	0.63	0.72	0.70	0.07	0.60	0.78	0.18
17:27	0.69	0.69	0.63	0.72	0.75	0.60	0.72	0.72	0.75	0.57	0.69	0.60	0.63	0.60	0.63	0.67	0.06	0.57	0.75	0.18
17:32	0.78	0.81	0.78	0.72	0.57	0.69	0.60	0.69	0.63	0.75	0.57	0.78	0.69	0.69	0.69	0.70	0.08	0.57	0.81	0.24
17:42	0.54	0.54	0.45	0.63	0.54	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.54	0.06	0.45	0.63	0.18
17:59	0.57	0.54	0.54	0.54	0.57	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.55	0.02	0.54	0.57	0.03

C.5 References

Brandt, Miriam J., Caroline Höschle, Ansgar Diederichs, Klaus Betke, Rainer Matuschek, Sophia Witte, and Georg Nehls. 2012. "Effectiveness of a Sealscarer in Deterring Harbour Porpoises (Phocoena Phocoena)." Final report to Project Management Jülich. http://bioconsult-sh.de/site/assets/files/1359/1359.pdf.

———. 2013. "Far-Reaching Effects of a Seal Scarer on Harbour Porpoises, Phocoena Phocoena." *Aquatic Conservation: Marine and Freshwater Ecosystems* 23 (2): 222–32.

Cooper, Lisa Noelle, Nils Sedano, Stig Johansson, Bryan May, Joey D. Brown, Casey M. Holliday, Brian W. Kot, and Frank E. Fish. 2008. "Hydrodynamic Performance of the Minke Whale (Balaenoptera Acutorostrata) Flipper." *Journal of Experimental Biology* 211 (12): 1859–67.

Cranford, Ted W., and Petr Krysl. 2015. "Fin Whale Sound Reception Mechanisms: Skull Vibration Enables Low-Frequency Hearing." *PloS One* 10 (1): e0116222.

Erbe, Christine. 2002. "Hearing Abilities of Baleen Whales." *Report CR* 65. http://cradpdf.drdc-rddc.gc.ca/PDFS/unc09/p519661.pdf.

Gordon, J., C. Blight, E. Bryant, and D. Thompson. 2015. "Tests of Acoustic Signals for Aversive Sound Mitigation with Harbour Seals." MR 8.1 version F2. Marine Mammal Scientific Support Research Programme MMSS/001/11. https://tethys.pnnl.gov/sites/default/files/publications/MR8-1_ADD_mitigation_VF2.pdf.

Harris, Fredric J. 1978. "On the Use of Windows for Harmonic Analysis with the Discrete Fourier Transform." *Proceedings of the IEEE* 66 (1): 51–83.

Houser, Dorian S., David A. Helweg, and Patrick WB Moore. 2001. "A Bandpass Filter-Bank Model of Auditory Sensitivity in the Humpback Whale." *Aquatic Mammals* 27 (2): 82–91.

Ketten, Darlene R., and David C. Mountain. 2011. "Modelling Minke Whale Hearing." WHOI & Boston University for the Joint Industry Programme.

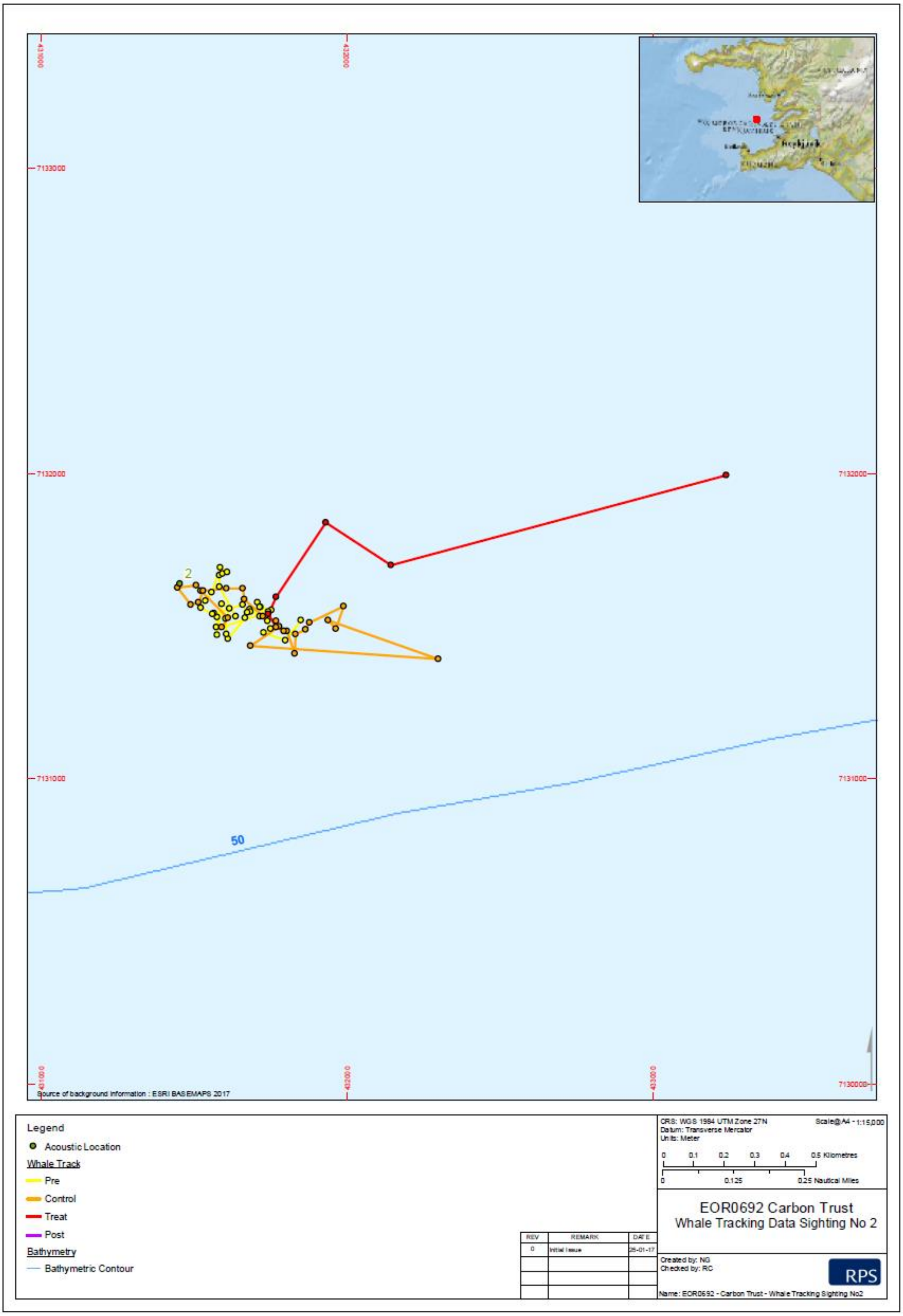
Marsh, H. Wyser, and M. Schulkin. 1962. "Shallow-Water Transmission." *The Journal of the Acoustical Society of America* 34 (6): 863–64.

National Marine Fisheries Service. 2016. Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-55, 178 p.

Schulkin, M., and J. A. Mercer. 1985. "Colossus Revisited: A Review and Extension of the Marsh-Schulkin Shallow Water Transmission Loss Model (1962)." DTIC Document. http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA164588.

Tubelli, Andrew A., Aleks Zosuls, Darlene R. Ketten, Maya Yamato, and David C. Mountain. 2012. "A Prediction of the Minke Whale (Balaenoptera Acutorostrata) Middle-Ear Transfer Function a." *The Journal of the Acoustical Society of America* 132 (5): 3263–72.

Appendix D - Response Maps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Acoustic Location
Whale Track
Pre
Control
Treat
Post
Bathymetry
Bathymetric Contour
REV
REMARK
DATE
0
Initial issue
25-01-17
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Datum: Transverse Mercator
Units: Meter
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0 0.125 0.25 Nautical Miles
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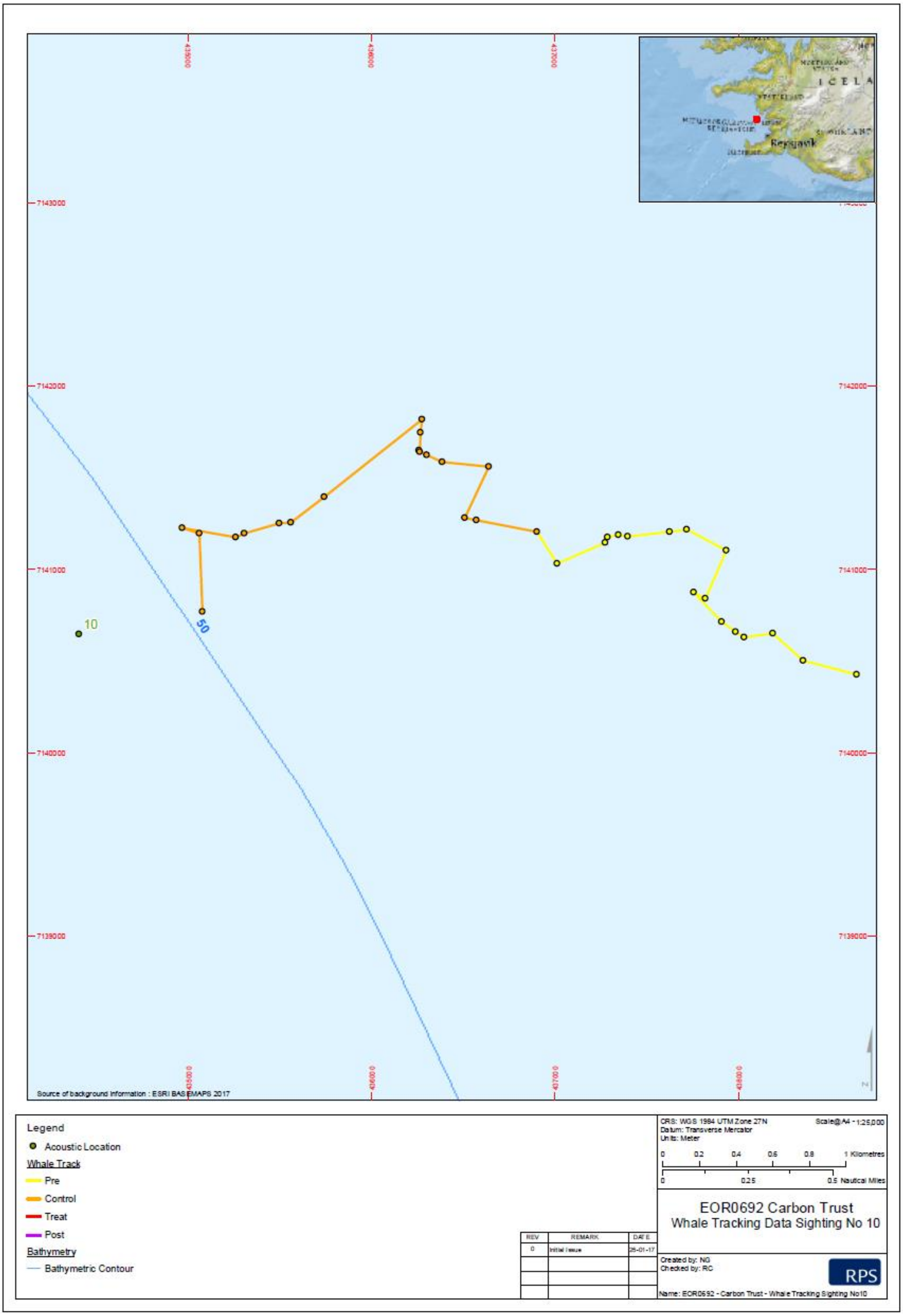
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Reykjavik
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Legend
Acoustic Location
Whale Track
Pre
Control
Treat
Post
Bathymetry
Bathymetric Contour
REV
REMARK
DATE
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25-01-17
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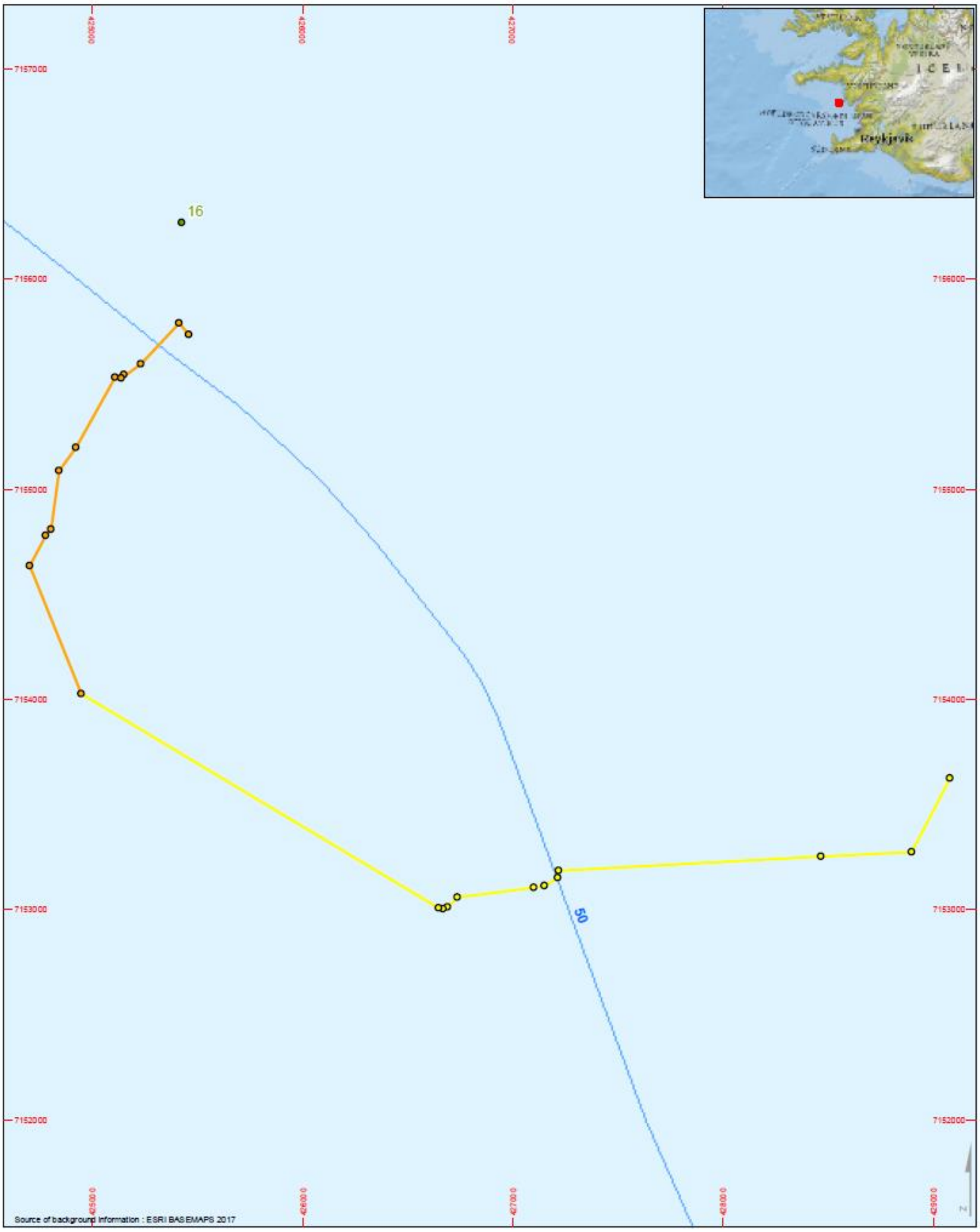

Legend
Acoustic Location
Whale Track
Pre
Control
Treat
Post
Bathymetry
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REV	REMARK	DATE
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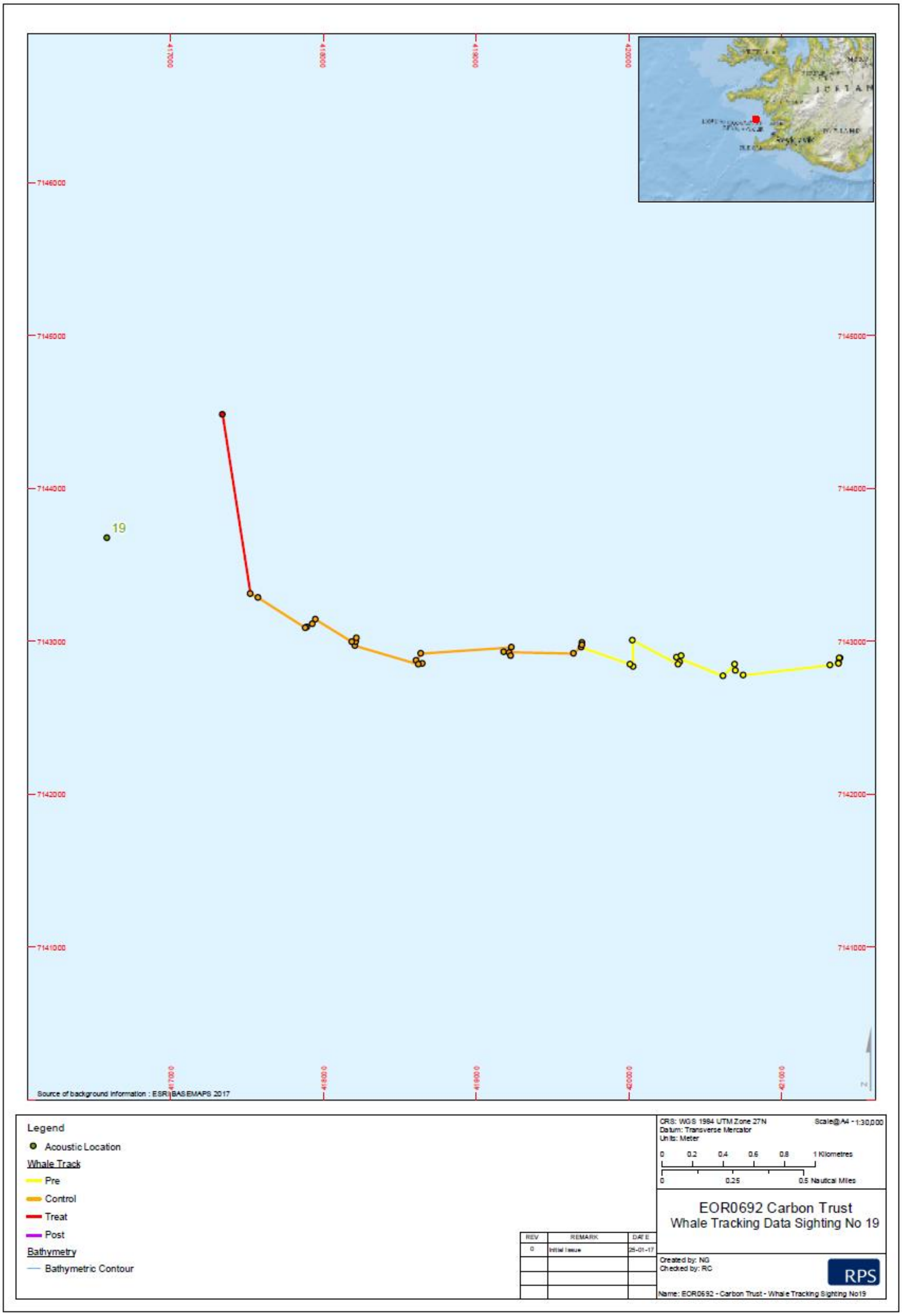

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Pre
Control
Treat
Post
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Bathymetric Contour
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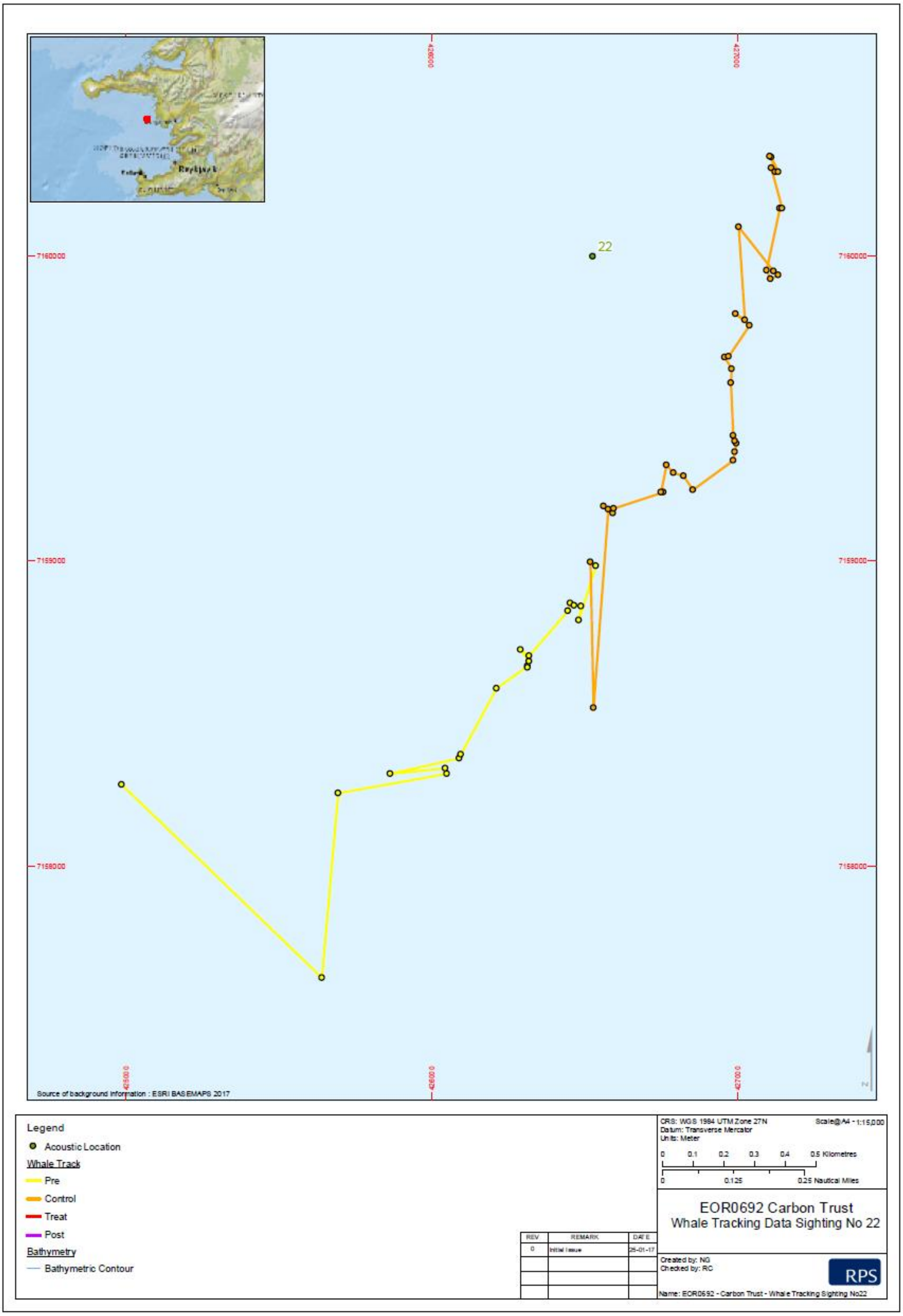
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Whale Track
Pre
Control
Treat
Post
Bathymetry
Bathymetric Contour
REV
REMARK
DATE
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Initial Issue
25-01-17
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Datum: Transverse Mercator
Units: Meter
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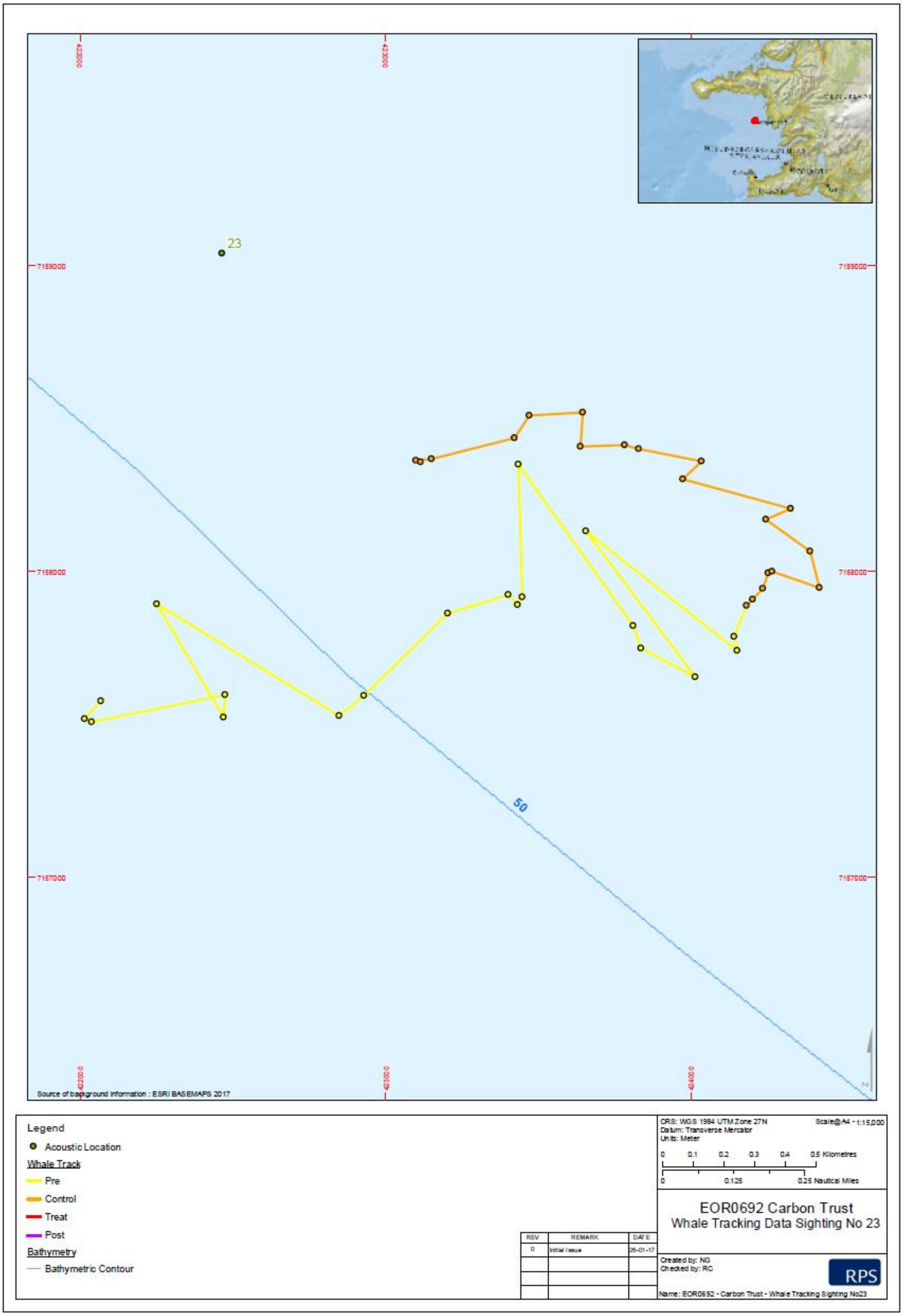
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Pre
Control
Treat
Post
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Bathymetric Contour
REV
REMARK
DATE
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25-01-17
CRS: WGS 1984 UTM Zone 27N
Datum: Transverse Mercator
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Scale@A4 - 1:15,000
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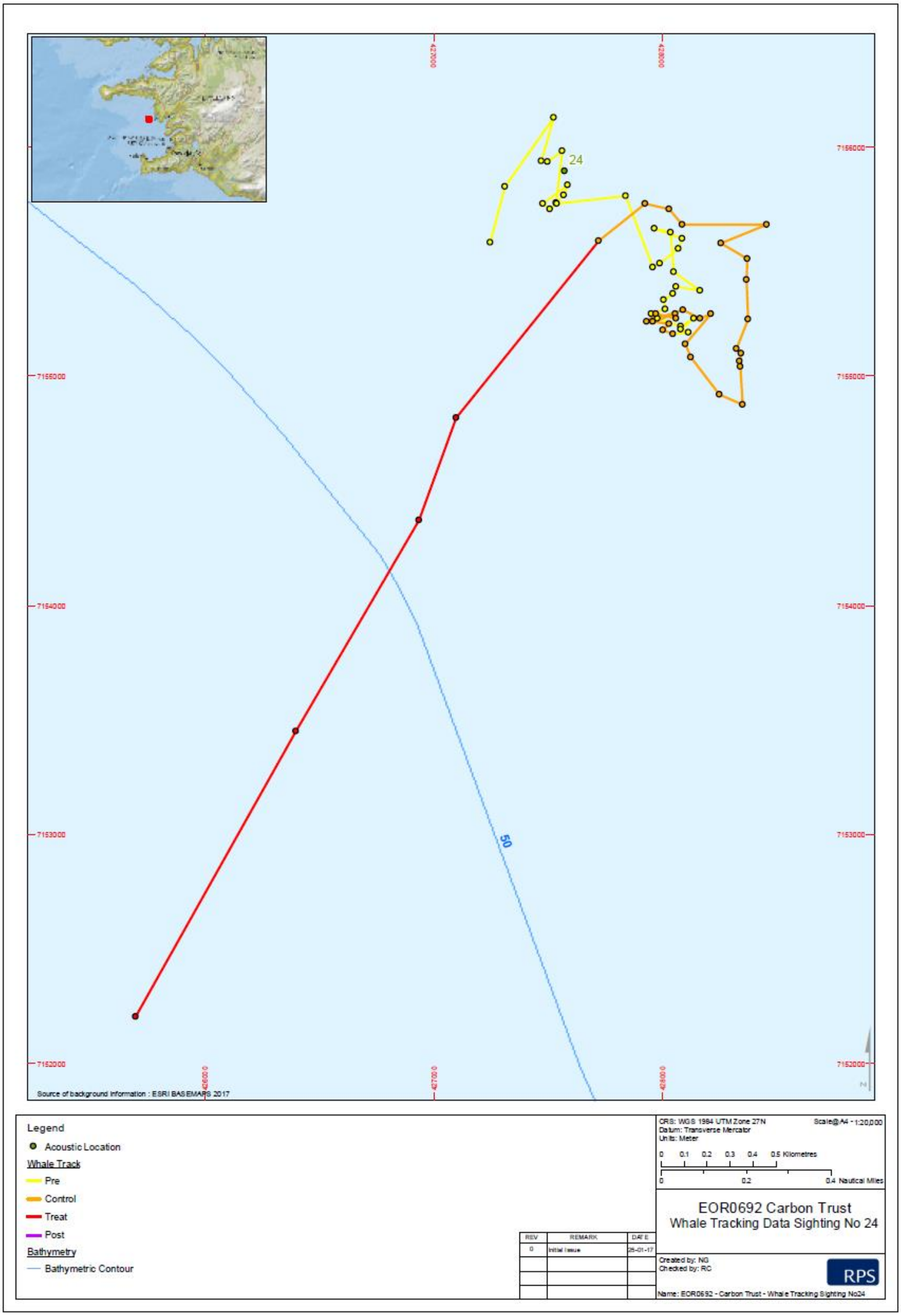

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Bathymetric Contour
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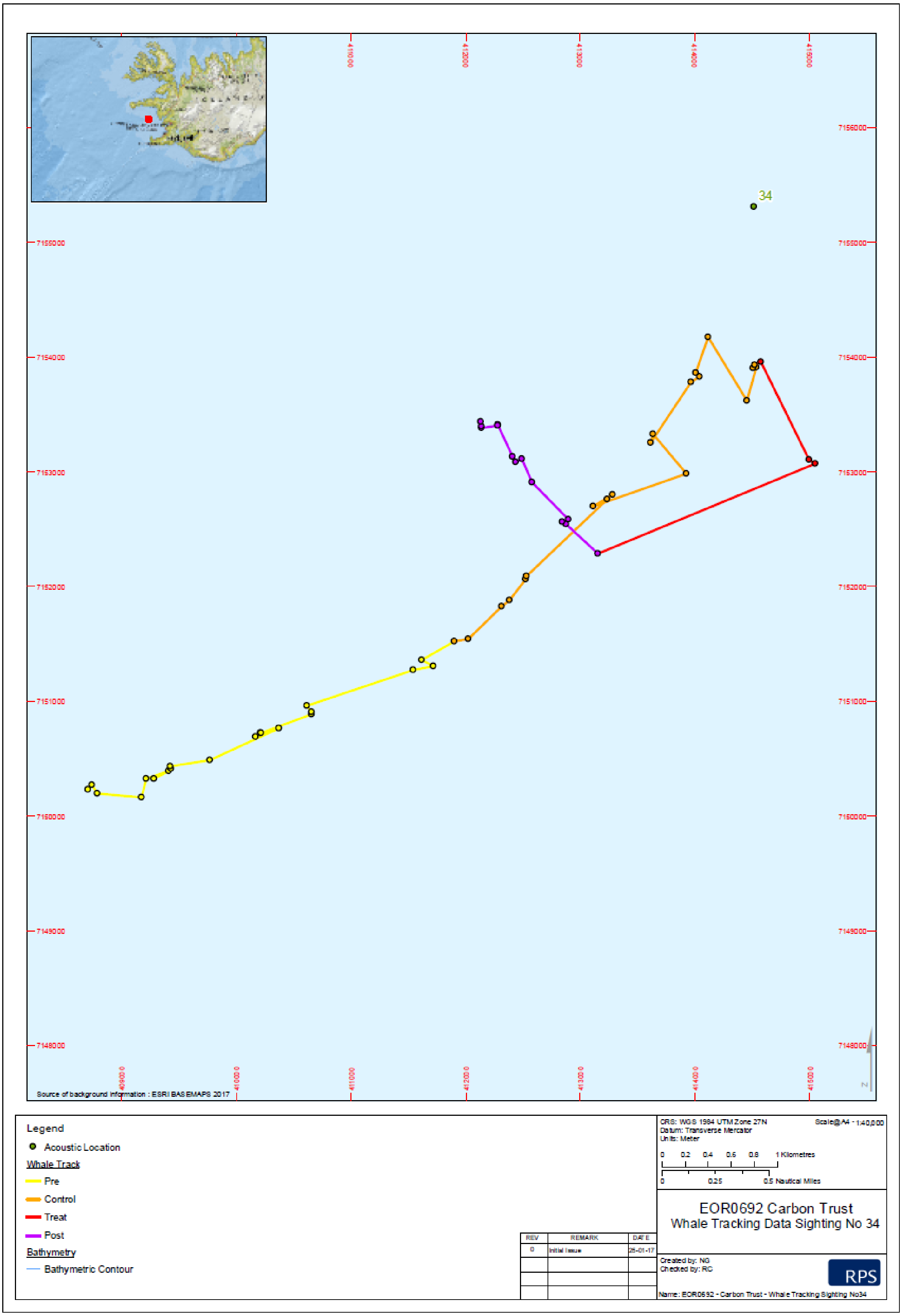
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Whale Track
Pre
Control
Treat
Post
Bathymetry
Bathymetric Contour
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REMARK
DATE
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Initial Issue
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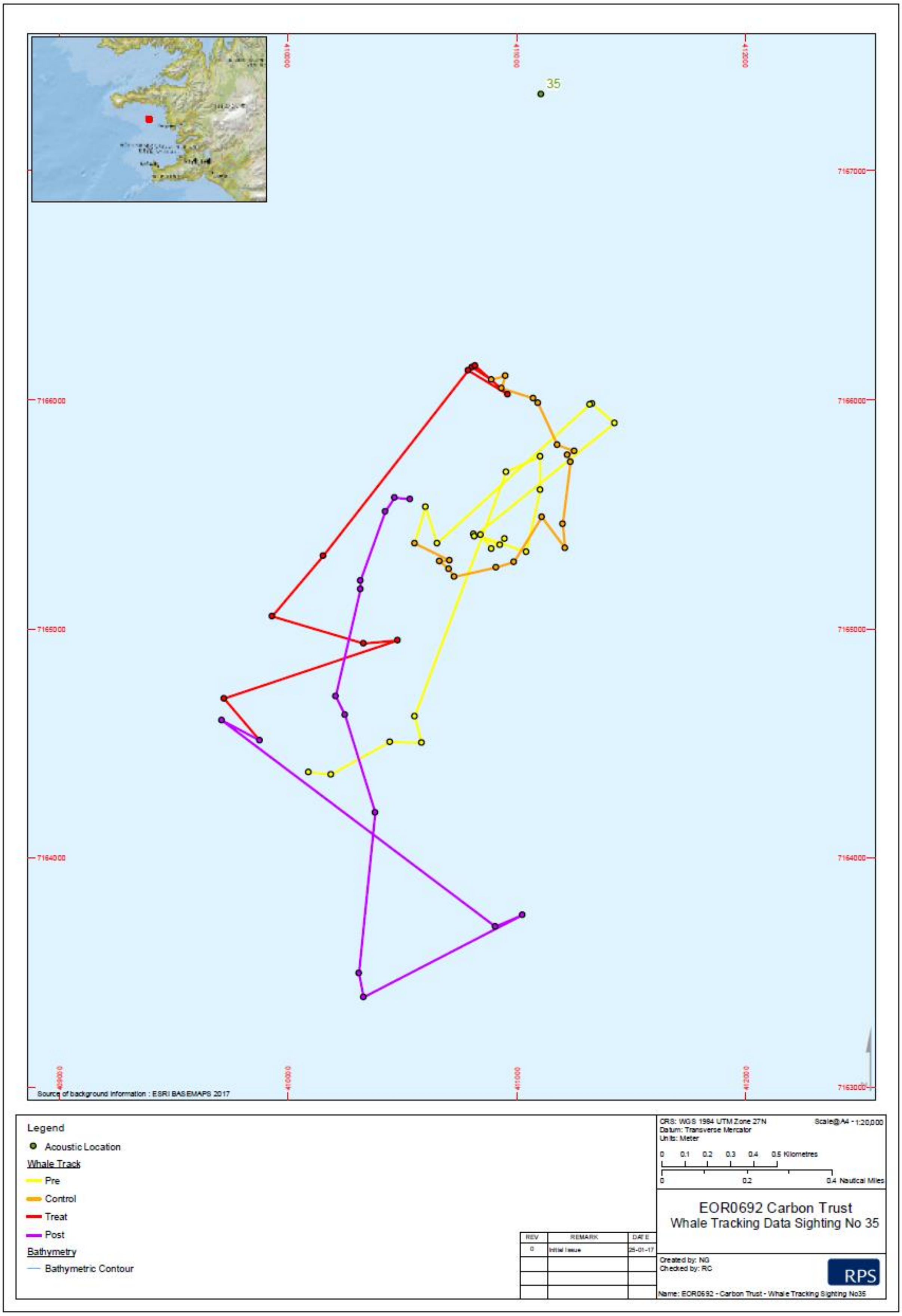
35
7167000
7166000
7165000
7164000
7163000
Source of background information : ESRI BASEMAPS 2017
Legend
Acoustic Location
Whale Track
Pre
Control
Treat
Post
Bathymetry
Bathymetric Contour
REV
REMARK
DATE
0
Initial Issue
25-01-17
CRS: WGS 1984 UTM Zone 27N
Datum: Transverse Mercator
Units: Meter
Scale@A4 - 1:20,000
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0 0.2 0.4 Nautical Miles
EOR0692 Carbon Trust
Whale Tracking Data Sighting No 35
Created by: NG
Checked by: RC
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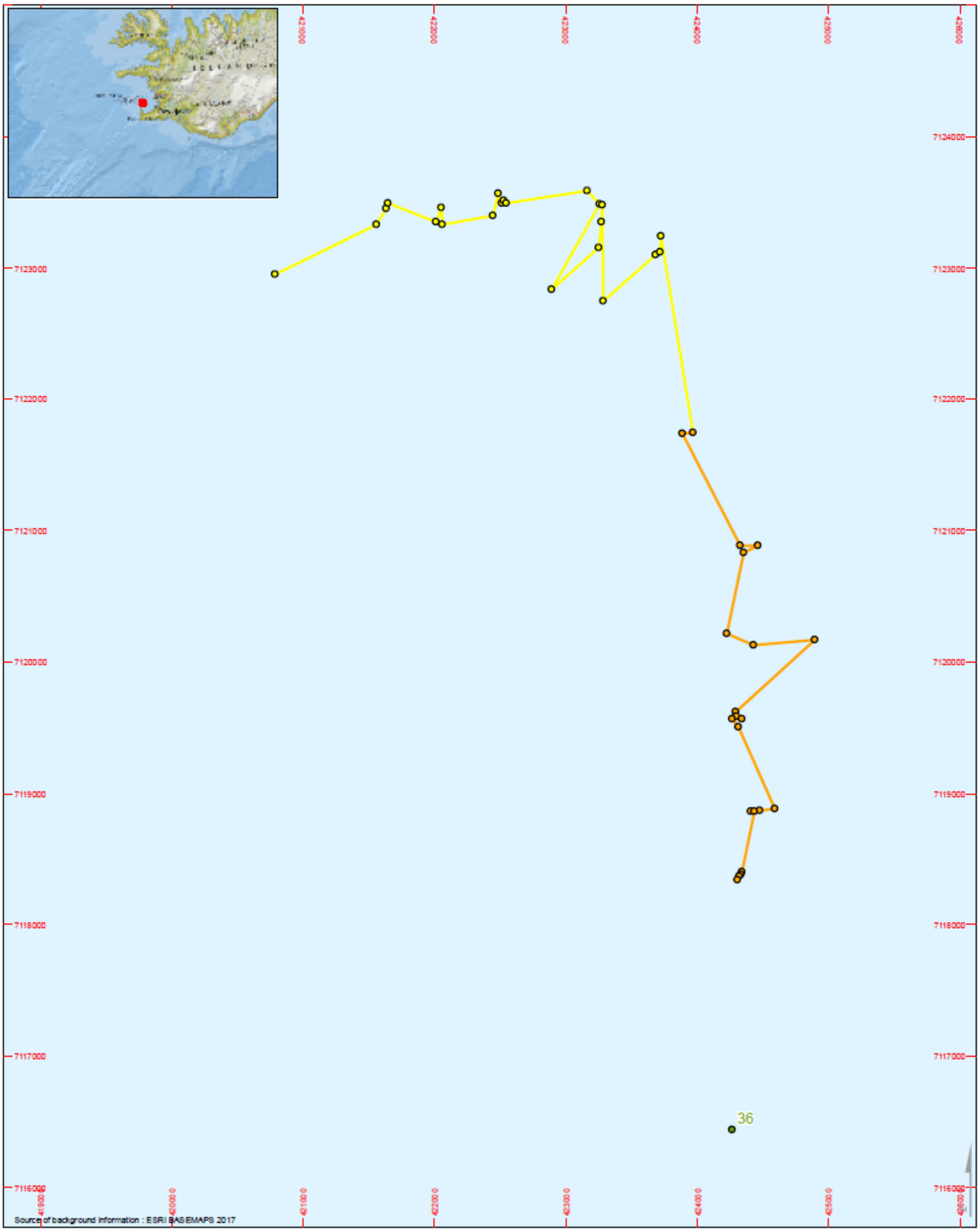


Legend
- Acoustic Location

Whale Track
- Pre
- Control
- Treat
- Post

Bathymetry
- Bathymetric Contour

REV	REMARK	DATE
0	Initial Issue	25-01-17

CRS: WGS 1984 UTM Zone 27N
Datum: Transverse Mercator
Units: Meter

Scale@A4 - 1:40,000

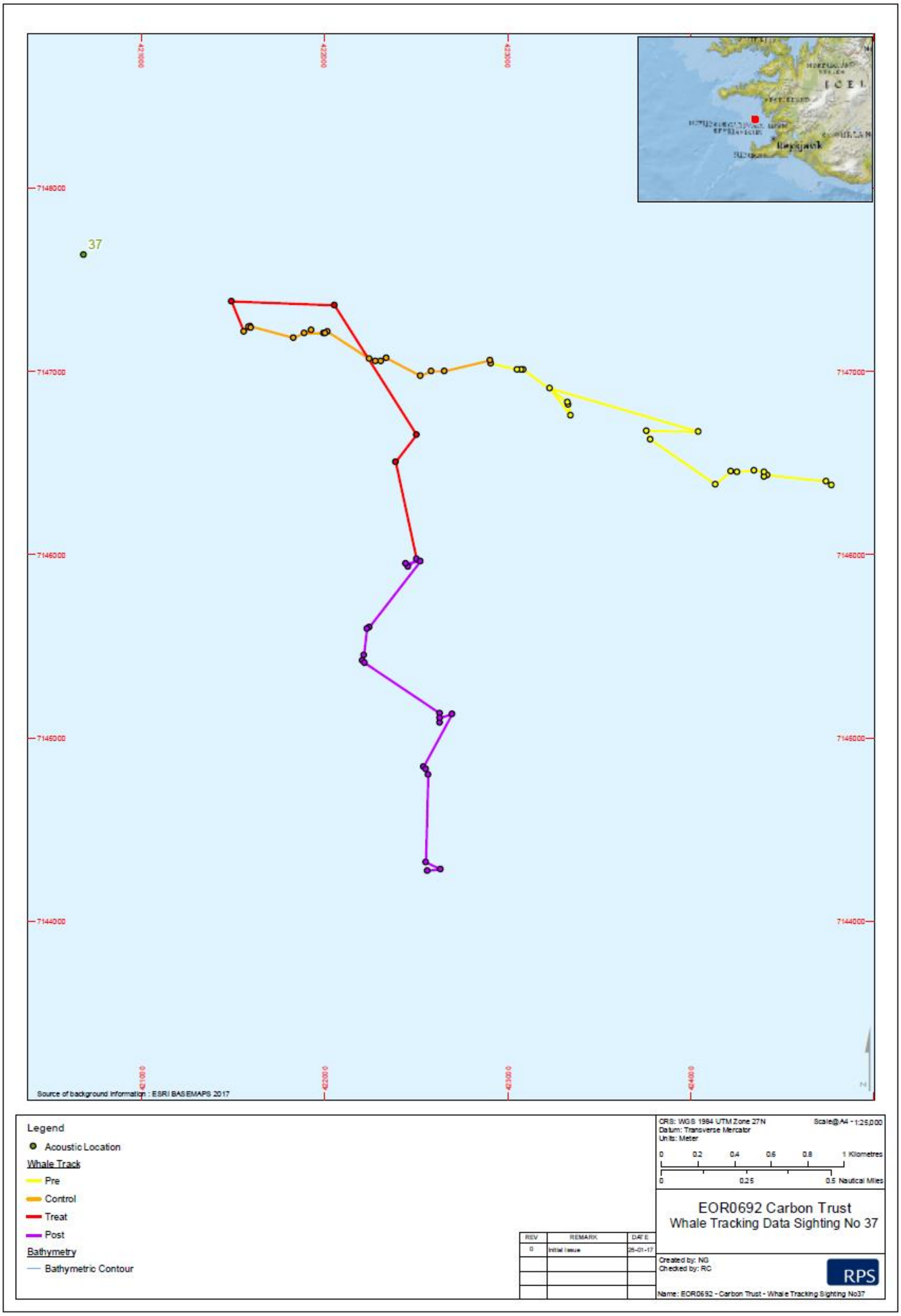
0 0.2 0.4 0.6 0.8 1 Kilometres
0 0.4 0.8 Nautical Miles

EOR0692 Carbon Trust
Whale Tracking Data Sighting No 36

Created by: NG
Checked by: RC

RPS

Name: EOR0692 - Carbon Trust - Whale Tracking Sighting No36


37
Reykjavík
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7147000
7146000
7145000
7144000
421000
422000
423000
424000
Source of background information : ESRI BASEMAPS 2017
Legend
Acoustic Location
Whale Track
Pre
Control
Treat
Post
Bathymetry
Bathymetric Contour
REV
REMARK
DATE
0
Initial Issue
25-01-17
CRS: WGS 1984 UTM Zone 27N
Datum: Transverse Mercator
Units: Meter
Scale@A4 - 1:25,000
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0 0.25 0.5 Nautical Miles
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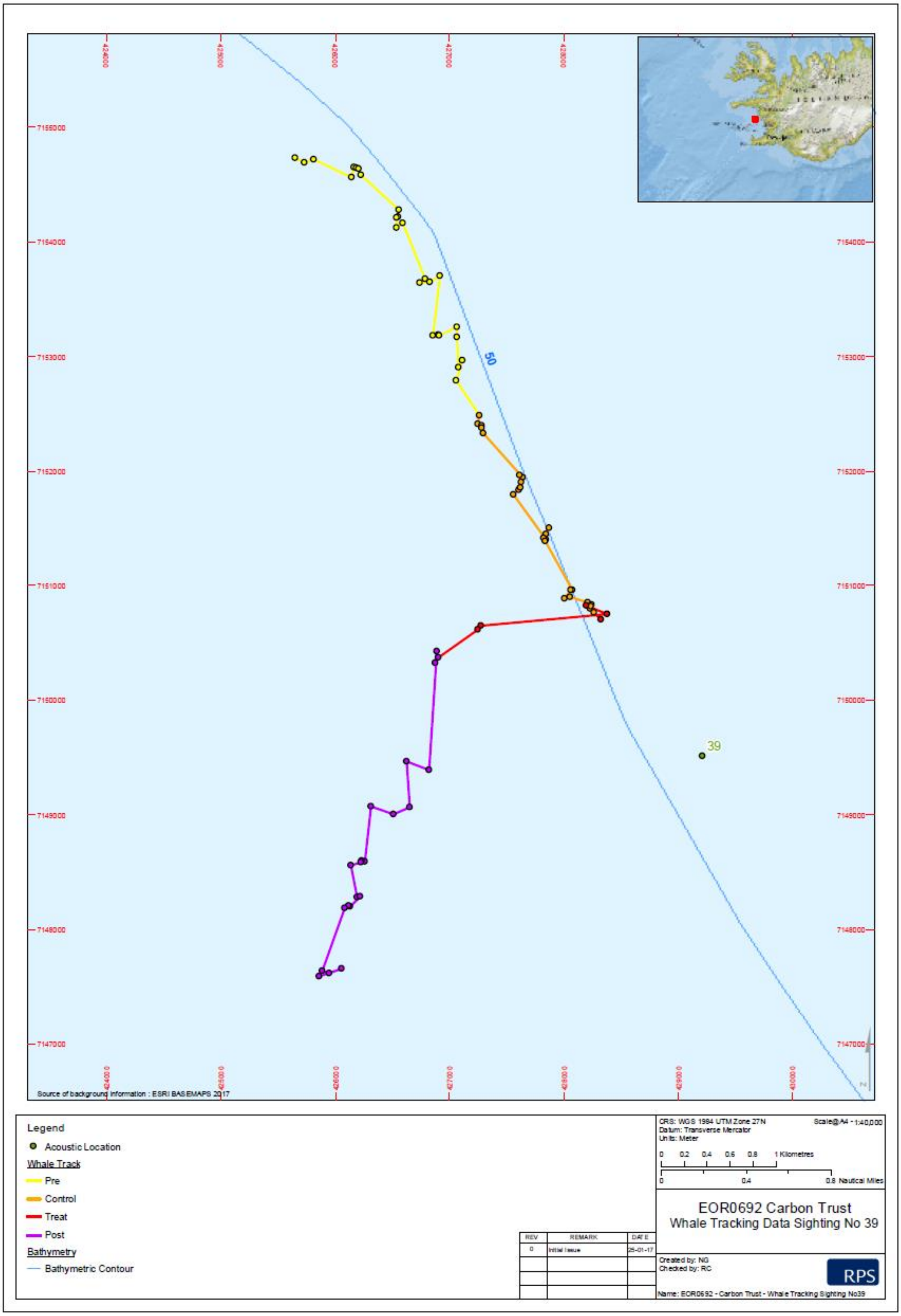
50
39
Source of background information : ESRI BASEMAPS 2017
Legend
Acoustic Location
Whale Track
Pre
Control
Treat
Post
Bathymetry
Bathymetric Contour
CRS: WGS 1984 UTM Zone 27N
Datum: Transverse Mercator
Units: Meter
Scale@A4 - 1:40,000
0 0.2 0.4 0.6 0.8 1 Kilometres
0 0.4 0.8 Nautical Miles
EOR0692 Carbon Trust
Whale Tracking Data Sighting No 39
REV
REMARK
DATE
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Initial Issue
25-01-17
Created by: NG
Checked by: RC
RPS
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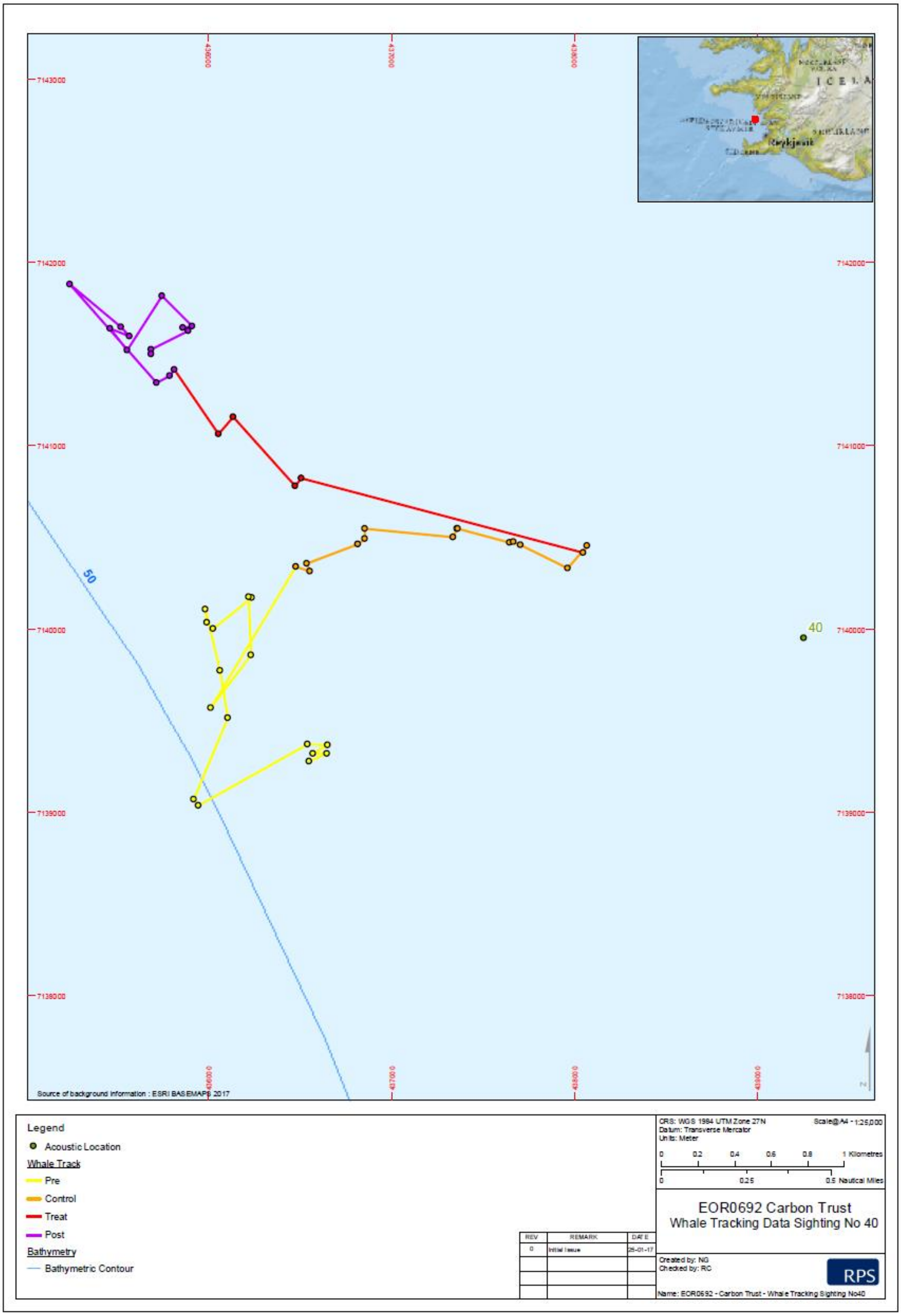
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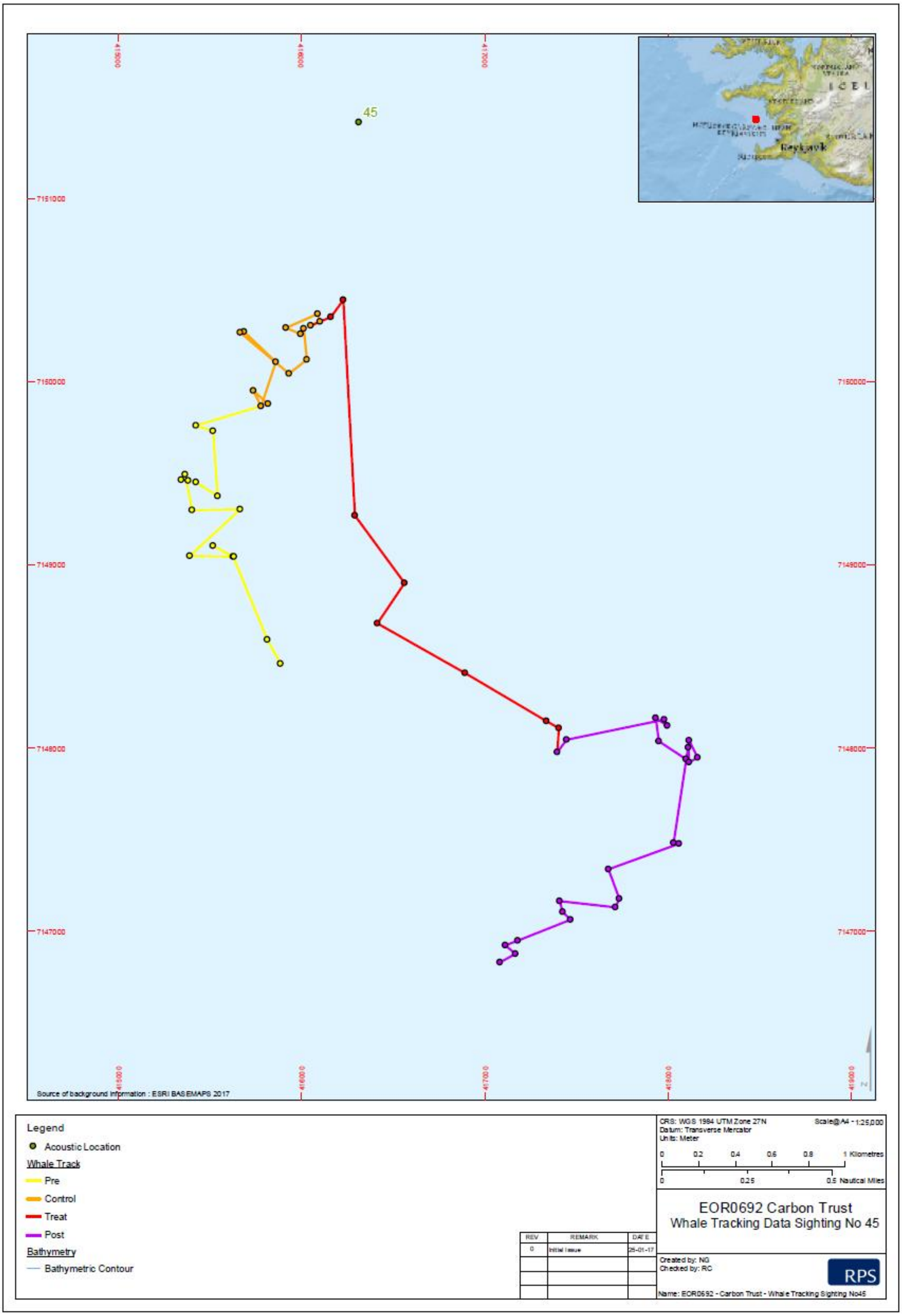
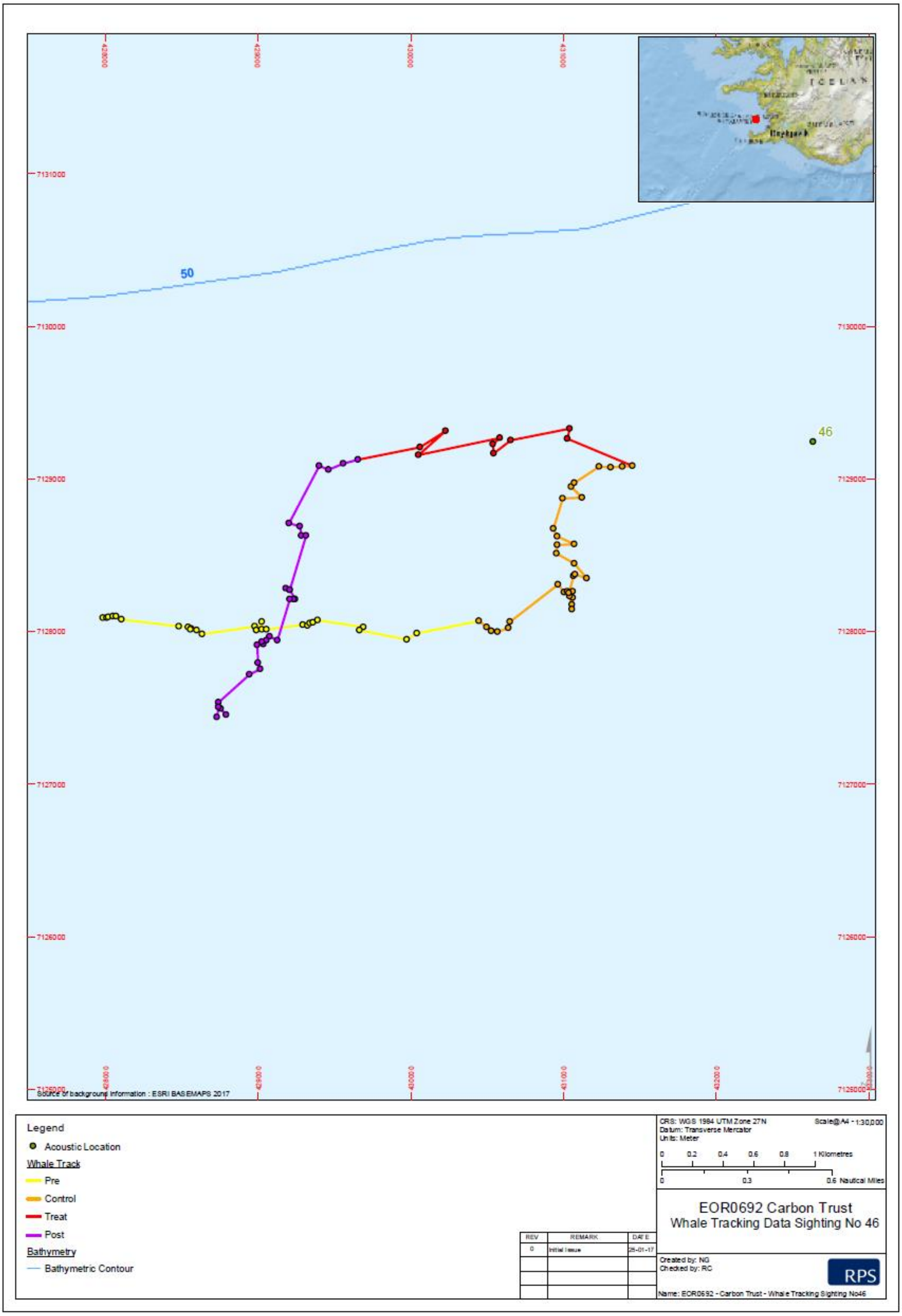
40
ICELA
Reykjavik
Source of background information : ESRI BASEMAPS 2017
Legend
Acoustic Location
Whale Track
Pre
Control
Treat
Post
Bathymetry
Bathymetric Contour
REV
REMARK
DATE
0
Initial Issue
25-01-17
CRS: WGS 1984 UTM Zone 27N
Datum: Transverse Mercator
Units: Meter
Scale@A4 - 1:25,000
0 0.2 0.4 0.6 0.8 1 Kilometres
0 0.25 0.5 Nautical Miles
EOR0692 Carbon Trust
Whale Tracking Data Sighting No 40
Created by: NG
Checked by: RC
RPS
Name: EOR0692 - Carbon Trust - Whale Tracking Sighting No40


45
Reykjavik
Source of background information : ESRI BASEMAPS 2017
Legend
Acoustic Location
Whale Track
Pre
Control
Treat
Post
Bathymetry
Bathymetric Contour
CRS: WGS 1984 UTM Zone 27N
Datum: Transverse Mercator
Units: Meter
1 Kilometres
0.5 Nautical Miles
EOR0692 Carbon Trust
Whale Tracking Data Sighting No 45
REV
REMARK
DATE
0
Initial Issue
25-01-17
Created by: NG
Checked by: RC
RPS
Name: EOR0692 - Carbon Trust - Whale Tracking Sighting No45


7131000
50
7130000
46
7129000
7128000
7127000
7126000
Source of background information : ESRI BASEMAPS 2017
Legend
Acoustic Location
Whale Track
Pre
Control
Treat
Post
Bathymetry
Bathymetric Contour
CRS: WGS 1984 UTM Zone 27N
Datum: Transverse Mercator
Units: Meter
Scale@A4 - 1:30,000
0 0.2 0.4 0.6 0.8 1 Kilometres
0 0.3 0.6 Nautical Miles
EOR0692 Carbon Trust
Whale Tracking Data Sighting No 46
REV REMARK DATE
0 Initial Issue 25-01-17
Created by: NG
Checked by: RC
RPS
Name: EOR0692 - Carbon Trust - Whale Tracking Sighting No46

Appendix E – Southall *et al.* (2007) Behavioural Response Severity Score Table

Response score	Corresponding behaviours
0	No observable response
1	Brief orientation response (investigation/visual orientation)
2	Moderate or multiple orientation behaviours Brief or minor cessation/modification of vocal behaviour Brief or minor change in respiration rates
3	Prolonged orientation behaviour Individual alert behaviour Minor changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source Moderate change in respiration rate Minor cessation or modification of vocal behaviour (duration < duration of source operation), including the Lombard Effect
4	Moderate changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source Brief, minor shift in group distribution Moderate cessation or modification of vocal behaviour (duration approx. = duration of source operation)
5	Extensive or prolonged changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source Moderate shift in group distribution Change in inter-animal distance and/or group size (aggregation or separation) Prolonged cessation or modification of vocal behaviour (duration > duration of source operation)
6	Minor or moderate individual and/or group avoidance of sound source Brief or minor separation of females and dependent offspring Aggressive behaviour related to noise exposure (e.g. tail/flipper slapping, fluke display, abrupt directed movement, bubble clouds) Extended cessation or modification of vocal behaviour Visible startle response Brief cessation of reproductive behaviour
7	Extensive or prolonged aggressive behaviour Moderate separation of females and dependent offspring Clear anti-predator response Severe and/or sustained avoidance of sound source Moderate cessation of reproductive behaviour
8	Obvious aversion and/or progressive sensitization Prolonged or significant separation of females and dependent offspring with disruption of acoustic reunion mechanisms Long-term avoidance of area (> source operation) Prolonged cessation of reproductive behaviour
9	Outright panic, flight, stampede, attack of conspecifics, or stranding events Avoidance behaviour related to predator detection