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Assessment of the potential for acoustic deterrents to mitigate the impact on marine mammals of underwater noise arising from the construction of offshore windfarms

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Table of Contents

List of Tables and Figures

Tables

Figures

Executive Summary

A number of anthropogenic activities that occur in coastal and offshore waters generate sound or impulses at levels which are sufficiently high to pose a risk of causing physical damage or hearing impairment in sensitive wildlife such as marine mammals. The use of explosives, for example, for well-head removal, certainly poses this risk and it is possible that pile driving during windfarm construction could also do so. One potential means of reducing the risk of damage to marine mammals from such activities is to move sensitive animals out of the high risk area by using aversive or alarming sounds produced by an acoustic mitigation device (AMD). This report investigates the potential for using AMDs for mitigation during windfarm construction, explores the types of acoustic signals that might be suitable for this application, and the devices available for producing them in the field. It makes recommendations in relation to the areas of research that would be needed to develop and quantify the performance of a working system, and reviews legal aspects of using AMDs for mitigation in UK waters.

In the absence of clear criteria from regulators in the UK or Europe for unacceptable exposure, we have worked to two acoustic exposure thresholds proposed by NOAA in the USA. These are that received levels for a single pulse should not exceed 180 dB re 1µPa for cetaceans and 190dB for seals, and the cumulative exposure should not exceed 195 dB re 1µPa^{2}s. A cumulative exposure model which accounts for animal movements and propagation conditions as well as source levels and duty cycles of piling activities and AMDs was used to explore the ranges to which animals would need to be moved to minimise the risk that these thresholds for acceptable noise exposure would be exceeded. Ranges varied widely between different likely scenarios. In part this reflects sensitivity to factors such as propagation conditions which vary between sites and with conditions, but which could be measured and more tightly defined in the model. However it is also the consequence of some fundamental unknowns, such as the behaviour of animals when exposed to aversive sounds and piling. The results from this modelling exercise should not be used to make firm predictions, but they do indicate that, whilst the risk of hearing damage to marine mammals from piling activities cannot be discounted, it could be greatly reduced if animals were induced to move out of the area before piling started. In typical conditions animals would need to be moved over ranges of hundreds or low thousands of metres to achieve this, and this sets indicative performance criteria for an effective AMD system.

An effective AMD system would broadcast a signal that was sufficiently frightening or aversive to cause marine mammals to move over substantial ranges. In the search for candidate signals we reviewed the literature on aversive or unpleasant sounds in humans. While there do seem to be certain acoustic characteristics that humans find unpleasant, these did not seem to be shared by even closely related primates. The military has invested a great deal of effort into developing powerful acoustic devices as non-lethal weapons. However, few if any practical and effective devices have been developed. It has proven very difficult to achieve required sound levels over substantial distances. Therefore the range of these weapons is very limited, and required exposures are often at levels that risk damaging the subject’s hearing.

There is a long history of the use of sonic deterrents to manage terrestrial pests, especially birds. Generally these devices have achieved only mixed success, but there are certainly important lessons to be learned for the current application. Often the efficacy of devices has not been properly tested until they are highly developed or even brought to market. This made it difficult to use the results from biological trials to develop better performing devices. A useful distinction can be drawn between devices using signals that are perceived as being biologically relevant by the targets (e.g. vocalisations of predators, alarm or distress calls) and signals that are not biologically significant. Typically, trials with the latter, non-biological, sounds show no, or only short term, success. It seems animals quickly habituate to sounds that are repeatedly presented and not reinforced. The more successful examples of sonic deterrents have used biologically significant sounds.

Marine mammals are acoustically sensitive animals and a substantial amount of work describing their responses to natural and anthropogenic sound have been published. Here we only mention examples where animals were displaced over considerable distances. Killer whales are the

primary natural predator of most marine mammals and they produce loud distinctive vocalisations. A number of playback experiments have shown that marine mammals flee from playback of killer whale sounds. ASDIC[1] and other early sonar devices used on whaling vessels were reported to frighten a range of species of whales. In fact whalers developed special whale frightening sonar devices because fleeing whales were more predictable and easier to catch. Mid-frequency military sonar seems to cause changes in the behaviour of beaked whales that might lead to stranding events, and there are also direct observations of avoidance behaviour by small and medium sized odontocetes. Acoustic deterrent devices (ADDs) are devices that have been specifically designed to deter marine mammals from certain activities, such as attacking aquaculture sites or becoming entangled in fishing nets. High powered aquaculture protection devices have been shown to greatly reduce porpoise and killer whale densities at ranges of several thousand metres. Lower powered ‘pingers’ for bycatch reduction exclude porpoise to ranges of up to a few hundred metres. Neither type of device seems to be very effective at excluding seals, however. Air guns are powerful low frequency noise sources used by the oil industry. Some coastal baleen whale species show avoidance at ranges of several miles, and controlled exposure experiments with seals in the UK showed that animals moved directly away from a small airgun.

It is notable that there are many examples of marine mammals being displaced over considerable ranges by acoustic signals, and few if any in the terrestrial mammalian literature. This may reflect the fact that there are no refuges for air-breathers at sea, so flight is their only option. The many examples of marine mammals moving substantial distances to avoid certain sounds provide grounds for optimism. Sonic deterrents used with terrestrial animals often become less effective with time because animals are highly motivated to visit a rich food supply in the area and readily become habituated to an acoustic device which is active for long periods. These issues are less likely to cause problems in this application because there is no strong attractor like food associated with the aversive signal. Signals will only be broadcast for short periods just before piling starts and any learned association is likely to be with a negative reinforcer, piling. Even so, it would be wise to minimise the risk of habituation by varying signals.

Any mitigation procedure needs to be assessed in the light of alternatives. Mitigation procedures usually employ visual and acoustic techniques to monitor for marine mammals within an exclusion zone. If animals are sighted, piling is delayed. Marine mammals are difficult to detect at sea, especially when sighting conditions are poor. Safety ranges are likely to be considerable, so the probability of detecting all animals within the exclusion zone will be low. Real time detection requires teams of skilled marine mammal observers, and often independent vessels are required to patrol the area, making these exercises expensive. Thus, substantial sums can be spent on real time detection without achieving an adequate level of risk reduction. AMDs by contrast, are unlikely to require dedicated personnel to operate them. Thus they promise to provie a higher level of risk reduction at a much lower cost.

In order to protect cetaceans, the use of AMDs in territorial waters (out to 12 miles) frequented by cetaceans during the construction of wind turbines is unlawful unless the appropriate licences have been obtained. Licences can be obtained on the grounds that AMDs are a justified, proportionate and necessary conservation measure, used only to protect cetaceans from harm. Scientific evidence of a quality that satisfies the precautionary principle will be required that AMDs do not themselves cause harm to cetaceans. Evidence of the effectiveness of AMDs should also be sought. Conditions are likely to be attached to licences, permitting use only for relatively short periods during construction and as part of a wider package including measurement of effects on animals and additional mitigation measures. A licence will not be required for the use of AMDs in UK offshore waters (beyond territorial waters up to 200 miles) providing that it can be shown with convincing evidence that the effect of temporary use of an AMD on the distribution and abundance of marine mammals is not substantial. However, before proceeding with any offshore operations without a licence, further research is likely to be

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[1] Anti-submarine Detection Investigation Committee. Early active acoustic detection devices developed by the Royal Navy

necessary and guidance should be obtained from the Marine and Fisheries Agency, the relevant nature conservation body.

The use of AMDs to exclude seals from an area where wind turbines are being constructed and installed is unlikely to be unlawful or require any special licence

The pressing requirement now, to allow the evident promise of AMDs to become a reality, is focused research to test candidate signals, measure how different species respond to them, and quantify the level of risk reduction that could be achieved by AMDs used on their own, or as part of a larger mitigation process. Although marine mammals are challenging research subjects, the data required - information on movements – is the most straightforward type of behaviour to measure. Different techniques are most appropriate for different species groups, and suggested practical and cost effective approaches which would be appropriate for UK species of most interest are discussed. The modelling work conducted here suggests that the risk of auditory damage to marine mammals from pile driving and some other activities is significant. Current mitigation procedures are expensive and unlikely to be fully effective. The appropriate use of AMDs could provide a more effective and less expensive alternative, and it is hoped that this promise will justify investment in the required research.

Glossary

Acoustic Deterrent Device (ADD): Underwater sound emitting device with source level < 185 dB re 1 µPa @ 1m often intended to deter marine mammals (usually cetaceans) from areas of danger (usually fishing nets).

Acoustic Harassment Device (AHD): High source level (> 185 dB re 1 µPa @ 1m) underwater sound emitting device intended to exclude marine mammals (usually pinnipeds) from certain areas (usually fish farms). Also known as **seal scarer** and **seal scrammer**.

Acoustic Mitigation Device (AMD): Underwater sound emitting device designed to exclude marine mammals from areas of exposure to high-intensity noise such as pile driving.

Anti-submarine Detection Investigation Committee: Early active acoustic detection devices developed by the Royal Navy.

Absorption: Conversion of sound into heat.

Ambient noise: Background noise in the environment without distinguishable sources.

Audiogram: Plot of the level of the quietest pure tone that an individual can detect over a range of frequencies.

Bandwidth: Range of frequencies of a given sound.

Decibel (dB): The logarithmic measure of the ratio between sounds intensity/pressure and an appropriate reference level.

Decibel (dB re 1µPa): Decibel measurement referenced to a level of 1µPa, commonly used for sound pressure levels (SPL) in water.

Decibel (dB re 1µPa-m): Measure commonly used to describe source levels in dB re 1µPa as would be heard at a distance of 1m from the source. Note that the 1m measurement is often purely hypothetical, the value being calculated from measurements made at much greater ranges.

Decibel (dB re 1µPa^{2}s) Acoustic exposure (The integration of squared RMS Sound Pressure Level over time).

Duty cycle: Percent of a time a given event occurs.

Hertz: The unit for frequency where 1 Hz = 1 cycle per second. One **Kilohertz (kHz)** is 1,000 cycles per second.

Energy Flux Density (EFD): The (acoustic) energy passing though a particular point per unit time and unit area.

Infrasonic: Sound with frequencies too low to be audible to humans (~ < 20 Hz).

Masking: Obscuring of sounds of interest by interfering sounds occurring close in time and at similar frequencies.

Micro Pascal (µPa): A measure of pressure, one millionth of a Pascal. The standard reference pressure for underwater sound. 1 µPa = 10$_{-5}$ µbar.

Octave band: Interval between two discrete frequencies having a frequency ratio of two.

One-third-octave-band: Interval of 1/3 of an octave. Three adjacent 1/3 octave bands span one octave.

Peak-to Peak (Pk-Pk): The amplitude difference between the most negative and most positive parts of the waveform within a pulse.

Permanent threshold shift (PTS): A permanent elevation of the hearing threshold due to physical damage to the sensory hair cells of the ear.

Pinger: Low power ADD device deployed on fishing nets to reduce bycatch.

Pulsive sound: Transient signals emitted in brief sequences (pulses) with short duration and often high peak sound pressure levels.

Propagation loss (Transmission loss): Loss of sound power with increasing distance.

Root Mean Square (RMS): The square root of the average squared amplitude over the duration of a pulse. RMS values are generally favoured by engineers since they relate more directly to energy and energy flux than peak-to-peak measures. However, for an impulsive sound, the calculated RMS level will vary depending on the period for which it is measured, thus rendering RMS measurements largely useless unless that time period is also quoted. For a continuous wave (e.g. a sin wave) RMS levels are approximately 9dB lower than peak–to-peak levels. For impulsive sounds, this difference may be much greater, depending in part on the integration period of the RMS measurement.

Seal scarer: see **AHD**.

Seal scrammer: see **AHD**.

Soft Start: Gradual ramping up of a sound source prior to main operations.

Source level: Acoustic pressure at a standard reference distance of 1 m. Unit in dB re 1 μPa at 1 m (sometimes given as: @ 1m).

Sound pressure level: Expression of the sound pressure in decibel (dB).

Temporary threshold shift (TTS): Temporary and reversible elevation of the auditory threshold often induced.

Tx: Transmission.

Ultrasonic: Sound with frequencies too high to be audible to humans (~ > 20 kHz).

Acronyms

See **Glossary** *for further definitions*

ADD Acoustic Deterrent Device

AHD Acoustic Harassment Device

AMD Acoustic Mitigation Device

ASDIC Anti-submarine Detection Investigation Committee

CEE Controlled Exposure Experiment

DCS Decompression Sickness

EFD Energy Flux Density

ICES International Council for the Exploration of the Sea

MMO Marine Mammal Observer

NOAA National Oceanographic and Atmospheric Administration (USA)

PTS Permanent Threshold Shift

RMS Root Mean Square

SL Source level

SPL Sound pressure level

TTS Temporary Threshold Shift

Units

dB Decibel

deg Degrees

Hz Hertz

kHz Kilohertz

km Kilometre

m Metre

ms Millisecond

m/s or ms^{-1} Metre per second

phon (unit of perceived loudness)

s Second

µPa Micropascal

1. Introduction

Some anthropogenic activities in the marine environment produce sound or pressure waves of such intensity that sensitive wildlife in the vicinity could be physically damaged. The hearing system, which has evolved to be most sensitive to sound, is most likely to be affected in this way. Marine mammals, which have very sensitive hearing, are a cause for particular concern. The use of underwater explosives can certainly cause physical harm to marine mammals(Ketten, 1995), and, as discussed in Sections 2 and 3, it is possible that their hearing could be compromised by pile driving activities. In such cases it is desirable not to conduct these activities if animals are within a range at which they could be damaged.

One approach to achieving this, which is currently routinely used, is to search for animals within a zone in which they are judged to be at risk, using visual and (if appropriate) acoustic monitoring with sufficient effort and for a sufficient length of time to be confident that there is a very low risk of animals being within the zone when the activity occurs.

A second approach, explored further in this report, is to induce any animals that are within the exclusion range to move out of the area to a safe distance before the activity begins. This could be achieved with aversive stimuli. Because the propagation of sound underwater is so much more effective than that of light, it is likely that acoustic aversive stimuli would be used.

Detection probability is low for many marine mammals. Visual detection in particular is strongly affected by weather conditions and light levels, while the effectiveness of acoustic detection varies between species and is affected by variability in vocal behaviour. Providing a high level of visual and acoustic monitoring offshore involves trained personnel and specialist equipment and can be expensive. The use of aversive sounds could be much less expensive, as well as having the potential to be more effective. These are all considerations that encourage an interest in the use of aversive sounds for mitigation, either on their own or as part of a combined mitigation effort. However, no devices or procedures for achieving this currently exist, and there are also potential issues pertaining to legality and the permits required to deploy a device which is intended to disturb marine mammals.

The purpose of this desktop study is to explore the potential for using aversive sounds as part of a mitigation strategy to reduce the risk of damage to marine mammals from pile driving during offshore windfarm construction. Many of the findings should also be relevant to other activities which carry the risk of damage, including the use of explosives underwater.

We start by reviewing and assessing the risk of damage from pile driving. Because this is a static activity that takes place over a considerable length of time, it is necessary to consider this using a model of cumulative acoustic exposure that includes animals' movement and propagation conditions. The output of this model defines the safety ranges in different conditions and this in turn specifies the distances over which animals will need to be removed for mitigation by any acoustic stimulus.

Acoustic removal would involve disturbing an animal's natural behaviour, albeit with a view to reducing the risk of the same individual's suffering damage. This raises a range of legal issues for different species in different areas. We review these, and the implications and requirements for obtaining permits for these activities.

The next task is to research the types of sounds that might be capable of causing marine mammals to move out of an exclusion zone. An ideal sound would cause animals to move appropriately at received levels that in themselves did not contribute significantly to the animals' risk of acoustic damage. Ideally an animal's responses to this sound should be innate, not learned, and should be consistent and independent of context. We start by reviewing the literature on aversive sounds and humans. We assess attempts to use sounds as non-lethal weapons, and to control human behaviour, including encouraging them to move from certain areas. We then move on to review literature on other vertebrates, and to the use of sonic deterrents to manage other wildlife interactions. Finally we review behavioural disruption and exclusion in marine mammals resulting from different types of sound sources.

Having identified some candidate aversive signals, it is necessary to research the types of devices capable of broadcasting them. This includes exploring existing devices and making suggestions for their development.

A synthesis of this information allows us to propose different mitigation scenarios and provide approximate costs and likely effectiveness of these scenarios.

Large degrees of uncertainty exist about most areas involved. In particular the fundamental performance; the probability of removing animals to a certain range is not known for any acoustic device. If managers are to have confidence in acoustic devices as a means of reducing the risk of damage to sensitive wildlife, then this must be measured. We review the research approaches that would be able to provide this information, and make recommendations for some specific research activities that are required.

2. Piling noise and potential effects on marine mammals

2.1. Pile driving: the process and concerns

Offshore wind power generation is an expanding industry in Northern Europe. Sounds produced during the construction and operation of windfarms have the potential to impact on marine life. Marine mammals, which have very sensitive underwater hearing, are a focus for particular concern (Koschinski *et al.*, 2003; Carstensen *et al.*, 2006; Madsen *et al.*, 2006; Thomsen *et al.*, 2006). Noise emissions during construction and operation are quite different and give rise to different concerns. Of the two, the construction of windfarms (in particular the pile driving process) has much greater potential for causing acute effects such as physical damage and hearing loss than the operation of the facility once built (Madsen *et al.*, 2006). It is these acute effects, and the potential for mitigating them using aversive sounds, which are explored in this report.

The process of windfarm construction involves many noisy activities including profiling, shipping, pile-driving, trenching and dredging (Nedwell and Howell, 2004). The foundations of the turbines are often large piles driven into the substrate. Pile driving is the activity which gives rise to most concern, as the broadband pulsive noise generated has a high source level (Richardson *et al.*, 1995; Madsen *et al.*, 2006; Parvin and Nedwell, 2006; BioConsultSH, in prep).

Shepherd *et al.* (2006) and Thomsen *et al*. (2006) describe the typical process of pile driving during construction of offshore windfarms. This involves first locating and installing a jack-up barge to hold the pile and hammer in position, and then positioning the pile and hammer. Once the pile has been located, checked for vertical alignment and allowed to settle, the piling commences with a period of lower-energy hammer blows to enable the alignment to be monitored and adjusted. Hammering the pile to the appropriate depth involves blows being delivered at a rate of approximately 30-60 per minute, and may continue over several hours (Thomsen *et al.*, 2006; Robinson *et al.*, 2007). The duration and noise output of a piling procedure may differ depending on substrate conditions, which vary considerably between sites. As the process is finalised, further checks are carried out to ensure the pile is set properly at the correct depth (Shepherd *et al.*, 2006). The source level and frequency of the sound generated is influenced by the size of the hammer and monopile and the nature of the seabed and sediment (Madsen *et al.*, 2006). Accordingly, the size of impact zones will also be dependent on these factors, in addition to the sound propagation characteristics of the area, and the hearing sensitivity of the species of concern. As the noise generated by pile driving activities is predominantly low frequency, with some higher frequency (including ultrasonic) components, its impacts can be wide-ranging and affect a number of species.

A series of sound measurement exercises have been undertaken in conjunction with the current round of windfarm construction in the UK and Europe. Unfortunately much of these data remain in unpublished reports that have yet to be peer reviewed and synthesised. However, a thorough review of these measurements is provided in a report currently in preparation for COWRIE (BioConsultSH, in prep). Table 1 summarises data from recent measurements made during windfarm constructions, including measures of peak-to-peak, RMS and energy flux density for piling at a windfarm site, as well as measurements during a soft start (Robinson *et al.*, 2007).

There is a trend toward the use of larger mono-piles for offshore windfarms. For example 4.5m piles are being used during the current round of construction and 6.5m piles are to be used on the Greater Gabbard and London Array (Shepherd *et al.*, 2006). Sound levels are expected to increase as piles get larger. Underwater noise measurements have not yet been made from 6.5m diameter piles but source levels have been derived by extrapolation from those of smaller diameter piles.

Parvin and Nedwell (2006) measured impact piling noise from 4.7m diameter piles during construction of the Burbo Bank offshore windfarm in 2006. Broadband sound recordings were taken at a series of ranges from the operation during the driving of two piles. Using measured noise data obtained at ranges from 100m to 25km from the construction operation, peak-to-peak source levels of approximately 249 dB re 1µPa @ 1m was determined. Parvin and Nedwell (2006) note that these measurements agree well with those made during construction of the Barrow (252 dB re 1µPa @ 1m for a 4.7m diameter pile), North Hoyle (249 dB re 1 1µPa @ 1 m for a 4.0 m diameter pile) and Kentish Flats (243 dB re 1µPa @ 1 m for a 4.3 m diameter pile) sites.

Both Parvin *et al.* and BioConsult SH have extrapoloated source levels for 6.5m piles by calculating likely increases in source levels between piles of 4.7 and 6.5m diameter (Parvin *et al.*, 2006; BioConsultSH, in prep). Parvin *et al.* (2006) calculated an increase of 8.4dB while BioConsult SH calculated an increase of 6-6.3dB.

2.1.1. Soft Starts

One potential mitigation measure that could be applied is the use of a 'soft start' when piling commences. In a soft start, piling would be initiated with lower energy blows and built up gradually over a period of time. Robinson *et al.* (2007) report measurements of a soft start for pile driving of a 2m pile test pile made in an undisclosed location in UK coastal waters. Difference in levels between the start and end of the soft start differed between acoustic metrics. At 57m the minimum pk-pk measured at the beginning of the soft start was 12dB below the mean for full energy piling. For measures of RMS the difference was 13dB, and for energy flux density the minimum for soft start was 8dB lower than the mean for the main piling activity. Robinson *et al.* (2007) found that levels built up evenly throughout the soft start. These are useful measurements and, provided animals move away from the piling site during soft starts, this procedure could reduce acute risks of damage. However, if soft starts are to be implemented as a mitigation measure, a number of factors should be considered:

Soft starts lengthen the piling operation, and may therefore increase the extent of behavioural disruption and habitat exclusions. A 600 blow soft start would increase the typical piling operation described by Robinson *et al.* (2007) by around 20%. Because soft starts also increase the number of pulses produced during a piling exercise they could actually increase the cumulative exposure that an animal receives. This will depend on the relationship between the reduction in the level of pulses at the beginning of the soft start, the speed at which animals swim away from the piling location and propagation conditions in the area. In general soft starts reduce the risk of the highest level effects, such as permanent threshold shift (PTS), but can increase the risk of some lower level impacts.

It is also not clear how reliably the measurements of soft start characteristics made from a 2m pile by Robinson *et al.* (2007) can be extrapolated to a much larger pile. It is therefore recommended that field recordings of soft starts on full scale piles be made to provide empirical data. Cumulative impacts could also be lessened if the strike rate is reduced during a soft start.

Table 1. A summary of recent measurements and predictions of pile driving source levels. Acoustic parameters measured were Pk-Pk (peak to peak), RMS (root mean square), EFD (energy flux density).

Pile Diameter (m)	**Acoustic Parameter Measured**			**Water Depth** **Propagation Coefficient**	**Where**	**Reference**
	Pk-Pk	**RMS**	**EFD**			
2	224-236	Pkpk – 18dB	Pkpk – 32db	8-15m 15logr	UK coastal waters	(Robinson *et al.*, 2007)
4	249			11-26m 17 log r	North Hoyle	(Parvin *et al.*, 2006)
4.2	257			4-43m 20log r	Scoby Sands	(Parvin *et al.*, 2006)
4.3	243			3m 20 log r	Kentish Flats	(Parvin *et al.*, 2006)

4.7	252			10-30m 18 log r	Barrow	(Parvin *et al.*, 2006)
4.7	249-250			7-10m 21-23 Logr	Burbo Bank	(Parvin and Nedwell, 2006)

We include a soft start, based on the measurements made by Robinson *et al.* (2007) as an option in the model of cumulative exposure (Section 3.).

2.2. Species of Concern

Marine mammals warrant special concern because of their acoustic sensitivity, the enhanced legal protection provided to most species and their status as charismatic megafauna of particular interest to the public. Windfarm construction has so far mainly taken place in shallow inshore waters, but will occur further offshore and in deeper waters in the future. Both species of UK seal, the grey (*Halichoerus grypus*) and common (*Phoca vitulina*), are likely to be affected by pile driving noise. Among cetaceans, inshore species such as the harbour porpoise (*Phocoena phocoena*) and bottlenose dolphin (*Tursiops truncatus*) are most likely to be affected. As farms move further offshore, white-beaked dolphins (*Lagenorhynchus albirostris)*, common dolphins (*Delphinus delphis*), Atlantic white-sided dolphins (*Lagenorhynchus acutus)*, killer whales (*Orcinus orca*) and minke whales (*Balaenoptera acutorostrata)* may also be impacted.

2.3. Marine mammal auditory sensitivity

Marine mammals, in particular cetaceans, have highly-developed acoustic sensory systems, which enable them to communicate, navigate, orientate, avoid predators and forage, in an environment where sound propagates far more efficiently than does light. Cetaceans produce and receive sound over a very wide range of frequencies. A measure of hearing sensitivity is an audiogram, a plot of the level of the quietest pure tone that an individual can detect at a range of frequencies (Richardson *et al.*, 1995). Audiograms have been measured for some of the smaller marine mammals that can be readily maintained in captivity. Nedwell *et al.* (2004) reviewed the available information on fish and marine mammal hearing, and summarise those audiograms which are available.

As with any mammal, hearing sensitivity varies between individuals within a population and hearing impairment results from a range of natural effects, including with age (Houser and Finneran, 2006). For no marine mammal species have audiograms been collected from a sufficient sample size to capture this likely variation in hearing sensitivity between individuals.

It should also be noted that there are no audiograms for the majority of marine mammal species, and it is very unlikely that audiograms will ever be measured from some substantial classes of marine mammals, including all the baleen whales and the larger odontocetes. Further, the extent to which audiograms can be used to predict an animal's susceptibility to hearing damage remains unclear (see below).

Generally marine mammals have been found to be most sensitive to sounds within the frequency range of their vocalisations (Richardson *et al.*, 1995). Baleen whales produce low frequency (10Hz to 10kHz) tonal sounds, with long duration and potential to travel long distances, and we might also expect them to be most acoustically sensitive at these lower frequencies.

2.4. Risks to Marine Mammals

There are two main areas of concern in relation to the effects of piling noise on marine mammals: physical damage, especially to the auditory system which would result in hearing loss, and behavioural disruption and habitat exclusion.

In the zone of masking, the overlap in the frequencies of sounds produced by piling noise and those used by marine mammals has the potential to mask animals' vocalisations, interfering with their reception and inhibiting the efficient use of sound (Richardson *et al.*, 1995). In the zone of responsiveness, the noise will cause behavioural change. Some behavioural changes could have biologically significant effects. For example, noise exposure may result in animals changing their use of certain habitats, or being excluded from them. Research carried out at the Nysted Offshore Windfarm has shown that porpoise densities decrease over considerable ranges during windfarm construction (Carstensen *et al.*, 2006). Such effects may well lead to significant impacts. However, because aversive sounds could only be useful in mitigating acute effects such as auditory damage, we will not consider the extent and implications of behavioural disruption and habitat exclusion further in this report.

2.4.1. Non-Auditory Damage

Very powerful impulses with fast rise times, such as those caused by explosions, can result in non-auditory damage (Ketten, 1995). An assessment of this risk requires measures of impulse, which are not available. In line with conclusions of existing Environmental Impact Assessments, we will assume that non-auditory damage will not be induced by pile driving, and this is not considered further here.

2.4.2. Damage to Hearing

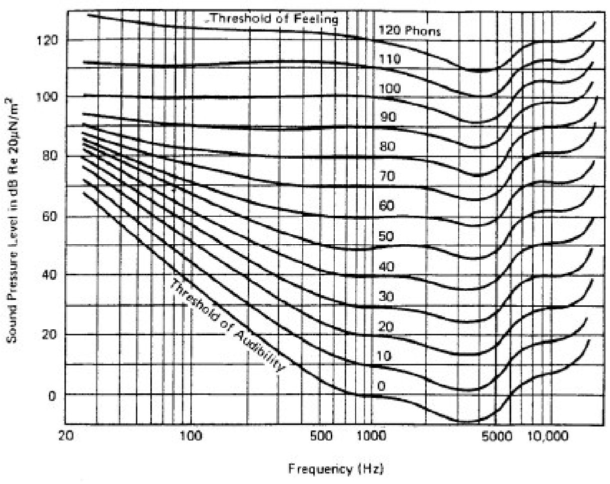
The auditory system has evolved to be particularly sensitive to sound. As a consequence, these are also the organs that are most vulnerable to being damaged by high levels of noise. Hearing damage is related to cumulative exposure, and pile driving is a static activity that may extend over several hours. Therefore, the risks it represents must be assessed in the context of a cumulative exposure model which incorporates factors such as animal movement and propagation conditions, as well as the source levels for the sounds under consideration. We have developed a simple cumulative exposure model for this purpose (see Section 3). The other important inputs to the model are range values for parameters such as source levels, propagation conditions and movements, and criteria for unacceptable risk. We discuss some of these in the following sections to explain and justify the values applied before introducing the model and presenting results from it towards the end of the Section.

2.5. Species-specific frequency weighting

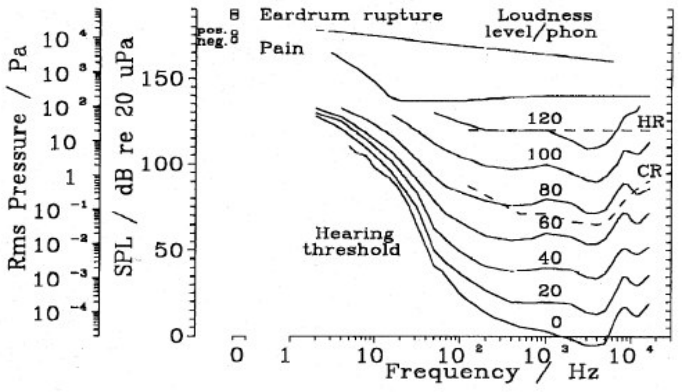
In assessments of risks from windfarm construction (but rarely in other acoustic risk assessments for marine mammals), a species-specific frequency weighting filter is often applied. This involves scaling received levels of noise in different frequency bands by an amount based on a species' sensitivity in that band. As explained below, we are uncomfortable with applying this approach to assessments of the risk of hearing damage.

Different species are differentially sensitive to sound at different frequencies. This differential sensitivity is usually summarised as an audiogram, a plot of the level of the quietest pure tone that an individual can detect over a range of frequencies. In humans it can be shown that this differential sensitivity is related to an individual's perception of the loudness of a sound (the sensation of loudness is expressed in phons).

To account for differential sensitivity in humans, measures of sound may be normalised or weighted by applying a filter that matches these plots of perceived loudness. In fact, the relationship between sound pressure level, frequency and perceived loudness varies depending on the intensity of the sound, and a series of different loudness curves has been derived for sounds of different intensity. As can be seen from Figure 1(a), the plot of perceived loudness over the auditory range is much 'flatter' – it varies less with frequency – for higher level sounds. Figure 1(b) shows a plot of sound pressure levels with a high risk of inducing hearing damage. It can be seen that this is quite flat, indicating no effect of frequency on vulnerability to hearing damage from high level sound.



(a)



(b)

Figure 1(a). Plots of equal loudness (Fletcher Munson curves).

Figure 1(b). Threshold of hearing (corresponding to 0 phon), curves of equal perceived loudness of 20,40, 60, 80, 100 and 120 phons, RMS sound pressure (logarithmic scale) and its level versus frequency. The threshold values are for binaural hearing of pure tones; monaural perception thresholds are higher. Also given are the thresholds of conditional (CR) and high (HR) risk of permanent hearing loss (dashed), of aural pain and of eardrum rupture. The high-risk threshold is also valid for the feeling of discomfort; the threshold for tickle sensation is slightly below the one for pain. From (Altmann, 1999).

The weighting commonly applied for humans, called A-weighting, is based on perceptions of loudness for rather quiet signals (40 phons). Other weighting curves have been developed which better predict human perception of other types and levels of noise. For example, the D-weighting was developed to predict perception of intense sounds such as those from loud low-flying aircraft. One might expect that, if they were to be used at all, weightings based on higher sound levels might be more appropriate in any assessment of a sound's ability to induce hearing damage. However, in spite of strong criticism from acousticians, A-weighting has been used in interpretation of a sound's ability to induce hearing damage in humans. This is largely for the sake of simplicity, and because the A-weighting is widely available on sound level meters. A cursory examination of Figures 1(a) and (b) would suggest that A-weighting would not be the appropriate filter to apply for assessing the risk of damage from intense noise and a weighting based on 0 phons, which is the audiogram, would be even less appropriate. It is also interesting to note that, even in subjects as well and easily studied as humans, these weighting curves are far from fixed. Recent measurements have resulted in a significant revision of the A-weighting curves, particularly at low frequencies.

Biologists have always paid attention to the differential hearing capabilities of different species in determining such factors as detection threshold levels for sounds of particular frequencies, usually by simply comparing a sound's level and frequency to the species' audiogram. When considering how 'loud' a broadband intermittent signal (such as piling noise) might appear to a particular animal, one would need to consider additional parameters, including filter bandwidth (usually assumed to be 1/3 octave in humans) and integration time (assumed to be 300msec).

Recently Nedwell and co-workers have sought to formalise a species weighting approach by introducing the dB(ht) which is essentially an A-weighting type scheme for many different species. By applying filters based on the audiograms for different species they aim to provide better predictions of a sound's ability to cause auditory damage and/or elicit a behavioural response. Their procedure provides a weighted measure of the total acoustic power of a sound. Whilst a consideration of an animal's acoustic sensitivity is key to an understanding of how it might perceive a sound, it is suggested that Nedwell's method for assessing risk of damage is not applied for the following reasons:

First, as discussed above, when predicting the potential for intense sounds to cause auditory damage, it is debatable whether the application of a weighting system based on differential sensitivity to low level (just perceivable) sound is appropriate. A weighting system based on an audiogram would be even less appropriate than the use of the strongly-criticised 40phon A-weighting system in humans.

Second, the method is reliant on accurate audiograms for the species in question. As discussed above, audiograms do not exist for many marine mammal species, and are largely confined to smaller species which are practical to keep in captivity. Even the audiograms which are available tend to rely on measurements taken from a small number of individuals, so generalisations about their accuracy for the species in general must be made with caution.

Third, auditory filter bandwidth and integration times are also necessary in order to apply the method to broadband pulsive sounds. This information is available for very few marine mammal species.

Finally, although we have seen the unpublished results of this method, to our knowledge it does not appear in any peer-reviewed publications, and no detailed description of how to apply it is available.

A consideration of sound levels relative to threshold sensitivities should be one of a number of factors to be considered in any assessment of likely behavioural response to sound. However, this is better achieved by applying the traditional method of comparing spectrograms and audiograms, preferably on a scale which matches the animal’s auditory filter (e.g. 1/3 octave). Reducing the assessment of any effect on a particular species to a single number might over-simplify a process which is necessarily inaccurate to a certain extent, owing to the uncertainties within the data on auditory sensitivities.

In conclusion, we agree with Madsen *et al.* (2006) who state (p 283) that ’we do not feel that differential weighting of pile driving sound levels for assessing the zones of injury would be made more reliable by comparison between species.’

2.6. Criteria and Thresholds for Unacceptable Risk

UK regulators have not stipulated any unacceptable risk criteria to apply to marine mammal noise exposure. However, temporary threshold shift (TTS) is often used as an experimental indicator of the onset of risk of hearing damage, and a common criterion applied elsewhere (for example in USA) is that activities must avoid the induction of TTS. Recently, several direct measures of TTS induced by noise exposure have been made in marine mammals (Au *et al.*, 1999; Finneran *et al.*, 2000; Schlundt *et al.*, 2000; Kastak *et al.*, 2005).

United States agencies have also produced figures on the sound exposure levels that should be avoided. NOAA originally defined the zone of injury as the range at which received level had fallen to 180dB re 1µPa (RMS) for mysticetes and sperm whales (*Physeter macrocephalus)*, and to 190dB re 1µPa for other odontocetes and pinnipeds. This ruling was made in relation to a permit for seismic surveys in offshore waters (NOAA, 1995); the guidance was subsequently updated to include all odontocetes within the 180dB re 1µPa sound exposure limit (NOAA, 1999). Airgun signals are loud, relatively short, low frequency pulses not unlike pile driving noise. This threshold only considers immediate sound pressure levels, and does not account for signal duration or cumulative exposure. It might also be noted that recent experimental evidence does not support the allocation of a higher threshold level for seals than for cetaceans (Kastak *et al.*, 2005).

More recent threshold values for marine mammals were provided by NOAA as part of a ruling on a permit application for a military sonar exercise (NOAA, 2006). This provides an acoustic energy threshold for TTS of 195 dB re 1µPa^{2}s. Being energy based, this takes account of the cumulative duration of exposure as well as for level. These thresholds were based on measurements made by Schlundt *et al.* (2000) of TTS induced in bottlenose dolphins and beluga whales (*Delphinapterus leucas)* after exposure to an intense 1 second narrow band tone. A threshold for PTS of 215 dB 1µPa -S was also specified by NOAA (2006) based on the typical values for the additional dB above TTS required to induce PTS in experiments with terrestrial mammals. It might be noted that the best acoustic sensitivity of harbour porpoise is higher than that of bottlenose dolphins and beluga whales, albeit at high frequencies, and porpoises may be more vulnerable to TTS than the species tested by Schlundt *et al.* (2000). A summary of some current and potential threshold values is given in Table 2.

Since the final draft of this report was completed the first results from work to measure TTS in harbour porpoise have become available (Lucke *et al.*, 2007). These results are so fundamentally important to this work that we cover them here and appended some runs of the cumaltive exposure model in section 3. These results are preliminary in that they are not yet published and are referenced here with the permission of the first author. A specific aim of this Lucke *et al's*.,study was to assess the likely impact of low frequency impulsive noise from pile driving on harbour porpoise heareing. The hearing sensitivity of a captive harbour porpoise was measured at three frequenciesm 4, 32 and 100kHz, using ABR techniques before and after exposure to a single pulse from an 20 in^3 airgun. The airgun generated a strong impulsive signal with most energy content below 500Hz, acoustically similar to pile driving noise. TTS was proven to occur at 4kHz after exposure to a single airgun pulse with received pressure levels above 184dB re 1µPa p-p, and a received energy of 165dB re 1µPa^{2}s. Threshold levels were also elevated at 32kHz but did not exceed the researcher's conservative TTS criterion. There were no indications of a threshold shift at 100kHz. Recovery of full sensitivity at 4kHz took more than a day to occur. Lucke *et al.,* (2007) noted that the study animal had an elevated hearing threshold compared to published audiograms which may have been due to auditory masking in the relatively noisy test environments or electrical "masking" in their equipment. They suggest therefore that the measured effects should be considered masked temporary threshold shifts (MTTS). MTTS is detected at higher exposure levels than TTS, thus we might expect the Luke et al's results to overestimate the exposure required to induce TTS and they should not be considered conservative.

From the perspective of windfarm development in UK waters, this is an extremely relevant and important result. It provides the first direct evidence of effects on the hearing of the commonest cetacean species at UK windfarm sites and the first evidence of impacts of low frequency impulsive sounds with similar characteristics to those from pile driving on the hearing sensitivity of any cetacean. This work indicates that, even though the hearing sensitivity of harbour porpoise is low at the frequencies at which most of the airgun sound energy occurs, TTS is induced at higher frequencies. TTS is induced at very much lower received energy levels in harbour porpoise than in the other cetacean species investigated so far.

Table 2. Some existing and suggested marine mammal sound exposure thresholds.

Source	**Level**	**Note**	**Effect**
NMFS(2003)	180-190dB re 1uPA (rms)		Non specific risk
NOAA(2006)	195dB re 1µPa^{2}s	Based on Schlundt *et al.* (2000)	TTS
NOAA(2006)	215 dB re 1µPa^{2}s		PTS
Kastak *et al.* (2005)	183 dB re 1µPa^{2}s	For common seals	TTS
(Lucke *et al.*, 2007)	165dB re 1µPa^{2}s	Harbour porpoise exposed to low frequency pulses	TTS
	185db re 1µPa^{2}s	Harbour Porpoise Extrapolation by adding 20dB to TTS	PTS

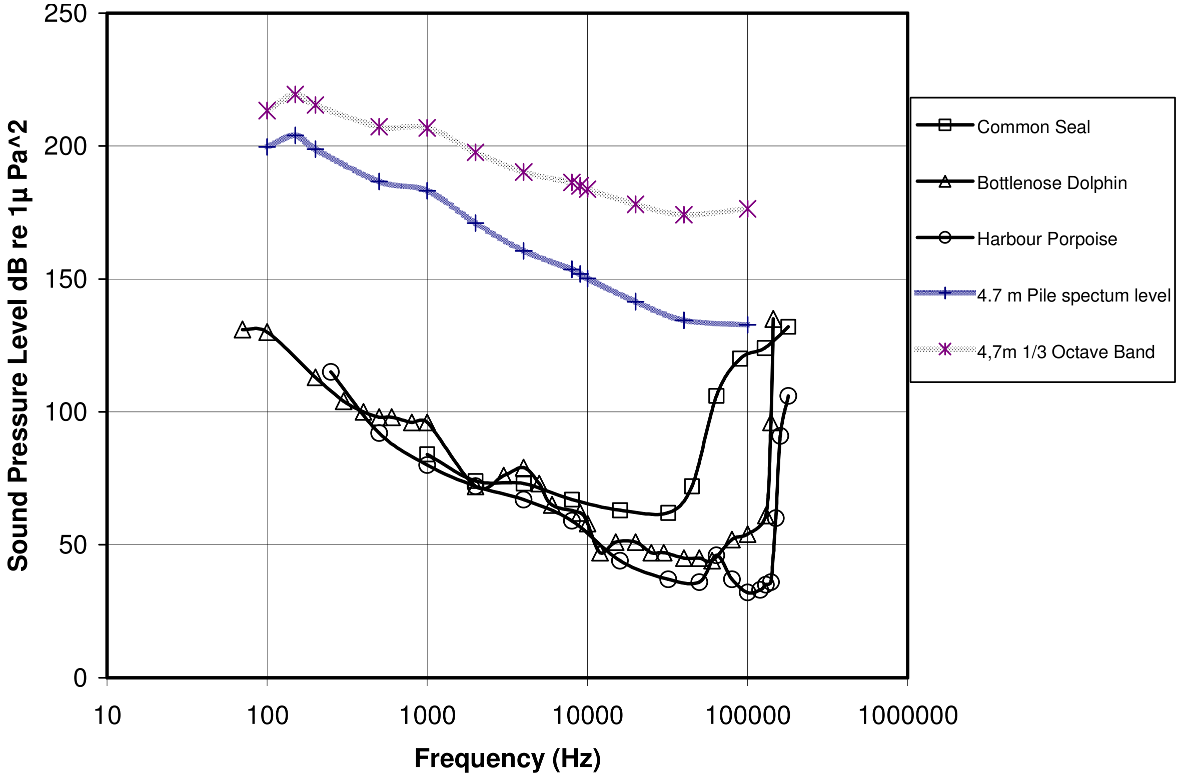


Figure 2. Audiograms for a harbour porpoise (Kastelein *et al.*, 2002), bottlenose dolphin (Johnson, 1967) and harbour seal (Mohl, 1968). Indications of spectrum levels for a 4.7m pile (re 1µPa2 /Hz) and 1/3 octave band levels are based on figures in Parvin *et al.* (2006).

Kastak *et al.* (2005) have investigated threshold shifts in three species of pinnipeds. Subjects were exposed to octave band sound, centred at 2500Hz for between 22 and 50mins. Sound levels were between 85 and 95 dB above the seal's sensation level at 2500Hz. Their results showed that TTS was affected by both sound level and duration, though the effect did not seem to be linear and there was significant variation between trials and between species. For one of the species tested, the common seal, their data indicated that TTS began to develop at sound exposure levels above 183 dB re 1µPa^{2}s.

3. A Cumulative Exposure Model

3.1. Preliminary Cumulative Exposure Model

Pile driving activity occurs in a single location over a period of several hours. The development of TTS, and the risk of hearing damage is a function of received acoustic energy and, in the case of pile driving, the received dose will accumulate throughout the period of the piling activity. Over this time, we would expect animals in the vicinity to be mobile and very probably to move away from the pile driving noise and from any aversive noise sources. Thus, to assess the risk of hearing damage and determine the required performance and efficacy of mitigation measures we need to employ a cumulative exposure model which incorporates animal movement and propagation loss with range as well as the source characteristics and duty cycles of the sound sources.

Here we provide results from a rather simple model written in visual basic. This model assumes that a pile driving activity could involve several different phases: the use of an aversive sound source (which may, if it is loud enough, itself contribute to cumulative sound exposure), a soft start, and a period of piling at full power. Animals are assumed to move directly away from the sound source at a constant speed.

In each model run, the subject is assumed to start at a particular range and move away from the pile location at a constant specified speed. At each noise event (e.g. pile strike or ADD emission), the source level for the noise event is determined, the range of the animal is calculated based on an assumed speed of movement, and a specified propagation loss is applied to determine a received level at the animal. This is then added to the animal’s cumulative dose. This process is repeated until the pile driving exercise is completed. For example Figure 3 shows received energy flux density levels for single pulses and the cumulative dose for an animal which was at 100m at the time that activity (in this case the use of an ADD) commenced. Changes in received levels and cumulative levels through the various stages of piling can be readily seen.

If the cumulative dose exceeds the threshold for TTS then the starting range for that run is noted. The procedure is then repeated with the starting range incremented by a specified amount (typically 10m). Runs are repeated until the maximum specified starting range is reached and the maximum of all the starting ranges for which the cumulative dose exceeded the threshold is output. The conclusion being that, under the conditions and parameters specified in that run of the model, animals that were within this range at the start of activities would have a sufficient cumulative exposure to induce TTS and animals beyond that range would not. Mitigation to minimise the risk of TTS should thus ensure that no animals are within this range at the commencement of piling.

The model can also be run many times over a range of likely parameter values to examine their effect on TTS threshold range.

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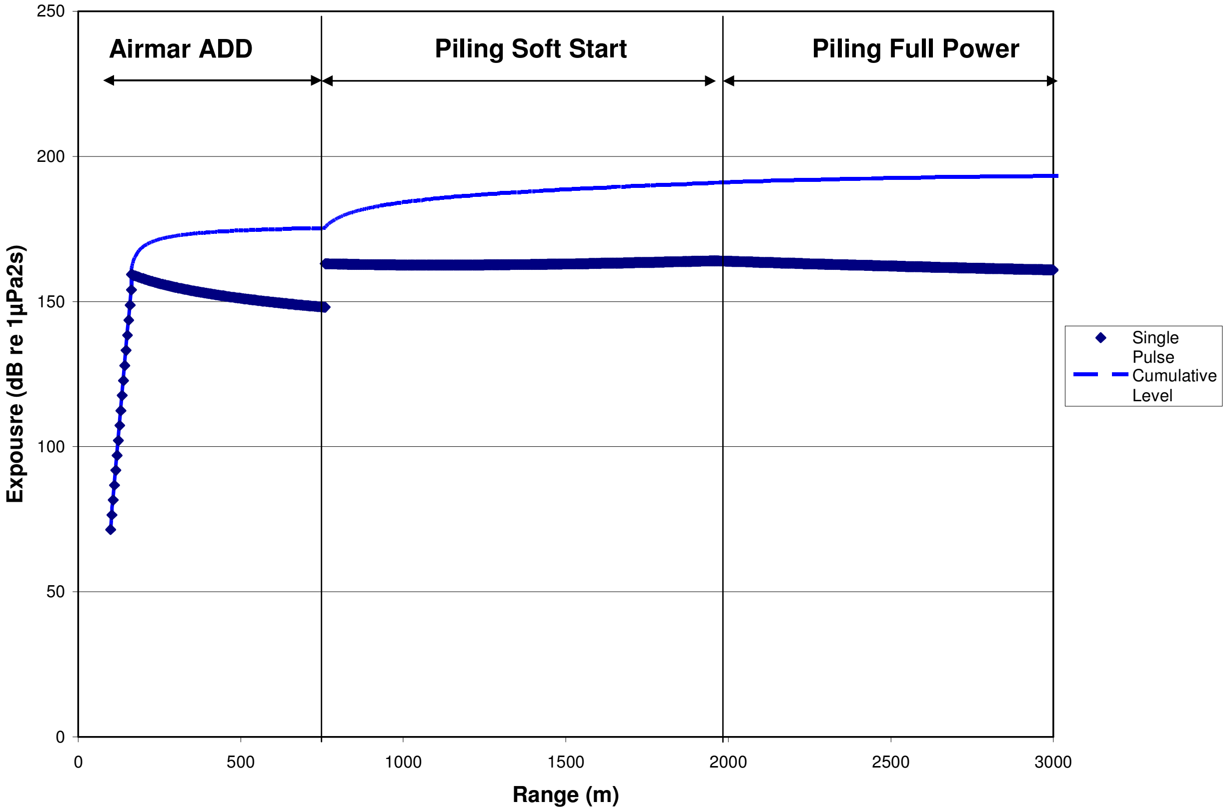


Figure 3. Received energy flux density levels for single pulses and the cumulative dose for an animal at 100m from the piling site at the commencement of a piling activity incorporating a high power ADD and a 600 strike soft start.

3.1.1. Parameter Values

A number of parameters need to be set in the model. Here we explain and justify the values used.

3.1.1.1. Animal Movements – Escape Speed

The manner in which animals move in response to pile driving noise and to any AMD signal employed is an important parameter in the model which has a very significant bearing on a subject's cumulative exposure. While it would seem logical that animals should move away from a powerful noise source, there are no reliable data quantifying short term animal movements in response to pile driving noise. However, here we assume that the animals move directly away from the sound source and we use theoretical considerations and field observations to suggest an escape speed.

In many larger swimming animals, oxygen consumption increases rapidly as speed increases beyond the energetic minima for transport, and this has the effect of constraining maximum swim speed for long range movements. In porpoises, Otani *et al.* (2001) found that during most dives porpoises swam relatively slowly (0.76-0.91 m/s) and the minimum cost of transport occurred at between 1.3 and 1.5m/s. In grey seals Sparling and Fedak (2004) showed that, as predicted, metabolic rate increased with swim speed resulting in shorter dives for higher swim speeds. The maximum swim speed they observed during dives was 1.4 m/s. A range of escape speeds between 0 and 1.5m/s thus seem reasonable to explore in the model.

3.1.1.2. Piling Source Levels and Characteristics

Source levels for large diameter piles are discussed in section 2.1. Based on this information we have used the following source levels

Table 3. Source levels for a 4.7m and a 6.5m pile.

Pile Diameter	**Sound Pressure Level (Peak to Peak)**	**Sound Pressure Level (RMS)**	**Energy Flux Density (single pulse)**
4.7m	252 dB re 1μPa	234 dB re 1μPa	220 dB re 1μPa^{2}s
6.5m	258 dB re 1μPa	240 dB re 1μPa	226 dB re 1μPa^{2}s

Increase in source level during ramp up:

Based on the measurements made by Robinson *et al.* (2007), we assume the following changes over ramp up:

Pk-pk – 12dB

RMS – 13dB

EFD – 8dB

Durations and Duty Cycles:

Main Piling: 3000 impacts at one impact every 2 seconds

Soft starts: 600 impacts (20 mins), based on Robinson *et al.* (2007)

3.1.1.3. Acoustic Mitigation Devices

For model runs with an AMD device, we have assumed that an Airmar ADD is used. The Airmar dBII has a source level of 194dB re 1μPa average RMS for each transmission, which consists of 32 18.5 msec pulses (Haller and Lemon, 1994). Each transmission lasts for 2 seconds thus the equivalent energy flux density per second is 194+3 197=dB re 1μPa^{2}s. Transmissions are repeated every four seconds.

Source Levels

194 dB re 1μPa RMS

197 dB re 1μPa^{2}s EFD

Duty cycle

17 blasts ramp up plus

150 blasts (10 mins)

300 blasts (20 mins)

3.1.1.4. Propagation Conditions

The simplest propagation equation takes the form:

Transmission Loss=nLog(range)

where the value of n varies with local conditions. In deep open water and at shorter ranges where spherical spreading can be assumed, the value of n is taken to be 20. In a perfectly ducted situation where spreading is cylindrical, the value of n would be 10. In shallow waters, where sound is reflected from the surface and the bottom, 15Log(range) transmission loss is often assumed. Sound is also absorbed by water. This effect is linearly related to range and is dependent on frequency; absorption being greater for higher frequencies. We have ignored absorption for our modelling exercise because at the frequencies at which most pile driving acoustic energy is concentrated, absorption is low (< 0.1dB per km), and this is negligible when compared to the other uncertainties in the process. Theile (2002), referenced in Thomsen *et al.*

(2006), developed a formula for propagation loss of pile driving noise in the North Sea. This indicated transmission loss of close to 15 Log(r), and was supported by field measurements (Thiele, 2002; Thomsen *et al.*, 2006). Measurements made by Parvin *et al.* (2006) suggested a propagation loss of 17 Log(r) at the North Hoyle windfarm site.

Propagation of broadband noise in shallow water environments is a complex phenomenon and many processes will affect the rate at which different frequencies are attenuated. This is, however, a topic of substantial commercial and military interest and complex models have been developed which can provide reliable predictions when parameters appropriate for a specific site are used. The output from such models and/or field measurements could be used to improve the predictions of cumulative noise exposure models but we feel that it is unlikely that this will change the qualitative conclusions. Therefore, for this exercise we have calculated transmission loss in the model with the simple equation TL= n Log(range), over a range of values of n between 15 and 22.

3.1.1.5. Exposure Thresholds

These are explored and explained in Section 2.6.

Auditory damage from a single pulse (NOAA, 1995 and NOAA, 1999):

180 dB re 1µPa sound pressure level RMS (cetaceans)

190dB re 1µPa SPL (RMS) (pinnipeds)

TTS from Cumulative exposure (NOAA 2006):

195 dB re 1µPa^{2}s Cumulative Energy Flux Density (EFD)

TTS from Cumulative exposure (Harbour Porpoise, Lucke *et al.,* 2007)

165dB re 1µPa^{2}s (EFD)

PTS from cumulative exposure (NOAA 2006):

215 dB re 1µPa^{2}s Cumulative Energy Flux Density (EFD)

PTS from cumulative exposure (Harbour Porpoise, extrapolation from Lucke et al., 2007)

185dB re 1µPa^{2}s (EFD)

3.1.2. Assessment of Damage Risk Threshold Ranges

The model has been used to explore the maximum ranges at which thresholds for unacceptable exposure would be exceeded in a variety of conditions. With so many variables and several criteria we have not explored all possibilities but focused on some likely scenarios

3.1.2.1. Single Pulse RMS Sound Pressure Level Thresholds

Table 4 summarises the ranges at which acoustic damage would occur based on single pulses

Table 4. Maximum start ranges at which thresholds of acoustic damage based on single pulses are exceeded (using sound exposure limits from NOAA, 1995 and NOAA, 1999).

Thresholds	**Soft Start (mins)**	**Escape Speed ms^{-1}**	**Propagation Spreading Factor n log(r)**	**Predicted Mitigation Ranges m**	
				4.7m 234dB	**6.5m 240dB**
180 dB re 1µPa	20	1.5	15	2,180	8,200
190 dB re 1µPa	20	1.5	15	110	350
180 dB re 1µPa	20	1.5	17	250	1,580

190 dB re 1μPa	20	1.5	17	60	150
180 dB re 1μPa	20	1.5	20	110	220
190 dB re 1μPa	20	1.5	20	30	70
180 dB re 1μPa	20	1	15	2,780	8,800
190 dB re 1μPa	20	1	15	110	950
180 dB re 1μPa	20	1	17	300	2,180
190 dB re 1μPa	20	1	17	60	150
180 dB re 1μPa	20	1	20	110	220
190 dB re 1μPa	20	1	20	30	70
180 dB re 1μPa	20	0	15	3,980	10,000
190 dB re 1μPa	20	0	15	850	2,150
180 dB re 1μPa	20	0	17	1,500	3,380
190 dB re 1μPa	20	0	17	380	870
180 dB re 1μPa	20	0	20	500	1,000
190 dB re 1μPa	20	0	20	150	310

3.1.2.2. TTS Resulting from Cumulative Exposure

Table 5 provides examples of starting ranges within which exposure thresholds would be exceeded for a variety of likely parameter values. PTS could be induced at considerable ranges when soft starts are short (or ineffective), transmission loss is low and escape speeds slow. Thresholds for TTS are likely to be exceeded over a much wider range of conditions and, in some cases, over very considerable ranges.

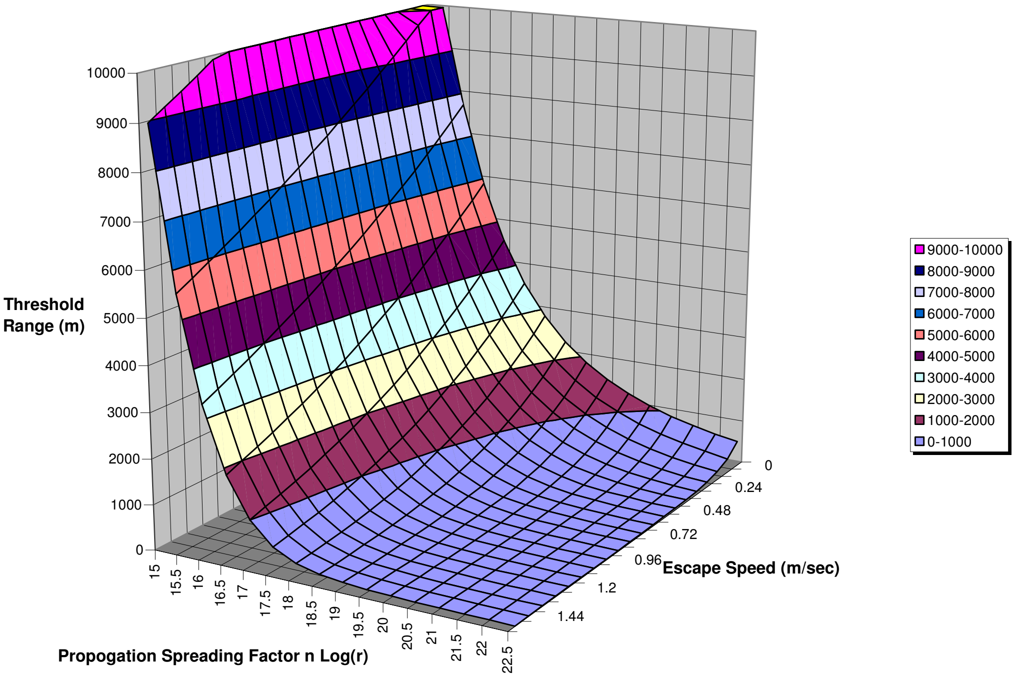
Table 5a. Maximum start ranges at which thresholds of acceptable exposure based on cumulative exposure, TTS and PTS are exceeded (using sound exposure limits from NOAA, 2006).

Thresholds	**Soft Start (mins)**	**Escape Speed ms^{-1}**	**Propagation Spreading Factor n log(r)**	**Predicted Mitigation Ranges m**	
				4.7m 220dB	**6.5m 226dB**
195 dB re 1μPa^{2}s TTS	20	1.5	15	5,360	>15,000

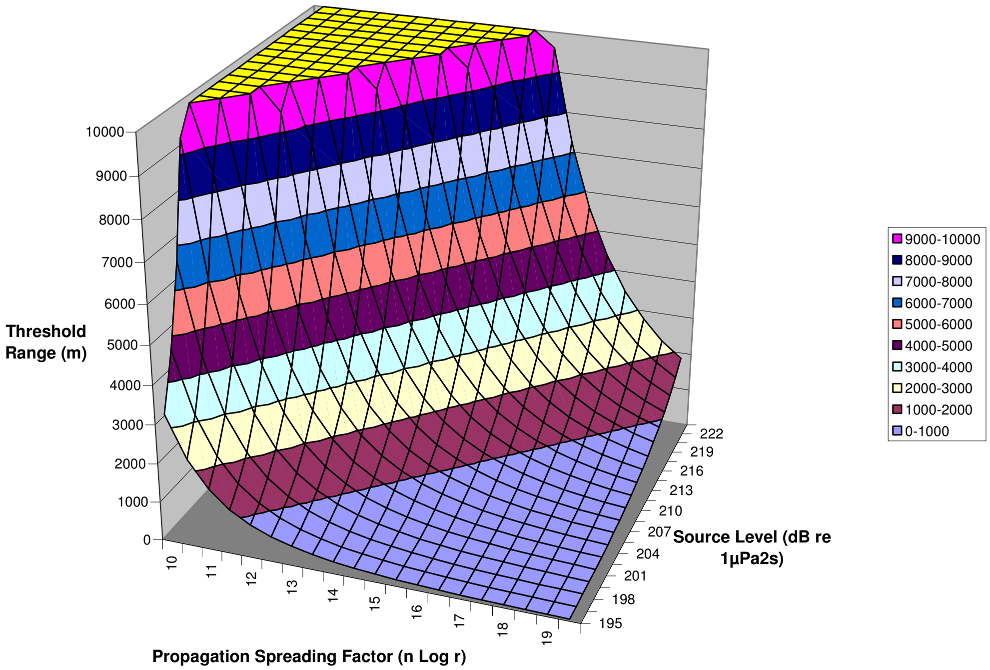
195 dB re 1μPa^{2}s TTS	20	1.5	17	350	3,290
195 dB re 1μPa^{2}s TTS	20	1.5	20	20	100
195 dB re 1μPa^{2}s TTS	20	1	15	6,770	>15,000
195 dB re 1μPa^{2}s TTS	20	1	17	860	4,500
195 dB re 1μPa^{2}s TTS	20	1	20	30	220
195 dB re 1μPa^{2}s TTS	20	0	15	10,230	>15,000
195 dB re 1μPa^{2}s TTS	20	0	17	3,450	7,780
195 dB re 1μPa^{2}s TTS	20	0	20	1,010	2,030
215 dB re 1μPa^{2}s PTS	0	1	15	10	110
215 dB re 1μPa^{2}s PTS	0	0.5	15	30	300
215 dB re 1μPa^{2}s PTS	20	0	15	470	1,190
215 dB re 1μPa^{2}s PTS	20	0	17	230	510
215 dB re 1μPa^{2}s PTS	20	0	20	100	200

Table 5b. Maximum start ranges at which thresholds for cumulative exposure resulting in TTS and PTS would be exceeded in harbour porpoise, based on recent measurements for TTS development Lucke *et al.* (200&).

Thresholds	**Soft Start (mins)**	**Escape Speed ms^{-1}**	**Propagation Spreading Factor n log(r)**	**Predicted Mitigation Ranges m**	
				4.7m 220dB	**6.5m 226dB**
165 dB re 1μPa^{2}s TTS	20	1.5	17	>10000	>10000
165 dB re 1μPa^{2}s TTS	20	1.5	20	>10000	>10000
165 dB re 1μPa^{2}s TTS	20	1.5	25	960	3000
185 dB re 1μPa^{2}s PTS	20	1.5	17	8330	>10.000
185 dB re 1μPa^{2}s PTS	20	1.5	20	390	2,330
185 dB re 1μPa^{2}s PTS	20	1.5	25	20	60



(a)



(b)

Figure 4.(a&b) Surfaces showing ranges at which 195 dB re $1\mu Pa^2s$ threshold for TTS through cumulative expose is exceeded over a range of combinations of energy flux density source levels (dB re $1\mu Pa^2s$), escape speed (m/sec) and propagation spreading factors 'n'. A simple propagation loss equation is assumed of the form n Log (range). Ranges are truncated at 10km.

These risks could be reduced if animals within these threshold ranges were caused to leave, by using an acoustic mitigation device for example. Powerful acoustic devices, such as an Airmar ADD would contribute to cumulative exposure. However, as Table 6 shows, use of an appropriate device for a sufficient length of time would effectively eliminate risks of auditory damage if animals consistently moved away from it.

Table 6. Example of use of AMD to reduce risk of TTS.

Source for Criteria	**Thresholds (dB re $1\mu Pa^2s$)**	**AMD tx Duration (mins)+**	**Soft Start Duration (mins)**	**Escape Speed ms^{-1}**	**Propagation Spreading Factor n log(r)**	**Predicted Mitigation Ranges m**	
						Seal	**Harbour Porpoise**
NOAA (2006)	195 (TTS)	0	10	1	15	6,920	6,920
NOAA (2006)	195 (TTS)	120	10	1	15	70	70
NOAA (2006)	195 (TTS)	0	0	1	17	900	900
NOAA (2006)	195 (TTS)	15	10	1	17	30	30
NOAA (2006)	195 (TTS)	0	0	1	20	90	90

The large spread of values in Tables 4 and 5 in part reflects sensitivity to values of parameters which are likely to vary between operations (such as propagation conditions and source levels) but could be measured for particular construction projects and then more reliably specified in the model. However, there are also some more fundamental unknowns represented here, such as auditory damage thresholds and animal behaviour, which have never been measured in the context of pile driving. Given the lack of directed research in this area this is unsurprising. Uncertainty will only be reduced when research to make these measurements is undertaken.

The recent measurements of TTS in harbour porpoise from Lucke *et al.,* (2007) serve to emphasise this point. The indications from these preliminary results are that harbour porpoise are very much more vulnerable to hearing damage than the odontocetes measured by other groups. The full implications of this finding for offshore windfarm construction have yet to be assessed by regulators but it certainly highlights the need for more effective mitigation procedures.

In considering results from this model, it is essential to keep in mind the tenuous nature of some of the data and many of the extrapolations that underpin them. These results cannot be used to make firm predictions of risks but rather to explore the parameters that will be most important to adjust and/or quantify in developing a precautionary mitigation strategy.

We draw some general and fairly qualitative conclusions from this exercise:

1. Propagation conditions have a very substantial effect. For example, mitigation ranges are low when 20 Log(r) propagation loss is assumed but can be very high when 15 Log(r) propagation applies. Both values are likely in some shallow water locations. Propagation can however be modelled and also measured in the field once operations begin.

2. According to this model, PTS could occur in some circumstances, for example, where there is no soft start and animals show little avoidance. However, this is an unlikely set of circumstances. Observations of avoidance reactions can be made to provide real data on responsive movements.

3. Thresholds for risk of hearing damage based on single pulses and cumulative exposure may be exceeded at substantial ranges, especially when transmission loss is low.

4. This exercise certainly does not support any suggestion that the risk of auditory damage to marine mammals from pile driving can be discounted.

5. The risk of damage can be substantially reduced if animals can be reliably removed from within hundreds to low thousands of meters before piling is initiated. Acoustic mitigation devices will thus need to be able to move animals over these types of ranges to be effective.

The results summarised in Tables 4 and 5 indicate required mitigation ranges in different conditions. Data like these will serve to set the performance criteria required from any AMDs used for mitigation. In Table 6 the use of an AMD to reduce risk of TTS using the NOAA (2006) criteria can be seen more clearly. If 15Log(r) propagation loss is assumed then animals could experience TTS at range of over 6km. To reduce this, animals would need to be moved to that range before piling began which would require an effective AMD to be used for 120 minutes before the initiation of piling.

Mitigation ranges depend very considerably on the propagation conditions. Conditions in inshore waters are often between 15 and 20 Log(r) requiring animals to be moved to ranges of several hundreds to thousands of meters before piling starts to avoid risk of TTS. Soft starts are of some help (provided animals respond to them appropriately) but will not, on their own, reduce risk sufficiently.

4. Review of aversive sounds

4.1. Aversive sounds and humans

4.1.1. Psychoacoustics

Humans are ideal subjects for studying the perception of different sound types and the relationship between perception and a sound's acoustic properties. In the context of this study it is useful to review human studies to explore whether there are any general characteristics of sounds that make them inherently aversive to humans, and how general these are across species.

Zwicker and Fastl summarise a large body of work conducted by German researchers investigating the human hearing sensations and constructing models that explain these in terms of a stimulus's acoustical properties (Zwicker and Fastl, 1990). They investigated and attempted to measure annoyance, and found that it was best explained by a sound's loudness, fluctuation strength, and 'sharpness'. The sensation of sharpness was correlated with a narrow frequency emphasis within a critical frequency band, with the effect being stronger for higher frequency sounds.

Several teams have explored the characteristics that make certain sounds aversive. Practical applications include the use of aversive sounds in conditioning procedures (Neumann and Waters, 2006), and also in military and societal-behavioural contexts.

Some general themes on the characteristics of sounds that are aversive emerge from this work. Humans find intermittent, unpredictable sound with varying intensities more annoying than constant sound. This may be because such sounds are difficult to habituate to and ignore (Talling *et al.*, 1998). Humans show a preference for consonance (combinations of certain tones that are comfortable to listen to) over dissonance (intervals between pairs of auditory signals which are not comfortable to the ears).

Kamo and Iwasa (2000) explain that consonances tend to be combinations of tones with frequency ratios close to combinations of two small integers. For example, a typical consonance is an 'octave', a pair of tones with a frequency ratio of exactly two. Another example is 'perfect fifth' (e.g. 'C' and 'G') with a frequency ratio close to three halves. In contrast, dissonances tend to have frequency ratios that are not close to a simple ratio. The fact that children show a preference for consonance over dissonance (McDermott and Hauser, 2004), suggests this might be an innate rather than learned response.

McDermott and Hauser (2004) investigated whether aversion to dissonance is also demonstrated in a closely related species. An archetypal aversive sound for humans is the noise of fingers being scraped down a blackboard. Acoustically, this sound is made up of several prominent harmonics overlaid with broadband noise. To test whether this aversion was shared by another primate species, McDermott and Hauser (2004) exposed both humans and cotton-top tamarins to the nail scraping noise. However, they found that whilst human subjects preferred to listen to white noise rather than the amplitude-matched screeching sound, the tamarins exhibited no preference.

Thus, while the phenomenon is not fully understood, the human aversion to dissonant and scraping sounds seems not to be shared by another non-human primate.

One suggestion to explain the preference for consonance over dissonance is that a noise will sound dissonant as the receiving system becomes over-stimulated, so dissonance may be aversive because it may be an indication that the auditory system is overloaded and may be at risk of damage. If this was the case we might expect to find an aversion to dissonance to be widespread in animals.

There are also sounds which humans find disgusting by association. The response to these is probably learned or conditional, and a result of previous exposure, rather than being unconditional. This is demonstrated by a recent online poll (http://www.sound101.org) by Cox (University of Salford). This invited web-users, varying in age, gender and nationality, to rate a range of unpleasant sounds. The 'fingers on a blackboard sound' was rated only 16th, whilst first place was the sound of a human vomiting. The properties of a person vomiting may not themselves intrinsically acoustically aversive unpleasant, but they are associated with an act which is unpleasant for the actor, may be associated with poisoning and generally provokes disgust. Whilst it was judged to be a 'worse' sound than the scraping noise, this judgement is in fact made on different criteria.

4.1.2. Applications of Aversive sound in Humans

4.1.2.1. Acoustic weapons

The military has explored the potential for using sound in weapons to incapacitate or change the behaviour of targets. This has a long history. In ancient times war cries or loud blaring instruments were used to intimidate or induce panic in opponents. For example Vinokur (2004) relates that Celtic tribes used a long horn-shaped instrument called the Carnyx to intimidate their enemies. Vinokur also describes the use by Russian forest robbers of loud shrill whistles to stun or disorient their victims, a practice which apparently continued into the 18th Century.

The potential use of powerful acoustic, infra and ultrasound signals as non-lethal weapons is a subject that appears to have a firm grip on the public's imagination. As a consequence, information on this subject tends to be found in the popular rather than scientific literature, and is often exaggerated and inconsistent. However, a thorough and considered assessment of real applications and the effects of acoustic weapons is provided by Altmann (1999).

The security information website, www.globalsecurity.org, also details the range of non-lethal acoustic weapons which have been trialled. In addition to simple high-intensity sound, infrasonic sound (again at high intensity), which is said to cause a number of physiological results affecting the internal organs, has been investigated. However, in his review Altmann (1999) states that, contrary to claims in several articles in the defence press, high-power infrasound has no physiological effects on humans.

The Curdler, was a device reportedly available to British troops in Northern Ireland. Altmann (1999) cites a 1969 publication on riot control which states that the sound, amplified by a 350W amplifier with a level 120 dB re 20 µPa at 10m produced a high shrieking noise at irregular intervals. This was apparently irritating rather than being painful or disorientating. However, Altmann also reports that, although the British government bought 13 of these systems in 1973, none was actually put into use, although the reasons for this are not given.

Loud rock-and-roll music was also played during Operation Just Cause, the 1989 mission to Panama that resulted in the capture of Panamanian President Manuel Noriega. Similar loud music was played by the U.S. Treasury Department's Alcohol, Firearms, and Tobacco team for the same purpose during the siege of the Branch Davidians in 1993 at Waco, Texas. This sound was also irritating, rather than inducing any physiological response.

In general the US military has found acoustic weapons to be ineffective unless used at intensities that were either impractical to deliver over a large area or likely to cause permanent hearing damage. (United States Army Medical Research Institute of Chemical Defense; https://ccc.apgea.army.mil/sarea/products/textbook/Web_Version/chapters/chapter_11.htm)

Vinokur (2004) notes that sounds become uncomfortable at 120 dB re 20 µPa, painful at ~140 dB, with eardrum rupture occurring at approximately 160 dB, and possible lung damage at 175 dB. Therefore, it is necessary to achieve received levels of between 120dB and 160dB, if acoustic signals are to cause discomfort but not cause injury. Producing these received levels over significant ranges is difficult. Thus, the practical implementation of such weapons is problematic, and the range of efficacy limited to a few hundred metres.

Jauchem and Cook (2007), in a review of anecdotal and laboratory reports of the effects of acoustic weapons, conclude that it is unlikely that high-intensity acoustic energy in the audible, ultrasonic or low frequency ranges could provide the basis for a useful non-lethal acoustic weapon. They note that the majority of the claims made for acoustic weapons in popular literature are exaggerated and some have turned out to be hoaxes.

In our case, we require to move animals hundreds of metres without adding appreciable risk of hearing damage. There seems to be little of practical value that can be learned from these attempts to develop acoustic weapons. However, some of these examples serve to emphasise how difficult it is to apply high levels of sound over substantial ranges.

4.1.2.3. Other applications of aversive sounds with humans

In a social context, acoustic devices have also been developed to control anti-social behaviour. A noise-emitting device called the Mosquito has been developed in response to concerns about teenagers gathering in groups around shops and other businesses (http://www.compoundsecurity.co.uk/teenage_control_products.html). The MK II Mosquito operates at 17.8kHz, emitting a pulse 4 times per second and automatically adjusts its volume to be 5 dB-A above the ambient noise levels in the immediate area. The device's manufacturers claim an effective range of 15-20m, and that the equipment is 'completely harmless'; teenagers 'are acutely aware of the Mosquito and usually move away from the area within an average of 8- 10 minutes'. However, it is not heard by adults (whose high-frequency hearing has deteriorated due to presbycusis).

4.2. Aversive sounds and terrestrial animals

Sound emitting devices have long been used to manage interactions between human activities and terrestrial animals. These devices employ loud startling noises (often with accompanying visual stimuli), ultrasound (favoured because it cannot be detected by humans) or a biologically significant signal. Examples of biologically significant sounds would include alarm, distress, alert or aggressive calls, and the calls of predators. One of the commonest applications for sonic deterrents is in frightening birds away from crops or airport runways. Devices available commercially mainly utilise predator calls, distress calls and pyrotechnics as acoustic deterrents. However, the effective ranges for many of these products have not been determined. Habituation to deterrent devices is also a significant problem, especially if animals are highly motivated to remain in the area (Harris and Davis, 1998). From his study on the behavioural responses of free-ranging feral pigeons (*Columbidae*) to deterrent devices (including acoustic devices) Haag-Wackernagel (2000) concluded that 'feral pigeons are able to surmount every deterring system, even when facing massive impairment (pain, injury), if their motivation is high enough', and noted that ultrasound had no effect at all.

Bomford and O'Brien (1990) reviewed literature on the effectiveness of a wide range of sonic deterrent devices. They noted that in many cases systems had been developed and brought to market before their effects on target species and their likely effectiveness had been properly assessed. Many of the studies they reviewed failed to provide an adequate test of effectiveness. To some extent this was a result of technical difficulties and economic constraints but they concluded that tests could be improved in the future by using better experimental design. They found that devices that used signals that had no biological significance were generally ineffective or offered only short term protection. In many cases animals quickly habituated to these signals. Broadcast of biologically relevant sounds, such as alarm calls showed the most promise, especially if attention was paid to minimising the extent of habituation (Bomford and O'Brien, 1990).

A number of studies have been completed since Bomford and O'Brien's review and they generally serve to support their conclusions. Several projects have reported poor results from non-biologically significant sounds, including ultrasound. For example Bomford (1990) investigated the efficacy the Hi-Tec Electronic Scarecrow, a broadband acoustic device that emitted a complex series of frequency sweeps extending up to 32kHz. Starlings (*Sturnus vulgaris*) which were feeding when the device was activated showed no reaction at all and within five minutes of the device being switched on, a flock of >500 starlings alighted and started feeding in front of a speaker. Over the course of the experiment, starling numbers increased, and were higher when the device was functioning than when it was switched off. There was no difference in the amount of food consumed when the device was on or off.

Ultrasound emitters are also sold as deterrents or conditioning signals for a range of animals, such as cats, dogs, rats, mice and deer, which have better high frequency hearing than humans. Nelson *et al.* (2006b) tested a commercially available ultrasonic cat deterrent device which triggers a 21-23 kHz ultrasonic alarm when an animal is in the vicinity. The deterrent had a moderate effect on subjects (a small reduction in the probability of a cat entering the garden, and a larger reduction in the duration of intrusions). The effect of the device increased over time, implying that cats learned to avoid the area with an active alarm.

Bender (2005) also investigated the efficacy of ultrasonic deterrents in reducing the risk of collisions between vehicles and kangaroos. She found that in captive trials with eastern grey kangaroos (*Macropus giganteus*) and red kangaroos (*Macropus rufus*), there was no change in vigilance levels of kangaroos in response to the ultransonic Roo Guard or Shu Roo kangaroo deterrents. Similarly the relative density of free-ranging eastern grey kangaroos was not affected by in the presence of an active Roo Guard and there was no reduction in the rate of kangaroo-vehicle collisions in field trials with the Shu Roo. By contrast, Bender found a biologically significant sound, the foot thump of a kangaroo (a signal made in response to a potential predator), to be more effective. Over 60% of kangaroos tested with playback of the foot thump took flight, and vigilance levels increased significantly.

Bender concluded that there are a number of critical criteria for auditory deterrents: 'the signal must be audible to the target species and perhaps should be directed at their best hearing frequency; the signal must be of sufficient intensity to overcome attenuation; the signal should be meaningful to the target species, (for example an alarm signal); the signal must generate an appropriate response, flight not freeze; and sufficient time must be allowed between playing of the auditory stimulus and the target species response.'

Promising results from a large well controlled study using biologically significant sounds to reduce damage in orchards by American crows (*Corvus brachrynchos*) are reported by Delwiche *et al.* (2005). In this trial four 25-second distress calls were broadcast with approximately 12 minutes between calls. To reduce the potential for habituation, a new call was used after 256 call events. The devices were also turned off every night. The study showed a significant reduction in bird damage during the two and a half month trial. Large flocks of crows responded to the stimuli by approaching the sound source, circling overhead whilst calling, and then dispersing. The authors report that the crow population in orchards subject to the broadcast distress calls seemed lower than in the previous year when no aversive stimuli were broadcast, although no data were collected to quantify this observation. Towards the end of the study there was evidence of habituation; after eight weeks some crows continued feeding in the presence of nearby operating broadcast units.

The extended history of the use of acoustic deterrents to manage interactions with pest species provides some examples of success but many other instances of the deployment of ineffective devices. This has lead to some mistrust and scepticism on the part of managers and customers, even though it is clear that, when used intelligently and appropriately, sonic devices can be helpful in certain circumstances. Several useful lessons can be used to guide the development of aversive sounds for mitigation. Signals perceived as being biologically relevant sounds are more likely to be effective than sounds that have no significance to the subjects. Knowledge of the biology of the target species will also allow more intelligent and effective operation. Habituation is always likely to occur when animals are exposed to signals without reinforcement. Thus, signal types should be changed regularly, broadcast locations moved and devices should only be activated when required. Adequate and well designed experiments are required to properly assess the effectiveness of sonic devices and these should be conducted early in any development process so that their results can be used to help design improved signals and procedures.

5. Aversive sounds and marine mammals

5.1. Sonar

5.1.1. Whaling sonar

ASDIC (the name given by the Royal Navy to its early development of sonar) was used in post-Second World War commercial whaling operations, both to detect whales, but also to frighten them, making them easier to catch (Mitchell *et al.*, 1981). Mitchell *et al.*(1981), summarise the use and efficiency of ASDIC in whaling. During the first post-war season, two newly-built Norwegian boats carried ASDIC and by 1946 ASDIC equipment used on German U-boats had been released by the British Admiralty for use by whaling fleets. By 1956, over 40 catcher boats from Norway, UK and Holland used the specially-produced Kelvin Hughes Echowhale Finder. The Japanese fleet tested a prototype in 1951, imported a British model in 1955 and first used a sonar-based searching technique in the Antarctic in the 1956-7 season. According to Harland (pers. comm.) the Japanese whalers routinely used sonar in the 1960's. By 1981 effectively the whole Japanese fleet were equipped with sonar (Mitchell *et al.*, 1981).

It appears that active sonar was only used to track animals that had been sighted visually rather than as a primary detection method, and there were also operational problems that restricted the efficacy of early ASDIC for tracking whales underwater. However, whalers found that the sound emitted by the ASDIC device seemed to irritate or frighten the whale. A whale exposed to ASDIC was more likely 'to bolt directly away from the catcher than adopt a dodging or cutting tactic' making them much easier to catch. They also stated that as ASDIC emissions could frighten all whales 'within miles', if it was deployed at the wrong time it could scatter a pod and make the hunt more difficult. Often, therefore, it might be used to hunt whales only at the end of the day.

According to Mitchell *et al.* (1981), this response of whales to ASDIC led the Norwegians to develop a 'whale startler' in the early 1950s, which 'used six oscillators to generate ultrasonic pulses in three directions', which seemed to 'scare the whale to the surface, inducing panic and "panting" and fatiguing the whale as quickly as possible'. This device was marketed by Electroacoustic G.M.G.H. in Germany and in the 1952-53 season was carried by 25 Norwegian boats. Mitchell *et al.* do not give any more details of the specification or characteristics of the 'whale startler', but it appears to have operated in a similar frequency range to ASDIC, as the authors state that the Norwegians attempted 'to combine the startler device with ASDIC, but soon abandoned the ASDIC due to 'interference'.

Source Characteristics of Whaling Sonars. The observations summarised by Mitchell *et al.* (1981) and others suggest that signals with similar characteristics to those of whaling sonar would be good candidates as aversive sound sources for marine mammal mitigation. Unfortunately, none of the whaling literature summarised by Mitchell *et al.* (1981) provides information on the characteristics of the sound emitted by these devices. Haslett (1967) describes a whaling sonar used in the Antarctic as emitting a 25msec pulse at 26kHz. A heterodyne unit was used to make the pulse audible, and the operator used the Doppler shift in the echoes returning from the moving whale to help discern it from other static targets. Haslett loc. cit. mentions the whale moving away from the vessel but not that this sonar was specifically used to frighten the animal. Mitchell *et al.* (1981) mention the use of Doppler shift as being a technique used after the initial trials with WWII sonar when purpose built sonar systems were available. We are indebted to Ed Harland, who has worked in the field of military sonar for many years, for his insights on this subject. According to Harland (pers. comm.), two whale catchers with wartime sonars were sent down to the South Atlantic to investigate their efficacy at detecting whales. These were searchlight sonars operating at around 16kHz. All UK sonars were the same in terms of the sonar transmit pulse and produced a narrow beam which could be directed by the sonar operator over a wide angle. The transducer was deployed within a retractable dome through of the hull of the ship. The specification of the sonar used by Japanese whalers in the 1960's has not been released. However, due to technological advances making lower frequency sonar easier to build, it is thought that the Japanese system was probably operated at 10 kHz (Harland, pers. comm.).

5.1.2. Military sonar

In recent years concern and considerable controversy has arisen around the effects of mid-frequency military sonar on several species of marine mammals. Beaked whales (*Ziphiidae*) seem to be the most susceptible group. Sonar causes mortality and mass stranding in this group. A recent review (ICES, 2005) lists mass stranding events occurring concurrently with sonar exercises extending back to 1963, soon after current mid-frequency sonar was introduced. Necropsies of beaked whales from several mass standings in the Canaries have revealed pathology consistent with decompression sickness (DCS) (Jepson *et al.*, 2003; Fernandez *et al.*, 2005). Causal mechanisms are not known, but one currently favoured hypothesis is that DCS is induced by changes in the animals' diving behaviour (Cox *et al.*, 2006). If this is correct, then it suggests that military sonar causes a dramatic behavioural change in beaked whales and possibly other species.

Some direct observations of behavioural responses to military sonar have also been reported. In the aftermath of the US intervention in Grenada in October 1983 military sonar signals appeared to silence sperm whales and cause them to scatter (Watkins *et al.*, 1985). A sperm whale research cruise coincided with military events in the area and although no military vessels were detected at the surface within 55km, considerable underwater activity was noted, including the use of intense, mid-frequency long-range sonar. Watkins *et al.*, report the submarine signals as being of several kinds with frequencies from 3250-8400 Hz in pulses of 0.14-0.45 s, usually in short sequences of 4-20 or more signals at rates of *ca.* 1-5/min. They heard the signals every few hours on some days and they were audible during some portion of 11 of the 13 days that they were with whales.

Watkins *at al*. assumed that sperm whales were occasionally directly subjected to these signals, and observed that the animals they were studying became scattered, very difficult to approach and silent. These behaviours were markedly different from those that they usually observed in that region and at time of year. Although the periods of silence by the whales seemed to last longer in response to higher levels of sonar, less intense signals also seemed to result in the whales being quieter and becoming more timid.

Similarly, during a cruise in March 1984, Watkins *et al.* (1985) detected one short sequence of military sonar (from a surface vessel observed by radar to be at a range of 21 km). The whales responded by falling silent even though the signals were not received at a high level. They became vocal again within an hour.

There are also reports of mid-frequency military sonar having behavioural effects on killer whales. On 5th May 2003, the activities of US Navy Guided Missile Destroyer SHOUP DDG 86 in the Strait of Juan de Fuca and the Haro Strait was reported as influencing killer whale behaviour (Fromm, 2006). The USS SHOUP's active sonar system projects signals in three back-to-back 200-Hz constant bandwidths centred at 2.9 kHz (full frequency band: 2.6 to 3.3 kHz) at a source level of 235 dB RMS re: 1µPa. (NMFS, 2005). Researchers reported that the 22 animals of the resident J-pod of killer whales that they were observing at the time stopped feeding, gathered in a tight group and swam close to shore for the duration of a sonar exercise during which sonar pulses were produced every 28 seconds approximately. The closest approach of the ship to the J-pod (approximately 2.5 km) occurred when the animals were located in Haro Strait on the west coast of San Juan. The estimated mean sonar levels received by J-pod killer whales ranged from approximately 121 to 175 dBRMS re: 1µPa (NMFS, 2005). The National Marine Fisheries Service (NMFS) investigation following the incident (NMFS, 2005) concluded that as a result of the 5 May 2003 sonar transmissions, J-pod killer whales experienced exposure levels likely to induce behavioural reaction which was consistent with eyewitness accounts of behavioural changes and unusual behaviours.

US and Japanese military activities have also been observed to affect melon-headed whale (*Peponocephala electra*) behaviour (Southall *et al.*, 2006). Whilst tactical mid-frequency sonar was operational on 3-4 July 2004, 150 to 200 melon-headed whales were observed milling in Hanalei Bay, Kauai, Hawaii for over 28 hours. Having entered the bay together, the animals remained there until removed with human assistance. It was thought unlikely that environmental factors were solely responsible for the unusual distribution (Southall *et al.*, 2006) and a spatial and temporal correlation with naval vessels transmitting active sonar was established. Whilst the authors stated that this did not provide conclusive evidence of a causal relationship, the anomalous nature of the behaviour, the proximity to naval activities, the direction of movement of the transmitting vessels and the likely propagation of their signals made a connection between the events plausible.

Rendell and Gordon (1999) observed that a pod of long-finned pilot whales (*Globicephala melaena*) encountered in the Ligurian Sea, Mediterranean, stayed bunched together and very close to the small survey vessel at a time when military research sonar could be detected by the vessel's acoustic monitoring equipment. Signals consisted of patterns of 0.17 sec pings at frequencies between 4-5 kHz. The authors later measured the whales' vocalisations and found that certain classes of whistle occurred significantly more often during and just after sonar output than at other times. This indicated that the sonar pulses provoked short term acoustic response in pilot whales, although the significance of this change in vocal behaviour is not clear. It also seems likely that the whales' anomalous grouping behaviour and close association with the research vessel was also caused by the sonar signals.

Mid-frequency military sonar has also been observed to affect the behaviour of baleen whales (Maybaum, 1993). Humpback whales (*Megaptera novaeangliae)* responded to pings from a 3.3kHz sonar by swimming directly away at an increased speed in a straight line. However Maybaum did not find that the sonar signals had any consistent effect on vocalisations or diving behaviour.

Generally, responses to controlled exposure to US Navy's newly developed SURTASS-LFA sonar, a low frequency sonar which produces very powerful sounds below 500 Hz, have been less dramatic. There were no obvious responses from fin (*Balaenoptera physalus*) and blue whales (*Balaenoptera musculus*) off California when they were played the sound (150 to 320 Hz at source levels of up to 215 dB re 1 μPa) (Croll *et al.*, 2001). However, during controlled exposure experiments off Hawaii, the length of male humpback whales' songs was found to increase by 29% during the transmission of 42-s LFA signals. The sonar was broadcast at less than full strength, with no focal singer exposed to a signal louder than 150 dB re 1 μPa (Miller *et al.*, 2000). Similarly, when US Navy SURTASS LFA sonar was active off the west coast of Hawai'i in March 1998, humpback whale songs that ended within a few minutes of the most recent sonar 'ping' had a tendency to last longer than those emitted during control periods, once seasonal and diurnal variation in singing behaviour had been accounted for (Fristrup *et al.*, 2003).

5.2. Killer Whale Vocalisations

Killer whales (*Orcinus orca*) are the most significant natural predator of many marine mammal species, and they also produce loud characteristic vocalisations. Killer whales produce three distinct forms of vocalisation: clicks, which function for echolocation; pure tone whistles and burst pulse calls (Schevill and Watkins, 1966). Burst pulse vocalisations consist of rapid sequences of clicks at repetition rates of hundreds or thousands per second which humans perceive as harsh screams or cries with a fundamental frequency equal to the repetition rate. These calls are often characterised by abrupt patterned changes in pulse repetition rate and also, independently, by changes in the emphasised frequencies within individual pulses, which are typically between 1 and 6kHz (Ford, 1989). The pulse rate determines the lowest harmonic while the frequency emphasis within pulses also affects emphasis within the higher harmonics. It is these pulsed calls that are so characteristic of killer whales which have been used in playbacks to other marine mammals. Miller (2006) measured the apparent source levels of three classes of killer whale vocalisations; whistles, stereotyped pulses calls and variable pulsed calls. He found that, with a source level of 140.2 +/- 4.1dB, whistles had a lower source level than pulsed calls. Within pulsed calls, the stereotyped calls (152.6 +/- 5.9dB) had a higher source level than varialbe calls (146.6 +/-6.6dB). **Ba**sed on these valued Miller calculated that stereotyped calls could be detected at a range of 13km in low sea states, and suggested that they might be used for long range communication (Miller, 2006). Stereotyped pulsed calls are distinctive and different types can be distinguished acoustically. Pods of resident killer whale off British Columbia have distinctive repertoires of between 7 and 17 discrete c pulsed call types (Ford, 1989). It is likely that pulsed calls could be useful as acoustic deterrents and there have been a number of attempts to use transmission of killer whale vocalisations to frighten marine mammals in order to control their behaviour or distribution.

In the earliest published example, killer whale calls were played to beluga in Alaska in order to deter them from predating on salmon smolt in the Kvivhak River (Fish and Vania, 1971). The beluga showed a strong avoidance response to the killer whale recordings. They also responded to randomly pulsed tones at 2.5kHz suggesting that the response might be generalised to a range of killer-whale like signals.

Killer whale vocalisations were used in an attempt to keep grey seals away from salmon nets in Scotland (Anderson and Hawkins, 1978). However these playbacks were not consistently effective. Cape fur seals (*Arctocephalus pusillus)* showed a distinctive reaction to killer whale calls, although this effect was reported to be transitory (Shaughnessy *et al.*, 1981).

The response of seals to killer whale sounds was also tested as part of the Swedish National Management Plan for grey seals in the Baltic Sea (Anon, 2002). Killer whale calls were played to a resting/slow moving common seal near Haröy on Norway's south west coast. The seal fled at high speed to the nearest rocky islet 200m away. When, in a second trial, killer whale calls were played to a grey seal in the Sea of Bothnia, Sweden, a slightly different response was observed. Although the seal swam away for approximately 1km, it then resumed foraging in spite of the presence of a nearby rocky islet on which it could have hauled out. There is no detail in this study as to the type of killer whale sounds used, or the distribution or abundance of killer whales naturally occurring in the areas studied.

Killer whale vocalisations have also been broadcast to common seals near haul out sites in British Columbia (Deecke *et al.*, 2002). These seals did not show a strong aversive reaction, and remained in the area, perhaps because flight was not the appropriate response so close to a haul out site. Deeke *et al.* did observe changes in the number of animals seen at the surface however and they used this opportunity to test differential response to different types of killer whale signals. Two distinct types of killer whales are found in waters off British Colombia. 'Residents' that feed on fish and 'Transients' which hunt marine mammals. Different pods have distinct vocal dialects. Seals in this study responded less to the calls of fish-eating pods that were resident in that area than to the calls of mammal-eating killer whales and to fish-eating killer whales from another location sufficiently remote for the seals not have encountered them. The seals' responses to mammal-eating transient and unfamiliar fish-eaters were indistinguishable from each other. These authors suggested that repeated exposure to the calls of fish-eating killer whales without attack had resulted in habituation to the specific calls of the locally resident pods. The authors suggest that it would make biological sense for animals to have a general (possibly innate) fear of all potential predator calls and to selectively refine this through habituation and learning.

This example indicates that some sophistication may be required when using predator calls and other biologically significant sounds, and it will be important to take the likely experience of local populations into account when choosing signals. In the first place it may be necessary that the local population has had sufficient experience of killer whales to have learned to fear them. However, it may also be sensible to avoid the possibility of using calls of any local killer whale groups that might not feed on mammals because local marine mammals may have learned that these groups do not represent a threat to them. The 'safest' strategy might be to use calls from a completely different area or to use synthesised sounds with appropriate characteristics.

One additional concern is the effect that killer whale playbacks might have on local killer whale groups in the area. Killer whales are rare but not unknown at most European windfarm sites.

5.3. Responses to other stimuli

Marine mammal behaviour has also been affected by broadcast of other stimuli. With reference to deterrents, Iida *et al.* (2006) attempted to provoke an aversive response in Steller sea lions (*Eumetopias jubatus*) using in-air and underwater playbacks of artificially generated frequency sweeps and strobe lights. They found that, in order of efficacy, in-air playbacks, then strobe lights, then underwater playbacks were the most effective.

Explosions above and below water have been tested in different situations in order to scare seals. A rocket-launched charge, which detonates with a flash of light and a bang and can be shot up to 300m (originally designed to be used to scare birds from airports) was used to try to drive seals away from the herring fisheries in the Sea of Bothnia, Sweden (Anon, 2002). The seals dived in response to the explosion, but returned a few minutes later, whether the explosion occurred above or below the water.

Generally, explosives carry a high risk of damage. They may startle animals but have not been shown to cause animals to move substantial distances and their use as an aversive signal for mitigation is not recommended.

There have also been studies using playback of signals to try to decrease collisions between marine mammals and vessels (Andre *et al.*, 1997; Nowacek *et al.*, 2004), but with little success. Nowacek *et al.* (2004) used controlled exposure experiments to investigate whether acoustic stimuli might be used to mitigate the threat of ship strikes to North Atlantic right whales (*Eubalaena glacialis)* in the Bay of Fundy. They tested the response of right whales to recordings of ship noise, the social sounds of conspecifics, and an 'alert signal' designed to alert the whales. The 'alert signal' was played back over an 18 minute time period and consisted of three 2 minute signals each played three times. The three signal types were (i) alternating 1 s pure tones at 500 and 850 Hz; (ii) a 2 s logarithmic down-sweep from 4500 to 500 Hz; and (iii) a pair of low-high (1500 and 2000 Hz) sine wave tones amplitude modulated at 120 Hz and each 1 s long. The whales did not react to the vessel noise, either recorded or actual. They reacted slightly to the social sound stimulus (recordings of socially active groups of right whales lasting for 1–5 s in the 500–4000 Hz frequency range) by changing heading to temporarily orient towards the source. The strongest response was to the alerting signal. Five out of six of those exposed to the signal curtailed their current foraging dive prematurely, ascended rapidly, and changed their surface behaviour. The sixth animal, which did not respond, was the last animal to be tested, and had been exposed to the sound in previous experiments on its conspecifics. Its lack of response may have been due to habituation. Although the experimenters were successful in eliciting a reaction the response of the whales to the alert signal – an ascent to, and increased time near the surface - would be likely to expose animals to an increased risk of a collision with a vessel.

The risk of stranding in cetaceans has also been reduced using playback. Mobley *et al.* (1988) describe how a humpback whale was encouraged to leave the Sacramento River and enter the open ocean by playback of feeding calls of conspecifics (Mobley *et al.*, 1988). In this case the sound used served more to attract than to repel the target animal.

As discussed earlier, many terrestrial applications broadcast the alarm calls of the target animals as deterrents. We are not aware of any specific vocalisations that have been identified as alarm calls in any marine mammals. This may simply be because these animals have not yet been sufficiently well studied, but it may also be the case that making alarm calls is not an adaptive strategy for animals living in an environment that is as open and free from refuges as the ocean. Alarm calls might also be less generally effective than predator vocalisations as they may be quite species-specific. Our intention here is to find a deterrent which can be effective with several species.

5.4. Acoustic deterrent devices (ADDs)

5.4.1 High Power Devices

5.4.1.1 Acoustic Characteristics

Acoustic deterrent devices are marketed specifically for excluding marine mammals, usually pinnipeds, from certain areas. As the finfish farming industry (predominantly salmon) has grown over the last 20 years, the use of powerful underwater sounds to minimise predation on farmed fish by pinnipeds, has also increased (Gordon and Northridge, 2002). The devices which generate these sounds are known as acoustic harassment devices (AHDs) or acoustic deterrent devices (ADDs). Acoustic Harassment Devices (AHDs) may also be known as seal scrammers or seal scarers. The terms 'AHD' and 'ADD' are often used interchangeably, although a distinction has been made by some between devices with lower sources levels (lower than 185 dB re 1 μPa @ 1m) being termed 'ADDs', whilst devices with source levels above this level, being termed 'AHDs'. However, the threshold for this distinction is largely arbitrary and, the distinction in terminology not relevant to this report, where the purpose of the devices will be to deter, not to harass. Therefore, we generally prefer to refer to all of these devices as 'ADDs'. In the context of future applications in mitigating the effect of offshore construction noise, we refer to them as 'AMDs' (Acoustic Mitigation Devices).

Although some of the earliest trials used biologically significant sounds, for example killer whale sounds (Anderson and Hawkins, 1978), the sounds emitted by current ADDs are not designed to have any biological significance. It is likely that their efficacy derives from their unpleasantly (even painfully) high power levels within seals' best hearing sensitivity (8-17kHz).

Table 7 summarises the acoustic characteristics of some commonly-used ADDs currently used at aquaculture sites in the UK. It should be noted that the output specifications quoted by ADD manufacturers do not always correspond with measurements taken in the field (Lepper *et al.*, 2004).

Table 7. The characteristics of some commercial acoustic deterrent devices commonly used in aquaculture. Max SL - maximum source level. (adapted from (Gordon and Northridge, 2002; Lepper *et al.*, 2004)).

Name of Device	**Frequency (kHz)**	**Max SL (dB re 1 uPa @ 1m)**	**Transmission Duration**	**Pulse Duration**	**Duty Cycle**	**Approximate Cost (ex VAT)**
Airmar dB Plus II	10 (tonal)	194 Db	2.25 seconds	1.4 – 2 ms	40-50%	£6,790.00
Ace Aquatec Universal Scrammer Mk 2 with	8-20 (broadband) (harmonics up to 30)	194 dB	4-5 seconds	frequency dependent	Activity dependent	£5,500
Terecos	2.5-100 (wide variation broad and narrow band)	179 dB (146 dB at frequencies > 27 kHz)	15 seconds – 2 minutes	200ms – 8 seconds	50/50	Dependent on system Generally rented

5.4.1.2. Effects on target species – seals

Ironically, although these devices are sold specifically to deter seal depredation at salmon farms, and there is some anecdotal support for this, there are no peer reviewed articles that demonstrate this effect, nor that seals are excluded from areas other than the immediate vicinity of active ADDs and certainly not over the distances required for this application (100s to 1000s of metres). Seals have a powerful incentive to interact with the fish pens and may have already come to associate them with food before the ADDs are activated. In addition, it seems that seals habituate to the ADD signals and may even develop strategies for avoiding the effects of these powerful signals. Jacobs and Turhune (2002) made measurements of ADD source levels, and observed effects on seal behaviour, and on haul out patterns at sites in the Bay of Fundy which were close to many aquaculture facilities with active ADDs. They found that the source level of the units they measured at two aquaculture sites were 179 and 178dB, which was 16 - 17dB lower than the manufacturer's specified source level of 195dB. They inferred that this was because this was an old unit and that a new device would emit at the specified level. The ADD with which they investigated behavioural effects had an output of 173dB. To investigate effects on seal behaviour, they flushed animals into the water from haul out sites. After collecting 'control' data they activated the ADD. They observed no startle response or overt behaviour and were unable to measure any avoidance. Seals surfaced as close as 43m from the active ADD. In another experiment they left an ADD running continuously in a passage through which seals had to swim to reach a haul out site. Numbers of seals hauling out were counted on days with and without active ADDs. There were no differences in numbers hauled out that could be correlated with ADD state. Several points should be noted however. They used an ADD with a low source level for their behavioural experiments. In inshore waters a 15log(r) propagation loss can be assumed, in which case the received levels from this device at 43m (their closest observation for a seal) might be achieved by a unit operating at the full specified power of 195dB at a range of some 1,200m. Further, the seals in this area had been exposed to ADDs for many years (possibly all of their lives) and their behaviour may not have been representative of that of naive seals. The behavioural observations were simple and conducted on animals that had already been disturbed by a vessel and by in-air noise, and the animals were in water close to their haulout site.

Nelson *et al.* (2006) analysed questionnaire returns from a survey of 35 fish farms in Maine USA to investigate the influence of various factors on rates of seal depredation. Distance from seal haul out sites and the proper maintenance of primary and secondary netting were both correlated with rates of seal attacks. The use of ADDs had no significant effect however, and only 50% of farmers rated them as 'fairly effective' (Nelson *et al.*, 2006a).

In UK waters, Robertson (2004) observed that the presence of an ADD at a fish farm in the Orkneys did not deter seals from using a nearby haul out site, which could only be accessed by passing within 1.5km of the active ADD. One seal was observed within 70m of a cage.

ADDs have also been used in the Baltic Sea to reduce gear and catch damage by grey seals at salmon-trap nets (as opposed to at fish farm sites) (Fjalling *et al.*, 2006). In this case there are good data that indicate a reduced depredation rate. The mean daily catch was significantly higher in traps with ADDs (25.5 kg d^{-1}) than in controls (12.0 kg d^{-1}), and catch damage was less (3.5 vs. 6.7 kg d^{-1}). The devices continued to be successful over three consecutive fishing seasons, although late in each season, damage to catches in nets with ADDs became more common, suggesting habituation within each season. The researchers modified most of the ADDs they used, to make the pulses and intervals less predictable so that it was less likely that seals would anticipate the onset of a pulse train. However, some unmodified ADDs with a fixed 90 second emission interval were also used. It was reported that some seals took advantage of this period to dive to the nets, keeping their heads above water when the device was emitting sound. It was also reported that some seals, in particular very large old males did not respond to the devices, either because of habituation or through age-related hearing loss.

A study of captive seals found that that ADD-type signals continued to be effective in deterring seals over short ranges (Kastelein *et al.*, 2006b). Captive common seals were exposed to four series of tone pulses spanning the frequency range from 8-45 kHz. Each pulse duration lasted 250ms, and was played every 5 seconds. The animals were exposed to one of the four frequencies for 45 minutes each day in rotation. All four frequencies continued to displace the animals over the 40 day period of the trial. That the seals continued to find all four frequencies aversive throughout the study suggests that operating the devices for short periods and changing the frequencies used might have reduced the extent of habituation. It must be noted however that these captive seals lacked the strong motivation to approach the sound that seals on salmon farms probably experience and displacement was only achieved over a short range.

ADDs used at fish farms or fish traps are often active fairly continuously for long periods of time, and are usually in proximity to a resource, fish, that the seals are highly motivated to acquire. These circumstances must encourage seals to habituate to and to devise strategies for avoiding the effects of, the devices. This would be unlikely to occur when an AMD was used occasionally during mitigation when any association would be with intense noise and other disturbing activities rather than food.

5.4.1.3 Effects on cetaceans

The use of such powerful sound sources in the habitat of several species of inshore cetaceans, which generally have better sensitivity to ADD signals than do seals, has led to concerns about the effects of powerful ADDs on these acoustically sensitive non-target species. Several studies have measured behavioural responses including habitat exclusion. For this application we are primarily interested in ADDs' ability to reliably move animals away from an area of risk (such as a site subject to pile driving or an explosion) over a short period of time.

Olesiuk *et al.* (2002) investigated the effects of Airmar ADDs on harbour porpoises during a series of controlled experiments extending over 18 weeks at Retreat Passage, British Columbia, Canada. The study was sub-divided into three six-week periods within each of which the ADD was inactive for three weeks then active for three weeks. Olesiuk *et al.* (2002) found that there was a complete exclusion of porpoises within a 200m radius of the source, only 1% of the expected number were observed within 600m, and densities were still only 8.1% of those expected at a range of 2,500-3,500m. 3.5km was the greatest range at which observations could be made, and it is most likely that effects extended beyond this range. Their observations also implied that porpoises which did enter the area affected by ADDs spent a shorter length of time within in it than when the ADD was inactive (1.1-1.9 resightings per sighting compared to 12.2-13.6 resightings per sighting). No evidence of habituation was discerned over the 18 week period of the study.

Johnston (2002) made a complimentary set of observations of the locations and movements of individual porpoises using a theodolite to track animals from an onshore vantage point on Grand Mannan Island on the east coast of Canada. He found complete exclusion out to a range of 645m at which the received level of the ADD was calculated to be 128dB (animals had approached within 6m of an inactive ADD). The mean closest approach of all tracks while the ADD was active was 991m with a calculated received level of 125dB (the mean closest approach for tracks when the ADD was not active was 364m). Presumably Johnson's data for active ADDs will include locations when the animals were still moving away from the device and so may underestimate the effective exclusion range. Johnston does not provide information on the speed with which animals moved away from the ADD but he does present data for sighting rates in 30 minute bins over the whole study area (out to 1.5 kms approx.). Examination of his Figure 3 shows that sighting rate is approximately half after 30 mins, is reduced to approx 1/10 in the second 30 minutes and no animals are seen at all over the remaining 30 minutes of observation.

A study in the Orkneys found that fewer harbour porpoises were detected acoustically in an area considered to be affected by an ADD when the device was active, than when it was inactive (Robertson, 2004).

Aversive responses in cetaceans are not restricted to harbour porpoise. Observations of killer whales in British Columbia (Morton and Symonds, 2002) indicated a reduction in the use of feeding areas in the Broughton Archipelago at a scale of tens of kilometres, which continued without the animals showing any sign of habituation over the six years that ADDs were in use. When the ADDs were removed the whales started to use this habitat again.

5.4.2. Lower power devices (pingers)

Lower power acoustic devices, often called pingers, have been used in attempts to reduce cetacean bycatch. By-catch, the capture of non-target species in fishing gear, is a conservation concern for cetaceans, especially small odontocetes such as the harbour porpoise, which are particularly vulnerable to bottom set gill nets (Goodson, 1997; Koschinski and Culik, 1997). One substantial strand of research aimed at minimising mortality has been directed towards acoustic devices (pingers); their deployment on fishing gear may deter cetaceans from approaching and becoming entangled with fishing nets and mitigate bycatch (Goodson, 1997; Koschinski and Culik, 1997; Kraus *et al.*, 1997; Stone *et al.*, 1997; Kastelein *et al.*, 2000; Culik *et al.*, 2001; Kastelein *et al.*, 2001; Carlström *et al.*, 2002; Teilmann *et al.*, 2006).

Pingers operate a lower intensity levels than AHDs (usually <150 dB re 1 µPa at 1 m), within mid- to high frequencies (2.5 – 100 kHz), with higher harmonic frequencies of up to 180 kHz. Signals are emitted as pulses or sweeps that vary in frequency and usually last around 3 seconds followed by a 4 second silence. Their zone of influence on harbour porpoise is thought to be approximately 500m (Culik *et al.*, 2001). The characteristics of selected pingers are shown in Table 8.

Table 8. Characteristics of selected low-intensity acoustic deterrents generally known as pingers.

Manufacturer	**Dukane Corp.**	**Aquatec Sub-Sea**	**Fumunda**	**Lien - L1**	**STM**	**Airmar**

	(discontinued)	**Ltd (C)**	**(C)**	**(H)**	**(C)**	**(C)**
Models	Net Mark 1000☐ (a); Netmark 2000 (b)	Aquamark 100(a); Aquamark 200 (b); Aquamark 300 (c)	FMP 332	Gearin (L2); McPherson (L3)	DDD 02 (a) DDD 02F (b)	Gillnet Pinger
Source level max/min (dB re 1μP @1m)	150 - 130	145	134 - 130	132 - 110	Up to approx 150	132
Battery	4 x 'AA' alkaline	1 x 'D' alkaline	1 x lithium	4 x PP3 alkaline	1.3Ah NiMH	1 x 'D' alkaline
Fundamental Frequency	10kHz (US)	(a) 20-160kHz frequency sweeps (DK); (b) similar to 'a' but the frequency sweep tuned for dolphins (DK); (c) 10kHz tonal (US)	10kHz (US)	(L1) 2.5kHz; (L2) 3.5kHz; (L3) 3.5 kHz	1-500kHz	10kHz
High-frequency Harmonics	Yes	Yes	Yes (Barlow); no (Goodson)	Yes (sometimes!)	No info	No info
Pulse duration (nominal)	300msec	300msec	300msec	300msec	Variable (around 100msec)	300ms
Inter-pulse period	4 second (regular)	(a, b) 4-30 second (randomised); (c) 4 second (regular)	4 second (regular)	<2 (L1) (regular)	Peak signals every 12-18 minutes (a) and 4-5 minutes (b)	4 second
Life (continuous operation)	~ 5 weeks	(a, b) 18 months to 2 years	12 months	3-4 weeks	(a) 300hrs (b) 90hrs	12 months
Wet switch	(a) no, (b) yes	Yes	No	Yes	Yes	No info
Battery change	Yes	No (option available soon)	Yes	Yes	Rechargeable	No info
Environmental (battery disposal)	None	20% discount for returned units against replacements	None	None	No info	No info
Spacing along nets (max. rec.)	100m	200m	100m	<50m	200m	≈100m (300 ft)
Price (ex VAT)	n/a	£1500 for 25 (£80 each up to 25 units)	No info	n/a	1-20 €223,00 21-50 €200,70	$60 each (available in boxes of 6 for

					51-100 €189,55 >100 €178,40	$360)

***Notes** . 'C' = commercially available; 'H' = homemade but used extensively in trials; 'L' = derivative of Jon Lien's original design for baleen whales; 'US' = emissions specified for regulated US fisheries; 'DK' = Type 1 emissions specified for regulated Danish fisheries. Note: PICE™ is not listed here as the commercial AQUAmark 100™ is an improved derivative which transmits the same wideband randomised acoustic signals (Reeves et al., 2001).*

Many controlled studies have shown that pingers significantly reduce bycatch (Kraus *et al.*, 1997; Larsen, 1999; Trippel *et al.*, 1999; Bordino *et al.*, 2002), and pingers are being widely adopted for by-catch mitigation. The mechanism by which pingers achieve bycatch reduction is still unclear but they seem to function, at least in part, by excluding animals from the immediate vicinity of nets. Laake and co-workers found that in their pinger trials, porpoise distribution changed in response to nets being alarmed (Laake *et al.*, 1998). The authors determined that the acoustic buffer (exclusion zone) had a radius of at least 125m, and potentially more. Culik and co-authors' study showed that their single PICE pinger created a total exclusion zone of 130m, with a mean closest approach distance of tracked harbour porpoise groups to the pinger of 414m (median 364 m, range 130 to 930 m) (Culik *et al.*, 2001). The authors compare this with a Lien pinger tested by Koschinski and Culik which forced harbour porpoises to remain outside a mean closest approach distance of 133m around the pinger (Koschinski and Culik, 1997). A study by Kastelein and colleagues found that tests of three different pingers using captive animals all resulted in porpoises consistently swimming as far away from them as possible (approximately 32m within the confines of a 34m pen) (Kastelein *et al.*, 2001). The authors suggest that if the pen had been larger, the animals would have moved further away. However a study on the reactions of bottlenose dolphins to pingers showed that the animals only diverted their travel slightly around alarmed nets (Cox *et al.*, 2003). There were no significant differences in the number of groups of dolphins observed or in the closest observed approach to the net when nets were alarmed or not alarmed. However, dolphins were observed to come within approximately 100m of the net more frequently with inactive than with active alarms.

A concern with the use of pingers on nets is the issue of habituation, which can reduce the devices' effectiveness over time (Cox *et al.*, 2001; Teilmann *et al.*, 2006). A study by Cox and colleagues found that harbour porpoises habituated to a pinger in inshore waters. Animals were initially displaced by 208m from the pinger. However, this range diminished by 50% in 4 days and after 10-11 days distributions during exposures were not significantly different from controls. Teilmann *et al.* (2006b) found that harbour porpoise responses to a sound diminished on repeated exposure to it. They suggest a variety of sounds and rates of exposure to ensure continued efficacy. Research has also been conducted into interactive pingers rather than constantly operating devices. In these, sound emission is triggered when the device detects echolocation (Leeney *et al.*, 2007). This has potential for lessening habituation, but does rely on an animal echolocating in order to function.

Cetacean sensitivity and responses to pingers may also differ between species, so devices must be specifically designed for the target species, and source levels adapted accordingly (Kastelein *et al.*, 2006a). In a study by Kastelein and co-workers, where an acoustic alarm was played to both a harbour porpoise and a striped dolphin (*Stenella coeruleoalba*), the porpoise reacted strongly (increasing its distance from the alarm and increasing the number of respirations), whereas the striped dolphin showed no reaction at all. Kastelein *et al.* note that, whilst based on the animals' audiograms both would have heard the alarm signal, their sensitivity clearly differed markedly.

Pingers appear to have few negative effects on pinnipeds, rather they may alert them to the presence of fish, acting as a 'dinner bell'. For example, a study using pingers to reduce bycatch of the Franciscana dolphin (*Pontoporia blainvillei)*, demonstrated a highly significant reduction in incidental capture of dolphins, but also showed that the use of pingers encouraged predation on nets by sea lions (*Otaria flavescens*). Sea lions caused more damage to those nets with pingers than those without and this effect increased over the course of the study (Bordino *et al.*, 2002).

These studies demonstrate that there are several examples of marine mammals moving considerable distances in response to particular sounds. Examples of this are rare or completely non-existent for terrestrial mammals. This may be because they are acoustically oriented animals in a medium that transmits sound well and offers few or no refuges in which they could hide. This is encouraging as far as the use of aversive sound for mitigation is concerned.

Both low powered (pingers) and high powered ADDs (seal scarers) have been used as mitigation devices during windfarm construction in Denmark (Carstensen *et al.*, 2006). However, this work has not provided any new data on the efficacy such devices for this application.

5.5. Behavioural responses to underwater industrial noise

A large amount of work has been done to investigate the effects of noise produced during offshore industrial activities on marine mammals. Specific marine mammal response thresholds have been determined for only a few combinations of species and noise types, and they tend to be quite variable even within species (Richardson and Würsig, 1997). Here we review some examples that provide information on exclusion, or animals' tendency to move away from a sound source.

5.5.1 Seismic

Seismic airguns are amongst the most powerful of man-made sound sources (>240dB RMS). During seismic surveys predominantly low frequency pulses are produced over long periods of time and in this respect they share some similarities with noise from pile driving.

Coastal baleen whales generally exhibit avoidance behaviour at substantial ranges. For example, some gray whales (*Eschrichtius robustus)* tracked off California slowed and turned away from a firing airgun, whilst others moved into areas where the airgun noise was reduced by topographical features (Malme *et al.*, 1984). Gray whales monitored in their summer foraging grounds off Sakhalin Island exhibited avoidance behaviour at ranges of up to 24km and showed behavioural changes such as faster, straighter swimming and shorter blow intervals at ranges of over 30km from active airgun arrays (Würsig *et al.*, 1999).

Bowhead whales (*Balaena mysticetus*) on westward autumn migration in the Beaufort Sea were found to avoid an area within 20km of operating airguns, at which distance broadband received levels of airgun pulses were typically 120–130 dB re: 1 µPa (Richardson *et al.*, 1999).

Responses of humpback whales to airguns have also been reported (McCauley *et al.*, 1998). They observed avoidance behaviour at a range of 5-8km from a full-scale array, and a typical stand-off range of 3-4km. At 5km typical peak-to-peak received levels of this array were 162 dB re 1µPa. Use of a smaller airgun in controlled exposure experiments resulted in whales avoiding an area within 2km of the noise source at which range received levels were similar (peak-to-peak received levels 159 dB re 1µPa).

Toothed whale responses to airguns have been less fully studied than those of baleen whales. Sperm whales have not been found to respond consistently to seismic surveys. Observations in the Gulf of Mexico suggested a decrease in sperm whale density in the area following seismic activity (Mate *et al.*, 1994). Two days after the survey commenced, numbers were down to approximately 30% of pre-survey abundance, whilst after five days no animals were detected. However Swift (1998) did not find that sperm whales west of Scotland demonstrated avoidance behavioural to airgun noise. He acoustically monitored sperm whales for one week pre-survey, three weeks during-survey and one week post-survey, and found there were more acoustic detections during the survey than before or after (although this change was probably due to a seasonal change in distribution rather than to whales being attracted to the airguns).

The behavioural effects of airgun noise on pinnipeds has been investigated using controlled exposure experiments (CEEs) with small airgun arrays (SL 215-224 dB re: 1µPs peak-to-peak) (Thompson *et al.*, 1998). Seals had been fitted with telemetry devices to enable their responses (movement, dive behaviour, heart rate and swim speeds) to be monitored before during and after the airguns were fired in controlled exposures lasting an hour. The heart rates of two common seals fitted with heart rate tags dropped from 35-45 beats/min to 5-10 beats/min for a short time, indicating a strong startle response. Six out of the eight common seals showed strong avoidance behaviour, swimming away from the sound source at speed, and typically moving for several km during the course of the exposure experiment. The seals had also been fitted with stomach temperature tags which showed that the animals stopped feeding completely during exposures. After the trials, behaviour appeared to return to normal. One of the animals however showed no behavioural response to the airguns, approaching within 300m of the sound source.

Grey seals also ceased foraging and moved away from the sound source. Some of them hauled out. These seals returned to normal behaviour shortly after the end of the trials (within two hours). As the airguns used in these trials were lower power than the large arrays commonly used for commercial surveys, seal behavioural responses could be expected to be more pronounced, of longer duration and over greater ranges under normal seismic survey conditions.

It should also be noted that other researchers have found very little evidence of responsive movement from arctic seals exposed to airguns in confined inshore waters during a seismic survey off Alaska (Harris *et al.*, 2001). These differences in observed response may be due to species differences, to differences in context and setting of the two studies or to differences in the research approaches employed.

The experimental exposures of common and grey seals to small low power seismic sources reported by Thompson *et al.* provide the clearest examples of the induction of substantial horizontal movement of the scale required for pile driving mitigation in pinnipeds. However, the variation of responses of seals and other marine mammals to seismic noise serves to underline the need for additional research to be carried out in this field.

5.5.2 Windfarm construction

Madsen *et al.* (2006) summarised current knowledge on the potential impacts of windfarm construction noise. In Denmark, the construction of two offshore windfarms, Nysted and Horns Rev have provided opportunities for monitoring the behavioural reactions of marine mammals to pile driving activities. At the Nysted site, researchers found that acoustic data logging of harbour porpoises showed a significant decrease in detections compared to data collected when there was no pile driving (Henriksen *et al.*, 2003; Tougaard *et al.*, 2005). Tougaard (2005) grouped classed clicks with interclick intervals of less than 10 minutes together as a single encounter or cluster; the median waiting time from the end of each pile-driving until the first recording of porpoise clicks and the median waiting time between detections of porpoise click clusters in periods without pile-driving activity were compared. When there was no pile driving activity, the median length of time between encounters was 6 to 23 hours. Under piling conditions the range was one to eight days. Significant effects were observed to a range of 10km from the construction site. The time between the first and the second encounter following the cessation of piling was not significantly greater then the time between encounters when there was no pile driving, which implies a recovery in porpoise activity in the area after each pile-driving session ended. As the data used in this study were acoustic, the decrease in detected clicks after pile-driving had occurred could be attributable to a decrease in echolocation behaviour rather than an exclusion of porpoises from the area. However, even if this were the case, the result was still that the animals showed a substantial behavioural response to pile driving activity.

At the Horns Rev site, the results were similar (Tougaard *et al.*, 2003). Median waiting times increased from <1hour to >4 hours during piling. In this study, visual observations were also carried out, which showed a change from non-directional to directional swimming under pile driving conditions implying that behaviour changed from foraging to travelling. The effects of the piling on porpoises at Horns Rev could be observed up to 15km away, both visually and acoustically.

(It might be noted that at Nysted site ADD devices were used as part of mitigation procedures during pile driving. It is possible that some of the reduction in porpoise detections at short range could be in response to ADD devices. However, Carstensen et al., (2006) argue that the relatively high frequencies of the ADDs would be absorbed more quickly than the lower frequencies that dominate piling noise and consequently ADDs would be unlikely to account for effects at the reference locations 10km from the construction site.)

This level of habitat exclusion may have biologically significant effects on individuals and populations, and this should be further investigated. However, from the perspective of this study it provides an indication that animals may respond appropriately to soft starts and piling noise, as we assumed in Section 3, and move away from the area of greatest risk.

6. Aversive Sounds Synthesis and Conclusion

It is clear from the reviews in Sections 3, 4 and 5 that there are a number of classes of sound that can be aversive and that may cause animals to move out of an area. By and large, these different categories have different constraints and possibilities for the current application.

Intense low frequency sounds can have a range of non-auditory effects on animals. These have been explored as the basis for non-lethal weapons systems in humans. However, they are unsuitable for the current application for a number of reasons: it has proven extremely difficult, even in air, to generate sufficiently intense sound at substantial ranges; effects seem to vary hugely between individual subjects and in different situations, and while some have reported dramatic unpleasant sensations, these have not induced humans to vacate the area of exposure. In addition, the use of such sounds may result in significant but unknown additional risks to the subjects.

Very intense sounds, especially at frequencies to which individuals are most sensitive, may be physically unpleasant and painful. It is possible that some powerful ADD devices have this effect on marine mammals at short ranges. Use of sounds of this type is not appropriate for this application for two reasons. They pose a risk, as great or greater than that of pile driving, to the hearing of the target animals and would certainly contribute to the cumulative acoustic exposure of the animals concerned. In addition, it would be very difficult, and certainly impractical, to achieve sounds at these levels over the substantial areas required for this application.

The human literature shows that some classes of sound seem to be inherently aversive and/or irritating even at lower received levels. For example, humans seem to find dissonant sounds aversive, and irregular and intermittent sounds irritating. However, it seems that even closely related species such as primates do not share these sensitivities, while in humans, there are no indications that such sounds would induce speedy predictable movement from particular areas as required for AMDs.

Another class of sounds is one that induces fear in the recipient. Within this category, two subclasses can be identified: sounds that are innately startling and those which have biological significance. Biologically significant sounds include the calls of predators and alarm calls. It is likely that responses to biologically significant calls have been reinforced by learning. It is sounds of this type that have shown the greatest potential in procedures for managing terrestrial wildlife ‘pests’. Examples of non-biologically significant sounds used for such applications are pyrotechnics and gas canons to scare birds from crops (though even in this case responses may have been reinforced by the animal’s experience of shooting). In terrestrial species biologically significant sounds used for pest control are often alarm calls, usually, but not exclusively, those of the target species.

Although marine mammals are generally much less well studied than terrestrial vertebrates, our review has shown that there are several candidate sounds that promise to be able to remove at least some species of marine mammals over significant ranges. Killer whale calls, and mid-frequency sonar type signals (which seem to share some properties with killer whale calls and may be generalised with them) have been shown to have effects on many species of marine mammal, though some caveats relating to differential responses in different contexts need to be considered during implementation. Powerful ADDs producing trains of intense pulses at 10kHz seem to be effective at excluding porpoise and possibly killer whales – their effect on other cetaceans has not been investigated. A complication here is their widespread use at aquaculture sites, which may result in some species, particularly pinnipeds, becoming habituated or even coming to associate them with feeding opportunities. Low frequency pulsive sounds from airguns have been shown to cause seals to move many hundreds of metres from the source.

It is striking that there are so many examples of marine mammals being induced to move over very considerable distances by acoustic signals and, by contrast, few, if any, examples of exclusion over similar ranges for terrestrial vertebrates. This may be a function of both the efficient propagation of sound underwater and the fact that there are no refuges in the underwater environment for air breathers, making flight the most appropriate response to danger.

Habituation and conditioning become extremely important considerations when using a stimulus to induce a behavioural response. An animal's response to a sound will be influenced by, and may change as a result of, repeated exposures to the sound and the nature of events with which it is associated. For example, animals will habituate to signals to which they are repeatedly exposed which are not reinforced by some significant associated event. Alternatively, animals may become sensitised to, or learn to respond to, signals that are associated with significant rewarding or aversive events. Habituation can be reduced to minimising an animal's exposure to sounds that are not reinforced by varying the characteristics of the signal. For the mitigation suggested here, it would only be necessary to use aversive signals for relatively short periods before activities that were in themselves disturbing, and this will limit the risk of habituation.

One general consideration that flows from this is that when a signal which is similar to one which animals may often experience in their wider environment is used for mitigation, there is a risk of habituation or conditioning that may influence the way that animals respond during mitigation exercises. Ideally then, signals used for mitigation should either be unlike others occurring in the wider environment or similar to those that are consistently negatively reinforced (e.g. those associated with predators). To avoid habituation, mitigation signals should be used for as short a period as necessary.

An animal's ability to learn can be subtle and does not always occur in the way one might predict. Thus, the potential for learning must to be taken into account when designing mitigation programs and ongoing monitoring may be necessary to determine that responses remain appropriate.

7. Relative Efficacy of Mitigation Approaches

7.1. Mitigation Approaches

Any new mitigation method needs to be assessed in the context of other available methods that might be seen as alternatives or be complimentary. Typically, procedures employed to mitigate the damaging effects of intense anthropogenic noise involve the near real time detection of marine mammals within and around the exclusion zone and the modification of noise production if animals are within range. Both visual and passive acoustic methods are used in European waters.

7.1.1. Real time detection and monitoring

All marine mammals are difficult to sight at sea. The species most likely to be present at most windfarm sites in UK waters, porpoises and seals, are amongst the most difficult to detect even in the best sighting conditions. It is usually required that piling continues day and night and in a variety of weather conditions.

The traditional method for detecting animals at sea is to search for them visually using a combination of naked eye and binoculars. Visual survey is the standard technique for assessing porpoise population densities and there are many datasets that provide information on how to monitor effectively for porpoises.

During a typical visual line transect survey a pair of observers will keep watch over the forward 180 degrees of sea. For piling mitigation, searching effort will need to extend around 360 degrees. As it may be difficult to see in all directions from any single point on a piling barge, more observers may be required. Mitigation monitoring for windfarm piling in UK has often been conducted from an independent vessel. Searching visually is onerous and tiring. During visual surveys, observers may be rotated and rested approximately every 30 minutes. It is not realistic to expect a single observer to maintain a high level of vigilance for more than an hour and with a duty cycle of more than 75%. In visual surveys, sighting probability can be affected by both availability and perception. In terms of availability, Barlow *et al.* (1988) determined that harbour porpoise are at or near the surface only 23.9% of the time; Reed *et al.* (2000) calculated the percentage time spent submerged as 89%. Sighting efficiency (perception) is significantly affected by sea state, rain or fog, sun glare, visibility and swell height. Palka (1996) showed that in Beaufort 2-3 sighting rates were reduced to one fifth of those at Beaufort 0. Visual surveys are impossible at night. Although night vision devices have been employed in some night time surveys they are difficult to use and have not proved to be of value.

Porpoises can be detected acoustically. They produce characteristic narrow band ultrasonic clicks with a centre frequency of around 125kHz. Special hardware and/or software has been developed to detect these animals (Chappell *et al.*, 1996; Gillespie and Chappell, 2002). Maximum detection range is approximately 800m but typical half strip widths during surveys are of the order of 200m. Real time semi-automated detection systems that provide bearings to detections have been developed for use with towed hydrophones. These can be deployed statically and reduced water movement and boat noise might improve performance.

Significant advantages of passive acoustic monitoring include the potential to continue monitoring for 24 hours a day, a much reduced effect of weather conditions on detection probabilities; greater possibilities for automation and a reduction in the number of field workers necessary to carry out a survey.

Currently available systems only provide bearings to detected vocalisations and do not provide locations in real time. In practice this is not a substantial concern as detection ranges and rates of movement are such that during mitigation any acoustic detection should be a cause for concern.

Bottlenose dolphins produce both audio band whistles and broad band clicks. Although the majority of the energy of a bottlenose dolphin click is ultrasonic, their clicks are also easily audible by humans. Monitoring in both the ultrasonic and audioband systems should be used for bottlenose dolphins.

It should be stressed that because seals do not often vocalise and are very hard to see at the surface, neither visual surveys nor acoustic monitoring are likely to be effective for monitoring the presence or abundance of seals around construction sites.

The most straightforward method for passive acoustic monitoring is deploying one or more hydrophone arrays from the construction platform itself. If the required mitigation range is greater than the detection range then either a pattern of radio-linked buoys or a patrolling vessel could be considered. Radio linked buoys do not have sufficient bandwidth to transmit ultrasonic signals such as porpoise clicks so they would have to incorporate ultrasonic click detectors. This would reduce the ability to distinguish porpoise clicks from other high frequency transients, and to determine bearing.

Because both visual and acoustic cues from marine mammals are intermittent (e.g. occasional surfacing or vocalisations) and detection is never certain, not being able to see or hear an animal at any particular time is not a reliable indicator of the absence of animals. Metrics based on patterns of detections, such as time since last detection, will probably provide the best information on the probability that animals are present at any time. However, though these are used in an ad-hoc way during current mitigation procedures, data to quantify these have not been collected. Collection of such data in a range of circumstances would be straightforward, especially for acoustic cues, though it will take time to build an appropriately sized dataset.

Operational factors must be considered in any real time mitigation scheme. For example, it takes time for decisions to be made on construction facilities and for actions to be taken. An allowance for such delays needs to be included when determining threshold ranges and probabilities of occurrence.

It is important to note that, because detection of an animal by any of the survey means discussed above is not perfect, risk can never be eliminated. For some species, however, risk can be reduced by improving the effectiveness of monitoring and maximising surveillance efforts at the appropriate time. However, the indications from the available data are that, over ranges of hundreds of metres in real world conditions, an increase in real time monitoring would not substantially reduce the risk to animals.

8. Financial Considerations

Current mitigation procedures involving real time detection require a minimum team of two MMOs, specialist equipment and, in some cases, require a dedicated or semi-dedicated vessel. The real cost of mitigation is commercially sensitive and we have not been able to discover any published figure for these. However, we estimate the cost of providing this level of at sea surveillance as being at least one thousand pounds per day. More importantly, while the level of risk reduction provided by this exercise has not been quantified, it is known to be low. During good conditions, the risk of animals being undetected if present within a several hundred metre mitigation zone is probably of the order of 10-50%, and this will be much higher in poor weather conditions and during night time operations. The cost of restricting operations to periods when real time mitigation could be carried out effectively would be very considerable – we suggest in the order of millions of pounds for a large project.

Until effective AMD systems are developed, their costs will not be known. However, based on Table 9, the cost of purchasing the required equipment is unlikely to exceed the mid-thousands of pounds. It is unlikely that skilled operators will be required and maintenance expenses should be low so running costs may be minimal.

The financial case for the use of AMDs, which promise to reduce risk to a greater extent in all weather and light conditions thus seems compelling.

Research to quantify the performance of AMDs and developing practical field equipment is needed, however. The required research is straightforward and, compared to other marine based research, not expensive. We judge the technical and scientific risks of poor success to be low but upfront investment is required. The main economic hurdles to taking this technique forward may well be structural. Funds are required in advance to develop systems which, once available and proven, would benefit a range of companies and offshore operators. However, budgets tend to be allocated to specific projects and environmental mitigation is rarely seen as a priority until late in the process.

9. Legal Considerations and Permitting

9.1. Introduction

The use of acoustic mitigation devices ("AMDs") raises significant legal issues. AMDs disturb the ordinary activities of protected marine animals in an effort to prevent other evils such as the risk of cetacean bycatch in fisheries, depredation at fisheries or aquaculture sites or harm resulting from human activities such as pile driving or the use of explosives underwater.

Below, we consider:

a) the current legal requirements governing the use of AMDs in the territorial coastal waters of England and Wales, the territorial coastal waters of Scotland, offshore waters and in and around Special Areas of Conservation;

b) the effect of recent further regulations implementing the Habitats Directive;

c) the steps that should be taken to ensure compliance with the law; and

d) possible future legal developments resulting from the Marine Bill White Paper.

In summary:

a) In order to protect cetaceans, the use of AMDs in territorial waters (out to 12 miles) frequented by cetaceans during the construction of wind turbines is unlawful unless the appropriate licences have been obtained.

b) Licences can be obtained on the grounds that AMDs are a justified, proportionate and necessary conservation measure, used only to protect cetaceans from harm. Scientific evidence of a quality that satisfies the precautionary principle will be required that AMDs do not themselves cause harm to cetaceans. Evidence of the effectiveness of AMDs should also be sought. Conditions are likely to be attached to licences, permitting use only for relatively short periods during construction and as part of a wider package including measurement of effects on animals and additional mitigation measures.

c) The use of AMDs to exclude seals from an area where wind turbines are being constructed and installed is unlikely to be unlawful or require any special licence.

d) A licence will not be required for the use of AMDs in UK offshore waters (beyond territorial waters up to 200 miles) providing that it can be shown with convincing evidence that the effect of temporary use of an AMD on the distribution and abundance of marine mammals is not substantial. However, before proceeding with any offshore operations without a licence, further research is likely to be necessary and guidance should be obtained from the Marine and Fisheries Agency and the Joint Nature Conservation Committee (the relevant nature conservation body).

9.2. Legal framework

The use of AMDs raises questions which involve complex and overlapping sources of law in multiple legal jurisdictions. Some types of law are binding on those who use AMDs, others are not:

a) The basic source of law in the UK is an Act of Parliament. An Act binds anyone within its territorial scope, which can be England only, England and Wales or the entire UK (including or excluding offshore waters beyond the 12 mile territorial waters limit), depending on the Act.

b) The Scotland Act 1998 provided for Scottish devolution, including the creation of a Scottish Parliament, with wide-ranging powers to pass its own legislation, including in the field of environmental protection. Following devolution, Scotland now has its own separate environmental law and in any event has always operated its own national system of criminal law.

c) An Act of the UK Parliament or the Scottish Parliament may give permission to pass regulations in the form of a Statutory Instrument. Such regulations are binding in their applicable area.

d) The Government of Wales Act 1998 created the Welsh Assembly, although the Assembly's powers are more limited than those of the Scottish Parliament. For present purposes, the Welsh Assembly Government has power to grant certain licences that may be necessary for the use of AMDs in Welsh inshore territorial waters.

e) EC law is contained in Regulations and Directives:

  i) A Regulation is binding on all persons in the European Union and takes precedence over any domestic law, including an Act of Parliament.

  ii) A Directive is somewhat different. It is an instruction to European Union member states to introduce laws or administrative measures by a set implementation date. Normally, a Directive is not binding on individuals until it has been implemented. If a Directive is not implemented properly, the European Commission may take enforcement action against a state requiring it to remedy the position. EC law Directives are usually implemented in the UK by Statutory Instrument, under powers granted by the European Communities Act 1972.

f) International treaties are agreements between states. In the UK an international treaty does not normally create any binding legal obligations on individuals or companies. Although there are various exceptions, the general position is that an international treaty must be incorporated in an Act of Parliament before it has any domestic legal effect. An example is the Human Rights Act 1998, incorporating the European Convention on Human Rights into domestic law. Before incorporation, the ECHR had little direct legal effect in the UK.

g) Case law interprets and applies legislation. The decisions of higher courts take precedence over those of lower courts. Throughout the UK, the decisions of the European Court of Justice ("ECJ") bind all other courts, followed by the House of Lords then (in England and Wales), the Court of Appeal and the High Court. In Scotland the rough equivalents to the latter two courts are the Inner and Outer Houses of the Court of Session.

9.3. Habitats Directive

The EC Habitats Directive (92/43/EEC) is the basis of UK law providing for the protection of cetaceans. Article 12 provides:

> **1. Member States shall take the requisite measures to establish a system of <u>strict protection for the animal species listed in Annex IV (a) in their natural range</u>, prohibiting:**
>
> > **(a) all forms of deliberate capture or killing of specimens of these species in the wild;**
> >
> > **(b) <u>deliberate disturbance of these species</u>, particularly during the period of breeding, rearing, hibernation and migration;**
> >
> > **…**
> >
> > **(d) deterioration or destruction of breeding sites or resting places.**
> >
> > **…**
>
> **3. The prohibition referred to in paragraph 1 (a) and (b) and paragraph 2 shall apply to all stages of life of the animals to which this Article applies.**

Annex (IV)(a) includes all species of cetacean.

Article 16 sets out the circumstances in which a state may derogate from Article 12:

> **1. Provided that there is <u>no satisfactory alternative</u> and the derogation is <u>not detrimental to the maintenance of the populations of the species concerned at a</u>**

> **favourable conservation status in their natural range, Member States may derogate from the provisions of Articles 12, 13, 14 and 15 (a) and (b):**
>
> **(a) in the interest of protecting wild fauna and flora and conserving natural habitats;**
>
> **(b) to prevent serious damage, in particular to crops, livestock, forests, fisheries and water and other types of property;**
>
> **(c) in the interests of public health and public safety, or for other imperative reasons of overriding public interest, including those of a social or economic nature and beneficial consequences of primary importance for the environment;**

"Favourable conservation status" is defined in Article 1:

> **(i) conservation status of a species means the sum of the influences acting on the species concerned that may affect the long-term distribution and abundance of its populations within the territory referred to in Article 2;**
>
> **The conservation status will be taken as "favourable" when:**
>
> **- population dynamics data on the species concerned indicate that it is maintaining itself on a long-term basis as a viable component of its natural habitats, and**
>
> **- the natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future, and**
>
> **- there is, and will probably continue to be, a sufficiently large habitat to maintain its populations on a long-term basis.**

The Habitats Directive therefore provides that a system of strict protection must be introduced for cetaceans, including a prohibition on deliberate disturbance. However, a state may derogate from this requirement where necessary to protect wild fauna or for other imperative reasons of overriding public interest providing that the favourable conservation status of the affected species is maintained.

The Habitats Directive applies not just to territorial waters up to 12 miles out (section 1 of the Territorial Sea Act 1987) but includes the exclusive economic zone of a member state (up to 200 miles out). This area includes the UK Renewable Energy Zone. See Case C-6/04 *Commission v United Kingdom*.

The Habitats Directive also requires the creation of a Europe-wide network of Special Areas of Conservation ("SACs"). The network of SACs is designed to ensure that the species listed in Annex II of the Directive are restored at a favourable conservation status in their natural range (Article 3(1)). Grey (*Halichoerus grypus*) and common (*Phoca vitulina*) seals are listed in Annex II.

Article 4 of the Habitats Directive states:

> **For aquatic species which range over wide areas, such sites will be proposed only where there is a clearly identifiable area representing the physical and biological factors essential to their life and reproduction.**

Article 6 of the Habitats Directive requires the protection of Annex II species in SACs:

> **1. For special areas of conservation, Member States shall establish the necessary conservation measures involving, if need be, appropriate management plans, specifically designed for the sites or integrated into other development plans, and appropriate statutory, administrative and contractual**

> **measures which correspond to the ecological requirements of the natural habitat types in Annex I and the species in Annex II present on the sites.**
>
> **2. <u>Member States shall take appropriate steps to avoid, in the special areas of conservation, the</u> deterioration of natural habitats and the habitats of species as well as <u>disturbance of the species for which the areas have been designated, in so far as such disturbance could be significant in relation to the objectives of this Directive</u>.**
>
> **3. Any plan or project not directly connected with or necessary to the management of the site but likely to have a significant effect thereon, either individually or in combination with other plans or projects, shall be subject to appropriate assessment of its implications for the site in view of the site's conservation objectives. In the light of the conclusions of the assessment of the implications for the site and subject to the provisions of paragraph 4, the competent national authorities shall agree to the plan or project only after having ascertained that it will not adversely affect the integrity of the site concerned and, if appropriate, after having obtained the opinion of the general public.**
>
> **4. If, in spite of a negative assessment of the implications for the site and in the absence of alternative solution, a plan or project must nevertheless be carried out for imperative reasons of overriding public interest, including those of a social or economic nature, the Member State shall take all compensatory measures necessary to ensure that the overall coherence of Natura 2000 is protected. It shall inform the Commission of the compensatory measures adopted.**
>
> **Where the site concerned hosts a priority natural habitats type and/or a priority species [i.e. cetaceans], the only considerations which may be raised are those relating to human health or public safety, to beneficial consequences of primary importance for the environment, or, further to an opinion from the Commission, to other imperative reasons of overriding public interest.**

In *Royal Society for the Protection of Birds v Secretary of State for Scotland* [2000] ScotCS 216 the Inner House of the Scottish Court of Session ruled on the meaning of 'significant disturbance' of protected species pursuant to Article 6(2) of the Habitats Directive. The case involved licenses granted to farmers on Islay to shoot barnacle geese. The Inner House held that the licenses were unlawful. The Court also considered the meaning of *significant* disturbance:

> > **What is not permitted is disturbance which adversely affects the ability of the species to maintain itself on a long-term basis on the site or - as the Commission puts it - which could contribute to the long-term decline of the species on the site [32].**
>
> Accordingly:
>
> > **... a measure which contributed to the protection of the living conditions of the geese in their special protection area and so conduced to the long-term viability of the species on the site [33]**
>
> would not amount to significant disturbance.

9.4. Implementation of the Habitats Directive

The Habitats Directive is implemented in the UK by the Conservation (Natural Habitats & c.) Regulations 1994 (SI 1994/2716) ("the Habitats Regulations").[2] These regulations have been

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[2] Separate regulations exist for offshore oil and gas installations (the Offshore Petroleum Activities (Conservation of Habitats) Regulations 2001). As these regulations do not apply to offshore renewable installations, they are not considered further.

amended on numerous occasions, most recently in England & Wales on 21 August 2007 by the Conservation (Natural Habitats & c.) (Amendment) Regulations 2007. Similar amendments were made in Scotland by the Conservation (Natural Habitats &c.) Amendment (Scotland) Regulations 2007 (SSI 2007/80). Somewhat confusingly, the version of Habitats Regulations that applies in Scotland is slightly different from that applying in England and Wales. However, for the reasons set out below, the differences are not likely to be significant. The Habitats Regulations have also recently been supplemented by additional regulations implementing the Habitats Directive to offshore sites (the Offshore Marine Conservation (Natural Habitats & c.) Regulations 2007.

The amendments introduced by the various sets of 2007 regulations were necessary because the European Court of Justice in Case C-6/04 *Commission v UK* and Case C-131/05 *Commission v United Kingdom* found the UK has failed properly to implement numerous parts of the Habitats Directive. In particular, the UK failed to extend protection to offshore waters (up to 200 miles out) and had introduced unjustifiable defences to the duty not to permit the intentional disturbance of the species protected under Annex IV(a).

Scotland

The Scottish version of the Habitats Regulations provide as follows:

> **39(2) Subject to the provisions of this Part, it is an offence to deliberately or recklessly disturb any dolphin, porpoise or whale (cetacean).**
>
> **(12) Subject to paragraph (13), a person guilty of an offence under this regulation is liable on summary conviction to imprisonment for a term not exceeding six months or to a fine not exceeding level 5 on the standard scale, or to both.**

However, a licence can be obtained to give permission for the disturbance of a cetacean:

44 Grant of licences for certain purposes

> **(1) Regulations 39, 41 and 43 do not apply to anything done for any of the following purposes under and in accordance with the terms of a licence granted by the appropriate authority.**
>
> **(2) The purposes referred to in paragraph (1) are-**
>
> **...**
>
> **(c) conserving wild animals...**
>
> **(e) preserving public health or public safety or other imperative reasons of overriding public interest including those of a social or economic nature and beneficial consequences of primary importance for the environment...**
>
> **(3) The appropriate authority shall not grant a licence under this regulation unless they are satisfied-**
>
> **(a) that there is no satisfactory alternative, and**
>
> **(b) that the action will not be detrimental to the maintenance of the population of the species concerned at a favourable conservation status in their natural range.**
>
> **(4) For the purposes of this regulation "the appropriate authority" means-**
>
> **(a) in the case of a licence under any of sub-paragraphs (a) to (d) of paragraph (2), the appropriate nature conservation body; and**
>
> **(b) in the case of any other licence granted under this regulation, the Scottish Ministers.**

> **(5) The Scottish Ministers shall from time to time consult with the nature conservation bodies as to the exercise of the Scottish Ministers' functions under this regulation; and they shall not grant a licence of any description unless they have been advised by the appropriate nature conservation body as to the circumstances in which, in the opinion of the appropriate nature conservation body, licences of that description should be granted.**

45 Licences: supplementary provisions

> **(1) Subject to the provisions of this regulation, a licence under regulation 44-**
>
> > **(a) may be, to any degree, general or specific;**
> >
> > **(b) may be granted either to persons of a class or to a particular person; and**
> >
> > **(c) may be subject to compliance with any specified conditions.**
>
> **(2) For the purposes of a licence under Regulations 44 the definition of a class of persons may be framed by reference to any circumstances whatever including, in particular, their being authorised by any other person.**

46A Offence of breaching licence condition

> **(1) It is an offence for a person authorised by virtue of a licence granted under regulation 44 on or after 15 May 2007 to contravene, or fail to comply with, any condition imposed on the grant of a licence.**
>
> **(2) A person shall not be guilty of an offence under paragraph (1) if that person shows that-**
>
> > **(a) that person took all reasonable precautions and exercised all due diligence to avoid commission of the offence; or**
> >
> > **(b) the commission of the offence was otherwise due to matters beyond that person's control.**
>
> **(3) a person guilty of an offence under paragraph (1) is liable on summary conviction to imprisonment for a terms not exceeding three months or to a fine not exceeding level 5 on the standard scale, or to both.**

A licence will only be granted where the conditions set out in the Habitats Regulations are strictly complied with. For example, in *R (Newsum) v Welsh Assembly Government* [2004] EWCA Civ 1565 the Court of Appeal upheld the Welsh Assembly Government's decision to refuse a licence to translocate a population of greater crested newts at the site of a proposed mine. The licence was applied for on grounds of imperative reasons of overriding public interest. The Court of Appeal approved the Welsh Assembly Government's conclusion that there was no strong public interest reason why this mine had to be worked. However, the Court of Appeal indicated that a licence would probably be available under paragraph 44(2)(c) of the Habitats Regulations (the 'conservation' ground).

Provision for the creation and management of SACs is also made in the Habitats Regulations. Regulations 7 and 8 implement site selection procedures. Regulation 3(3) requires all competent authorities (ministers, nature conservation bodies, local authorities etc.) to exercise their powers to secure compliance with the Habitats Directive:

> **In relation to marine areas any competent authority having functions relevant to marine conservation shall exercise those functions so as to secure compliance with the requirements of the Habitats Directive.**

Further, powers are given to make management schemes, to direct their creation where needed and to pass byelaws:

34 Management scheme for European marine site

> **(1) The relevant authorities, or any of them, may establish for a European marine site a management scheme under which their functions (including any**

power to make byelaws) shall be exercised so as to secure in relation to that site compliance with the requirements of the Habitats Directive.

(2) Only one management scheme may be made for each European marine site.

(3) A management scheme may be amended from time to time.

(4) As soon as a management scheme has been established, or is amended, a copy of it shall be sent by the relevant authority or authorities concerned to the appropriate nature conservation body.

35 Direction to establish or amend management scheme

(1) The relevant Minister may give directions to the relevant authorities, or any of them, as to the establishment of a management scheme for a European marine site.

(2) Directions may, in particular—

(a) require conservation measures specified in the direction to be included in the scheme;

(b) appoint one of the relevant authorities to co-ordinate the establishment of the scheme;

(c) set time limits within which any steps are to be taken;

(d) provide that the approval of the Minister is required before the scheme is established; and

(e) require any relevant authority to supply to the Minister such information concerning the establishment of the scheme as may be specified in the direction.

(3) The relevant Minister may give directions to the relevant authorities, or any of them, as to the amendment of a management scheme for a European marine site, either generally or in any particular respect.

(4) Any direction under this regulation shall be in writing and may be varied or revoked by a further direction.

(5) In this regulation "the relevant Minister" means, in relation to a site in England, the Secretary of State and the Minister of Agriculture, Fisheries and Food acting jointly and in any other case the Secretary of State.

36 Byelaws for protection of European marine site

(1) The appropriate nature conservation body may make byelaws for the protection of a European marine site under section 37 of the Wildlife and Countryside Act 1981 (byelaws for protection of marine nature reserves).

(2) The provisions of subsections (2) to (11) of that section apply in relation to byelaws made by virtue of this regulation with the substitution for the references to marine nature reserves of references to European marine sites.

(3) Nothing in byelaws made by virtue of this regulation shall interfere with the exercise of any functions of a relevant authority, any functions conferred by or under an enactment (whenever passed) or any right of any person (whenever vested).

Section 37 of the Wildlife and Countryside Act 1981 sets out the types of byelaws that may be made:

37 Byelaws for protection of marine nature reserves

(1) The appropriate conservation body may, with the consent of the Secretary of State make byelaws for the protection of any area designated as a marine nature reserve under section 36.

> **(2) Without prejudice to the generality of subsection (1), byelaws made under this section as respects a marine nature reserve—**
>
> **(a) may provide for prohibiting or restricting, either absolutely or subject to any exceptions—**
>
> **(i) the entry into, or movement within, the reserve of persons and vessels;**
>
> **(ii) the killing, taking, destruction, molestation or disturbance of animals or plants of any description in the reserve, or the doing of anything therein which will interfere with the sea bed or damage or disturb any object in the reserve; or**
>
> **(iii) the depositing of rubbish in the reserve;**
>
> **(b) may provide for the issue, on such terms and subject to such conditions as may be specified in the byelaws, of permits authorising entry into the reserve or the doing of anything which would otherwise be unlawful under the byelaws; and**
>
> **(c) may be so made as to apply either generally or with respect to particular parts of the reserve or particular times of the year.**

<u>England and Wales</u>

The <u>English and Welsh</u> version of the Habitats Regulations is similar (although not identical). Regulation 39 of the Habitats Regulations provides:

> **39 Protection of certain wild animals**
>
> **(1) A person commits an offence if he—**
>
> **(a) deliberately captures, injures or kills any wild animal of a European protected species;**
>
> **(b) <u>deliberately disturbs wild animals</u> of any such species in such a way as to be <u>likely significantly to affect</u>—**
>
> **(i) the ability of any significant group of animals of that species to survive, breed, or rear or nurture their young; or**
>
> **(ii) the <u>local distribution or abundance of that species</u>;**
>
> **...**
>
> **(12) In paragraph (1)(b)(i), "significant" means significant in relation to the objectives of the Habitats Directive.**
>
> **(13) In any proceedings in which a person is charged with an offence under sub-paragraph (b) of paragraph (1) by reason of an effect mentioned in paragraph (i) of that sub-paragraph, the court shall have regard to any guidance given by the appropriate nature conservation body as to the criteria for determining whether a group is significant.**
>
> **(14) In any proceedings for an offence under paragraph (1), where this paragraph applies the defendant shall not be taken deliberately to have done**

> **anything mentioned in sub-paragraph (a), (b) or (c) of that paragraph merely because—**
>
> > **(a) his actions had the result that he did the thing in question; and**
> >
> > **(b) he intended those actions and knew that they might have that result.**

Therefore, greater disturbance of marine mammals is permitted in England and Wales than in Scotland:

> a) Only <u>deliberate</u> rather than <u>reckless</u> disturbance is prohibited (although reckless disturbance of a cetacean in English or Welsh territorial waters is unlawful under the Wildlife and Countryside Act 1981 – see below).
>
> b) The threshold for proving a breach of the Regulations is higher. The disturbance must be in such a way as to be likely *significantly* to affect either the ability of a significant number of animals to prosper, or the local distribution or abundance of that species. The views of the relevant nature conservation body will be relevant in determining whether a disturbance is significant.
>
> c) The definition of "deliberately" is framed very narrowly. It is not enough just to show that a person's actions had the result of disturbing a protected species. Nor is it enough to show that the person intended the actions and knew they *might* have that result. To be unlawful, it must be shown that the person specifically intended and sought to disturb the protected species.

<u>Offshore</u>

Provision is made for the protection of offshore marine sites in the 2007 Offshore Regulations. The relevant duties to avoid disturbance of protected species are, for relevant purposes, the same as those in the Habitats Regulations applicable in England and Wales. Licences for disturbance are available from the Marine and Fisheries Agency.

<u>Special Areas of Conservation</u>

A substantial number of UK sites have also been designated as SACs for marine mammals. The UK SACs for seals centre on breeding sites and are found at the following locations:

Berwickshire and North Northumberland Coast
Cardigan Bay, Ceredigion
Faray, Orkneys
Islay Skerries, Argyll and Bute
Lismore, Argyll and Bute
Lleyn Peninsula, Ceredigion
Lundy Island, Devon
Isle of May, Fife
Monarch Isles, Western Isles
Moray Firth, Highland
Mousa, Shetland Islands
Murlough, Down
North Rona, Western Isles

Pembrokeshire Marine Reserve
Sanday, Orkney Islands
Isles of Scilly
North-west Skye, Highland
Strangford Lough, Down
Firth of Tay, Angus
Treshnish Isles
The Wash, Lincolnshire and Norfolk
Yell, Shetland Islands

In addition, Cardigan Bay, the Moray Firth and the Lleyn Peninsula have been designated SACs for the bottlenose dolphin (*Tursiops truncatus*). No SACs have been designated for the harbour porpoise (*Phocoena phocoena*), nor have any SACs yet been designated outside of UK territorial waters. However, this is likely to change in the near future.

9.5. The Habitats Regulations and AMDs

Our view of the legal position under the Habitats Regulations in the UK is as follows:

a) *Offshore operations*: Since 21 August 2007, the Habitats Directive has been extended to cover offshore waters.

b) *"Disturbance" in Scotland*: All of the different versions of the Habitats Regulations rely on the concept of the disturbance of a protected species. It cannot seriously be doubted that using an AMD involves the deliberate disturbance of cetaceans. Indeed, this is the whole point of an AMD – to disturb marine mammals by encouraging them to move away from an area where they are at risk of injury. Defra agrees: its March 2005 *Nature Conservation Guidance on Offshore Windfarm Development* notes that "**acoustic deterrents – acoustic harassment devices or 'porpoise pingers' in order to deter porpoise from piling areas**" are "**construed to be a 'deliberate disturbance' and some form of a consent to carry out this activity may be required**" (p. 49).

c) "Disturbance" in England and Wales and Offshore. However, to amount to an offence in England and Wales (or offshore), the disturbance must have a "significant" effect on the local distribution and abundance of the protected species. Whilst the use of an AMD will affect the local distribution and abundance of marine mammals (indeed, this is their purpose), when used during the construction of a windfarm, their effect is intended to be temporary. Providing that evidence can be obtained that marine mammals return to the site of a windfarm after a short construction phase and that use of the AMD does not have any other adverse effects on distribution, abundance or the marine mammals themselves, there is a strong argument that the use of an AMD does not amount to significant disturbance. Guidance can be obtained on this issue from the relevant nature conservation body.

d) *Licensing*: A licence will therefore be needed before AMDs may be used in inshore waters in Scotland where cetaceans may be present and may be required in England and Wales and offshore. Under Regulation 44, the appropriate authority may grant a licence for the disturbance of protected species. A licence may be granted for the purposes of conserving wild animals or for imperative reasons of overriding public interest including social or economic reasons and beneficial consequences for the environment. A licence could be granted for the use of AMDs to mitigate against the risk of damage (from pile driving for example) under any or all of these grounds because AMDs:

    i) assist in conserving marine mammals by taking active steps to protect them from harm or damage;

ii) have beneficial consequences for the environment for the same reasons; and

iii) are necessary adjuncts to the safe and environmentally responsible construction of offshore renewable energy installations, which are imperative in the public interest, given the government's commitment to tackling climate change by the use of renewable energy generation.

For a licence to be granted, it must also be shown using convincing scientific evidence that there is no satisfactory alternative to the use of AMDs and their use will not affect the favourable conservation status of cetaceans in their natural range. The precautionary principle will apply. The precautionary principle is a basic principle of EC environmental law and requires that where there are threats of serious or irreversible damage, a lack of scientific certainty will not be used as a reason for not carrying out cost-effective measures to prevent environmental damage. The importance of the precautionary principle is illustrated by Case C-127/02 *Waddensee* where the European Court of Justice held that there had to be no reasonable scientific doubt that cockle picking did not adversely affect a protected site. Here, there are two aspects to the application of the precautionary principle. First, a licensing body will expect to see good quality scientific evidence that AMDs do not themselves cause any long-term harm to marine mammals. However, overwhelming evidence for the efficacy of AMDs may not be required to obtain a licence. AMDs are themselves a mitigation device designed to assist developers comply with the precautionary principle. A strong argument can be made that the precautionary principle may require the use of AMDs, even if it cannot yet be conclusively shown that they are likely to assist in the protection of marine mammals.

We consider that AMDs are likely to offer benefits which cannot reliably be obtained using other mitigation measures and, providing that their use is limited to the construction phase, will not affect the favourable conservation status of cetaceans in their natural range.

This view appears to be shared by Defra who, in their consultation paper on the draft amendments to the Habitats Regulations, indicate that they intend to licence the use of AMDs by fishing vessels (para. 24). There is no good reason why AMDs used during construction of wind turbines should be treated differently. The licence granted can be a blanket licence (e.g. for the use of approved AMDs in constructing wind turbines generally or indeed to any activity that carries a risk of causing damage to marine mammals) or specific to a particular installation, person or company. The licence can have conditions imposed, such as to restrict use of AMDs to minimum period necessary during construction or setting appropriate power levels. Conditions could also be imposed requiring proof of the efficacy of AADs in reducing risk of damage of the activity under consideration, AMDs to be used only as a component part of a comprehensive package of mitigation measures such as 'soft starts', passive acoustic monitoring and the use of qualified and experienced marine mammal observers Further conditions requiring the monitoring of the use of AMDs and for the assessment of their effect could also usefully be imposed. The appropriate authority to grant the licence will depend on the area in which the licence is applied for.

d) SACs: Given the very strict protection that cetaceans enjoy in any event, the additional regime applying to SACs is, in our view, of little practical importance. However, the position of seals in (who do not enjoy the strict protection granted to cetaceans) in and around SACs created for their protection requires further examination. The Scottish Executive's "Legislative Matrix for the Management of Scottish Seal Populations" notes:

> **<u>Management Tools</u>: The [Habitats] regulations allow management of seals through non-lethal measures i.e. acoustic deterrents and tensioned anti-predator nets.**

> **<u>Constraints</u>: The use of acoustic deterrents and tensioned anti-predator nets will be subject to the test of significant disturbance of the seal population within an SAC.**

The question is therefore whether the use of an AMD during the construction of a wind turbine would lead to the significant disturbance of the seal population within a SAC. Of course, the windfarm may not itself be inside the SAC. What is relevant is whether the AMD is audible and effective within the SAC. Applying the test in the *RSPB* case, if it can be shown that:

i) the use of AMDs is in the long-term best interest of seals in the SAC;

ii) AMDs are only used for a temporary period and where strictly necessary;

iii) their use is combined with other mitigation measures;

iv) there is good evidence that seals return to the SAC once use of the AMD has ceased;

v) their use does not cause any long-term decline of the species on the site (e.g. through disruption to breeding patterns)

it is unlikely that the <u>temporary</u> use of AMDs during the construction of wind turbines would breach Article 6(2) of the Habitats Directive.

In any event, we consider that the use of AMDs can in any event be justified for the reasons given above. Of course, there may be other objections to the construction of a windfarm in or near a marine SAC or SPA for birds. We do not deal with these here.

9.6. Wildlife and Countryside Act 1981 (as amended)

Further protection for marine mammals is contained in the Wildlife and Countryside Act 1981 (as amended) ("WCA"). The WCA contains an overlapping legislative regime for the protection of marine mammals. WCA applies throughout the UK up to the territorial 12 mile limit (section 27(5)), with variations in Scotland which are not relevant for present purposes. Section 9(4A) provides for the offence of intentional or reckless disturbance of cetaceans:

> **Subject to the provisions of this Part, if any person intentionally or recklessly disturbs any wild animal included in Schedule 5 as-**
>
> **(a) a dolphin or whale (*cetacea*)…**
>
> **he shall be guilty of an offence.**

Section 9 contains a further "incidental results" defence:

> **(1) Nothing in section 9 shall make unlawful-**
>
> **(c) any act made unlawful by that section ("an unlawful act") if he shows-**
>
> **(i) that each of the conditions specified in subsection (3A) was satisfied in relation to the carrying out of the unlawful act…**
>
> **(3A) Those conditions are-**
>
> **(a) that the unlawful act was the <u>incidental result of a lawful operation</u> or other activity;**
>
> **(b) that the person who carried out the lawful operation or other activity-**
>
> **(i) took <u>reasonable precautions for the purpose of avoiding carrying out the unlawful act</u>; or**
>
> **(ii) did not foresee, and <u>could not reasonably have foreseen, that the unlawful act would be an incidental result of the carrying out of the lawful operation</u> or other activity; and**
>
> **(c) that the person who carried out the unlawful act took, immediately upon the consequence of that act becoming apparent to the person, <u>such</u>**

> **<u>steps as were reasonably practicable in the circumstances to minimise the damage or disturbance to the wild animal</u>… in relation to which the unlawful act was carried out.**

Section 16 of the WCA gives power to grant a licence:

> **(3) Sections 9…(4A) do not apply to anything done-**
>
> **…**
>
> **(c) for the purpose of conserving wild birds, wild animals or wild plants or introducing them to particular areas.**
>
> **if it is done under and in accordance with the terms of a licence granted by the appropriate authority.**
>
> **…**
>
> **(9) In this section "the appropriate authority" means-**
>
> **…**
>
> **(c) in the case of a licence under… any of the paragraphs (a) to (e) of subsection (3), the relevant conservation body.**

The legal position under the WCA in the UK is as follows:

a) *Offshore operations*: WCA does not apply to operations outside of the territorial 12 mile limit.

b) *Disturbance*: For the same reasons as set out above, use of AMDs will amount to the disturbance of marine mammals. The concept of "significant" disturbance used in the English and Welsh Habitats Regulations and the Offshore Regulations does not apply to the WCA.

c) *Incidental results*: The incidental results defence is unlikely to be applicable to the use of AMDs for mitigation. First, the unlawful act was not an incidental result of a lawful operation, for the reasons set out above. Second, the conditions in WCA require that all reasonable steps be taken to avoid disturbance and that the disturbance is unforeseen. Neither condition is satisfied with the use of AMDs, the purpose of which is to disturb marine mammals, albeit for a good reason.

d) *Licensing*: Accordingly, a licence is required. The licensing regime is very similar to that under the Habitats Regulations, albeit that the grounds for granting a licence are currently different. In the WCA, there is at present no licence available on the grounds of imperative reasons of overriding public interest. However, a licence should be available on the ground that the use of AMDs is for the purpose of conserving wild animals.

9.7. Conservation of Seals Act 1970

Further protection for seals is contained in the Conservation of Seals Act 1970. Section 17(2) of the Act provides that it applies only in territorial waters:

> **Nothing done outside the seaward limits of the territorial waters adjacent to Great Britain shall constitute an offence under this Act.**

In addition to prohibitions on the killing of seals by certain means, the Act creates close seasons in which no seal may be killed or injured:

> **2 Close seasons for seals**
>
> **(1) There shall be an annual close season for grey seals, that is to say seals of the species known as *Halichoerus grypus*, extending from 1st September to 31st December both inclusive and an annual close season for common seals, that is to say seals of the species known as *Phoca vitulina*, extending from 1st June to 31st August both inclusive.**

> **(2) Subject to sections 9 and 10 of this Act, if any person wilfully kills, injures or takes a seal during the close season prescribed by subsection (1) of this section for seals of the species so killed, injured or taken he shall be guilty of an offence.**

The Secretary of State is also empowered to make further orders prohibiting the killing, injuring or taking of seals in specified areas:

> **3 Orders prohibiting killing seals**
>
> **(1) Where, after consultation with the Council, it appears to the Secretary of State necessary for the proper conservation of seals he may by order prohibit with respect to any area specified in the order the killing, injuring or taking of the seals of both or either of the species mentioned in section 2 of this Act.**
>
> **(2) Subject to sections 9 and 10 of this Act, if any person wilfully kills, injures or takes a seal in contravention of an order made under subsection (1) of this section he shall be guilty of an offence.**

Several areas have been designated by the Secretary of State:

a) In England, all those territorial waters (i.e. out to 12 miles) that border the North Sea (Conservation of Seals (England) Order 1999, SI 1999/3052.

b) In Scotland:

  i) the Moray Firth (Conservation of Seals (Scotland) Order 2004, SSI 2004/283; and

  ii) (in respect of common seals only) the Orkney and Shetland Islands and territorial waters adjacent to them and the territorial sea adjacent to the east coast of Scotland from Garron Point in the north to Torness Point in the south (Conservation of Seals (Scotland) Order 2007, SSI 2007/126).

Section 9 of the Act sets out exceptions:

> **9 General exceptions**
>
> **(1) A person shall not be guilty of an offence under section 2 or 3 of this Act by reason only of—**
>
> **...**
>
> **(b) the unavoidable killing or injuring of any seal as an incidental result of a lawful action;**

Section 10 gives power to grant licences to kill or take seals for proper purposes.

In the close seasons and the designated areas, the only restriction is to the killing, injuring or taking of seals. There is no prohibition on the mere disturbance of seals, which remains lawful. The temporary use of AMDs does not appear to cause actual injury to seals. The Scottish Executive take the same view and their guidance indicates that the use of AMDs in prescribed areas and during the close seasons is a lawful means of excluding seals from an area. Further, AMDs are a means of preventing the injuring of seals from pile driving or the use of explosives underwater, which would potentially be an offence under the Act.

9.8. Fisheries – EC Regulation 812/2004

EC Regulation 812/2004 (“the Fisheries Regulation”) contains measures designed to minimise incidental bycatch of cetaceans in fisheries. It requires certain larger fishing vessels to use AMDs when using certain kinds of nets in areas where cetacean bycatch is a particular problem. The AMDs must comply with the technical specifications set out in the Regulation. The preamble to the Fisheries Regulation refers to the need for protection of cetaceans (by reference to the

Habitats Directive) and confirms that AMDs have proven successful and their use should therefore be made compulsory in areas with a high level of cetacean bycatch.

Although the Fisheries Regulation does not apply to the use of AMDs in the construction of wind turbines, it provides a useful indication that:

a) the EC considers that AMDs are a valuable and necessary means of deterring cetaceans from approaching fishing gear;

b) their use is compatible with the Habitats Directive; and

c) the use of AMDs can be justified based on <u>evidence of effectiveness</u>.

9.9. Marine Bill

Further changes to the legislative regime are likely following the publication of the Marine Bill White Paper on 15 March 2007. At present, no draft Bill has been published, so it is only possible to comment on the impact of the proposed Marine Bill in very general terms. The White Paper sets out proposals to simplify the complex licensing regime for the construction and operation of renewable energy installations at sea so that only a single consent will be required (paras. 5.94-5.104). However, no substantive changes to the Habitats Regulations or the WCA are proposed (paras. 6.24-6.25, 6.120).

9.10. International Law

There are various international treaties that deal with the protection of marine life, such as ASCOBAMS and CMS. None of these treaties have been incorporated into domestic law and therefore do not impose any legal obligations on developers. They operate only at the level of international law. They are binding on states, not individuals or companies.

10. Practicality, Feasibility and Research Requirements

There are no devices or acoustic signals that have been shown to consistently exclude marine mammals over the ranges required for pile driving mitigation. This is largely because the research to measure this has not been done. However, the reviews in Sections 4 and 5 suggest several promising candidates for use as aversive signals. Sections 4 and 5 also show that often when acoustic deterrents have been used in the past initial promising responses quickly wane, as animals, which are often highly motivated to remain in the area to feed, become habituated to the deterrent signal. We remain optimistic about the possibility of achieving consistent and useful results for this application, however, for a number of reasons. In the first place, the natural response of marine mammals to a frightening stimulus seems to be to move away over considerable distances. This may well be because alternative avoidance strategies, such as hiding, are not available to them and because few marine mammals maintain territories at sea. Habituation is a potential problem, but measures such as changing signals and playback locations can be used to reduce this. Devices will only need to be active for short periods of time. Perhaps most importantly, in this application animals are not being moved away from a super-abundant source of food. The associations that animals are likely to make with the signals from an AMD, if any, would be with the piling activity that would follow it, and these are likely to act as negative rather than positive reinforcements.

This of course raises the requirement for underwater sound generators capable of producing the desired signals at an appropriate sound level. Table 9 summarises characteristics of some underwater sound sources that might be useful for mitigation.

Underwater sound can be produced mechanically. Perhaps the most widely used example of this is the seismic airgun. Underwater sirens and whistles have also been developed but their source levels are quite modest and these devices are not widely used (Mitchell and Muster, 1968). One important constraint with most types of mechanical sound production devices is that they are quite limited in the range of sound types that can be produced.

Most modern underwater sound projectors generate sound using electostrictive ceramics. Generally, the production of lower frequency sounds requires larger and more powerful equipment, especially if a directional beam of sound is required. Devices to produce simple high frequency signals can be relatively small, efficient and inexpensive, for example ADD devices. The broadcast of signals that are lower frequency and more complex generally requires larger and more expensive equipment and this trend can be seen in Table 9. However, the increasing use of underwater speakers by synchronised swimmers has provided a market which is leading to the introduction of more affordable underwater broadcast systems, see for example systems from Lubell Labs in Table 9.

A class of underwater sound production devices which has so far not been widely used in this field but we feel might warrant further investigation is small (often expendable) military devices such as active sonobouys and torpedo jamming and counter measure appliances. Here, the requirement to produce small autonomous devices and to mass produce for a military market has resulted in designs that might be readily adapted to the requirements of field acoustic mitigation, and we feel that this is an area that warrants further investigation. We are grateful to Alan Wignall and Matt Cox from Ultra Electronics for discussing this application and possible adaptations with us.

Table 9. Underwater sound sources with potential mitigation use.

Name of Device	Frequency (kHz)	Max SL (dB re 1 uPa @ 1m	Notes	Duty Cycle	Approximate Cost (ex VAT)
ADDs (high power)					
Airmar dB Plus II	10 (tonal)	194 Db	2.25 seconds tx length	40-50%	£6,790.00
Ace Aquatec Universal Scrammer Mk 2 with	8-20 (broadband) (harmonics up to 30)	194 dB	4-5 seconds tx length	Activity dependent	£5,500
Terecos	2.5-100 (wide variation broad and narrow band)	179 dB (146 dB at frequencies > 27 kHz)	15 seconds – 2 minute tx length	50/50	Dependent on system Generally rented
Pingers					
Aquatec Sub-Sea Ltd (C) Aquamark 100(a); Aquamark 200 (b); Aquamark 300 (c)	(a) 20-160kHz frequency sweeps (DK); (b) similar to 'a' but the frequency sweep tuned for dolphins (DK); (c) 10kHz tonal (US)	145	300msec every 4-30 second (randomised) (a, b); (c) 4 second (regular)	(a, b) 4-30 second (randomised); (c) 4 second (regular)	£1500 for 25 (£80 each up to 25 units)
Loudspeakers					
Lubell Labs LL916	200Hz-20kHz	180dB +/- 15dB			$1874 Including amplifier
Lubell Labs LL9162T	250Hz-20kHz	184db @900Hz 194db @ 10.6kHz			$2300 Including amplifier
Lubell Labs LL1434 HP	800Hz-9kHz	195 +/- 8dB	Only short transmissions possible at higher frequencies		$6925 Speaker 2400watt Amplifier
Compact Autonomous Military Devices					
Active Sonobouy (Ultra Electronics)	1400-2200Hz	210 dB re 1 uPa RMS	Band width could be adapted to 1-8kHz at 180dB		

Acoustic Countermeasure Device (Ultra Electronics)	10-90kHz	180 – 190 dB re 1 uPa RMS			~£2000

Killer whale signals and signals that share their acoustic characteristics, are avoided by many, perhaps most, marine mammals. Research has shown that seals can recognise the calls of particular non-mammal eating killer whale pods and do not respond to these. A solution to this is to use unfamiliar killer whale calls or 'generic' killer whale-like vocalisations. It is also reported that seals do not move away from killer whale signals if they are close to their haul out sites. This behaviour may well be shown in response to any alarming signal and may represent a general limitation for the use of aversive sounds in mitigation close to haul out sites.

High fidelity playback of killer whale vocalisations would require quite expensive and bulky underwater speakers and amplifiers, and it is not yet clear whether a single unit would produce sufficiently powerful signals to be effective at the required ranges. A device that produces killer whale-like sounds synthetically, for example by generating a series of pulses in appropriate patterns, might well be more efficient and practical.

There is good anecdotal evidence that mid-frequency military sonar, and whaling sonars that were derived from them in the years after the Second World War, can induce responses in a range of whales and smaller odontocetes including movements away from the sound source. Some uncertainty remains about the signal characteristics of whaling sonars. Military mid-frequency sonar that has been implicated in recent marine mammal events sounds somewhat like killer whale calls and it is possible that this contributes to its aversive effect, and that there is a general tendency for marine mammals to respond to 'harsh sounding' mid-frequency tonal sounds.

There is a considerable body of research that shows that harbour porpoises, and some other odontocetes, are excluded over substantial ranges by ADD devices. Such devices are already produced commercially and one might envisage practical applications in which either a small number of powerful (AHD type) devices or a larger number of low power (pingers) were deployed to clear an area before pile driving. Indeed, such devices have been used for mitigation during windfarm construction in Denmark (Carstensen *et al.*, 2006). There is little evidence though that these signals are effective against seals. A major concern with the use of these devices is that in many areas they are already in wide and continuous use in fisheries or aquaculture. At best this may lead to habituation, at worse, the association of these devices with fishing nets or fish pens could lead to the development of a positive association, the so called 'dinner bell' effect, so that they might attract animals. As discussed in Section 5, there is some evidence of this occurring in seals.

Strong avoidance of airgun signals has been shown by both species of seal found in UK waters. There is also evidence that airguns are avoided by some baleen whale species. However they seem to have little or no consistent effects on small cetaceans. Airguns are available commercially but there would be issues related to their use in routine mitigation. Airguns themselves are expensive (several thousand pounds) and require a large compressor to provide the compressed air on which they operate (though operation of small guns over short periods can be achieved using compressed nitrogen cylinders). Airguns are somewhat cumbersome to deploy, would require dedicated and trained personnel and pose a number of safety issues. The widespread use of airguns in oil and gas exploration in some areas would also raise concerns. Animals in these areas would have extensive exposure to airguns and may have become habituated.

One important practical consideration concerns the acoustical power of AMDs deployed and the number that will be required to achieve the desired reduction in exposure risk. These decisions will depend on a range of information much of which is not yet available and some of which will be site-dependent. From Section 3 we can see that the range to which animals must be moved before piling commences will depend on factors such as piling source levels, local propagation conditions and species sensitivity. The speed with which animals move away from a particular type of AMD and the range to which they can be excluded can be measured by behavioural research described in Section 10, and a final consideration will be the relative cost and acoustic power of different AMD devices. It may be the case that the required level of removal can be achieved using a single device or that a number of lower powered devices will need to be spread over an area. A third option would be for a boat to tow a sound production device in a pattern designed to exclude animals from a larger area. All of these options seem feasible; the extent to which they present additional practical issues is likely to vary significantly between different sites and construction activities and cannot be further considered here.

In summary, although no ‘off-the-shelf’ AMD system exists for this application, a number of devices that may be suitable for this requirement as they are, or could be readily adapted, are available. No insurmountable technological or practical concerns have been identified, but work is needed to discover how animals respond and to develop practical procedures and protocols. Learning the lessons presented by Bomford and O’Brien (1990) in their review of the development of sonic deterrents for terrestrial animals, we should now proceed by testing responses of animals to promising signals and then, if warranted, develop devices to produce them effectively.

10.1. Research Requirements

If acoustic mitigation devices (AMDs) are used, the aim will be to deploy them at a source level at a spatial density and over a period of time that will reduce the probability of animals being present within an exclusion area to an acceptable level. The size of the exclusion area will depend on the characteristics of the noise source and propagation conditions. The simplest deployment of AMDs would be a single unit at the pile-driving site. However, in some circumstances this may not be sufficient. It might only be feasible to clear larger areas by deploying multiple units or by patrolling the site towing a mobile unit. The numbers of AMDs required, their source levels, and the length of time they will need to be active before piling begins will depend critically on the behaviour of the target animals. For almost all species/signal type combinations this is an unknown and unpredictable quantity, and a targeted research program will be required to measure it.

This review suggests that there are good prospects of developing AMDs that will provide effective and inexpensive mitigation for activities such as pile driving or the use of explosives. Such methods would be doubly beneficial where mitigation is required for activities that carry a risk of causing damage to marine mammals, reducing both the risk of damaging individual animals while also reducing operating costs for the industry. However, the review also highlights high levels of uncertainties which mean that mitigation procedures aiming to achieve a low level of risk are inevitably very restrictive. Carefully directed research programs are required to address key uncertainties. Reducing uncertainty will allow the development of more effective, and probably less restrictive and less expensive, mitigation measures.

If operators and regulators are to rely on AMDs as an important component of mitigation procedures, then it is important that their performance and reliability are well characterised. Here we focus on the research required to determine the most appropriate sounds to use with different target species, and the levels and deployment procedures that will be required to achieve a high probability of removal of animals from the mitigation zone.

10.1.1. Behavioural response studies

The most fundamental unknowns in this process relate to animal behaviour, essentially how animals move in response to different sound types. It is important that operators and regulators appreciate the fact that it is not possible to predict the effects of a particular sound source on the behaviour of a particular species of marine mammal purely from theoretical models. The only reliable method for assessing responses to particular stimuli is to observe and record the movement patterns of animals before during and after exposure to that sound source. This can most easily be achieved where the observer has control over the sound source, i.e. during controlled behavioural response studies. An appropriate research program will therefore consist of a series of controlled exposure experiments to assess the behavioural response to any proposed AMD signal.

Simple animal behaviour, such as movement, is relatively straightforward to measure using one of a number of observation and/or telemetry methods. However a considerable number of replicates may be required to capture the expected variability.

Developing appropriate AMD methods will be a two-stage process. We will need to identify the most effective, practicable and least harmful AMD signals, and this will be followed by a series of trials to quantify their effectiveness under a realistic range of conditions. For experimental purposes, it will be appropriate to use quite general and flexible sound sources, such as pre-existing devices (e.g. high power ADDs, pingers and underwater speakers that can broadcast a variety of signals). Once signals have been tested and shown to elicit the appropriate responses in target animals, it may be necessary to adapt existing equipment or to develop effective and efficient devices for routine field use, but this development will be dependent on the results of behavioural response studies.

Movements of marine mammals can be measured using a range of techniques, and the most effective suite of methods to apply will vary between species groups. SMRU recently hosted a three day international workshop specifically to review the technology available for measuring the behavioural responses of marine mammals to sound, and this review draws on material from that workshop.

10.1.1.1. Seals

Seals can be readily captured, and telemetry devices can be securely attached to their fur using glue. These robust, relatively long term attachment methods have encouraged the development of a range of sophisticated telemetry devices.

Systems of VHF and ultrasonic acoustic telemetry have been used successfully to measure the short-term behavioural responses of common and grey seals to noises from small arrays of seismic airguns. These real time tracking studies were accomplished using small vessels (outboard powered inflatables and/or modest ocean-going yachts) and allowed testing of responses under tightly controlled conditions that enhanced interpretation of results (Thompson *et al.*, 1998).

Developments in telemetry systems and tracking technology over the last decade have greatly improved the ease and precision with which such work can be undertaken. For example, Argos linked satellite telemetry tags that broadcast location information from fast lock GPS can provide the fine-scale, real-time tracking required to assess responses. The same devices can be programmed to provide long-term tracking of movement patterns before during and after experimental periods. This allows medium and long-term effects to be assessed and also provides the opportunity to relocate individual seals to conduct repeated trials to assess the effect of behavioural state, context and habituation.

Although it is a non-trivial exercise, it is relatively straightforward to design and conduct a series of repeated exposure trials with a wide range of sound sources under realistic field operating conditions. Such studies could be readily combined with longer term tracking studies to monitor foraging behaviour of seals in the vicinity of windfarm sites before, during and after construction.

10.1.1.2. Cetaceans

Generally, cetaceans are less amenable to tagging than seals, although recent developments in tag attachment methods and miniaturisation of transmitters and data loggers mean that it is now possible to obtain useful results from some of the likely target species in UK waters. However, cetaceans’ use of acoustics and their surface behaviour may mean that alternative research methods employing passive acoustic monitoring and visual monitoring might also be effective.

Harbour porpoise have only been tagged in special situations where they have become impounded in fish traps and can be captured to allow tags to be attached (Read and Westgate, 1997; Teilmann, 2000). There are no such fish traps in UK waters, and it is unlikely that a telemetry based study is an effective option for this species.

However, visual observations provide a means of monitoring porpoise presence and, to some extent, activity levels. One practical approach would be to conduct AMD trials in areas that can be monitored from elevated locations onshore. Shore-based observers can measure relative densities, and track the movements of individuals during periods when sound sources are and are not active. The research conducted by Olesiuk *et al.* (2002) and Johnston (2002) provide good examples of this type of approach. It may be possible to conduct such research further from shore by using a quiet vessel or taking advantage of offshore platforms such as oil rigs or indeed windfarm pylons to provide observation points. In some circumstances it might be helpful to use passive acoustic monitoring either from towed or static hydrophones to supplement visual effort. However, researchers would have to take care not to confuse a change in vocal behaviour, such as a reduced vocalisation rate, with a real change in local density.

Compared to telemetry studies this approach would provide less detailed data on the response of individuals and is unlikely to provide longitudinal data from repeated exposures of an individual animal. However, it can provide a large sample size of exposures to different individuals.

Bottlenose Dolphins occur in UK inshore waters, but any form of capture or restraint and therefore long-term attachment of telemetry devices is problematic. Because their populations are smaller, opportunistic encounters such as those envisaged for porpoise, are less likely to occur. However, it is possible to identify most bottlenose dolphins using photographs and it would be important to record this information whenever they are encountered during windfarm development or experimental trials to manage the degree of exposure of any particular individual and to explore phenomena such as habituation or sensitisation. In this case visual tracking of individuals or groups from a quiet tracking vessel with an elevated vantage point might be the most effective way to collect data. Well-studied populations of bottlenose dolphins could provide opportunities for visually-monitored AMD trials. However, in UK waters most such populations are the focus of intensive dolphin watching operations that make such studies more contentious.

Larger cetaceans, such as **minke whales**, can be effectively tracked using small telemetry devices that are attached with suction cups and stay attached for several hours. Attachment times of 8-12 hours are routine and provide sufficient time to conduct a complete controlled exposure experiment involving the collection of pre-exposure control, exposure and post exposure data. Typically these devices incorporate a VHF tag to allow the animal to be tracked, and archival data storage that collects detailed information on the subject's behaviour and dive patterns. Archival tags designed specifically for acoustic behavioural response studies (e.g. D-Tags built by WHOI) also provide high-resolution sound recordings that allow accurate measurement of the received level of the sounds being investigated. Although the tag attachments are much shorter than for seals these methods can provide highly detailed data from a large sample of individuals.

In practice the methods of testing would be similar to those recommended for seals, with the exception that a tracking vessel would need to remain within VHF range (i.e. line of site from the mast head ~20km) of the study animal throughout the trial period to ensure recovery of the data logger.

10.1.2. Synergies

Behavioural response studies such as these have been recommended for studying the responses of marine mammals to a range of noise types such as airguns. Some of the costs of this research could be spread if these studies were combined. In some cases responses of the same telemetered animal to different sound types could be explored and, with careful experimental design, different sound types could even act as controls for others. This may not be possible when short duration telemetry attachments are used, but in these cases field costs and facilities could be shared to reduce expense.

AMDs may have applications in mitigating other interactions between humans and marine mammals. Explosives are used routinely to remove well-heads, and as more UK oil fields are decommissioned this is an activity that seems set to increase. Explosives have the potential to kill or injure marine mammals as well as damage their hearing and conventional methods of monitoring are particularly ineffective. AMDs offer an effective solution that would merit investigation.

Moving animals out of harm's way using sound has also been suggested as a response to oil spills; in fact it forms part of the Talisman oil spill response plan for the Moray Firth, although no specifics of the devices that might be used are provided (Gubbay and Earll, 1999).

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