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AN ASSESSMENT OF CURRENT METHODOLOGIES FOR MITIGATING THE POTENTIAL EFFECTS OF ANTHROPOGENIC UNDERWATER SOUND ON MARINE LIFE, AND RECOMMENDATIONS FOR BEST PRACTICE

Compton, Ross Craig

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University of Plymouth

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AN ASSESSMENT OF CURRENT METHODOLOGIES
FOR MITIGATING THE POTENTIAL EFFECTS OF
ANTHROPOGENIC UNDERWATER SOUND ON
MARINE LIFE, AND RECOMMENDATIONS FOR BEST
PRACTICE

by

Ross Craig Compton

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Ross Craig Compton

An assessment of current practice for mitigating the potential effects of anthropogenic underwater sound on marine life, and recommendations for best practice

Abstract

Underwater sound from anthropogenic sources such as seismic surveys, marine renewable device installations and naval exercises has the potential to disturb and cause injury to a variety of marine species. There is particular concern for the potential effects upon marine mammals, which utilise sound to communicate, hunt and navigate. Observed effects include behavioural changes and reduced sighting rates, with unknown consequences for individuals or populations over time. Potential effects on marine mammals include sound induced damage to auditory systems, altered diving behaviour potentially resulting in decompression sickness, stranding and death. The aim of the thesis was to develop a framework of best practice measures relating to mitigating the potential effects of underwater sound on marine mammals during offshore exploration and development operations. In order to mitigate the potential effects of underwater sound, regulatory guidelines have been developed and implemented around the world, principally for seismic surveys. These guidelines limit the activation of seismic sources when in proximity to marine species, and involve the use of specially trained personnel on survey vessels known as Marine Mammal Observers (MMOs). A critical review of the guidelines identified variation in the level of precaution applied to measures, such as the distance at which species can be sighted before reducing sound output from the operation. MMOs collect sighting information for all encounters with marine species, resulting in large volumes of data detailing species occurrence and behaviour. A sample dataset was found to be subject to

variation in quality due to the different academic backgrounds and training levels of personnel. The data lacked the necessary detail to help interpret the potential effects of seismic surveys upon marine mammals, likely due to the lack of expertise regarding animal behaviour among those collecting the data. A questionnaire was conducted to determine any differences of opinion regarding current mitigation practice and the underlying issue between stakeholder groups. There was no difference of opinion between stakeholders regarding the importance of underwater sound compared to other environmental issues facing marine species such as overfishing. Areas of consensus were evident, with most stakeholders finding current mitigation practice to be only ‘somewhat’ effective, and that sightings data collected by MMOs should be better utilised, with it being more useful for adding to our knowledge of marine mammal distributions than for determining the effects from operations. A framework for enhancing the collection, use and dissemination of MMO data is described with recommendations for the development of a Global Positioning System (GPS) enabled smartphone/ tablet based field data collection system, linked to an internet based geographical information system to enhance species distribution analysis. By coupling this with a simplified mitigation methodology, the outcome would enhance the risk management of operations in relation to where species are known to occur, with mitigation aimed at reducing exposure at critical times or in critical habitats. Simplifying mitigation and enhancing data collection and use will benefit stakeholders in managing essential operations responsibly.

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List of Abbreviations

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ABR	Auditory Brainstem Response	(4)
AHD	Acoustic Harassment Device	(42)
CEEs	Controlled Exposure Experiments	(24)
CPUE	Catch per Unit Effort	(30)
CSA	Cetacean Sightings Application	(135)
DECC	Department for Energy and Climate Change	(89)
DEHLG	Department of Environment Heritage and Local Government	(37)
EEZ	Exclusive Economic Zone	(58)
EIA	Environmental Impact Assessment	(51)
ENFA	Ecological Niche Factor Analysis	(149)
ERMC	Environmental Risk Management Capability	(152)
FLO	Fisheries Liaison Officer	(66)
GAM	General Additive Modelling	(149)
GIS	Geographical Information Systems	(129)
GLM	General Linear Modelling	(149)
GPS	Global Positioning System	(iv)
GUI	Graphical User Interface	(138)
IAGC	International Association of Geophysical Contractors	(52)
HS	Habitat Suitability	(132)

ISO	International Organization for Standardization	(134)
JNCC	Joint Nature Conservation Committee	(33)
LoFS	Life of Field Seismic	(11)
MSP	Marine Spatial Planning	(150)
MMO	Marine Mammal Observer	(iii)
MPA	Marine Protected Areas	(50)
NGO	Non-Governmental Organization	(86)
NMFS	National Marine Fisheries Service	(38)
OBIS-SEAMAP Ocean Biogeographic Information System – Spatial		
	Ecological Analysis of Mega-vertebrate Animal Populations	(131)
OGP	Oil and Gas Producers Association	(90)
PAM	Passive Acoustic Monitoring	(46)
PDA	Personal Digital Assistant	(146)
PON	Petroleum Operators Notice	(89)
PTS	Permanent Threshold Shift	(22)
RES	Relative Environmental Suitability	(152)
rms	Root mean squared	(19)
SEL	Sound Exposure Level	(22)
SL	Source Level	(6)
SMRU	Sea Mammal Research Unit	(34)
SOFAR	Sound Fixing and Ranging Channel	(5)
SPL	Sound Pressure Level	(6)

TL	Transmission Loss	(5)
TTS	Temporary Threshold Shift	(22)
UK	United Kingdom	(17)
VLIZ	Vlaams Instituut Voor de Zee	(142)
VSP	Vertical Seismic profile	(15)
WGS	World Geodetic System	(140)
WTP	Willingness to Pay	(126)

List of Units

psi Pounds per square inch

in³ Cubic inch

Hz Hertz

kHz Kilohertz

m Metres

bar-m Bar metres

dB decibels

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Author's declaration

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award without prior agreement of the Graduate Committee.

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Chapter 1. Introduction

1.1 Anthropogenic sound and cetaceans

There is an increasing level of interest in the effects of anthropogenic sound on the marine environment, particularly the potential effects of widespread marine geophysical exploration upon marine mammals (Boyd et al., 2011; OSPAR Commission, 2009; IACMST, 2006; Gordon et al., 2003; Richardson et al., 1995). The European Union adopted the Marine Strategy Framework Directive (MSFD) in 2008, which includes eleven qualitative descriptors of ‘Good Environmental Status’ (GES). Underwater sound is covered by descriptor 11, which states that GES is achieved when “the introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment” (Directive 2008/56/EC).

Marine mammals and many other marine species have evolved to use sound as the primary means to communicate, navigate and for hunting prey, due to the rapid attenuation of light and the efficient propagation of sound underwater (Hatch and Wright, 2007; Tyack, 2008; Hildebrand, 2009, Urick, 1983). Consequently, there is concern for the potential effects of increases in anthropogenic underwater sound on both the behaviour and physiology of marine species (Tyack et al., 2008).

There are a wide variety of anthropogenic sound sources that input sound into the oceans associated with industries such as; oil and gas exploration and extraction, shipping (both freight and passengers), construction, and the military (Richardson et al., 1995). This variety of sources increases the

ambient levels of noise in the oceans. There are other more local impacts from sources such as naval sonar, seismic exploration, and pile-driving activity (Dahl et al., 2007).

1.1.1 Sound production and hearing in cetaceans

Descended from land-dwelling ungulates, cetaceans have undergone a range of evolutionary changes making them highly adapted to a fully aquatic existence (Ketten, 2000). This includes significant adaptations to the three principal divisions of the mammalian ear; the outer ear, the middle ear and the inner ear (Ketten, 2000). Elements of the outer ear present in other mammals; the concha and pinna or ear flap, are no longer present. While a residual auditory canal is still present, in general they are fully occluded with cerumen and in odontocetes have no connection with the tympanic membrane (Ketten, 2000). Sound conduction via fatty tissues in the jaw region are thought to be the primary means of sound conduction in odontocetes, as first proposed by Norris (1968). Whether the canal retains any functionality is unknown at present, though in mysticetes it is linked to the tympanic membrane, so the potential for a sound conduction function cannot be ruled out (Ketten, 2000). The middle ear is highly adapted to the pressure changes experienced while diving, with large, dense ossicles (particularly in mysticetes), though specific middle ear function remains an area of active debate (Ketten, 2000). Compared to land mammals, the vestibular system of the inner ear is much reduced, potentially linked to a reduction in head movements due to the fusing of cervical vertebrae (Ketten, 1997). Cochlea adaptations are linked to functional groups in terms of the frequencies utilised, whereby mysticetes have wide, thin basilar membranes

with no stiffening, indicating adaptation to low frequencies, while odontocetes have stiff basilar membranes, showing adaptation to ultrasonic frequencies (Ketten, 1997).

Along with different frequencies, odontocetes and mysticetes also produce different types of sounds. Odontocetes produce a variety of tonal and pulsed sounds including rapid burst pulses and echolocation clicks that are broadband in nature (Au et al., 2000). Sound production in odontocetes is relatively well studied, with much research dedicated to establishing whether sound production is laryngeal or nasal (Au et al., 2000). From early work by Wood (1964, 1968) and much since, we have an understanding of sound production from fatty projections (known as ‘monkey lips’) close to the nasal area within a dolphin’s head that then passes through the fatty ‘melon’ within the forehead before being projected into the water (Au et al., 2000).

Marine mammals utilise sound of differing frequencies depending on the species, due to physiological variations in both sound production and reception systems. Considering cetaceans in particular, there are key differences between the large baleen whale species (*Mysticetes*), and the toothed whale species (*Odontocetes*). While we do not have measures of auditory sensitivity for many species, in particular baleen whales, the peak spectra of sounds produced by different species provide an estimate of that sensitivity (Ketten, 1997). It is generally agreed that baleen species utilise low frequency sound (~10 Hz to ~10 kHz) and produce a range of moans, songs and in some cases infrasonic calls, while toothed species will utilise higher frequency sounds (~1 kHz to ~150 kHz) such as narrow band whistles for communication, and broad spectrum clicks for echolocation of prey items (Richardson et al., 1995; Ketten, 1992, 2000; Southall et al., 2007).

In order to understand the ability of an animal to detect sounds of varying frequencies, audiograms can be generated to define the hearing sensitivity of the subject. This kind of data exists for a variety of odontocete species, primarily due to studies carried out on captive animals, but is lacking for mysticetes due to both practical and ethical constraints. Audiograms for odontocetes generally indicate low sensitivity (high threshold for sound perception) below 1 kHz with increasing sensitivity (lowering threshold for sound perception) until the functional maximum for the given species is exceeded whereby sensitivity will decrease again, resulting in a U-shaped curve (Ridgeway and Carder, 2001). Such data can be generated using behavioural studies, whereby captive animals either respond or do not respond to acoustic stimuli of different frequencies, or by an electrophysiological method termed the auditory brainstem response (ABR) (Szymanski et al., 1999).

The concerns for noise pollution in the oceans relate to the broad overlap between anthropogenic sound sources and the frequencies used by marine mammals, and the worry that noise pollution will interfere with the biological functions of sound in these animals, especially at the low frequencies used by baleen whale species (Di Iorio and Clark, 2009). Before considering acoustic sources in detail, it is important to understand the basic concepts of underwater sound, due to the complexities of sound propagation and measurement.

1.2 Sound in the ocean

Sound is the term given to the pressure changes caused by the displacement of particles in an elastic medium arising from a mechanical disturbance. This disturbance creates a longitudinal wave that propagates

through the medium (Hastie, 2009). The wave creates local pressure fluctuations due to the elasticity of the medium, where (in the case of the ocean) water molecules will be alternately compressed and rarefied as the wave is transmitted.

There are a number of important ways of characterising a sound. The rate of pressure change defines the *frequency* of the sound wave, measured in Hertz (Hz), while the magnitude of these differences defines the *amplitude* (Hastie, 2009). The SI unit for the measurement of sound pressure (amplitude) is the Pascal (Pa), which can be defined as force per unit area (Newton (N) per m²). However, the logarithmic scale *decibels* (dB) has become the common measure of sound pressure due to the wide range of intensities perceptible to the ear of the receptor (e.g., cetacean). It describes power and voltage ratios which must be reported with a reference pressure and in underwater acoustics this is 1 micropascal (μPa) (Hildebrand, 2009; Richardson et al., 1995).

As a sound wave travels through a medium there are losses and variations in propagation due to a number of physical and environmental factors. Transmission loss (TL) is the principal loss, and is the weakening of the signal with increasing distance from the source (Urick, 1983). In an unbounded environment a sound spreads from the point of origin spherically (*spherical spreading*), in all directions, with energy decreasing with distance due to a limited amount of energy being distributed over an increasing area (Urick, 1983; Richardson et al., 1995; Hastie, 2009). When the environment is bounded, spreading is constrained such that sound is reflected (though some acoustic energy will also be lost) from a bounding surface such as the seafloor, sea surface or boundaries created by the effects of temperature and pressure, as in the SOFAR channel. Propagation within a bound environment is termed

cylindrical spreading, and results in lower levels of loss due to the containment of the sound and smaller area over which the energy is spread when compared to spherical spreading (Richardson et al., 1995; Urick, 1983). Further loss results from attenuation by absorption; a process by which acoustic energy is converted into heat (Hastie, 2009). Absorption is greater for high frequency sound than low frequency, meaning low frequency sound has the potential to propagate further (Urick, 1983; Hastie, 2009).

Sound pressure level (SPL) is a key measure of the sound pressure produced by an acoustic source, which describes the force per unit area (Hildebrand, 2009). Measurements of a single source are referred to as source level (SL), and are often taken at varying distances from a source, and require the use of a standard reference distance (1 m), where the output of an ‘ideal point source’ (small and omnidirectional) could be assumed, but for which any measurement of a large distributed source such as large vessel would be highly variable (Hildebrand, 2009). The source level is determined after accounting for the expected propagation loss between the reference distance and measurement distance (Richardson et al., 1995). Taking into account both the reference pressure and reference distance for underwater acoustic sources, source levels will therefore be quoted as dB re 1 μ Pa @ 1 m.

When considering sound in the ocean, it is commonly important to relate it to ambient noise levels. Ambient noise can be defined as the “naturally-occurring acoustic environment in the ocean, caused by wave breaking, marine life etc” (Morfey, 2001). The level of ambient noise can affect the detection of any signal of interest, whether that is commercial sonar units used for industrial or military purposes, or marine species communicating. The relationship between signal and noise is termed the signal-to-noise ratio (Morfey, 2001).

Ambient noise varies with time, location, and season and covers a range of frequency bands (Richardson et al., 1995). Wenz (1962) described ambient noise in detail, and formulated the now widely reproduced and adapted ‘Wenz curves’ (shown in Figure 1-1), illustrating the significant biological, anthropogenic and natural sources of ambient noise, along with indications of factors such as the increase in surface noise with increasing Beaufort wind force. What is important to draw from this diagram is the level of overlap between the frequencies of ‘biologics’ and both natural sources of sound, such as precipitation and ice movements, as well as anthropogenic sources, including shipping and industrial activity.

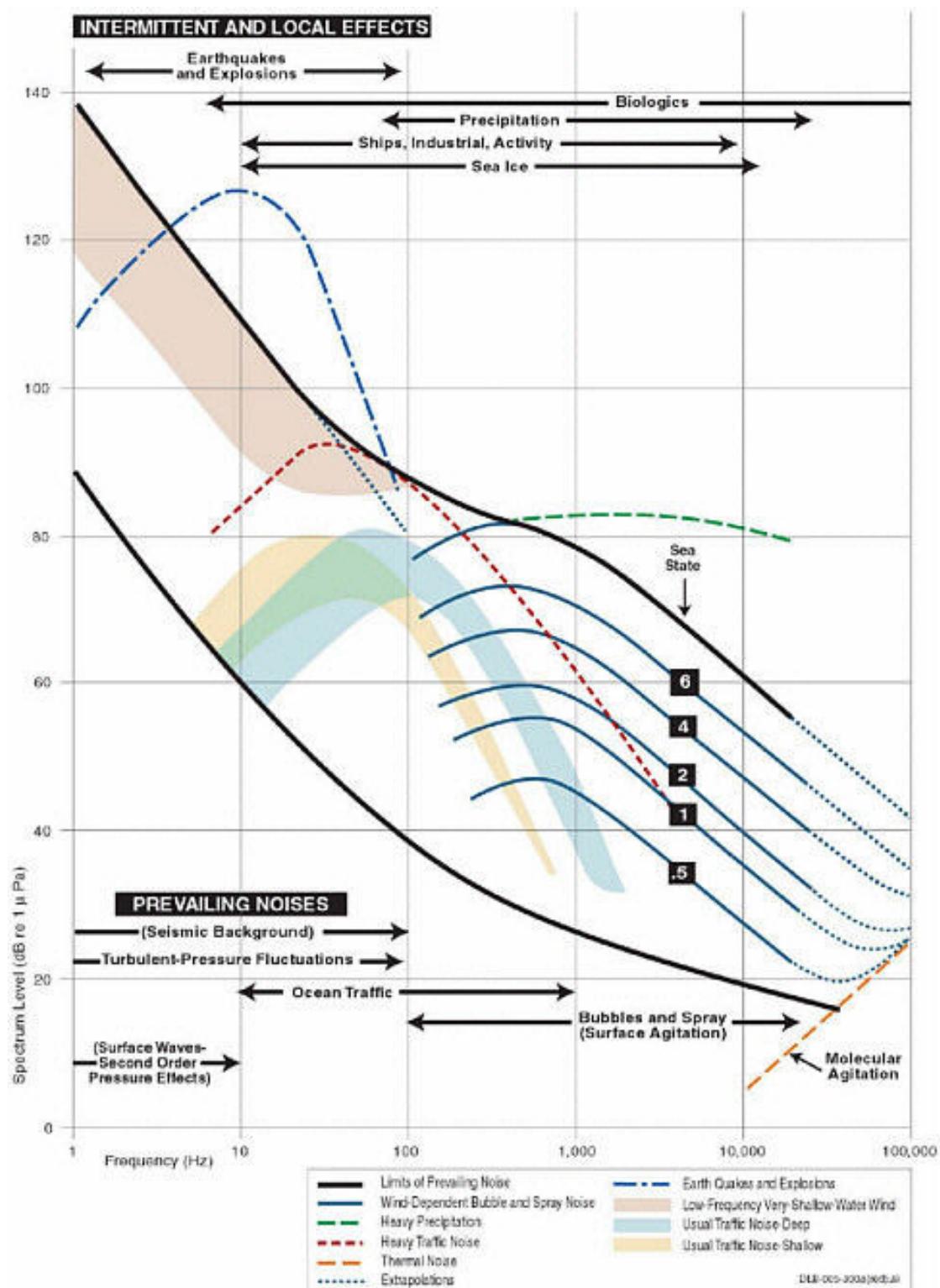


Figure 1-1; Ambient noise sources and levels (National Academy of Sciences, as adapted from Wenz, 1962). The curves show the increase in average ambient noise levels with increasing sea state, as well as the noise levels for anthropogenic sources such as shipping, and natural sources including precipitation and natural seismic events.

Marine species span a wide range of frequencies, with early recordings of blue whale calls ranging from 12.5 to 200 Hz (Cummings & Thompson, 1971), and harbour porpoise clicks having a peak frequency of approximately 130 kHz (Clausen et al., 2010). Species of snapping shrimp also produce high amplitude clicks with energy up to a frequency of 200 kHz, and as such are a major source of sound in the ocean, capable of interfering with signal reception for military and industrial activities, as well as marine species such as cetaceans (Au and Banks, 1998). The lower frequencies of ambient noise are dominated by sources such as underwater earthquakes and shipping, while higher frequencies are dominated more by the surface motion of the sea, along with resulting bubbles and spray (Wenz, 1962).

In order to understand the potential impact of sound sources upon marine species it is important to characterise them using common measures such as those outlined above, as well as considering the temporal and spatial properties. Sounds may be transient and often pulsatile (such as a pile-driver) or continuous in nature (such as an oil platform) (Richardson et al., 1995). The following sections give a summary of key sources of anthropogenic sound input into the ocean.

1.2.1 Geophysical operations

Marine seismic survey operations primarily occur to investigate the geological structure of the seafloor in order to locate hydrocarbon traps. Seismic data acquisition relies upon the recording of reflected sound signals using from 1 (2D seismic) and up to 20 (3D seismic) ‘streamers’ that are multi-kilometre

long cables containing hydrophones (Gulland and Walker, 1998). Seismic surveys can be days to months in duration, and can cover hundreds of square kilometres. A survey vessel will tow a seismic source and data acquisition system (see figure 1-2) along a set planned network of survey lines designed either to provide an initial overview of subsurface geology (typically using the 2D method), or get a detailed picture of a previously identified geological feature (typically using the 3D method).

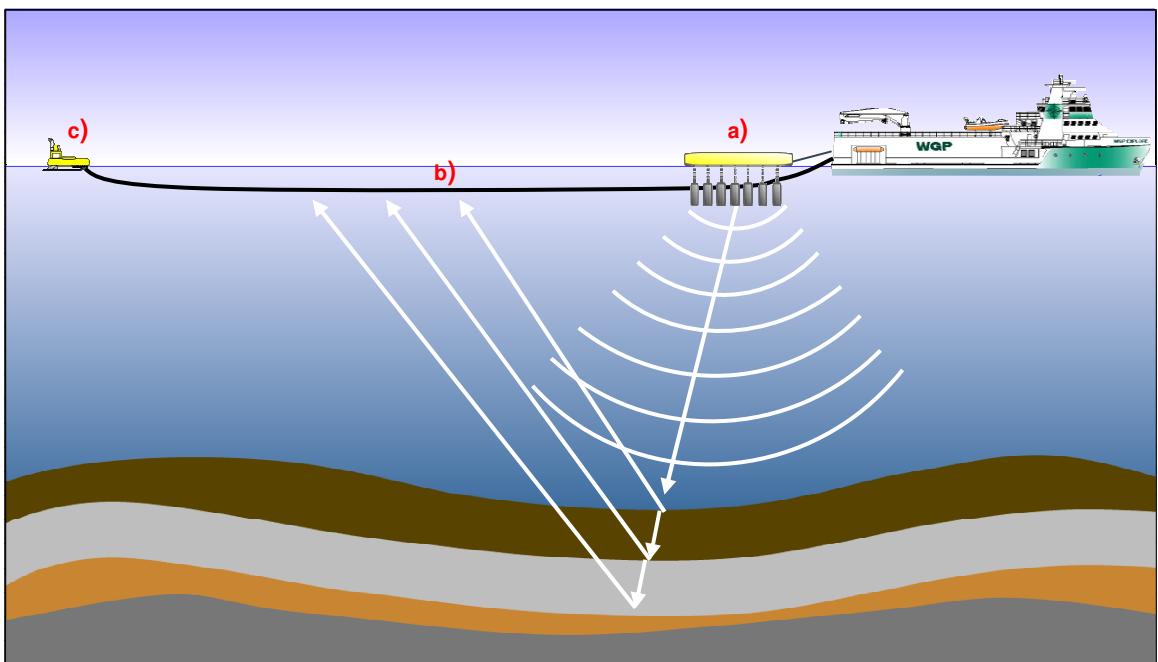


Figure 1-2; Typical seismic survey equipment; a) the seismic source or 'airgun array', b) the data acquisition system comprised of a single or multiple hydrophone streamers, and c) a tail buoy providing GPS positioning information. Sound produced by the seismic source travels through the water column and substrate. The reflected and refracted sound waves are recorded by the data acquisition system for analysis and interpretation. Diagram reproduced with the kind permission of WGP Seismic Ltd.

The nature of the data collection during 2D and 3D surveys means that the sound emission is transient. However, there is a current trend towards 4 component (4C) and time-lapse (4D) seismic acquisition in order to monitor the changes in hydrocarbon reservoirs and maximise individual well and overall reservoir productivity. Also known as ‘reservoir monitoring’ or ‘life of field seismic (LoFs)’, 4D seismic surveys can either take the form of 3D surveys repeated over time, or more commonly use 4C (four component) technology that is placed on the seabed. This method also provides the advantage of the detectors being in exactly the same location during repeated data collection phases where a source vessel will run survey lines above the sensor array. These systems use a combination of a hydrophone and three geophones in order to detect both *P*-waves (pressure) and *S*-waves (shear), providing a detailed picture of how production reservoirs are changing (Kearey et al., 2002). This move toward studying the life of the field may result in areas being subject to seismic survey activity for longer periods which may lead to a greater potential for causing disturbance to marine species in the vicinity of such operations, as discussed in section 1.3 onwards.

A further technique which has become widely used is multi or wide azimuth seismic surveying. Complex geological formations are not always imaged accurately by conventional techniques that tend to be of narrow azimuth. Multi and wide azimuth techniques increase the range of geological target illumination resulting in data that contains fewer artefacts (Long et al., 2006). These techniques use multiple vessels, with how many being dependent on the specific objectives of the survey, but an example would be the use of one recording vessel and two source vessels. Such operations represent a large ‘footprint’ in terms of vessel activity and acoustic input into the ocean.

1.2.1.1 The seismic source

Prior to the mid 1960s, explosive sources such as dynamite and nitrocarbonitrile (NCN) were used as the seismic source (Parkes and Hatton, 1986; Dobrin and Savit, 1988; Jones, 1999). While a variety of sources have been used over the years, ‘airguns’ have since become the most common sound source utilised by the geophysical exploration industry, due to increased safety, high reliability and repeatability (Richardson et al., 1995; Kearey et al., 2002). A seismic source, or ‘airgun’ is a chamber that is charged with compressed air (approx. 2000 psi) which is then released at set intervals through ports in the side of the gun (see figure 1-3), resulting in a high pressure bubble (Kearey et al., 2002). Sources vary in volume (expressed in cubic inches) and typically range from approximately 30 in³ to 800 in³ (Caldwell and Dragoset, 2000). Smaller ‘mini-gun’ sources of 10 in³ may be used for site survey operations.

The release of the air is achieved by opening the ports of the gun either by the movement of an external sleeve or an internal shuttle, allowing the air to vent (Dragoset, 2000; Gulland and Walker, 1998). When the air is released a primary pulse is generated which is followed by a series of bubble pulses caused by the oscillation (cyclical expanding and collapsing) of the air bubble which cause reverberation and lengthen the overall pulse (Kearey et al., 2002). The sound generated travels through the water column and the earth’s subsurface. It is the reflections and refractions of this pulse that are detected using the hydrophone streamers (Dragoset, 2000; Gulland and Walker, 1998). The recorded signals from such reflected sounds are then processed in order to determine the rock types and likely locations of hydrocarbon bearing layers (Kearey et al., 2002).

The seismic source pulse is a low frequency impulsive sound with broadband source levels of 220 – 255 dB re 1 µPa @ 1 m (Richardson et al., 1995). The dominant frequencies of source pulses lie within the 0 – 120 Hz range, though there are significant levels of high-frequency sound up to 20 kHz also produced by the pulses (Goold and Fish, 1998). This can be seen in figure 1-3, where the spectrogram (a plot of frequency over time) shows the initial pulse and primary return from the seabed, clearly showing the frequency content of a typical seismic source pulse. The dominant frequencies overlap with those used by baleen whales (10 Hz – 1 kHz), with the high-frequency component also overlapping with the frequency range used by many odontocetes (10 – 150 kHz) (Richardson et al., 1995). Efficient propagation may result in source pulses being audible at distances of tens to hundreds of kilometres (Richardson et al., 1995).

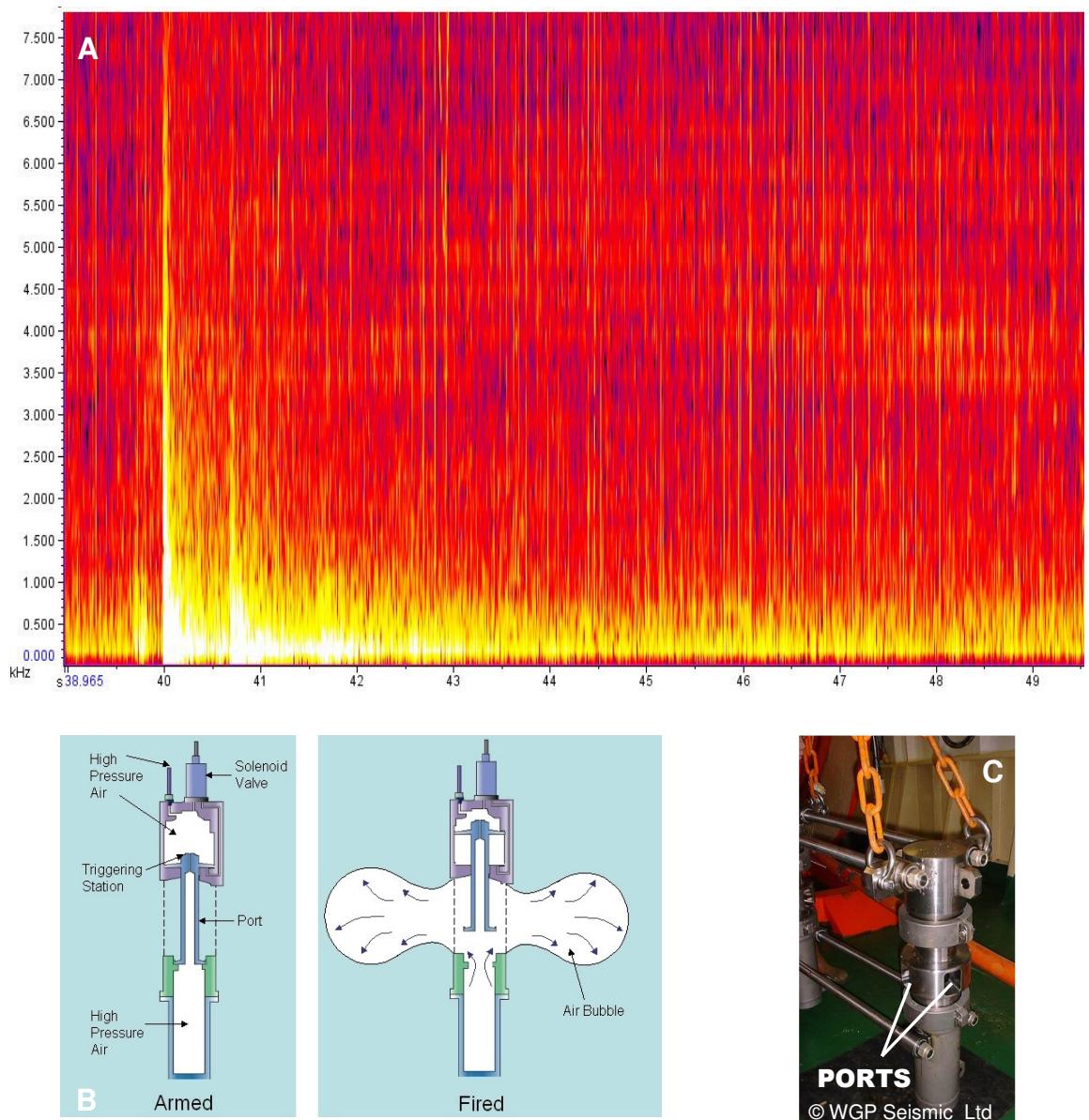


Figure 1-3; A) Spectrogram displaying the pulse from a seismic source. Higher amplitude is indicated by the bright yellow and white areas, showing that the dominant frequency content of the pulse is below 500 Hz, though some energy can be seen extending up to approximately 7 kHz in this example. B) Schematic of a seismic source or ‘airgun’ while pressurized (armed) and upon release of the compressed air via the side ports (fired) whereupon the pulse is produced due to oscillation of the air bubble. C) Photograph of a typical seismic source or ‘airgun’.

1.2.1.2 Source arrays

The size of source arrays can vary depending on the type of survey being conducted, which is determined by the geophysical objectives. For example, in preparation for the placement of marine installations (e.g., oil rigs, wind turbines), high resolution ‘site surveys’ are conducted. The source used for such surveys could consist of a single, small capacity airgun. Similarly, ‘vertical seismic profile’ (VSP) surveys are conducted over or within a short offset of the borehole, and use small source arrays of typically three airguns. For large exploration surveys of the type described in section 1.2.1, it is common for seismic sources to be arranged in arrays of typically between 25-50 individual chambers in order to increase the power of the source and produce a large enough peak sound pressure to penetrate seafloor geology (Parkes and Hatton, 1986; Dragoset, 2000).

The sound pressure output of a source array is linearly proportional to the number of sources used (assuming equal chamber volumes), with output measured in bar metres (bar-m) (Caldwell and Dragoset, 2000; Dragoset, 2000). To overcome problems with reverberation and create a symmetric sound energy emission, source arrays are ‘tuned’ by the selection of a range of guns of different sizes (Caldwell and Dragoset, 2000; Dragoset, 2000). This method aims to create a sound field in which the primary pulses from the airguns interfere constructively, while the bubble pulses interfere destructively, resulting in a high energy pulse (Kearey et al., 2002). However, it is the introduction of varied gun sizes into the array that widen the frequency spectrum of the pulse (Dobrin and Savit, 1988), resulting in greater potential for effects upon a wider range of marine species. Figure 1-4 illustrates a typical airgun array, comprised of a range of airgun sizes.

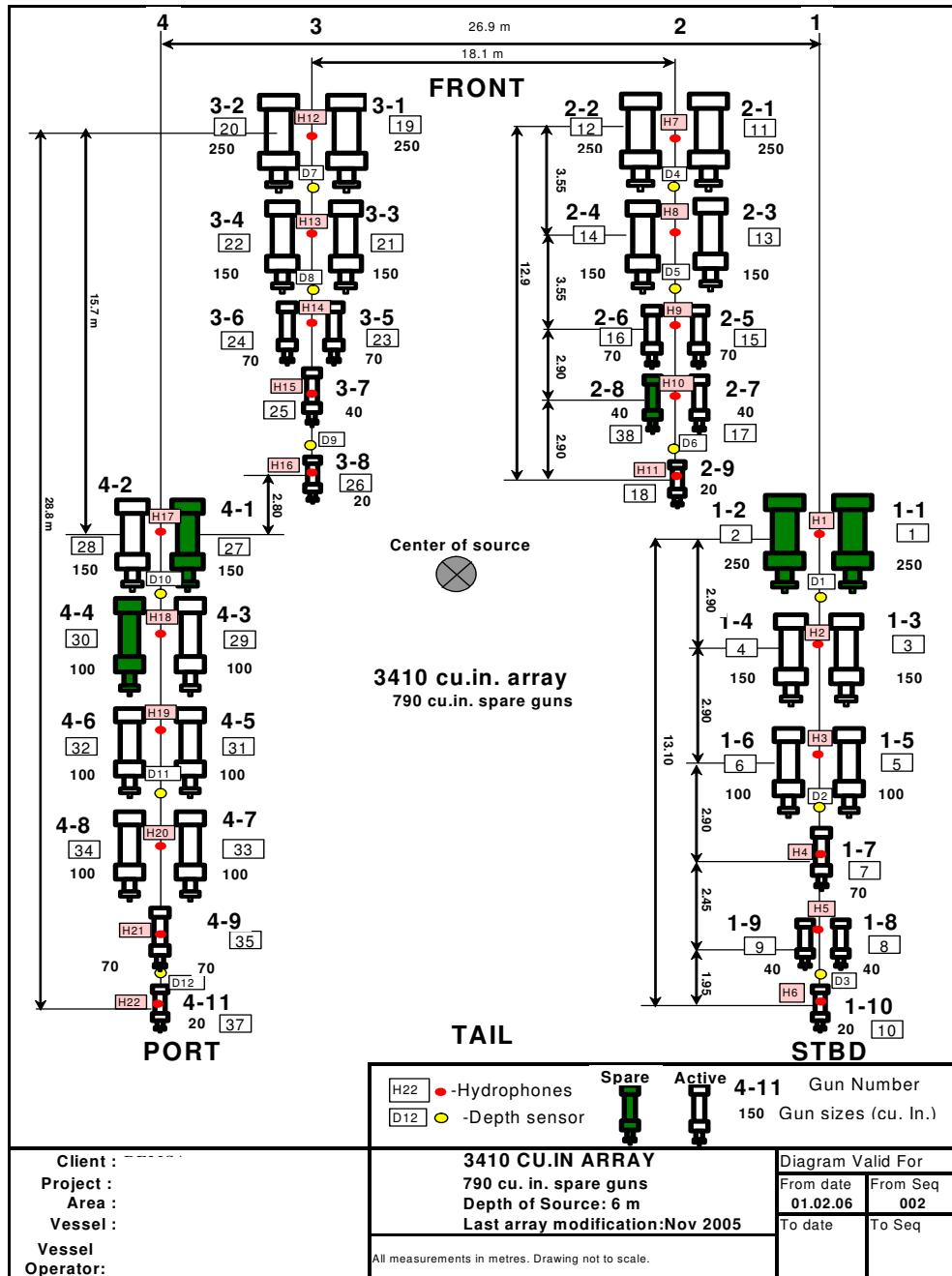


Figure 1-4; A typical seismic source or ‘airgun’ array, consisting of 4 sub-arrays with an operational volume of 3410 in³. Each sub-array is made up of individual source elements of varying capacity in order to ‘tune’ the array to produce a sound pulse with an appropriate wavefront and volume in order to achieve the geophysical objectives of the survey. As objectives vary with the geology at different sites, the array will vary in size and form. Each array will contain a number of in-water spares, as indicated in green. Hydrophones are distributed throughout the array for calibration, as are depth sensors in order to ensure a constant towing depth. While not a ‘point’ source, due to the distributed nature of the array elements, the array has a geometric centre as indicated.

In terms of establishing the potential effects of sound from an airgun array on marine mammals, there are two pieces of information that must be taken into account. Firstly, an airgun array is not a point sound source when measured in the near field (less than \approx 250 m from the array) as peak pressures from the individual guns will not be arriving simultaneously at the receiver. This means that simple back calculations of the acoustic intensity produced are inaccurate (Caldwell and Dragoset, 2000). Secondly, airgun arrays are designed to concentrate sound vertically, with the horizontal SPL being approximately 20 dB lower than those received directly below (or above) the source (Caldwell and Dragoset, 2000). This means that the zone of potential impact would be relatively small in the horizontal plane, though that zone will vary with frequency.

1.2.2 Construction piling

The UK has a target to source 15% of its energy requirements from renewable sources by 2020 (DECC, 2012). The drive for renewable energy in the UK and increasingly worldwide has led to a significant development of offshore wind farms as well as the potential for wave and tidal devices. While the benefits of renewable energy production are many, the construction of marine installations in a variety of shallow and near-shore habitats has raised concerns about the variety of potential impacts on the marine environment, including the input of sound from construction, operation and maintenance of such installations (Madsen et al., 2006; Hildebrand, 2009).

Offshore wind turbines may be placed using gravity based or anchored floating systems, however, the most common method is for steel monopile foundations to be rammed into the seabed using a pile-driver (Nedwell and Howell, 2004; Madsen et al., 2006). The monopile may take several hours to drive into the seabed to a depth where the foundation is stable, depending upon the substrate, with pile strikes being delivered roughly every second (Madsen et al., 2006). While the dominant frequency content and amplitude of the pile strike will vary with pile size, substrate and other factors, Nedwell and Howell (2004) have demonstrated broadband source levels from the piling operation of 215 dB re 1 µPa @ 1 m (zero to peak).

1.2.3 The use of explosives

Chemically based explosive sources ceased to be used in the marine geophysical industry, due largely to the introduction of the safer, more repeatable pneumatic source – the airgun. However, explosives are still a feature of industrial and military operations at sea, including such uses as removal of structures (e.g., abandoned well-heads and shipwrecks), naval ship-shock trials (to test the impact of nearby explosions on vessel hulls) and the removal of explosive remnants of war (Hildebrand, 2009).

Underwater explosives are the loudest anthropogenic point sources, and known to be capable of resulting in blast injury (Richardson et al., 1995). Detonation creates a shock wave with a rapid rise time to a high peak pressure, followed by a series of oscillating bubble pulses (Urick, 1982). The rapidity of the rise time to peak pressure is related to the extent of the blast injury, with the gas containing organs of animals such as the lungs particularly susceptible to

damage (Richardson et al., 1995). The size of charges used will vary greatly with application, with seismic surveys having used tens of kilograms when explosives were used a source, while a ship-shock trial may use thousands of kilograms (Richardson et al., 1995). A 0.5 kg charge of TNT has been demonstrated to produce a broadband pulse of 267 dB re 1 μ Pa @ 1 m instantaneous peak pressure (Richardson et al., 1995).

1.2.4 Commercial shipping

Commercial shipping is widespread, highly variable, and increasing in terms of both fleet size and the gross tonnage of vessels (Hildebrand, 2009). Vessels produce noise from a variety of sources within the structure, but the most significant impact is due to cavitation from the propulsion system (Hatch and Wright, 2007; Hildebrand, 2009). The characteristics and amplitude of the source will vary with ship size and type, but large commercial vessels such as container ships can produce low frequency (below several hundred Hz) sound in the range of 180 – 190 dB re 1 μ Pa rms (Hatch, 2009; Richardson et al., 1995).

1.2.5 Naval Sonar

The frequency range of sonar units varies with task, but commonly used naval sonar are for search and surveillance tasks such as locating submarines, and tend to be low (below 1 kHz) to mid (1 – 10 kHz) frequency in order to be useful over long ranges. While there is little published information about the characteristics of military sonar units, they are known to produce high amplitude

pulsed and tonal signals, in excess of 200 dB re 1 µPa @ 1 m (Richardson et al., 1995). Units commonly used for these applications are the AN/ SQS range of hull mounted systems, which are mid-frequency units with estimated source levels in excess of 220 dB re 1 µPa (D'Spain et al., 2006). These have been implicated in cetacean stranding events when used in naval exercise such as in the Bahamas in 2000, where 17 beaked whales stranded (D'Spain et al., 2006).

1.3 The potential effects of sound upon cetaceans

Despite correlations between cetacean stranding events and seismic activity being demonstrated (Engel et al., 2004); a causal link between cetacean stranding and seismic exploration is disputed (OGP/ IAGC, 2004). There is however, a growing body of evidence detailing a host of behavioural effects on a wide variety of species caused by a variety of underwater noise sources, as well as the potential for physical damage and auditory damage (Richardson et al., 1995; Mate et al., 1995; Gordon et al., 1998; Gordon et al., 2003; Stone, 2003; ICES, 2005). Potential and demonstrated effects are categorised and discussed below.

1.3.1 Physical injury

There is no irrefutable evidence that an anthropogenic sound source has resulted in direct physical injury to marine mammals, though a causal link was implicated in the case of two beaked whales stranded in the Gulf of California during a scientific seismic survey being conducted by the *RV Maurice Ewing* (Malakoff, 2002). The long rise time of a seismic pulse means that there is less

potential for damage than may be caused by high explosives used for operations such as well-head abandonment (Gordon et al., 2003). However, mechanisms that may result in tissue damage and subsequent stranding have been postulated.

Jepson et al. (2003) examined ten beaked whales from a mass stranding of 14 animals that occurred in the Canary Islands approximately 4 hours after the onset of a naval exercise using mid-frequency active sonar. Lesions found within body tissues were consistent with bubble formation resulting from rapid decompression (Jepson et al., 2003). Symptoms of decompression sickness or 'the bends', including gas and fat emboli within the vital organs of stranded beaked whales have also been demonstrated by Fernández et al. (2005) and in stranded Risso's dolphins (*Grampus griseus*), common dolphins (*Delphinus delphis*) and harbour porpoises (*Phocoena phocoena*) (Jepson et al., 2005).

Beaked whales have been shown to be particularly sensitive to the effects of sound with a number of notable stranding events reported in relation to naval exercises (Cox et al., 2006; Southall et al., 2007). The likely cause of such decompression sickness has been hypothesised as being a behavioural startle or fright response leading to a sudden change in the normal ascent rate and dive profile of the animal in order to avoid the sound emission, resulting in excessive nitrogen super-saturation (Jepson et al., 2003; Gordon et al., 2003; Cox et al., 2006). A further potential cause of bubble formation may result from the initiation of bubble growth caused by sound (Crum and Mao, 1996). While the precise mechanism remains poorly understood, it is most likely to be the result of a combination of such factors (Fernández et al., 2005).

The apparent susceptibility of beaked whale species to sound is primarily linked with mid-frequency naval sonar, above the dominant frequencies produced by seismic source arrays. The high frequency content (approximately 1 kHz) of the seismic pulse has been demonstrated as being in the region of 20 to 40 dB lower than the peak energy frequencies (Tolstoy et al., 2004) and so the potential for severe physical trauma to beaked whale species caused by seismic airguns may be lower than from naval sonar, though considerable uncertainty remains.

The high sound pressure levels produced by airgun arrays have the potential to result in physical damage to the auditory system of marine mammals (Richardson et al., 1995). Termed ‘threshold shift’ (a reduction in hearing sensitivity due to an up-shift in the hearing threshold), such auditory damage may be temporary (TTS – temporary threshold shift) or permanent (PTS – permanent threshold shift) depending on the exposure level and duration (Southall et al., 2007). Recovery from TTS is dependent on the duration and extent of exposure and chronic exposure has the potential to lead to PTS, as can a single exposure of sufficient amplitude for a given subject (Southall et al., 2007). A reduction in hearing ability would have severe implications for any affected individual by reducing its capability in terms of locating prey, communicating with conspecifics and navigating, with potential population effects if large numbers are exposed to similarly damaging sound (Gordon et al., 2003).

TTS has been demonstrated experimentally in bottlenose dolphins and beluga whales (Nachtigall et al., 2004; Finneran et al., 2005). Finneran et al. (2005) exposed bottlenose dolphins to 3 kHz tones of between 1 and 8 seconds duration, at sound exposure levels (SELs) from 192 to 203 dB re 1 μPa^2 s.

From a sound exposure level of 195 dB re 1 $\mu\text{Pa}^2 \text{ s}$ and upwards, there were significant differences in the hearing threshold between exposure and control sessions, with TTS of between 2.8 and 5 dB demonstrated, with recovery taking minutes to hours depending on the exposure (Finneran et al., 2005). Using a 20 in³ seismic airgun as a sound source, Lucke et al. (2009) demonstrated TTS in a harbour porpoise. The subject was exposed to sound exposure levels of 140.5 dB re 1 $\mu\text{Pa}^2 \text{ s}$ to 167.2 dB re 1 $\mu\text{Pa}^2 \text{ s}$, with hearing sensitivity monitored at 4 kHz, 32 kHz and 100 kHz. TTS was evident at 4 kHz, but not at the higher frequencies, where the seismic airgun produces much less acoustic energy (Lucke et al., 2009).

1.3.2 Behavioural

Due to the low-frequency nature of the seismic pulse, the largest concern and body of evidence for seismic exploration causing behavioural disturbance is for species of baleen whale, though behavioural reactions have been documented for a wide range of species. One of the earliest studies illustrating the apparent effects of noise exposure on marine species showed that migrating gray whales (*Eschrichtius robustus*) off the coast of California reacted to received sound levels in excess of 160 dB re 1 μPa by orienting away from the sound and increasing their respiration rates (Malme et al., 1984). In addition, 90% avoidance of the airgun source was observed at a range of 1.2 km where received sound levels were \approx 180 dB re 1 μPa (Malme et al., 1984).

Lower reaction thresholds (\approx 140 dB re 1 μ Pa) have been demonstrated for bowhead whales (*Balaena mysticetus*), which tend towards shorter surfacing and dives as well as fewer blows per surfacing, with effects evident 5-10 km from the source (Ljungblad et al., 1988; Richardson and Würsig, 1997). Avoidance of sound sources by bowheads has also been demonstrated, with displacement occurring within a range of 3 – 7.2 km corresponding to received sound levels in excess of 152 dB re 1 μ Pa (Ljungblad et al., 1988).

McCauley et al. (2000) carried out a number of Controlled Exposure Experiments (CEEs) where humpback whales were approached by a vessel operating a single 20 in³ seismic source. A number of clear behavioural reactions were observed, such as groups containing females showing marked avoidance at an average range of 1.3 km, while male humpbacks appeared to be attracted to the noise exposure, potentially due to the similarity between the airgun pulse and the sound produced by male breaching signals used to signal presence and breeding intentions (McCauley et al., 2000). Another important observation during this series of trials was that the overall sighting rate within 3 km of the sound source was higher while the airguns were not operating (McCauley et al., 2000).

The behavioural responses of odontocete species in relation to seismic surveys have been subject to less scrutiny, though clear effects have been illustrated. Bowles et al. (1994) observed a decrease in the sighting rate of southern bottlenose whales (*Hyperoodon planifrons*) and a cessation of vocalising by sperm and pilot whales in response to low frequency emissions during the Heard Island Feasibility Test (an experiment to see if man-made signals could be detected across oceans). In the Gulf of Mexico, Mate et al. (1994) observed a one third reduction in sperm whale density after the onset of

a seismic survey. However, elsewhere it has been reported that exposure to received sound levels of \approx 130 dB re 1 μ Pa rms did not elicit any changes in the vocal behaviour or local distribution of sperm whales (Madsen et al., 2002).

CEEs were again utilised by Miller et al. (2009) in order to examine the effects of exposure to a seismic airgun source upon sperm whale behaviour. Eight individual sperm whales were exposed to sound levels from 140-160 dB re 1 μ Pa (peak to peak), and while no avoidance of the sound source was evident, there were changes to foraging behaviour indicated by a reduction in the number of ‘feeding buzzes’ made at depth (Miller et al., 2009). This study highlights that although avoidance may not necessarily occur, potentially important behavioural changes that could impact on the energetics of individuals may occur (Miller et al., 2009).

Weir (2008a) analysed field observations from a ten month 3D seismic survey offshore Angola, and also found sperm whales did not respond in any overt way, and nor did the encounter rate or distance to sightings differ significantly between periods of seismic source activation and non-activation. What was found was that Atlantic spotted dolphins (*Stenella frontalis*) occurred at significantly greater distances during source activation, along with more neutral and negative behavioural responses recorded (Weir, 2008a). Weir (2008b) also observed the reactions of a group of short-finned pilot whales (*Globicephala macrorhynchus*) to a seismic airgun array during its initial ramp-up procedure (see section 2.3.3). After initially showing an avoidance response, the group of animals then displayed surface logging behaviour, with their direction of movement variable (Weir, 2008b). With both cases, the encounter of animals at the surface during source activation, which for sperm whales increased slightly (though not significantly), it is postulated that there may be an

element of vertical avoidance, with animals moving to the surface in order to avoid an area of the water column being ensonified (Weir, 2008a; Weir, 2008b).

A report by Stone (2003) examined data collected by MMOs aboard seismic vessels (see section 2.3.4), and documented greater ranges to three baleen species during active operations (airguns firing); minke, sei and fin whales, as well as lower sighting rates and greater sighting distances to a range of odontocetes including killer whales, bottlenose dolphins and *Lagenorhynchus* species in particular. Stone and Tasker (2006) demonstrated that small odontocetes show the strongest avoidance of active airguns, which with the observations by Weir (2008a, 2008b) is in contrast to the widely held theory that mysticetes are more vulnerable to the effects of airguns due to overlap between the peak output frequencies and likely auditory sensitivities. However, avoidance of the active arrays by mysticetes was also observed (Stone and Tasker, 2006).

1.3.3 Perceptual

The ability of an individual to perceive a sound as meaningful, such as a communication call from a conspecific, may be compromised due to an elevated background noise level such that the communication is *masked* (Tyack, 2008; Clark et al., 2009). Auditory masking may be defined as; ‘the process by which the threshold of hearing for one sound, called the *maskee*, is raised owing to the presence of another sound, called the *masker*’ (Morfey, 2001). This can be measured *in situ* by measuring the difference between ambient noise and the subsequent noise level after the onset of a particular sound and comparing with the source levels of animal vocalisations. This

reduction in the signal to noise ratio has the potential to result in the subject having communicative and social function, prey finding and navigation impaired, which may lead to changes in behaviour in order to compensate (Tyack, 2008). Such changes could include spatial avoidance, temporal avoidance, or changes to the signal strength, repetition and duration, all of which have potential knock-on effects in terms of energetics (Tyack, 2008; Clark et al., 2009).

Lemon et al. (2006) looked at the effect of powerboat approaches on bottlenose dolphins, finding that there was no likelihood of masking due to vocalisation source levels being approximately 34 dB higher than the masking threshold, despite the powerboats increasing background noise levels by 7 dB in the frequency range of whistles. However, sources such as geophysical instruments and naval sonar are far louder, increasing the chance that the ability of an animal to detect a relevant sound signal is diminished (Wartzok et al., 2003; Richardson et al., 1995).

Di Iorio and Clark (2009) demonstrated what was believed to be a response to masking from a geophysical source, whereby blue whales increased their vocalisation rate. The suggested reason for this is that this would increase the probability of the vocalisations being received by conspecifics (Di Iorio and Clark, 2009). Similar responses have been demonstrated, such as humpback whales vocalising for longer in response to sonar (Miller et al., 2000), though opposite responses have also been reported including cessation of calls from blue whales (McDonald et al., 1995), sperm and pilot whales (Bowles et al., 1994) and a reduced vocalisation rate in common dolphins (Goold, 1996).

The responses to masking marine mammal vocalisations are clearly variable, and at least in the short term it is difficult to understand the level of biological significance. However, this disruption to signals used for finding prey, navigation and social cohesion may compromise the ecological fitness of individuals, social groups and populations, depending on the scale of the effect (Gordon et al., 2003).

1.3.4 Stress

Vertebrates exhibit stress in relation to a wide variety of physiological and psychological factors that result in a generalised ‘stress response’, namely the production of stress hormones such as cortisol (Iwama et al., 1999; Kubilay and Uluköy, 2002). The stress response within fish species is well documented, with stressors ranging from natural and anthropogenic changes in water quality to handling and crowding in aquaculture systems (Iwama et al., 1999; Kubilay and Uluköy, 2002). Prolonged exposure to stressors places energy demands on the individual, whereby biochemical responses can become manifest as physiological consequences affecting individuals and therefore populations. Such consequences can include lower fecundity, immunosuppression and retarded growth (Iwama et al., 1999).

A variety of behavioural responses have been demonstrated among marine mammals to anthropogenic sound stimuli (see section 1.3.2). It is hypothesised that alongside these responses, there is also the potential for those animals to experience a biochemical stress response, similar to that demonstrated within fish and other vertebrates (Wright et al., 2007). There have been few studies investigating the stress response in marine mammals, and

those conducted have been captive studies with small sample sizes, leading Wright et al. (2007) to caution against any inference as to what the effects on wild animals may be due to the compounding stressors experienced by captive animals.

Romano et al. (2004) studied the levels of catecholamines, cortisol and aldosterone within the blood of a captive beluga whale and bottlenose dolphin before and after exposure to impulsive sounds from a seismic water gun and brief tonal sounds. A statistically significant increase in adrenaline and noradrenaline levels was found in the beluga whale after exposure to impulsive sounds, while increased aldosterone levels were found in the bottlenose dolphin, indicating stress responses from both animals (Romano et al., 2004). This is in contrast to an earlier study by Thomas et al. (1990) which found no significant increase in catecholamine (adrenaline) levels within beluga whales, though this was in response to the playback of operational sound from an oil drilling platform, rather than impulsive sounds.

1.3.5 Effects on other species

While much discussion here and in the wider context of the potential effects of underwater sound on marine life is focused on cetaceans, underwater sound may impact upon a wide range of other species, including fish and invertebrates (Popper, 2009). This directly impacts the species in question, but may have indirect impacts upon marine mammals in terms of reduced prey abundance or altered prey distribution, and also raises concern among

stakeholders such as fisheries due to potentially adverse economic consequences (McCauley et al., 2000; Gordon et al., 2003; Parry and Gason, 2006).

A similarly wide range of observed and potential effects have been documented for fish species as discussed above, including immediate death in response to high intensity sounds (Popper and Hastings, 2009). Significant damage to the sensory cells within the ears of pink snapper was demonstrated after exposure to a single airgun towed to within 15 metres of the caged fish, at a source level of 222.6 dB re 1 μ Pa @ 1m peak to peak (McCauley et al., 2003). An initial behavioural ‘startle’ response was demonstrated in sea bass during experimental passes with a 2500 cu in capacity airgun array, with pre and post biochemical analysis illustrating elevated levels of cortisol and catecholamines subsequent to exposure, indicating a clear stress response (Santulli et al., 1999). Experimental passes of an airgun array with an output of 196 dB re 1 μ Pa @ 1m within close range of coral reef fish showed a similar behavioural startle response, with increased swimming speeds and changes in direction (Boeger et al., 2006). Further, Boeger et al. (2006) noted a level of habituation to the seismic source over the course of the study, though no mortality or obvious external damage was observed.

Parry and Gason (2006) studied the catch per unit effort (CPUE) of rock lobsters in relation to seismic surveys conducted off western Victoria between 1978 and 2004, and found no evidence of a decline. A study of the effects of airguns on snow crabs also found no evidence of behavioural reactions or significant changes in catch rate (Christian et al., 2003). However, retarded development of eggs was evident, though only at very close ranges to the source (<2 m) (Christian et al., 2003).

1.4 Aims of the present study

It is widely understood that the range of marine operations have the potential to increase noise levels within the oceans at varying scales, and at levels that have the potential to result in deleterious effects upon marine species, with the principal concern being for marine mammals. This study focuses on the development and variation between methods of mitigating these potential effects in the field during operations and what further evidence and uses can be derived from field observations. Different stakeholders are likely to have differing and strong opinions about both current practice and how it should be developed in the future. By combining this developing knowledge of the pros and cons of current practice, it is then possible to work towards an enhanced method of mitigating these effects in order to improve both the conservation of marine species and ensure expediency for all stakeholders by sharing and utilising the data gathered. In order to address the foregoing, the following aim was determined;

1.4.1 Aim

To develop a framework of best practice measures relating to mitigation of the potential effects of underwater sound on marine mammals during offshore exploration and development operations, focusing on the collection, use and dissemination of accurate marine fauna sighting data.

1.4.2 Objectives

1. To critically review current mitigation measures designed to minimise the potential effects of underwater sound on marine species.
2. To review data collection in relation to its use for determining the potential effects of marine operations on aspects of marine mammal behaviour.
3. To garner opinion from stakeholders on the scientific basis, current practice and future development of mitigation guidelines.
4. To collate cetacean data in a spatial database with associated data relating to anthropogenic activities and administrative boundaries to create a planning tool to inform spatio-temporal mitigation.
5. To develop an improved methodology to manage the effects of offshore exploration and development activities on marine species.

Chapter 2. Mitigating the effects of sound

The input of noise from anthropogenic sources has the potential to impact upon marine mammals to varying extents, which has resulted in a variety of mitigation measures that are now widely used to reduce the probability of causing physical harm and to minimise the disturbance of marine mammals. The measures presented here all have common features, being largely based on the Joint Nature Conservation Committee (JNCC) guidelines introduced within UK waters in 1995, and for the most part are based on common sense assumptions such as that marine mammals will move away from an increasingly aversive sound stimulus (the soft-start). However, there is also variation among the guidelines internationally, relating to ongoing research into areas such as; the efficacy of the soft-start, what constitutes a ‘safe’ sound exposure level for different species and what distance from the source this relates to in terms of a safety zone, and mitigation methods and tools such as passive acoustic monitoring. Some guidelines are clearly more precautionary than others, while there have also been differences designed to take into account the special status of particular species, populations or local habitats.

2.1 Introduction

A growing number of nations with highly developed marine geophysical exploration activities have recognised the potential for impacts upon marine life. As seismic exploration and other industrial activities such as offshore windfarm construction increase (Jasny et al., 2005; Madsen et al., 2006), guidelines and regulations that aim to minimise disturbance and potential damage to marine mammals during seismic surveys and other operations have been formulated.

The UK's '*Guidelines for minimising acoustic disturbance to marine mammals from seismic surveys*' produced by the JNCC were the first such guidelines to come into effect (2010). Introduced in 1995, developed from a draft produced by the Sea Mammal Research Unit (SMRU), these guidelines have been used as a model by other countries when producing their own mitigation guidelines. The Brazilian guidelines for example, drew elements from both the UK and USA guidelines. In addition to this, the USA guidelines allow for the use of JNCC recording forms for all sightings. Despite this leading role, nations such as Brazil and New Zealand have perceived the need for further or enhanced mitigation methods compared to the UK (IBAMA, 2005; DoC, 2005).

This chapter examines the mitigation measures central to the various guideline documents, in order to identify the similarities, differences and deficiencies within them. Specific deficiencies for further consultation between industry, government and the environmental lobby are highlighted. Considered here are guidelines and regulations from the UK, USA (Gulf of Mexico and California), Canada, Australia, New Zealand, Brazil, Sakhalin and Ireland. Guidelines in other regions such as Alaska are currently being developed, with ongoing consultation and review a common process to all existing guidelines.

2.2 Scope of guidelines

Cetaceans form the primary focus for each of the guidelines described here as there is most concern for this group of species. There is however, variation between the countries, with some not covering all cetaceans and others covering a much broader range of marine life including seals, turtles and

finfish (JNCC, 2010; BOEM, 2012; DFO, 2005). The only guidelines that are cetacean specific, are those set out by Environment Australia. Table 2.1 summarises these and other key differences discussed below.

Despite the knowledge that seismic exploration produces high frequency sound (Goold and Fish, 1998) which may affect small cetaceans, with hearing in this range, some guidelines fail to include adequate mitigation measures. Canadian and Australian guidelines fail to include a requirement for dolphins or porpoises. New Zealand requires mitigation measures to be taken when in proximity to Hector's (*Cephalorhynchus hectori*) and Maui's dolphins (*Cephalorhynchus hectori maui*), due to specific conservation concern for these animals, but does not include others. Both Hector's and Maui's dolphins are listed as 'species of concern', a designation that includes all whales and other species that may be recommended as concern arises (DoC, 2005).

Each set of guidelines is put in place in order to implement national and/or international environmental policies. On a national basis there are acts of government such as the Marine Mammal Protection Act in the USA and the Countryside and Wildlife Act in the UK, which variously protect species against capture, harm or harassment. The guidelines discussed here fulfil the aims of such laws (the details of which do not warrant discussion here), as well as work towards fulfilling aspects of international treaties such as the United Nations Convention on the Law of the Sea, signed in 1982, which imposes a broad obligation on states to prevent and reduce *all* sources of pollution, including ocean noise.

Table 2-1; Matrix of key similarities and differences between the national guidelines for the mitigation of acoustic disturbance to marine mammals

Country/Region	UK	USA ^(GOM)	USA ^(California)	Canada	Australia	New Zealand	Brazil	Russian Fed. ^(Sakhalin)	Republic of Ireland	Greenland
Year introduced/updated	2010	2012	1999	2007	2008	2005	2005	2003	2007	2011
Applicable sound sources	Airguns, piling and explosives	Airguns	Airguns	Airguns	Airguns	Airguns	Airguns	Airguns	Airguns, multibeam and side-scan sonar	Airguns ¹
Cetacean specific?	No	No	No	No	Yes	No	No	No	Yes ²	No ³
All cetaceans included?	Yes	No ⁴	Yes	No ⁵	No ⁶	Yes ⁷	Yes	Yes	Yes	Yes
Safety zone distance	500 m ⁸	500 m	180 dB ⁹	500 m	3 km ¹⁰	1 - 1.5 km ¹¹	0.5 - 1 km ¹²	180 dB ¹³	1000 m	500 m
Sighting-free period ¹⁴	20 mins	30 mins	30 mins	30 mins	30 mins	30 mins	30 mins	?	?	20 mins
Soft-start?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Shut-down during firing?	No	Yes	Yes	Yes ¹⁵	Yes ¹⁶	Yes	Yes	Yes	No	Yes ¹⁷
Poor/no visibility soft-start?	Unrestricted	Requires PAM	Unrestricted	PAM preferred	Restricted ¹⁸	Unrestricted	Prohibited	Unrestricted	Prohibited	Unrestricted
Status of PAM	Encouraged	Required ¹⁹	Not recommended ²⁰	Encouraged	Encouraged ²¹	Encouraged	Encouraged	?	?	Required
Info. on 'sensitive' areas?	Yes	Yes	Yes	No	Yes ²²	Yes	No	Yes	?	Yes ²³

¹ While the guidelines are aimed at mitigating the potential impacts of sound from airgun arrays, the requirement is for observers to be present during 'seismic surveys'. As such, mitigation has been applied to controlled source electro-magnetic (CSEM) surveys, and analogue site surveys.

² Surveys in proximity to seal habitat may be subject to restriction for these species also.

³ The mitigation measures apply to all marine mammals. In addition, the onboard observers are required to carry out dedicated seabird observations in order to provide data to the regulator.

⁴ Shut-down procedures are for whale species only.

⁵ Dolphins and porpoises excluded.

⁶ Small cetaceans excluded.

⁷ Central measures are for 'species of concern' only.

⁸ Applicable zone for explosives is 1000 m, and for piling operations the zone must be 'no less' than 500 m, with case by case assessment based on potential sound output.

⁹ Distance of safety radius calculated using transmission loss modelling on a case by case basis.

¹⁰ 3 km is an 'observation zone' within which the presence and movement of whales is to be monitored in case of entry into the inner zones for 'power-down' and 'shut-down', the radii of which vary depending upon the source greater than or lower than 160 dB re 1µPa².

¹¹ 1.5 km observation zone. Further mitigation may be introduced at 1.5 km for groups with calves, 1 km for groups without calves and at 200 m for species not classed as 'species of concern'.

¹² A distance of 1 km is termed the 'area of guard' which should be monitored at all times and is an area that if animals are within, the soft-start must be delayed. An area of 500 m within this is termed the 'area of security', within which seismic production must cease if animals enter it.

¹³ Distance for cetaceans calculated by transmission loss modelling and verified in the field. 190 dB safety zone for pinnipeds.

¹⁴ The period of time which must be free of animal sightings in order to allow commencement of the soft-start.

¹⁵ If species encountered is listed on schedule 1, 2 or 3 of the Species at Risk Act.

¹⁶ Reduce to minimum firing.

¹⁷ The shut-down can only be implemented during the soft-start procedure.

¹⁸ Start-up may commence if there have not been 3 or more power-down or shut-down procedures within the previous 24 hour period, or if operations have not been under way for at least 24 hours combined with the presence of a spotter plane/vessel that has made no sightings of marine mammals.

¹⁹ Required in order to initiate soft-start during hours of darkness or times of poor visibility.

²⁰ Insufficient development for recommendation, but its use for detecting species such as sperm whales is recognised and therefore may be recommended for surveys in areas where sperm whales are known to be present

²¹ May be stipulated as part of survey licence, depending on the area and season.

²² The guidelines include provision for an 'adaptive management' procedure. Given temporal or spatial proximity to biologically important habitat, further mitigation may be applied, including larger mitigation zones, requirement for PAM, cessation of night-time operations if power-downs/shut-downs occur on three consecutive days and so on.

²³ The guidelines identify protection zones for 3 species; narwhal, bowhead and walrus.

Prior to the introduction of guidelines for Irish waters by the Department of Environment, Heritage and Local Government (DEHLG) in 2007, all guidelines had been focused on mitigating the effects of seismic airguns. The Irish guidelines are the first to introduce mitigation (within bay and estuary environments only) for sound source equipment used for hydrographic surveys, namely side-scan and multi-beam sonar systems (DEHLG, 2007). As such, the Irish guidelines are applicable to all acoustic seafloor surveys, and set the precedent for a further chapter in the development of similar guidelines.

2.3 Mitigation methods

2.3.1 Minimising Sound Output

The ocean environment is a noisy place for marine mammals to inhabit, with significant background noise in the 1 to 1000 Hz frequency range stemming from natural sources as well as increasing anthropogenic input (Wenz, 1962; Richardson et al., 1995). In order to limit the additional input from the seismic airgun sources, some guidelines emphasise the use of the lowest practicable volume throughout operations (DEHLG, 2007; JNCC, 2010; IBAMA, 2005). Other recommendations include seeking to reduce the level of high frequency sound output (JNCC, 2010).

2.3.2 Safety zones

To reduce the chance of causing physical damage to cetaceans, safety zones or exclusion zones around the sound source have become a key mitigation tool within any given set of guidelines. This is due to the recognition

that the potential for temporary or permanent hearing impairment in marine mammals is greatly increased within a few hundred metres of the sound source (Richardson et al., 1995). The safety zone is generally defined as the radius where received sound levels are believed to have the potential for at least temporary hearing impairment (HESS, 1999). The safety radius common to the UK, USA and Canadian guidelines and regulations is 500 m centred on the sound source, which is deemed to be the distance at which most cetaceans may be reliably observed (JNCC, 2010). However, it should be noted that the sighting distance for some species, such as the harbour porpoise may be considerably less than 500 m, depending upon weather conditions.

While this distance may be sufficient to prevent physical injury, the potential for TTS, behavioural disturbance and auditory masking is likely to extend beyond this zone (Harwood, 2002). With the range of documented disturbance reactions discussed often occurring at distances greater than 1 km, it could be argued that with significant responses occurring beyond the fairly arbitrary mitigation zone of 500 m, guidelines that include this zone are not adequately ‘minimising disturbance’. The Irish guidelines specify a 1000 m safety zone (DEHLG, 2007). These guidelines, like the others are based on the JNCC precedent, but the large safety zone represents added precaution over the 500 m norm.

The United States National Marine Fisheries Service (NMFS) has identified safety radii defined by sound pressure levels likely to cause behavioural disturbance (level B harassment) and potential physical harm (level A harassment) (MMS, 2004). An isopleth of 160 dB re 1 μ Pa rms (root mean squared) has been identified for the inducement of behavioural responses, and between 180 dB re 1 μ Pa rms (for cetaceans) to 190 dB re 1 μ Pa rms (for

pinnipeds) for the likely induction of auditory damage and other physical injury (HESS, 1999; MMS, 2004). Depending on the capacity of the seismic source and the site specific attenuation of sound, a sound pressure level of 180 dB re 1 μ Pa rms is achieved at distances varying from less than 200 m to over 1 km (Pierson et al., 1998). The NMFS requires the application of propagation loss models in order to identify where the 180 dB re 1 μ Pa rms isopleth occurs, in order for the implementation of this as the safety radius for use off California (HESS, 1999). Although not included in the Canadian guidelines, the Department of Fisheries and Oceans in the Pacific region issue letters to applicants, recommending the use of the 160 dB re 1 μ Pa and 180 dB re 1 μ Pa isopleths as safety radii (M. Joyce, pers. comm.). The guidelines from Sakhalin also require the provision of safety radii based on sound pressure levels; 180 dB re 1 μ Pa for cetaceans and 190 dB re 1 μ Pa for pinnipeds (SEIC, 2003).

The Australian Department of the Sustainability, Environment, Water, Population and Communities (formerly Environment Australia) requires that a safety zone of 3 km is monitored, though mitigation actions are only taken with a 2 km ‘low power zone’ for surveys using a source that is likely to exceed 160 dB re 1 μ Pa².s at a 1 km range (DEWHA, 2008). Such an area should easily extend beyond the distance at which a ‘safe’ sound exposure level is reached, but represents an enormous challenge in terms of reliable detection, identification and range estimation, either visually or with the aid of acoustic monitoring. Previously, only a forward facing 210° sector was monitored. Focusing observations forward and to the sides of the seismic source does not allow for animals that may surface behind the vessel, and since the guidelines were revised and reissued in 2008, 360° observations have been required (DEWHA, 2008).

The guidelines from New Zealand request that a safety zone of 1.5 km be monitored at all times, with this distance being the critical pre-firing distance in terms of implementing further mitigation methods for all species identified as ‘species of concern’ (DoC, 2005). During seismic production, further mitigation is initiated within 1 km of the source, with the exception of groups that include calves, in which case the 1.5 km radius remains. The 1 km radius is based on the sound pressure level of 180 dB re 1 µPa, assuming the use of a gun array of 2000 – 3000 cubic inch capacity (DoC, 2005). This is an oversimplification given site specific differences resulting from water depth, temperature and salinity that will affect the distance at which that sound pressure level is reached. Additionally, no information is provided within the document for contractors who may operate a larger capacity array. The increased distance of 1.5 km is based on evidence that suggests groups containing calves may be more vulnerable to disturbance (McCauley et al., 2000). For those marine species not listed as ‘species of concern’, a distance of 200 m is specified.

The Brazilian guidelines recommend a similar dual zone approach. An area of 1 km, termed the ‘area of guard’ is monitored at all times, and acts as a restraint to the start of production if this zone is breached by marine mammals. If the ‘area of guard’ is breached during production, the seismic crew are to be kept updated by the MMO in case the animals sighted move within the second mitigation zone. In addition, an ‘area of security’ is a 500 m radial source buffer, which if breached results in the shutdown of production until the ‘area of guard’ can be declared clear again for a period of least 30 minutes (IBAMA, 2005).

Case by case calculation of where a safe level of sound is achieved based on site specific sound speed profiles and airgun parameters would be of benefit in order to identify safety radii that are appropriate and precautionary.

However, safety radii must also be of a size that can be effectively monitored utilising the mitigation tools available. The calculation of safety radii based on sound levels represents a far more scientific way forward than the arbitrary designation of a 500 m radius. The 180 dB re 1 μ Pa radius used in California is termed the level ‘A’ harassment zone, representing the sound pressure level above which physical damage may occur. More recent research has indicated that higher sound levels may actually be appropriate, which serves to highlight that while it is important to use precaution when developing guidelines, research may show that it is possible to lessen the stringency of guidelines while still affording protection to species of concern to the best of current knowledge. Southall et al. (2007) categorised cetaceans into three functional groups in terms of auditory sensitivity (low, mid and high frequency), and recommended that for each group a sound exposure level of 198 dB re 1 μ Pa².s represents a precautionary injury criteria.

2.3.3 Soft-start

The term ‘soft-start’ or ‘ramp-up’ refers to the gradual build up of energy released from the seismic source from a basal level (firing of a single airgun, generally the smallest) with subsequent activation of additional sources in ascending size order over a period of 20 to 45 minutes (variation with guidelines, as per table 2.1), in order to allow animals to move away (JNCC, 2010; DFO, 2007; BOEM, 2012; Boertmann et al., 2010; IBAMA, 2005; DEWHA, 2008; DoC, 2005; SEIC, 2003; DEHLG, 2007). The California guidelines alone provide operational instruction as to the level of volume

increase at each stage of the soft-start, requiring a 6 dB per minute increase (HESS, 1999).

The soft-start procedure is based upon the assumption that animals will move away from the seismic source as the sound builds and becomes potentially more aversive, thus limiting the chance of auditory or other physiological damage, though this has not been shown experimentally (Richardson et al., 1995). Each of the guidelines considered in detail here includes a soft-start procedure, and is required to be carried out each time the guns are to begin firing, with the exception of breaks in firing of less than 30 minutes under Canadian guidelines (DFO, 2007). The guidelines from Sakhalin, the Gulf of Mexico (GoM) and Brazil prohibit the commencement the soft-start during hours of darkness or poor visibility. Under the GoM guidelines, a passive acoustic system is required in order to ensure that no cetaceans are present before the soft-start can commence (BOEM, 2012). Under each of the other guidelines, the soft-start procedure can commence at these times with no form of confirmation that the safety zone is clear of cetaceans.

The effectiveness of the soft-start method is likely to vary between species and circumstances (Pierson et al., 1998), and there is concern that this procedure may lead to habituation, as has been reported with the proximity of whale-watching vessels, as well as the use of acoustic harassment devices (AHDs) to keep marine mammals away from fishing gear (Hildebrand, 2004). AHDs have typical source levels of 185 – 195 dB re 1 μ Pa @ 1 m, and emit variable waveforms at varying time intervals in order to reduce the potential for habituation to occur (Hildebrand, 2004). However, seals have been shown to alter behaviour by lifting their heads out of the water away from the sound field in response to such devices, and harbour porpoises have been demonstrated to

habituate to similar deterrent devices within two weeks (Mate and Harvey, 1987; Cox et al., 2001). Habituation leading to long-term exposure to high sound levels may lead to chronic auditory damage (Pierson et al., 1998). However, AHDs also have the potential to be used prior to an operation in order to act as a warning to nearby mammals. This deliberate disturbance of animals in turn lowers the chance of them being exposed to potentially damaging sounds from the given operation. The JNCC are recommending that this technology be trialled during piling and explosive operations (JNCC 2010b, 2010c).

A further potential problem with the ramp-up method is the possibility of attracting animals by initially weak sounds (Pierson et al., 1998). This has been illustrated experimentally by Shapiro et al. (2006), who when exposing sperm whales to a received sound level below 160 dB re 1 μ Pa rms, found individuals orienting towards the sound source rather than moving away from it. The soft-start/ramp-up has become a standard mitigation tool, but its effectiveness in light of such findings should be the focus of further research. CEEs such as the above example represent a controversial but powerful technique for determining the response of animals to anthropogenic sound and define the real risks associated with offshore operations (Tyack et al., 2003).

2.3.4 Visual observations

This is the most commonly used method of monitoring the mitigation zone, and should be carried out by suitably trained MMOs (JNCC, 2010a; BOEM, 2012; IBAMA, 2005; ICES, 2005). The role of an MMO is to monitor for marine mammals during daylight hours within the given safety zone in order to record sightings and implement mitigation as appropriate to the given guideline.

Within some jurisdictions, it is necessary to identify the species due to differing mitigation requirements for different species.

The standard procedure is for an observer(s) to keep watch from a suitable location which allows a clear 360° view of the sea surface beginning no less than 30 minutes prior to commencement of the soft-start. This pre-watch period is 60 minutes for waters deeper than 200 m under Irish and UK guidelines (DEHLG, 2007; JNCC, 2010a). Observers scan the sea surface with the naked eye, and use 7x50 binoculars, or high powered pedestal mounted binoculars if the vessel is equipped to aid sighting and species identification (Barlow and Gisiner, 2006). The number of observers used varies between countries and the circumstances of a particular survey. In the UK, one observer is the norm, but two are required between April 1st and September 30th due to the longer daylight hours, particularly in northerly latitudes (JNCC, 2010). Brazilian guidelines require at least three observers to be aboard, in order that at least two can divide the 360° visual field, and allow rotation of duty to avoid excessive fatigue (IBAMA, 2005).

If a marine mammal is detected within the safety zone, it is the responsibility of the MMO to advise the seismic crew that further mitigation is necessary, so it is essential that an effective communication line between the MMO and party manager is established (JNCC, 2010a; BOEM, 2012; ICES, 2005; DoC, 2005; IBAMA, 2005). There are two key mitigation procedures that the MMO can request, dependent on the guidelines being implemented (see table 2-1):

1. If a marine mammal is detected within the safety zone within the pre-watch period, the soft-start must be delayed until the zone has been clear of cetaceans for x minutes.
2. The source array must be shut down if the safety zone is breached by the species covered under the given guideline document, with recommencement delayed until the zone has been clear for x minutes.

There are a number of variations to these key mitigation steps. Within Greenland waters, the soft-start procedure can be halted if the mitigation zone is breached during this procedure (Boertmann et al., 2010). Within Australia, the layered mitigation zone approach requires a two-stage power-down of the source and then shut-down, depending on the proximity of the animal (DEWHA, 2008).

The JNCC guidelines in their current form do not require a source shutdown during operations; a key mitigation measure included within the guidelines from all other countries as well as the voluntary guidelines of some companies. This represents a lack of precaution given the lack of understanding of the likelihood of habituation (Richardson et al., 1995) and the possibility that animals surfacing near the vessel have been undetected due to a deep dive and have already been subjected to a high level of sound.

MMOs working within UK and GoM waters have to undergo a short training course and follow a particular method of reporting for the observations. The JNCC and MMS specify the MMO syllabus for the UK and GoM respectively. Each syllabus contains an overview of the relevant legislation, an overview of seismic operations, a description of the role of an MMO, instructions about data recording and reporting mechanisms, and finally some tips and

information about the detection and identification of marine mammals (JNCC, 2010a; BOEM, 2012). Both syllabi lack training in the field and require no prerequisites. There is currently no equivalent course for other areas, so training is often ad-hoc, and the expertise of MMOs depends upon their background resulting in high variability. Since the observation techniques and mitigation tools are the same the world over (with the exception of details identified here, and easily conveyed during training), it would seem prudent to improve and standardise observer training, such that an observer trained in the UK is equally qualified to work offshore Canada for example, and vice versa.

2.3.5 Passive acoustic monitoring

Visual monitoring has a number of problems besides human error. Visual monitoring is not reliable at night (even with night-vision, due to reduced field of view), and during the day may be compromised by adverse weather conditions such as increasing sea state and precipitation (Richardson et al., 1995; Lewis et al., 1998; ICES, 2005; Moscrop and Swift, 1999). In addition, cetaceans spend a large proportion of their time underwater, with an example of male sperm whales demonstrated to spend approximately 80% of their time submerged (Gordon and Steiner, 1992).

Passive Acoustic Monitoring (PAM) represents an important way to overcome the issue of not being able to reliably use visual observations during hours of darkness and poor visibility. It can also augment visual observations, increasing both the likelihood and range of detection for all vocalising cetacean species, particularly deep-divers such as sperm whales and members of the Ziphiidae (Barlow and Taylor, 1997; Pierson et al., 1998; Dolman, 2004).

Comparison of visual and acoustic detection rates has shown that the combination of the two methods can increase the number of animals detected by between five and eight times, with significant numbers of animals heard but never seen (Gillespie and Chappell, 1998). Reliable passive acoustic detection is problematic for species such as the Ziphiids due to a lack of data regarding their vocalisations (Barlow and Gisiner, 2006). However, there is data for species such as the northern bottlenose whale (*Hyperoodon ampullatus*) (Hooker and Whitehead, 2002) and other large beaked whales, and a growing database of beaked whale vocalisations which when combined with advances in passive acoustic monitoring technology may result in greater effectiveness for the beaked whales (Barlow and Gisiner, 2006).

At the present time, the use of PAM technology is widely encouraged by most regulators, and a requirement offshore Greenland and in UK areas of high cetacean sensitivity (Boertmann et al., 2010; JNCC, 2010a; MMS, 2007; DEWHA, 2008; DFO, 2005; IBAMA, 2005; DoC, 2005). The New Zealand Department of Conservation for example, state that operations within areas identified as being of ecological importance should consider the use of PAM before operating at night (DoC, 2005). Within the GoM only, PAM is a requirement during hours of darkness and poor visibility, a soft-start may *only* commence if a PAM system is deployed and no cetaceans have been detected for a period of at least 30 minutes (BOEM, 2012). In this context, PAM facilitates seismic production which otherwise could not commence. Making the use of PAM a requirement in this manner encourages industry to invest in its development, such that systems become more reliable and effective, in turn supporting the wider uptake of PAM. PAM does have limitations, particularly range estimation, which of course is all important with regard to ensuring that a

mitigation zone of x metres is effectively monitored. The JNCC note this limitation and state that inaccuracies should be quantified where possible and built into the mitigation, such that an inaccuracy of +/- 300 m results in a mitigation zone (within the context of the UK) 800 m (JNCC, 2010). Significant developments are being trialled at the present time, with one of the industry's largest survey contractors, WesternGeco, exploring the utility of the entire hydrophone streamer array for detecting marine mammals during operations (Groenaas et al., 2011).

2.3.6 Temporal and spatial restrictions

The wealth of research activities in some locations has aided the identification of areas of ecological importance, based on the presence of endangered species, high cetacean diversity, general marine biodiversity, or regular aggregations of cetaceans for feeding, breeding or migrating. The key recommendation for these areas is that work be avoided at such times of the year when aggregations are known to occur. The New Zealand Department of Conservation (DoC) for example have identified six permanent and two seasonal 'areas of ecological importance' with details of their location and particular species of concern listed in the reference document that accompanies the DoC's guidelines (DoC, 2005).

The JNCC splits the UK sector into three areas with differing cetacean sensitivities. The Moray Firth, Cardigan Bay and the West of Britain are listed as being of highest cetacean sensitivity, and as such are subject to particular

requirements in terms of using experienced MMOs and a strong recommendation to use PAM (JNCC, 2010a). These recommendations are made in the consent notice issued to seismic survey contractors.

The Australian guidelines include a large number of maps displaying feeding and breeding areas and migration paths for humpback, blue and southern right whales (DEWHA, 2008). Permits are required for work within all of these areas, with additional mitigation methods recommended on a case by case basis which may include aerial or guard vessel observations of the area (DEWHA, 2008). The guidelines from Sakhalin require that seismic surveys be carried out during July, August or September. This is to avoid western grey whales, which during those times are aggregated at feeding grounds to the north of Sakhalin (SEIC, 2003).

Areas and species of ecological importance will clearly vary in terms of extent and temporal duration, and it is the responsibility of government agencies and research institutions to continue research in order to identify the best ways in which to further limit the potential impacts of acoustic disturbance on those areas and species. Agencies such as the JNCC have already begun to use the wealth of data that can be collected using MMOs to look in detail at the potential effects of acoustic disturbance as well as marine mammal distributions (Stone, 2003). This should continue, however there is far more potential for data collection and use through collaboration with the oil and gas and geophysical exploration industries, as many companies already allow the use of data collected by MMOs for academic study, for example; Repsol (R. Koemans, pers. comm.).

The further designation of Marine Protected Areas (MPAs), in order to delineate areas that are of seasonal or continual importance for a range of species represent the simplest and most effective way of ensuring that no disturbance is caused to the regular inhabitants of these areas. Furthermore, to limit the influence of marine operations in the vicinity of closed areas, it would be advisable to apply an exclusion zone to the perimeter that is of a width equivalent to the mitigation zone employed by the largest source operating in the area for each given operational season (Sobel, 1995; Hooker et al., 1999).

2.3.7 Aerial and dedicated research vessel surveys

The use of aerial surveys or surveys carried out using dedicated research vessels can be recommended on a case by case basis under the Australian, Californian and Sakhalin guidelines (DEWHA, 2008; HESS, 1999; SEIC, 2003). The goals are generally to monitor before, during and after operations, in order to obtain real-time information concerning the locations of cetaceans in relation to the seismic activity, as well as to identify important areas and any detectable changes in distribution or numbers due to the operations (HESS, 1999). Aerial surveys are limited in their usefulness during seismic surveys due to the requirement to fly at approximately 300 m altitude in order to avoid causing direct disturbance themselves, as well as the logistical constraints and high costs that are involved (Pierson et al., 1998). Within Australian guidelines, there is a particular focus on ‘adaptive management’, whereby spatial or temporal proximity to areas of important habitat may result in further mitigation requirements being placed on the operator (DEWHA, 2008).

2.3.8 Implementation of voluntary measures

As seismic exploration expands into frontier areas where there may be no guidelines in place, many industrial clients are taking the initiative to implement similar mitigation protocols on a voluntary basis. For example, the company Repsol YPF (2005) requires survey contractors to mitigate for cetaceans and pinnipeds using a 500 m safety zone, and for turtles using a 125 m safety zone. The standard pre-firing watches, soft-starts and delays in firing are implemented, with the addition of voluntary shutdown during acquisition if either safety zone is breached (Repsol YPF, 2005).

Following the advice of Environmental Impact Assessments (EIAs), many clients voluntarily use the JNCC guidelines in areas that have nothing in place. For example, the US based oil company Hess Corporation recently required the use of JNCC guidelines working offshore Libya (M. Attree, pers. comm.). Similarly, clients working offshore Angola have implemented JNCC guidelines amended for the particular conditions of the area (C. Weir, pers. comm.). Angolan waters have been identified as a seasonal calving ground and migration route for humpback whales as well as a year round nursery for sperm whales and other large species. Again, based on evidence that calves may be more vulnerable to disturbance (McCauley et al., 2000), a shutdown of production is ordered if any whale calf (excluding blackfish) breaches the 500 m source safety zone (C. Weir, pers. comm.).

The trade body representing the geophysical industry, the International Association of Geophysical Contractors (IAGC) has also developed and implemented a set of minimum mitigation measures for their members to

implement as best practice when carrying out operations in areas that are not subject to specific regulation.

2.3.9 Summary

The range of guidelines introduced have a number of common mitigation methods central to their application, but vary in the detail of factors such as the size of the mitigation zone around the sound source, as summarised in table 2-1. This has the potential to lead to confusion for operators that work in various jurisdictions due to the global nature of exploration work. This also highlights that marine species are afforded varying levels of precaution in terms of mitigation. That some companies have chosen to implement measures that are in some cases more strict than statutory guidelines such as those from the JNCC shows how seriously some elements of industry take the issue, as well as reflecting particular local concerns such as the presence of humpback breeding grounds in Angolan waters leading to special care being taken when calves are present.

Given the overall commonality, it would be of benefit to all stakeholders to have a single common set of mitigation measures to implement regardless of region, that should include an element of ‘adaptive management’ in order to take into account local conditions such as the presence of MPAs or marine species of heightened conservation concern. In order for any mitigation protocol to be effective, it should balance precaution with practicability, both for the personnel responsible for implementing the measures (such as MMOs) as well as the personnel responsible for a given operation.

The differing application of guidelines to different groups of cetaceans is based on concern for some species in particular (such as Hector's dolphins in New Zealand) a belief that due to the low frequency nature of the seismic pulse, dolphins in general need not be mitigated for in the same way as other species (BOEM, 2012). However, based on the understanding that the seismic pulse does contain significant high frequency energy (Goold and Fish, 1998) and precaution in light of demonstrable TTS in the harbour porpoise in relation to seismic sources as well as evidence of lateral spatial avoidance by small cetaceans (Stone and Tasker, 2006; Barkaszi et al., 2012), operations should implement mitigation for all species of cetacean. Guidelines such as those from the JNCC (2012a) are also applied to pinnipeds, as well as being recommended for turtles and basking sharks. A precautionary approach should be applied to the presence of marine megafauna not regularly encountered, such as manatees, dugongs, walrus and so forth, depending upon their conservation status and the operation being planned. It should also be noted that seismic surveys and other operations also take place in freshwater environments where species such as hippopotamus are present and that in the absence of research or guidelines, operators are should implement mitigation such as JNCC guidelines as best practice.

It is clear that MMOs are required in order to monitor for marine species and implement any further mitigation measures that may be applicable due to the proximity of species. The numbers of personnel on board varies, from a minimum of 1 in areas such as the southern North Sea, to a stipulation by BOEM (2012) that 3 personnel should be on board, fulfilling a four hours on; 2 hours off shift pattern. Clearly the staffing level should be appropriate to the number of daylight hours and therefore potential observation window, as well as

the common sense approach of ensuring that there is an MMO on duty at all times, allowing for comfort breaks and adequate rest between shifts. There is also the space on board a given vessel or platform to bear in mind, which in some cases may be very limited. The JNCC (2012a) currently advise that 2 MMOs should be employed when daylight exceeds 12 hours, but it would be more beneficial to have 2 as the minimum, increasing to 3 when daylight exceeds 12 hours.

The soft-start is a common-sense technique that has become ubiquitous, despite varying in length between some protocols. Research should be focused on the effectiveness of this technique, including the costs of deliberate disturbance from the use of AHDs, versus the benefit of reducing the likelihood of more significant damage to marine species by exposing them to operational sound levels. Until any clear evidence to suggest an alternative, it is recommended that the soft-start be carried out prior to operations, with the JNCC's recommendation of a 20 minute minimum and 40 minute maximum representing a workable standard.

The size of mitigation zones varies greatly depending upon the level of precaution, including dual zone approaches based upon differing mitigation requirements for different species (DoC, 2005). A dual zone approach may improve communication between mitigation personnel and operational personnel where such is lacking, in order that operational personnel are warned regarding the presence of animals when they enter an outer zone, before then having to implement mitigation measures due to an inner zone being breached. The potential zone of impact around a sound source will vary with species, but implementing different zones for different species adds complexity that should be avoided. Noise exposure criteria suggested by Southall et al. (2007) provide

an appropriate basis for setting the size of a mitigation zone, which should also be based on factors such as the marine mammal functional groups likely to be encountered during an operation as well as site specific conditions that may affect the propagation of sound. Zones calculated using these criteria should be rounded *up* to the nearest hundred metres for precaution and in order to simplify implementation. An additional 500 m secondary zone would be a useful precautionary measure in order to improve communications as mentioned, such that all parties within an operation are aware of when further mitigation is necessary. It should be noted that there are a variety of factors which affect the distance at which cetaceans may be sighted, including species size, sea state, glare, viewing height above sea level and so on (Barlow et al., 2001). The detection of small cetaceans at large ranges will be compromised, reducing the effectiveness of large mitigation zones for smaller species.

PAM is currently the only reliable tool for use during hours of darkness and poor visibility. The shortcomings of this technology are well known in terms of having poor low frequency ability and being restricted to vocalising animals by its very nature, but investment is improving its capabilities (Groenaas et al., 2011). In order to mitigate at times when visual observation is not possible, PAM should be utilised. This would represent the use of best available technology (BAT).

Shutting down of the seismic source due to the proximity of marine mammals during operations is a common mitigation method used in a number of areas, for example, the GoM (BOEM, 2012). This procedure is not ubiquitous however, based on the assumption that animals moving toward an active operation are not disturbed or harmed by it. In light of the uncertainties and the potential for animals to become habituated, leading to the potential for chronic

exposure (Pierson et al., 1998), it would be prudent to have a shutdown procedure.

Drawing upon the protocols discussed, these points represent the basis of a common protocol for large scale marine seismic operations. Greater specificity would be required for different types of operations such as site surveys and vertical seismic profiling. Adaptive management measures should be applied on a local basis in order to factor in the perceived risks to local populations of species that may be of conservation concern, the proximity to MPAs and operation being planned.

Chapter 3. MMO data collection, data quality and analysis

The previous chapter introduced the various mitigation measures that may be implemented during seismic surveys and other operations in order to mitigate the potential effects of sound upon marine species. The role central to the implementation of these methods has become the MMO. Sighting observation data collected by MMOs results in a body of information from each survey detailing what species were seen, where and when, as well as information relating to how those species behaved in relation to the operation. In this chapter, the method of data collection is critiqued, by reviewing a dataset collected by MMOs of variable training levels and assessing how that data can be utilised for answering questions relating to how marine species react to seismic surveys.

Data was found to vary in quality based on whether the MMO was trained and dedicated to the role, or a crew member working as an MMO. The distance to sightings was found to vary with the status of the seismic source, with that distance significantly greater when the source was active for both long-finned pilot whales and Atlantic white-sided dolphins. No significant differences were found between behavioural states when the seismic source was either active or inactive.

3.1 Introduction

Since 1995, marine geophysical surveys within the United Kingdom exclusive economic zone (EEZ) have been conducted in accordance with the *Guidelines for minimising acoustic disturbance to marine mammals from seismic surveys*, administered by the JNCC (2010). Under these guidelines, geophysical vessels are required to carry at least one trained MMO in order to monitor for the presence of marine mammals, and implement further mitigation depending upon the proximity of that mammal, as described in Chapter 2. In this role, the MMO compiles data relating to vessel operations, survey effort and location, as well as a range of information for each marine mammal sighting.

Unlike a dedicated research cruise with observer teams and strict protocols, the data collected by MMOs will vary greatly between observers, as there are no pre-requisites to becoming an MMO with the exception of JNCC sanctioned (or similar within the jurisdictions of the relevant agency in other countries) basic training which includes an introduction to seismic survey techniques and marine mammal identification. Further, depending upon the licence conditions for a survey, ship's crew may be able to perform observation duties without training. Stone (2003) details this variation by job type, with a higher percentage of recording forms correctly filled in by dedicated (trained) MMOs than by ship's crew asked to perform MMO duties. Dedicated MMOs were also found to record a greater range of behavioural categories than ship's crew (Stone, 2003). The observing of marine species such that species identification and interpretations of their behaviours are accurate is a product of experience and education. Therefore, the uses of MMO data for detailed analyses may be limited to a small percentage of an otherwise large dataset.

Acting on the advice of environmental impact assessments or in order to comply with an oil company client's corporate environmental policy, many geophysical contractors have implemented the JNCC guidelines in a variety of locations outside of UK waters either in part (recording of marine mammal sightings by bridge crew, and/or implementation of soft start procedures), or fully (implementation of delays to seismic source activation due to marine mammal proximity). Much of the data collected by contractors is returned to the JNCC, as this organisation represents a repository that may collate and use such data.

This data is collected using three standard recording forms developed by the JNCC and regularly updated;

- Record of Operations – a daily log of information detailing the hours of seismic operations and related mitigation action
- Location and Effort – a log of MMO effort in relation to meteorological conditions which is completed at the start and end of watches, and also when weather conditions change
- Record of Sightings – completed each time a marine mammal (or other species being mitigated for) is sighted

In June 2012 the forms were updated and now include a further 'Cover Page' that records summary information about the geophysical survey. The data forms available within Appendix 2. Earlier versions of the forms had fewer form fields.

The data collected by MMOs working within UK waters has previously been studied in order to assess the implementation of the guidelines and elicit the effects of geophysical surveys upon marine mammals (Stone, 2003; Stone

and Tasker, 2006). The results demonstrated disturbance to cetaceans, though there was considerable variability between species and it remains unclear to what extent the disturbance may have long-term population level effects.

The aims of this chapter are to;

- Assess the quality of the sighting data and comment on the effectiveness of MMOs in the collection of sighting and behavioural data.
- Assess critical sighting information such as distance from source in relation to vessel activity and observer, in order to identify potential differences between times of seismic source activity and inactivity, as well as differences between trained and non-trained observers.
- Explore behavioural responses of mammals in relation to the status of the seismic source.

3.2 Methodology

A set of MMO data consisting of over 300 hand-written JNCC sighting sheets. The data represents a useful resource of geographically referenced marine mammal sightings, behavioural observations, as well as a qualitative indication of the uptake of precautionary mitigation measures in regions where there is no requirement by a government agency such as the JNCC.

The data spans a period from 1996 to 2005, and is made up of observations by professional observers hired to implement mitigation guidelines in some areas, as well as opportunistic sightings by crew members and the

dedicated efforts of crew members implementing best practice on behalf of clients in areas lacking regulation. During that time period, the data forms have changed to some degree, with additional data fields being added over time. Additionally, the official JNCC forms were not always used to record data, with companies adapting the forms and producing their own versions, which have the same content.

To facilitate analysis, the dataset was first digitised from the raw paper recording sheets. The data is concentrated in six regions (Table 3-1), collected during a variety of seismic operations. The process of entering this data allowed for quality control in terms of the completeness and accuracy of the data from some surveys. As Stone (2003) found, recording sheets were not always completed in their entirety or correctly, depending upon the training and experience of the MMO. While an MMO has three data sheets to complete (to record sightings, observation effort and vessel operations), only sightings are considered here due to the incomplete nature of the effort and operations data.

Table 3-1; Geographic regions of data coverage. Sighting reports were categorised into broad regions, with example countries of data origin listed.

Region	Countries	Number of sighting reports
South Atlantic (SA)	Falkland Isles, Brazil	23
Gulf of Mexico (GoM)	USA	7
Northwest Atlantic (NWA)	Canada, Greenland	80
Northern East Atlantic and Europe	Ireland, Netherlands, Norway	180
Mediterranean and Black Seas (MBS)	Georgia, Algeria, Libya	3
West Africa (WA)	Gabon, Angola, Namibia, Ghana	85

A quality assessment whereby data was assigned a quality grading from 1 (highest) to 3 (lowest) based on the following criteria was carried out;

- Role of the observer – data were either collected by a trained MMO, or alternative personnel with unknown training relating to marine mammal observation.
- Coordinate accuracy – coordinates need to have been recorded in a clear format and include at least degrees and minutes.
- Data completeness – 3 categories were used to grade completeness; > 90%, 80-90% and <80%.
- Evidence of copying and pasting such as positions, times or other information unlikely to be repeated in a series of consecutive sightings was automatically graded as quality 3.

Data could only be assigned a maximum quality grading of 1 if collected by an MMO, if the coordinate accuracy criteria was met, and over 90% of form fields were complete. If the data was collected by an MMO, with 80-90% of the form fields being complete, or a non-MMO with over 90% complete, this data was given a grade 2 rating. Data collected by an MMO, but with less than 80% forms fields completed, or by a non-MMO with less than 90% form fields completed was given a Grade 3 rating. These gradings are summarised in table 3-2, below.

Table 3-2; Data quality grading summary

Quality grading criteria met	Quality grading
Data collected by a trained MMO, coordinate accuracy met, >90% form fields complete.	1
Data collected by a trained MMO, coordinate accuracy met or not, 80-90% form fields complete.	2
Data collected by a trained MMO, coordinate accuracy not met, <80% form fields complete.	3
Data collected by personnel of unknown training, coordinate accuracy met, >90% of form fields complete.	2
Data collected by person of unknown training, coordinate accuracy met or not, <90% of form fields complete.	3

Due to the varying quality of the data, some was excluded from certain analyses. For example, all data graded as quality 3 was excluded from the analysis of behavioural observations in relation to vessel activity.

3.3 Results

3.3.1 Sightings summary

A total of 43 separate species categories have been recorded, including 29 species categories, 3 different categories for mixed species sightings, 2 categories for fin whales that cover the possibility of the sighting being a similar species, and 10 ‘Unidentified’ categories. The most commonly sighted toothed whale species were sperm whales (*Physeter macrocephalus*) and long-finned pilot whales (*Globicephala melas*). Common dolphins (*Delphinus delphis*) and Atlantic white-sided dolphins (*Lagenorhynchus acutus*) were the most frequently

sighted delphinids (see Figure 3-1). Of the baleen species, fin whales (*Balaenoptera physalus*) and Bryde's whales (*Balaenoptera brydei*) were the most frequently sighted (see Figure 3-2). The two most common 'unidentified' categories were 'unidentified dolphin', and 'unidentified whale' (see Figure 3-3). A small number of sightings of other species were recorded, including grey seals and leatherback turtles.

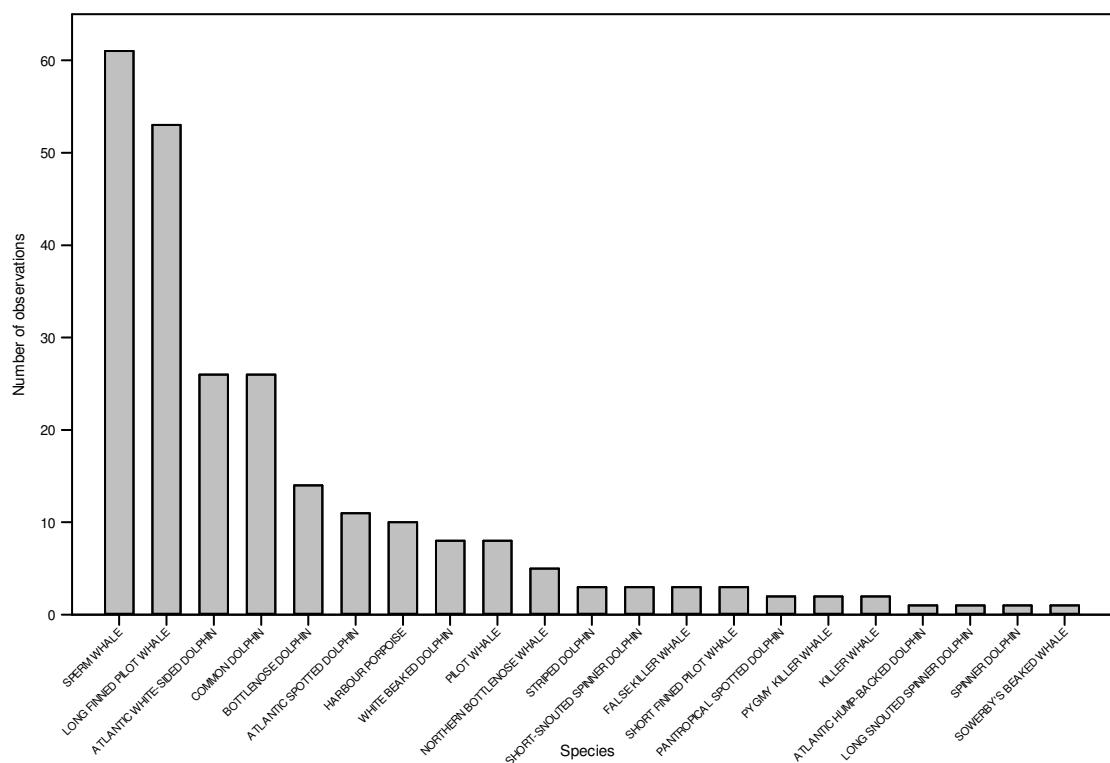


Figure 3-1; Frequency of odontocete species observations.

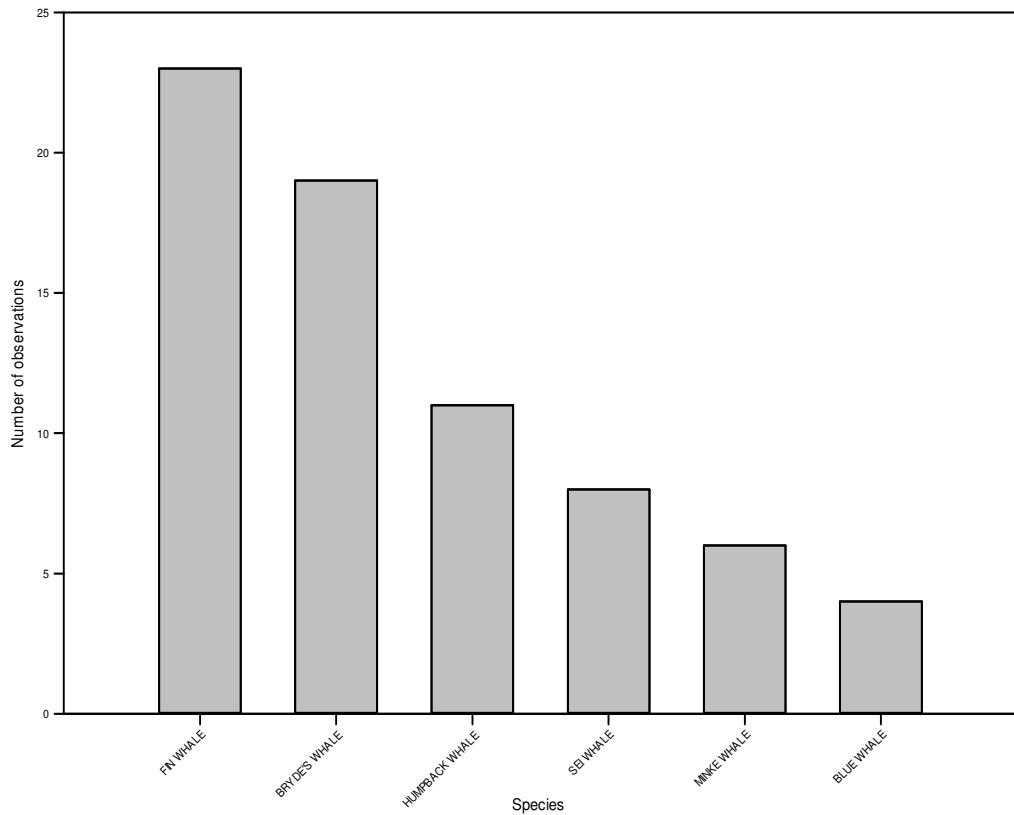


Figure 3-2; Frequency of mysticete species observations.

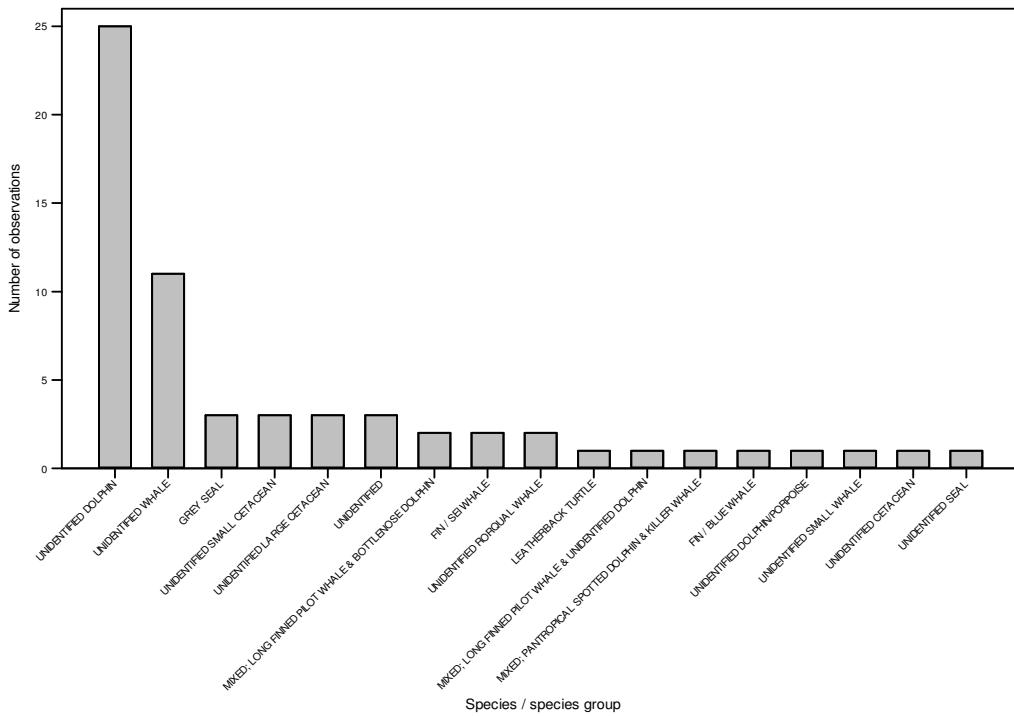


Figure 3-3; Frequency of observations for other marine species, mixed groups and unidentified cetaceans.

3.3.2 Observer summary

As shown in Figure 3-4, the majority of the data was collected by dedicated MMOs (63%). The second largest category of data was recorded by unknown crew members (27%), and the remainder of the data was recorded by the Fisheries Liaison Office (FLO) and other bridge crew. These can include a variety of personnel such as vessel Captains, Officers of the Watch, as well as survey personnel such as the oil company ‘Client Representative’. Only the MMOs are known to have received at least JNCC MMO induction training, so 63% of the data can be said to have been collected by trained individuals. The remaining 37% are assumed to have been collected by non-trained personnel, though it is possible that they could have received in-house training and familiarisation which cannot be confirmed or compared with the JNCC course.

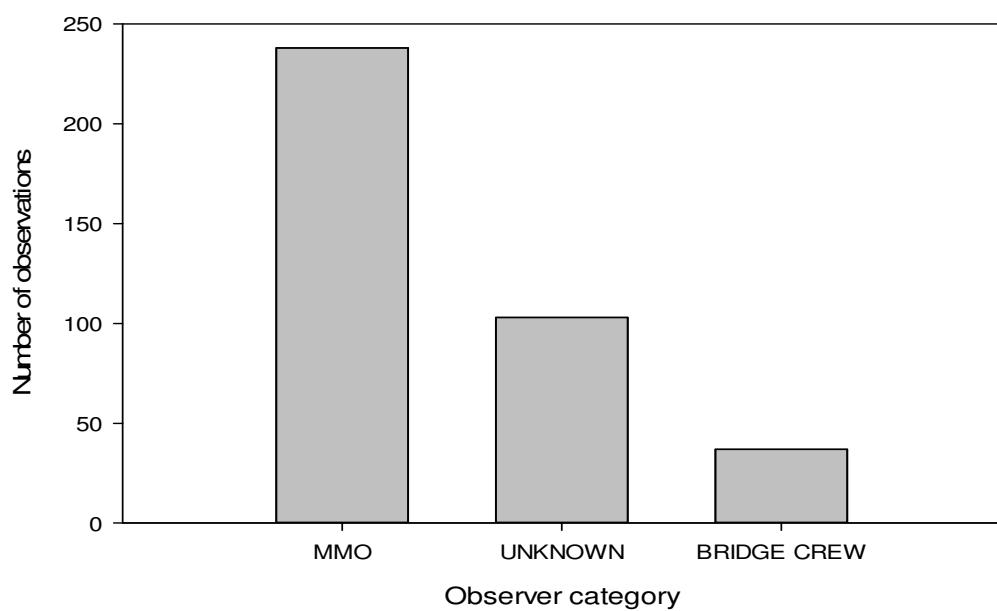


Figure 3-4; Frequency of observations per observer category.

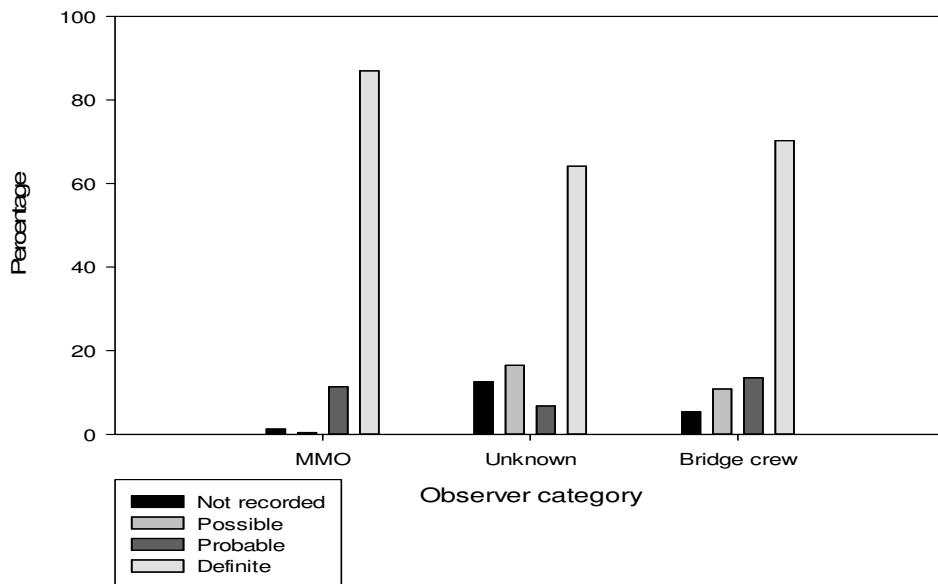


Figure 3-5; Percentage of observations by species identification certainty level between the three observer categories.

Trained MMOs recorded the certainty of their species identification as 'definite' more than other observer groups, with 87% recorded as definite, see Figure 3-5. Unknown and Bridge crew observers (untrained) still recorded high percentages of 'definite' species identifications (64% and 70% respectively), but also recorded more species identifications as 'probable', 'possible', or provided no record at all. Unknown observers did not record a measure of certainty for the species identification more often than either bridge crew observers or MMOs.

3.3.3 Sighting report quality

Fifty one percent of the data was graded as quality 1, making it eligible for all subsequent analyses. A reasonably high percentage of the data (34%) was graded quality 3, due to incomplete form fields and obvious transcription

errors where repeated forms had the same values for items such as position, number of adult and juvenile animals within sighted groups and so forth, lowering the confidence that the data has been accurately recorded. Of the data graded quality 2, 83% of sightings were made by MMO personnel, while no data within the quality 3 category was recorded by MMOs.

Positional accuracy was high overall, with all data meeting the necessary criteria in terms of being completed in a format that could be understood and transcribed, as well as being recorded to degrees and minutes accuracy. Seventy percent of positional data was recorded to a greater accuracy including seconds or decimals of a minute.

3.3.4 Sighting distance in relation to seismic source activity

Data for the distance to sighting is not normally distributed (Kolmogorov-Smirnov goodness of fit test; 0.193, $p < 0.01$). Of 378 recorded sightings, no distance to sighting was recorded for 27 observations. The average distance to sighting was 1282 m. Figure 3-6 shows the distance to sighting for all species, and then separately for odontocetes and mysticetes when the seismic source was inactive and active. The ‘all species’ and ‘odontocete’ histograms show that more sightings were at greater distances during times when the seismic source was active.

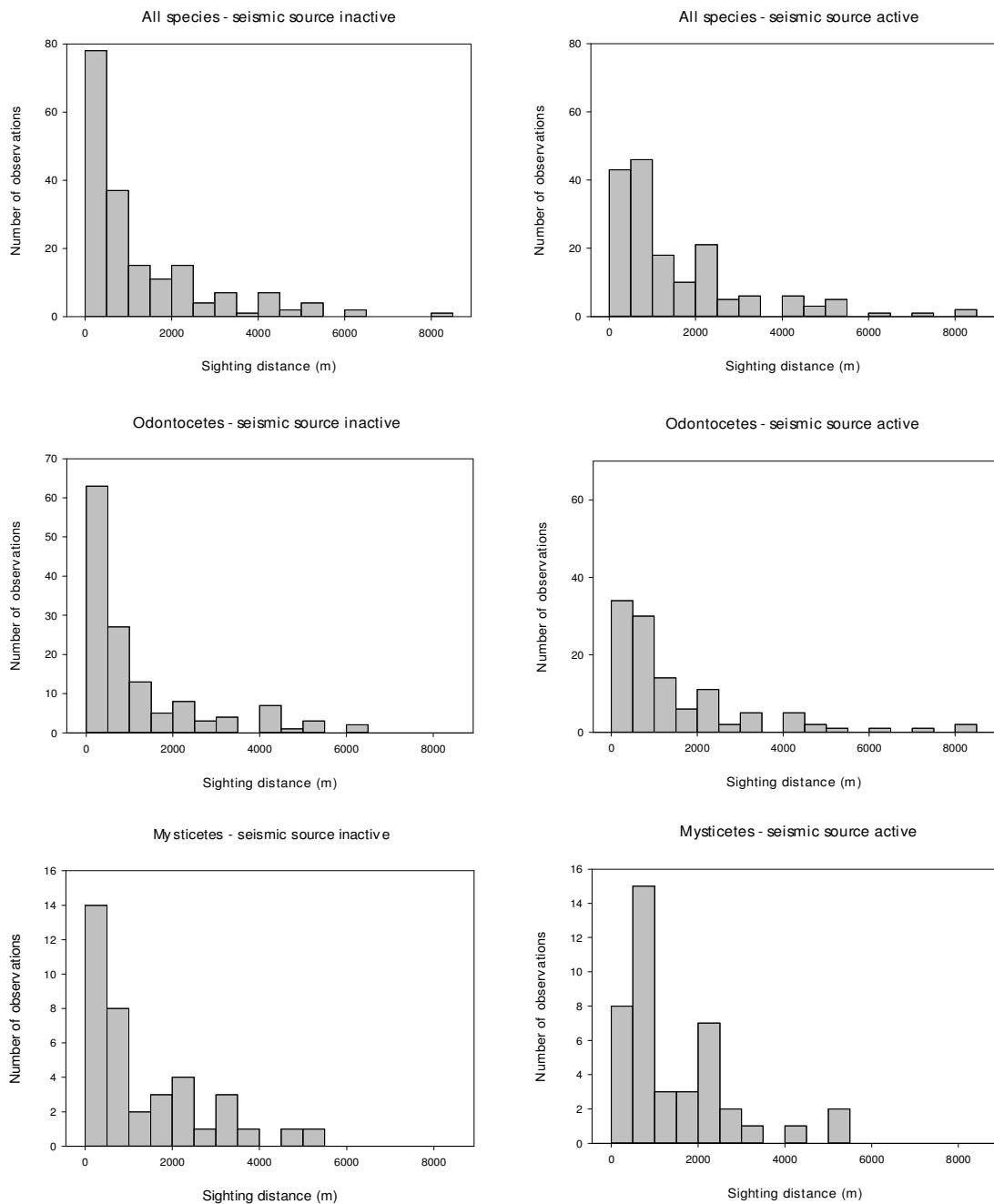


Figure 3-6; Histograms illustrating the frequency of observations against sighting distance for all species (top panels), Odontocetes (middle panels) and mysticetes (bottom panels), during times when the seismic source was inactive (left panels) and active (right panels).

Taking the dataset as a whole, and looking at the sighting distance in relation to the status of the seismic source, shows a significant difference, with sightings occurring at a greater distance when the seismic source is active (Kruskal-Wallis test; $n = 351$, $H = 6.16$, 1 d.f., $p = 0.013$). The median sighting

distance for when the source was inactive was 600 m, and 800 m for when the source was active. Figure 3-7, below compares the data under the two seismic source conditions, highlighting the minimum sighting distance recorded, 1st quartile, median distance (2nd quartile), 3rd quartile and maximum sighting distance recorded. As can be seen in Figure 3-7 and subsequent boxplots, the data contains a number of outliers, with sightings at significant distances, outside of the range of the bulk of the data.

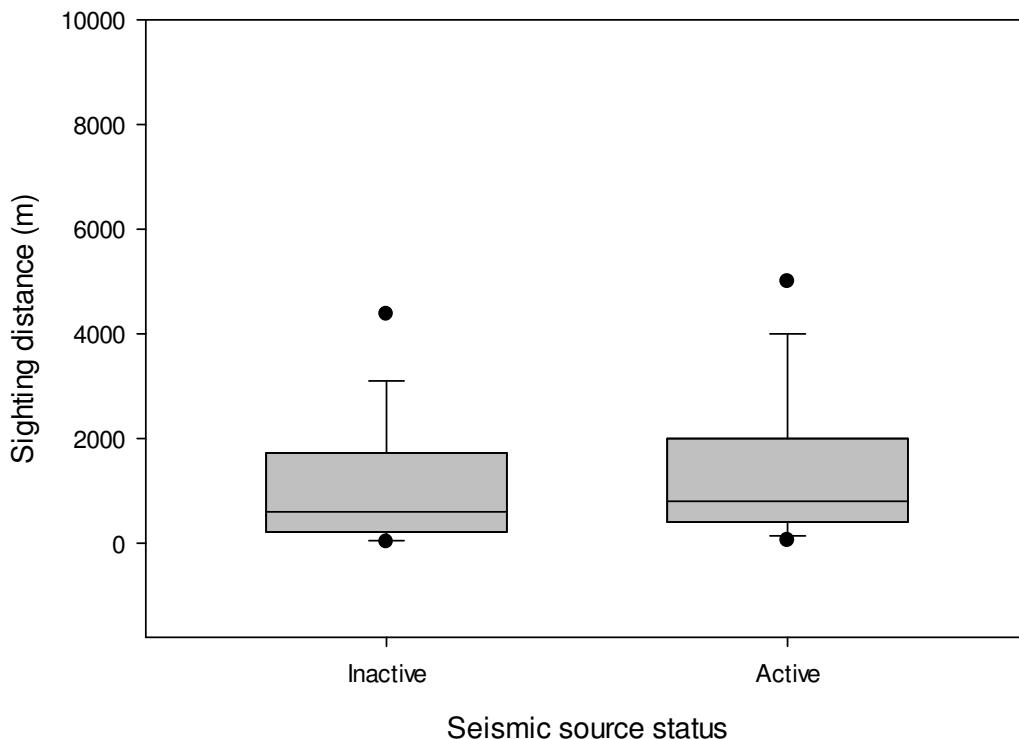


Figure 3-7; Boxplot showing comparative distance to sighting for all observations during inactive and active seismic source conditions.

Comparing the distance to sighting in relation to seismic source status for odontocetes and mysticetes separately was carried out. ‘Unidentified dolphins’ were classed as confirmed odontocetes, and ‘unidentified rorqual whales’ were classed as confirmed mysticetes. All other ‘unidentified’ observations were

excluded from further analysis in order to not introduce variability caused by unconfirmed species or species group identification.

Comparison of odontocete and mysticete groups showed a significant difference, with odontocetes sighted at greater distances when the seismic source was active (Kruskal-Wallis test; $n = 250$, $H = 4.91$, 1 d.f., $p = 0.027$).

Figure 3-8 and Figure 3-9 summarise the distance to sighting related to seismic source status for the two groups. Odontocetes were sighted at a mean of 1075 m and median of 500 m when the seismic source was inactive, compared to a mean of 1351 m and median of 600 m when the source was active.

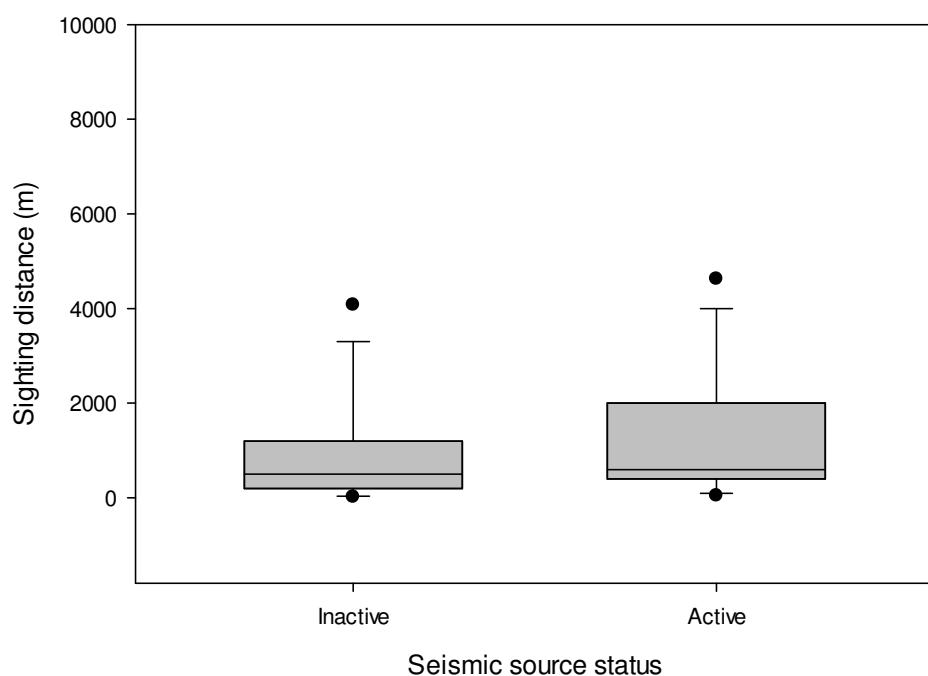


Figure 3-8; Boxplot showing comparative distance to sighting for odontocete observations during inactive and active seismic source conditions.

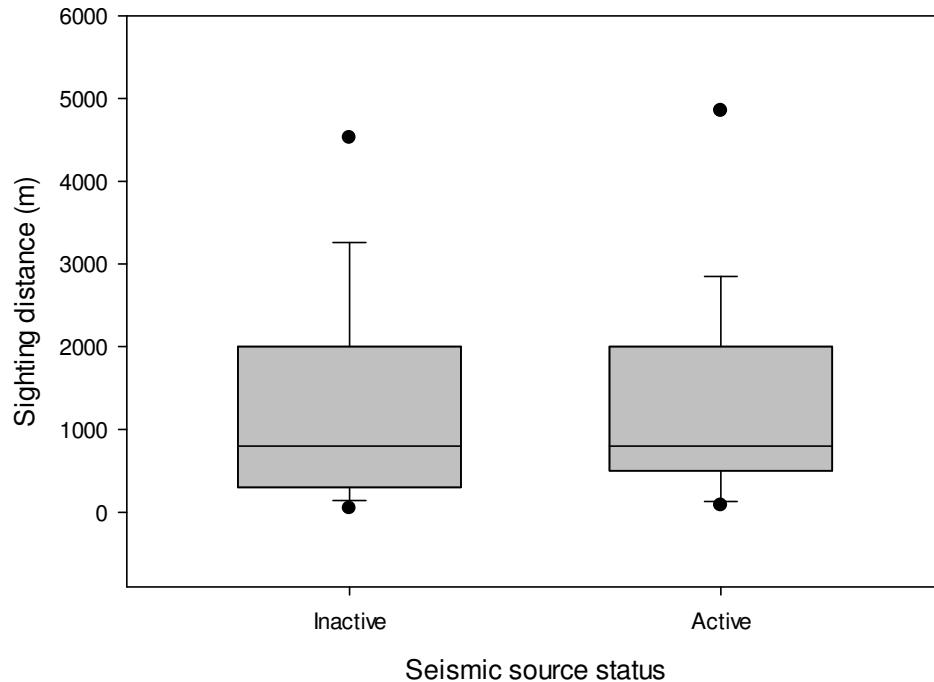


Figure 3-9; Boxplot showing comparative distance to sighting for mysticete observations during inactive and active seismic source conditions.

Using a minimum sample size of 5 observations per species for the seismic source status, it was possible to carry out further analysis for 6 species; 2 mysticetes (fin and Bryde's whales), 2 large odontocetes (sperm and long-finned pilot whales) and 2 delphinids (common and Atlantic white-sided dolphins).

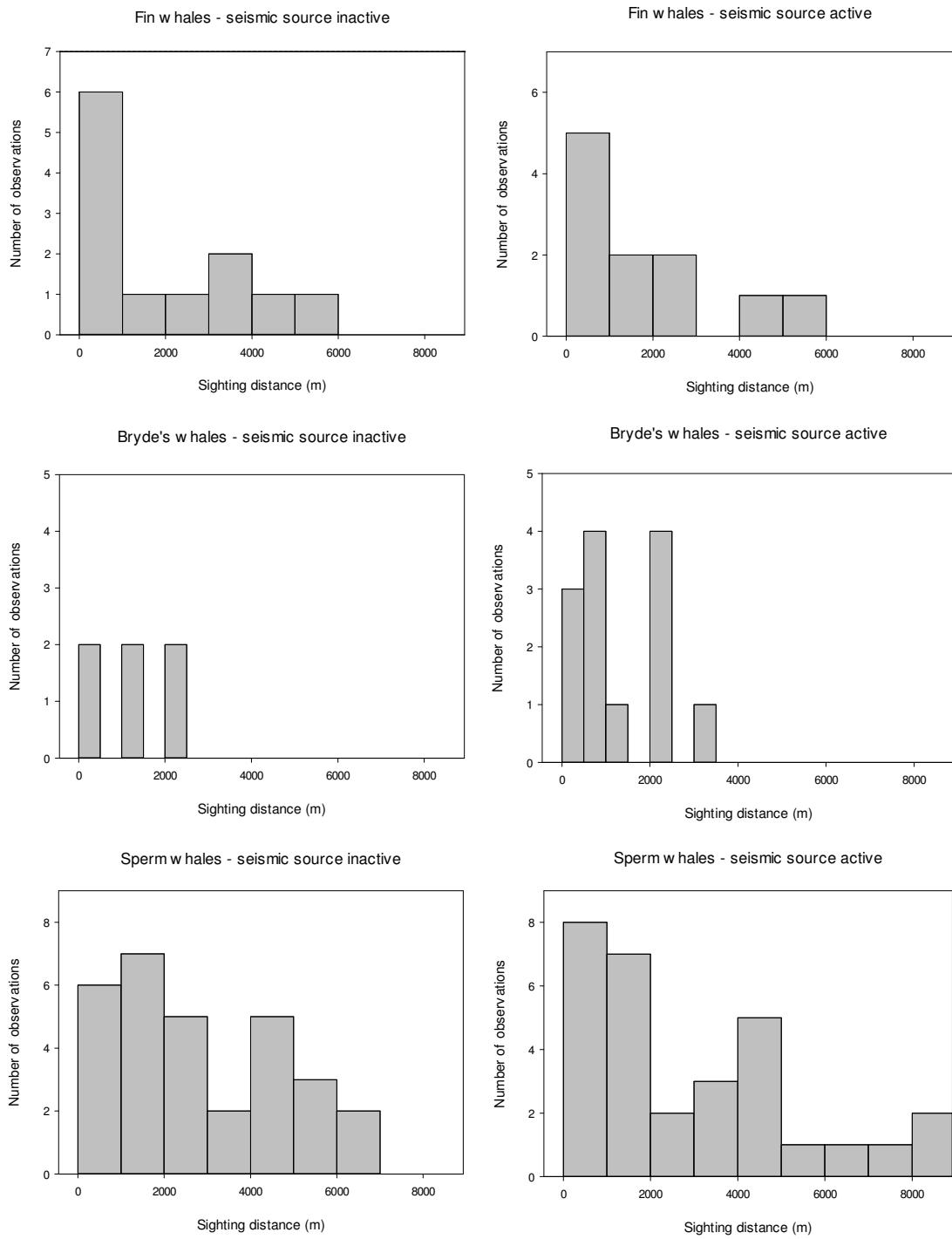


Figure 3-10; Histograms illustrating the frequency of observations against sighting distance for fin (top panels), Bryde's (middle panels) and sperm whales (bottom panels), during times when the seismic source was inactive (left panels) and active (right panels).

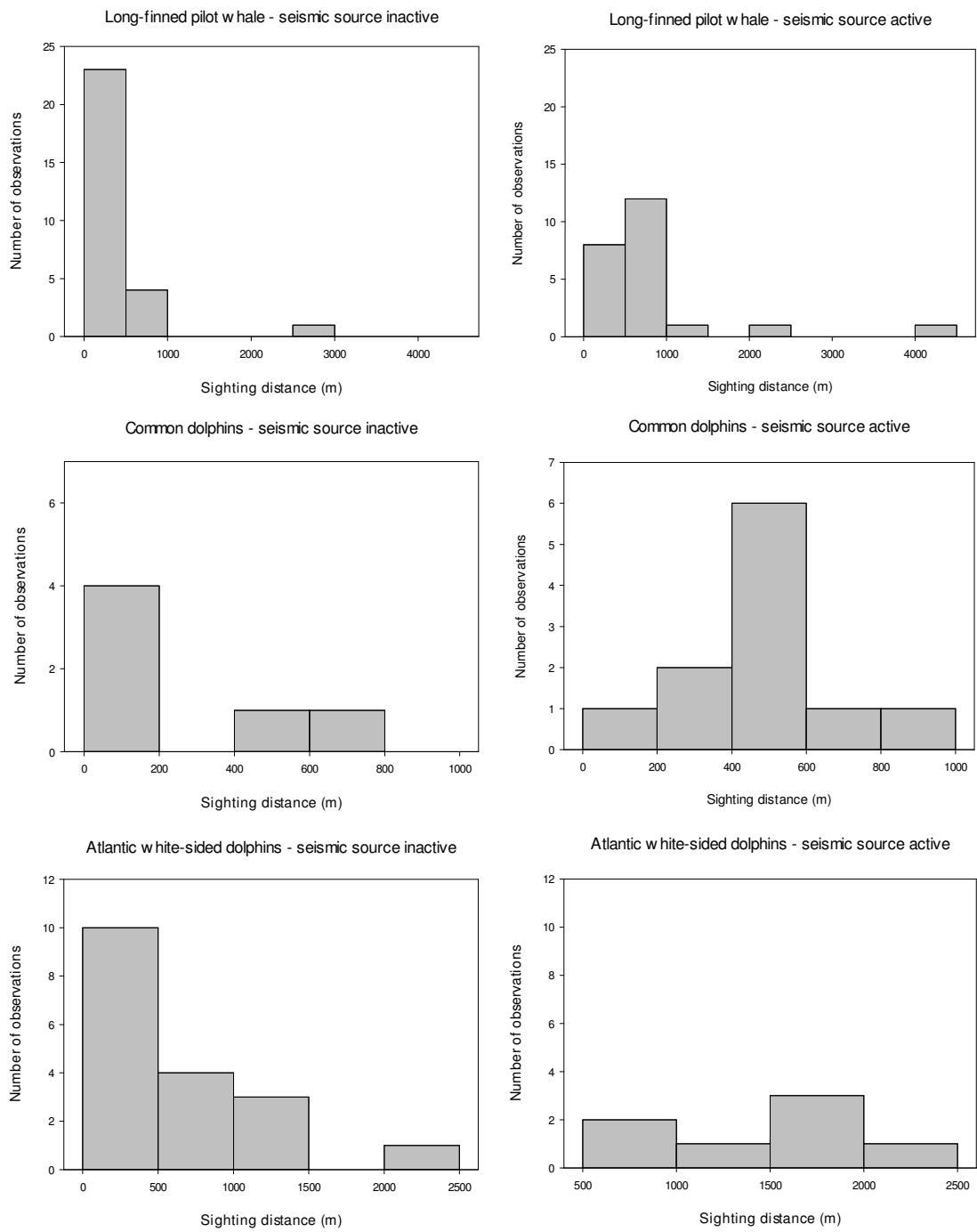


Figure 3-11; Histograms illustrating the frequency of observations against sighting distance for long-finned pilot whales (top panels), common dolphins (middle panels) and Atlantic white-sided dolphins (bottom panels) during times when the seismic source was inactive (left panels) and active (right panels).

Figure 3-10 and Figure 3-11 summarise the distance to sightings for these six species under inactive and active seismic source conditions. For each data set, the data was not normally distributed, and so the non-parametric Kruskal-Wallis statistic was used again to compare the results under the two seismic source conditions; inactive and active. A statistical analysis comparing the distributions of these data are summarised within Table 3-3 below.

Table 3-3; Results of a statistical comparison of distance to sighting in relation to seismic source status for 6 individual species.

Species	Kruskal-Wallis test result	Significance
Fin whale, <i>Balaenoptera physalus</i>	n = 23, H = 0.05, 1 d.f., p = 0.829	Not significant
Bryde's whale, <i>Balaenoptera brydei</i>	n = 19, H = 0.03, 1 d.f., p = 0.861	Not significant
Sperm whale, <i>Physeter macrocephalus</i>	n = 60, H = 0.04, 1 d.f., p = 0.848	Not significant
Long-finned pilot whale, <i>Globicephala melas</i>	n = 51, H = 10.60 1 d.f., p = 0.001	Significant
Common dolphin, <i>Delphinus delphis</i>	n = 17, H = 2.59, 1 d.f., p = 0.108	Not significant
Atlantic white sided dolphin, <i>Lagenorhynchus acutus</i>	n = 25, H = 7.92, 1 d.f., p = 0.005	Significant

Both long-finned pilot whales and Atlantic white-sided dolphins were seen at greater distances when the seismic source was active. For long-finned pilot whales, the mean sighting distance increased from 335 m to 693 m, and the median from 200 m to 500 m. For Atlantic white-sided dolphins the mean

sighting distance increased from 567 m to 1271 m, and the median from 425 m to 1500 m. Figure 3-12 and Figure 3-13 compare the distance to sighting related to the seismic source status for these two species.

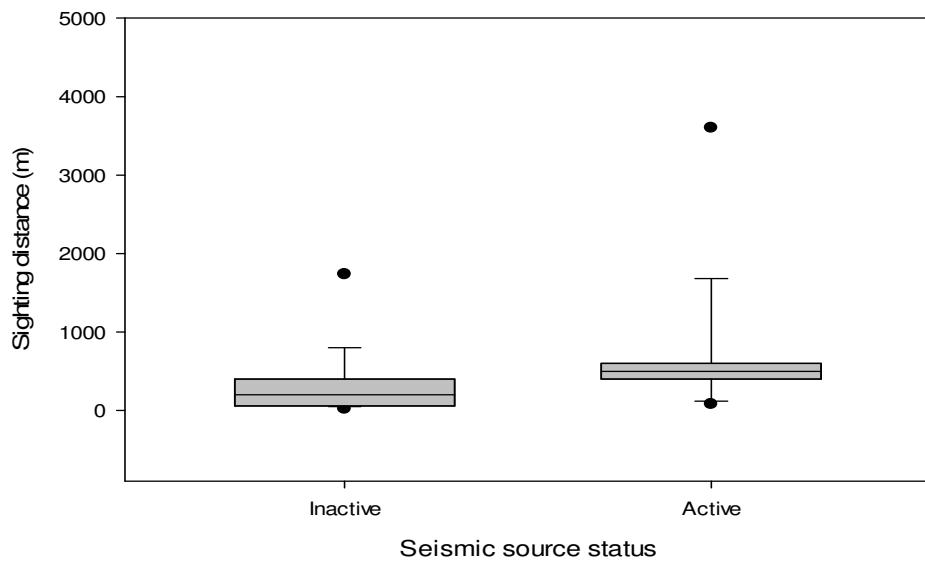


Figure 3-12; Boxplot showing comparative distance to sighting for long-finned pilot whale observations during inactive and active seismic source conditions.

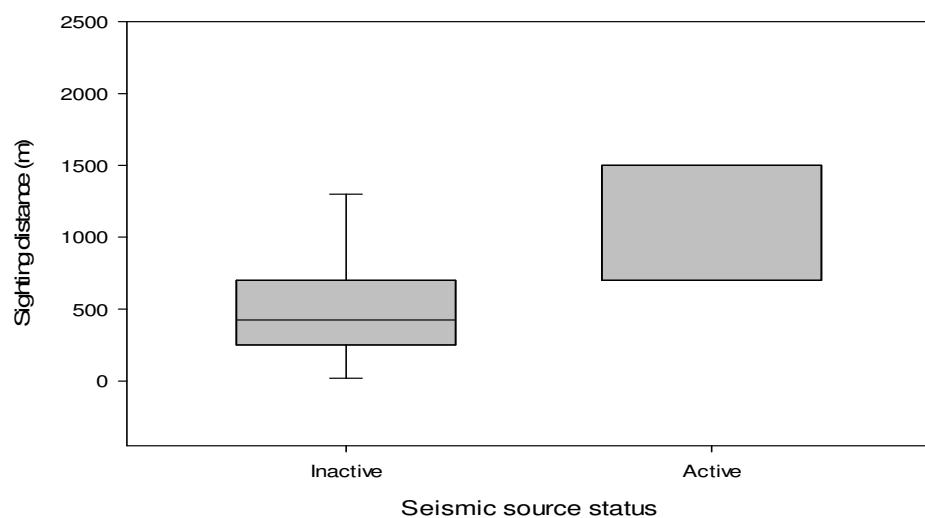


Figure 3-13; Boxplot showing comparative distance to sighting for Atlantic white-sided dolphin observations during inactive and active seismic source conditions. The box for sightings when the source was active is based on a small sample size (n=7).

3.3.5 Behaviour in relation to seismic source status

The recording of behavioural data was highly varied. A total of 36 different behaviours were recorded, with different terms used to describe what could be interpreted as the same behaviours, variations in speed and direction for behaviours such as swimming, and general comments such as 'maintaining distance from vessel'. For this section of the data analysis, all data graded 2 or 3 was excluded, leaving a total 191 observations. Of these, 106 were made during times when the seismic source was inactive, and 85 were while the seismic source was active.

Figure 3-14 below, shows the frequency of behaviours recorded for all species. There are few large differences in the frequency of observed behaviours, though 'surfacing' is more apparent when the seismic source is inactive, as is both 'slow' and 'fast' swimming. Incidences of animals being noted as 'turning away from the vessel' were only recorded when the seismic source was inactive. The sample size for most behaviours was too low to allow for statistical comparison. However, when comparing the frequency of 'blowing', 'logging', 'swimming' and 'fast swimming' between times when the seismic source was inactive and active, no significant differences were found ($\text{Chi-Sq} = 5.468$, d.f. = 3, P-Value = 0.141).

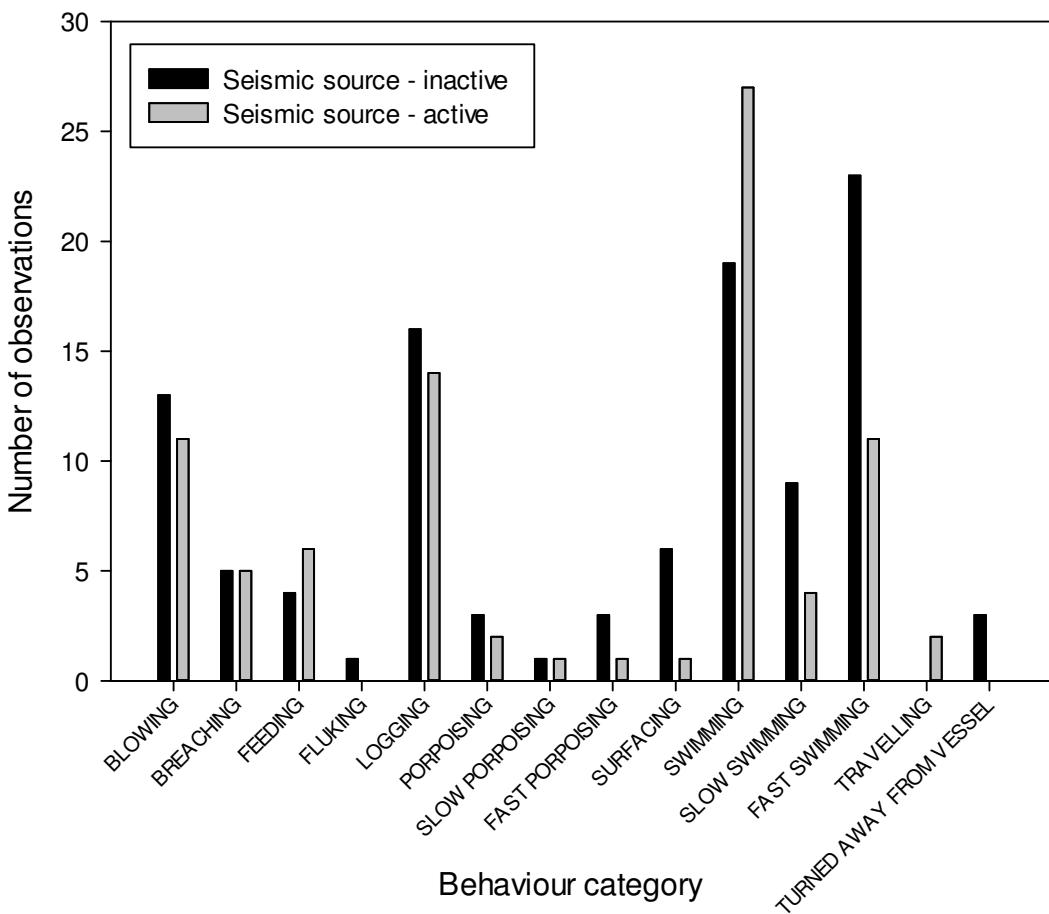


Figure 3-14; Frequency of behaviours recorded for sightings while the seismic source was inactive and active.

3.3.6 Directional movement in relation to seismic source status

While the bearing to a sighting either based on compass points or in relation to the vessel was recorded widely within the dataset, clear information regarding any changes to directional movement was sparse. Directional information was missing from 46 records, due to the recording of stationary behaviours such as ‘logging’ or behaviours where from brief observations, direction may be hard to identify, such as ‘surfacing’. It was possible to discern a directional change for only 53 observations. Of those, the polarity could be

assigned as positive (toward the vessel), or negative (away from the vessel) for 47 observations. Excluding all quality 3 data, left 26 usable observations. As shown in Figure 3-15, more cetaceans are observed as moving away from the vessel when the source is active. When the source is inactive, there is little difference in the number of observations of animals moving either towards or away from the vessel. This observed relationship cannot be tested statistically due to the low sample size. For the vast majority of records, no discernable directional change was evident.

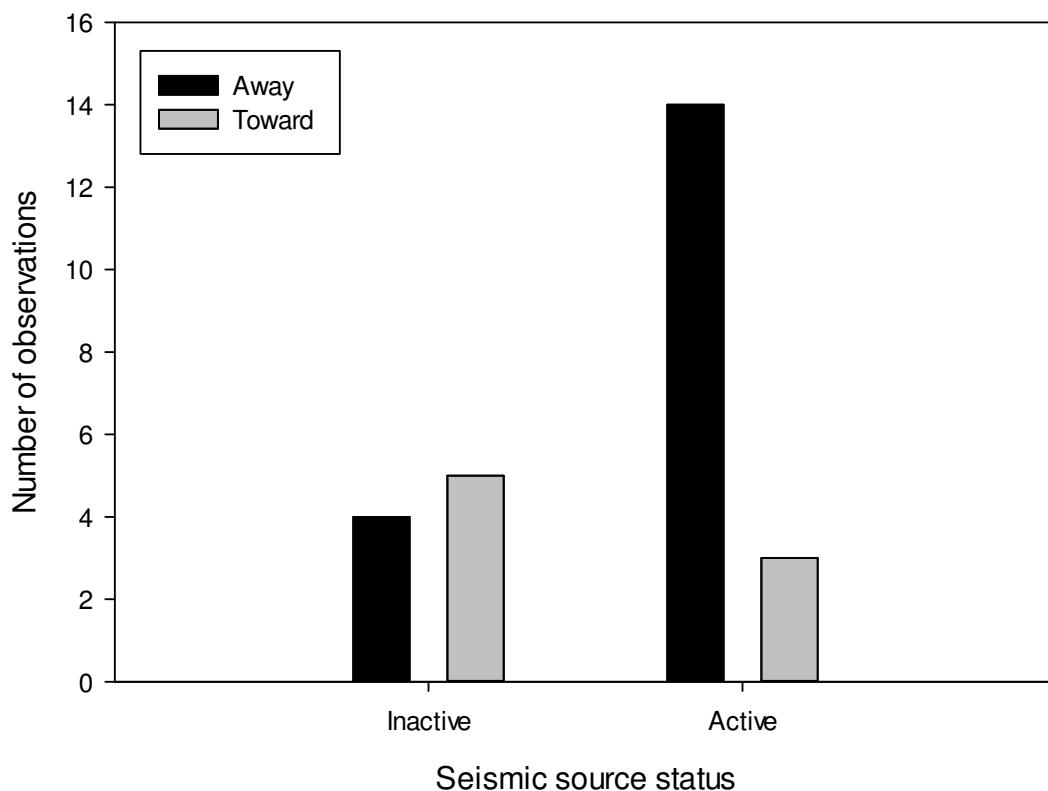


Figure 3-15; Comparison of directional movements in relation to the vessel by seismic source status.

3.4 Discussion

3.4.1 MMO data quality and usage

The quality of the data collected in this study has been shown to vary depending upon the training level of personnel collecting that data. Unsurprisingly, data collected by personnel known to have undergone an MMO induction course is more complete than that collected by other personnel, as has been demonstrated in the past (Stone and Tasker, 2006). The MMO training course is designed to familiarise personnel with seismic surveys, marine mammals, the mitigation guidelines and data recording requirements. Historically, there has been little advice on the completion of the forms in terms of what is an acceptable for the recording of a sighting position (decimal degrees, degrees minutes seconds, degrees and minutes only etc), behaviours (MMOs may have no specific knowledge of animal behaviour), and in some instances a number form fields may not be completed (Weir, 2008; Stone and Tasker, 2006).

The use of hard copy forms and secondary spreadsheets for data collation introduces a further opportunity to introduce recording and geo-referencing errors and compound the variability that makes collation of such data into a database problematic (Vivoni and Camilli, 2003). This also raises questions about the usability of the data for behavioural and distributional studies. The latest forms (in spreadsheet format) include data validation rules for the first time, meaning that information has to be entered in a certain format, and in some cases the choice of entry is restricted to options contained in a ‘drop-down’ list, with guidance notes appearing automatically. While this is a

step forward in terms of data quality, the forms also require more information than ever, have significant redundancy, and still have the problem of being a two-stage process with hard copy ‘deck forms’ and digital spreadsheets.

Variability in the recording of behaviour is problematic in a number of ways. In the context of the present study, personnel may not have been trained as MMOs, and therefore have potentially no information as to what behaviours may be exhibited by cetaceans or their terminology. Trained MMOs will also vary in the level of ethological understanding, with potentially their only introduction to the complex area of animal behaviour being during the initial MMO induction course. Variable and potentially inaccurate recording of behaviour by non-specialists can be further compounded by those seeking to interpret results in order to establish what effects are and are not evident in relation to operations such as seismic surveys.

What has been recorded accurately more widely, is the position and species or lowest taxonomic group of the sighted animal. This serves to highlight that the data collected can represent a useful resource regarding the occurrence of species at the very least, while detail regarding the behaviour or directional movements during sightings may remain both subjective and difficult to interpret.

3.4.2 Sighting distance in relation to seismic source activity

In contrast with previous findings by Stone and Tasker (2006) mysticetes as a group were not found to be sighted at significantly greater distances during times when the seismic source was active, rather than inactive. This was clear when looking at individual mysticetes species also. Odontocetes as a group,

and then two individual odontocete species; long-finned pilot whales and Atlantic white-sided dolphins, were found to be sighted at significantly greater distances when the seismic source was active, which is partly consistent with previous findings (Stone and Tasker, 2006; Barkaszi et al., 2012), though Stone and Tasker, 2006) did not find long-finned pilot whales to be sighted at greater distances during periods when the source was active. However, Weir (2008) has previously noted responses of short-finned pilot whales in relation to a soft-start procedure whereby animals moved away from the increasing sound stimulus. Barkaszi et al. (2012) also looked at the distance from the source during periods of ‘mitigation’ firing (when the source is reduced to an output of 160 dB re 1 μ Pa @ 1 m rms) as well as soft-start, finding that taken as a whole, all cetaceans were sighted at greater distances during mitigation firing, but not during soft start. As a group, delphinids were sighted at a greater distance during mitigation firing, but not soft-start, whereas the opposite was found for baleen whales, though from very low sample sizes (Barkaszi et al., 2012).

It should be noted that the sample sizes for all analyses for individual species were low. These analyses did not have restrictions based on data quality, on the assumption that any observer is capable of estimating distance, with bridge crew equally used to observing objects at sea and estimating distance as MMOs are with sightings of marine species. There will be inherent variability, but this cannot be quantified. JNCC recording forms now require personnel to record how they establish the distance to sighting; whether by eye, the aid of reticule binoculars, rangefinder etc. This kind of information would help in order to compare different methods of establishing the distance to sighting. Species identification over long distances is questionable (Barlow et al., 2001), though trained MMOs were found to be more confident of having

positive identifications. A complete description of the animal sighted can aid quality assurance of data at a later date, but is poor in most cases. Use of ‘unidentified species group’ categories may be more appropriate where species cannot be confirmed due to sighting distance or poor sighting conditions.

A further limitation of this relatively small dataset is that there are not enough observations of use from times of other seismic source activities such as the soft-start phase, as also noted by Stone and Tasker (2006). The soft-start is widely used in order to ‘warn’ marine mammals, with the theory that any in the vicinity will move away. However, this is an area of debate as noted in chapter 2, and any responses during these times would be of value in further analysis. Such data are likely to be limited in any dataset, due to the relatively infrequent and short periods of time when soft-starts occur, relative to periods of full power acquisition during a survey, or no source activity due to poor weather, transit, maintenance and so forth.

The consistent finding that odontocetes, particularly small species are sighted at greater distances from the seismic source when it is active supports the view that mitigation should cover all species. Lateral spatial avoidance was not evident for mysticetes from the data presented here, though has previously been reported by Stone and Tasker (2006) and Barkaszi et al. (2012).

3.4.3 Behaviour of marine mammals in relation to seismic source status

No significant difference was evident between the behaviours observed while the seismic source is inactive, as compared to when it is active (Figure 3-14). Behaviour has proven to be an area difficult to interpret from the dataset due to a number of factors. Data collected by non-trained observers was

excluded from any analysis, to ensure that records used were collected by persons who had been briefed on common cetacean behaviours. However, there was great variation among the data, with some observers having recorded single behaviours, and others having recorded several. Clear descriptions of behavioural changes during sightings were not apparent for the vast majority of data. Further, although briefed during training regarding cetacean behaviours, the content is very limited so the accuracy of any ethological observations is likely to be severely limited. Sample size was restricted in analyses by Barkaszi et al. (2012) due to a lack of consistent recording of behavioural states during sightings, though statistically significant behavioural responses were identified between periods of the seismic source being active or silent. Behaviours such as breaching, porpoising and surfacing were more prevalent when the source was active, perhaps indicating vertical avoidance of the sound source (Richardson et al., 1995).

3.4.4 Directional movement in relation to seismic source status

The data (Figure 3-15) showed that animals are more likely to move away from a vessel when the seismic source is active, consistent with findings by Stone and Tasker (2006). However, this could not be tested statistically due to a small sample size once the data was limited to grade 1 and 2 only. For the majority of records, it was not possible to discern any directional movements, due either to the sighting being at significant distance, the animals themselves were stationary, no movements having been recorded, or the movements being unclear so as to be impossible to interpret accurately.

3.4.5 Summary

The quality of sightings data was found to vary, with trained MMOs more likely to record data fully and accurately. Data analyses highlighted that the distance to sighting was significantly greater for some species during times when the seismic source was active compared to when it was inactive. The behaviour of species in relation to the status of the seismic source was difficult to establish due to incomplete data recording resulting in very low sample sizes. This highlights that the data is not well suited to behavioural analyses, despite an understanding of behaviour in relation to the seismic source being an important outcome of analysing data collected by MMOs. Low sample size also hindered analysis regarding the directional movement of animals in relation to the status of the seismic source, with more animals noted as moving away when the source was active. However, it was not possible to test this statistically. The quality of data and difficulty with the recording of behavioural observations by personnel that are not animal behaviour specialists is seen as a weakness that should be addressed.

Chapter 4. Stakeholder liaison; purpose, effectiveness & future of mitigation

With a wide range of stakeholders involved in mitigating the potential effects of underwater sound on marine life, it is important to understand their views on the issue at hand, as well as current mitigation practices. Utilising a questionnaire, these views have been sought, highlighting where stakeholders differ in opinion, and where there is consensus regarding a number of key themes such as how data collected by MMOs could be better utilised. Stakeholders were found to differ in their opinion on the importance of underwater sound in the context of other marine environmental issues, but not at a statistically significant level, with non-governmental organisations (NGOs) viewing it as more important than industry and the military. There was a high degree of consensus regarding what was seen as the most important issue facing the marine environment (overfishing). Stakeholders also concurred that current mitigation is not as effective as it could be, and not enough is being done to utilise the data collected in the field by MMOs.

4.1 Introduction

The mitigation methods described so far (see Chapter 2) have some immediate consequences for the financial costs of vessel operation and this must be balanced against the benefits to marine life. The economic costs can be easily calculated, and depending on the type of survey operation, may be tens of thousands of dollars for 2D seismic operations to hundreds of thousands of dollars to operate per day for larger 3D surveys, or multi-vessel operations. Operations may only be stopped for a period measured in minutes, but that

delay may result in the vessel having to return to parts of the survey where geophysical data was not acquired, increasing the duration and cost of the survey.

These costs represent a loss of profit to the geophysical or construction contractor, as time spent not acquiring data is usually paid at a lower rate by an oil company client. The delays associated with mitigation methods therefore increase the overall cost of an operation, which will ultimately be a factor that increases the price of the end product (hydrocarbons or energy) as these costs may simply be passed onto the consumer. The benefits of applying mitigation methods are harder to measure in monetary terms, though in many areas of the world whale-watching has become an important industry worth hundreds of millions of dollars (Hoyt and Hvenegaard, 2002), and the fishing industry is vital to many economies, with some concern for any potential impact upon the catch rates of commercial species (Engås et al., 1996).

When considering these costs and benefits, and the regulation they stem from, any stakeholder involved with the application or review of mitigation procedures may question their purpose and effectiveness, each taking a potentially very different view depending on whether one's goals are the protection of the environment, the development of sustainable resource use, or the maximisation of shareholder dividends (Himes, 2007). The JNCC guidelines have been strongly criticised as being deficient in a number of areas, including having a lack of scientific basis with regard to planning, the implementation of the soft-start (and concern that it may attract, rather than deter some species) and the size of the mitigation zone (Parsons et al., 2009).

Parsons et al. (2009) further criticise the lack of experience and training seen among MMOs, insufficient numbers of MMOs to effectively monitor operations, low levels of compliance and a lack of enforcement, before going on to recommend a number of measures that in their view would be more appropriate for mitigation in light of recent research and precaution in the face of data deficiencies. Streever et al. (2008) present an industry perspective from the point of view of one of the world's largest oil companies, *British Petroleum (BP)*, highlighting that the issue of marine mammal and industrial sound is complex and requires knowledge of a number of very different subjects including acoustics, marine mammal biology and policy. They state that information is not only incomplete, but also compounded by emotional assumptions and statements not supported by data (Streever et al., 2008).

As Streever et al. (2008) highlight, industry funds varying aspects of research, though significant funds come from NGOs, the military and traditional governmental scientific research councils. Of concern with regard to these varying funding sources is the assertion that there is significant bias in the results published, with the conclusions drawn reflecting the interests of the sponsor, as to whether there are tangible consequences upon marine species (Wade et al., 2010).

The "effectiveness" of guidelines designed to minimise the disturbance to cetaceans ultimately requires a measure of how species have, or have not, responded to the presence of potentially detrimental anthropogenic sound sources. In the short term this may be represented by stranding events attributed to the hypothesised reaction to a sound source (Jepson et al., 2003). In the medium to long term this may be measures of abundance and distribution of populations of marine mammals. However, such measures require detailed

and long term analyses, which will need to distinguish between a wide range of variables (hydrology, prey abundance, seasonal migration, disease, etc.) that may impact upon species.

4.1.1 Stakeholders

In terms of the day to day application of mitigation guidelines, there are three main stakeholders. Firstly, there are the regulatory agencies that issue exploration licences, and require mitigation guidelines to be implemented as a licence condition. To use the example of the UK, the regulatory agency is the Department for Energy and Climate Change (DECC) to which an operator applies for an exploration consent via the submission of form PON14a (Petroleum Operators Notice) detailing the intended operation. The JNCC act in an advisory capacity, recommending mitigation appropriate to the area in which the operation is to be conducted, which the DECC detail as a condition with the consent notice issued to the operator.

The second key stakeholder is industry. This is comprised of energy companies who wish to develop hydrocarbon fields or marine renewable installations, and the survey and construction contractors responsible for the acquisition of geophysical data or installation of marine renewable devices such as wind turbines. Generally it is the operator who holds the exploration consent or similar licence, though this may also be a survey contractor for surveys that are ‘speculative’ or ‘multi-client’ in nature, where data is collected and then sold, rather than collected over an area designated by a single energy company. Both operators and contractors may also be represented by industry organisations, comprised of key industry spokespersons that collaborate to

tackle issues that affect the industry as a whole. Examples include the International Association of Geophysical Contractors (IAGC) and Oil and Gas Producers Association (OGP).

The third stakeholder is the support industry which supplies MMOs and mitigation consultancy services in order to assist companies with the application of mitigation guidelines such as those from JNCC. These personnel are at the interface between the regulator and industry, and are present to advise operations in the application of mitigation guidelines, observe the operation and marine wildlife and report on compliance levels at the end of an operation.

External to the stakeholders not involved with these day to day procedures, are a number of stakeholders who may inform, comment on and guide the development of mitigation guidelines. These include the scientific research community and NGOs, which range from conservation organisations to learned institutions with overarching interests in the management of the marine environment. Other marine users, such as the fishing industry, shipping industry, and military, also play a role due to indirect involvement and developing awareness of noise impacts from their operations. In the case of the military, they are also subject to similar mitigation to that of the seismic industry and have expert knowledge of topics such as underwater sound. The public is a further stakeholder, who may make informed comment based on broad interest in a subject (e.g., conservation), to support of an issue promoted by an NGO or in response to newsworthy events in the media.

The aim here was to examine the notion of the ‘effectiveness’ of mitigation guidelines and to investigate how different stakeholder groups view current mitigation practice, by using a questionnaire designed to ascertain stakeholder attitudes on two key aspects;

- Scientific basis – the potential impacts of underwater sound on marine life and how this is seen in the wider context of other marine environmental issues.
- Current management practices – how mitigation is currently implemented during operations, and how data might be utilised.

It is hypothesised that;

- There will be differences among the stakeholder groups with regard to how important underwater sound is viewed in relation to other marine environmental issues, with NGOs rating it more importantly than stakeholders such as industry.
- Groups such as industry and the military will view the likelihood for potential impacts from underwater sound upon marine life as being lower than other stakeholders.
- NGOs will view current mitigation policy as being less effective than other stakeholders.
- The 500 m mitigation zone will be viewed as ineffective and impractical by all stakeholders.
- PAM will be seen as an ineffective mitigation tool by industry.

- Stakeholders will see the best way to reduce grey areas within guidelines as having a broader range of mitigation guidelines and greater operational specificity.
- MMO and PAM training will be viewed as of adequate effectiveness.
- Stakeholders will concur that not enough is done with the data collected in the field by MMOs.

4.2 Methodology

4.2.1 Survey Design

The questionnaire was designed based on the two key areas above, using a combination of closed questions, five point Likert scales and open questions in order to allow wider opinions to be sought in order to inform potential further research (Oppenheim, 1992). Demographic information was collected in order to understand the educational background, stakeholder affiliation and general familiarity with the various aspects of the underwater sound and marine life issue.

Due to the number and geographical spread of stakeholders, and in order to maximise the potential number of respondents, the questionnaire was made available via the internet using Survey Monkey (www.surveymonkey.com) from 5th to the 30th September 2011. The URL for the survey was disseminated using stakeholder mailing lists, the professional networking website ‘Linked In’ (www.linkedin.com), as well as directly via email to professional contacts working within the general field of underwater sound and marine life in some

way, including research, regulatory and industry backgrounds. A brief introduction to the study was prepared to inform respondents of the general background, scope and purpose of the questionnaire, before leading on to the questions. All responses were kept anonymous.

The questionnaire comprised 36 questions (see Appendix 1). This included a section requesting demographic information including sex, age and general information to ascertain the respondent's educational and professional background. This was then followed by five sections covering the following topics;

- Underwater sound and marine life – a section asking questions relating to the perception of underwater noise in relation to other environmental issues facing marine wildlife and the perceived risks to different species from anthropogenic underwater sound.
- Underwater sound; principles, measurement and sources – a section relating to how underwater sounds are measured and characterised.
- Guidelines and policies – questions seeking opinions on current mitigation practices and how they might be developed and improved.
- MMO and PAM training – a section asking questions about the adequacy of current training for personnel implementing mitigation guidelines in the field and how training might be improved.

- Data usage – a section seeking opinion on the usefulness of data collected during mitigation and potential improvements to the use and dissemination of that data.

Finally, a comments section was made available to allow respondents to speak freely regarding any issues with the questionnaire or related topics they felt to be pertinent to the general discussion that were perhaps not covered within the questionnaire. It also allowed respondents to record their contact information should they wish to receive the outcome of the survey directly in due course.

While some respondents may have had expertise across the full range of topics, it was considered likely that marine biologists (as an example) may not have expertise in the measurement of underwater sound. In order to ensure that responses were made by respondents that were suitably informed to answer specific topics, filter questions were implemented using ‘question logic’ within Survey Monkey. At the start of each section a question was framed to ascertain the respondents level of expertise in each given section topic area. Those responding with ‘no knowledge’ or ‘passing knowledge’ were automatically directed to the next section. Those answering with ‘general knowledge’, ‘technical competence’ or ‘expert’ were able to continue with the questions in that section. Similar filter questions were enabled in order that those respondents that were MMOs or PAM operators could then state which training they had undertaken and how long ago, and those respondents involved with hiring MMOs and PAM Operators could comment on the training they look for when considering candidates for employment.

4.3 Results

4.3.1 Demographics

A total of 346 respondents attempted the survey. Of those, 202 completed all sections they were eligible to complete, factoring in the filter questions relating to expertise in each topic area. Of those 346 respondents, 3 did not disclose their sex or age group. From the remainder, 61% were female and 39% male. A narrow majority of respondents were aged between 30 and 39 (31.5%), with the 20-29 and 40-49 age ranges being the second and third largest groups of respondents at 30.9% and 19.9% respectively. Figure 4-1 below summarises the respondents by sex and age range, from where it can be seen that the sex profile changes with age. More females responded from the younger age ranges, whereas a higher percentage of males responded from the older age ranges.

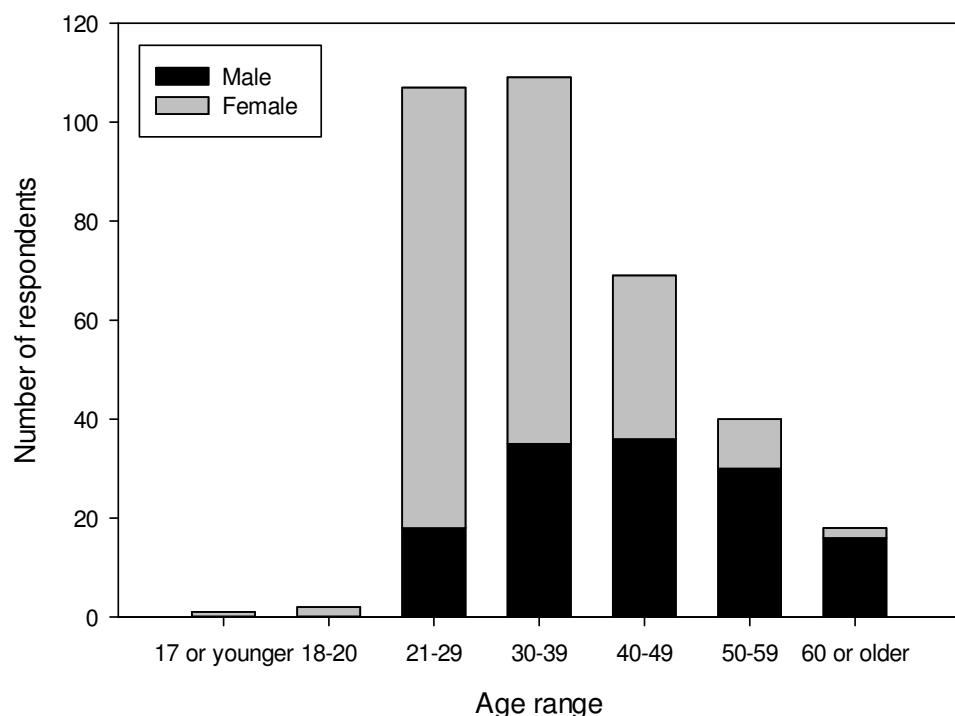


Figure 4-1; Sex and age profile of the respondent group.

'Academia' represented the largest group of respondents, with the 'military' being the smallest group, as shown in Figure 4-2 below. Respondents were also asked to state the number of years they had worked as part of that stakeholder group, which showed that the 'industry' group had the highest average in terms of years within that sector.

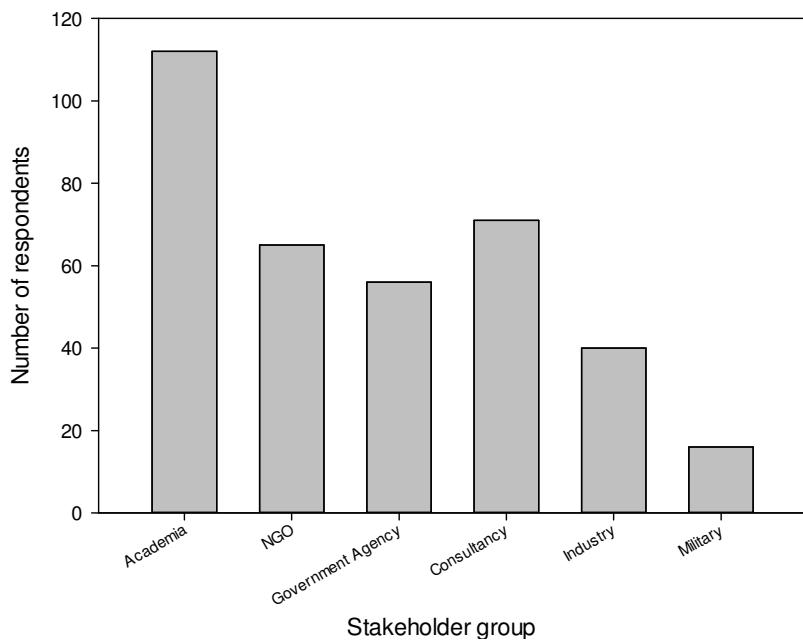


Figure 4-2; Number of respondents by stakeholder group.

The respondent group was generally highly educated, with 96% educated to at least undergraduate degree level, and 23% of those that answered (77 from 336) were educated to doctorate level. Further analysis of educational background by stakeholder affiliation shows no large differences in educational background; though there was a greater percentage of higher degree and doctorate level respondents within academia. Despite being asked to comment on their current position, some respondents listed more than one stakeholder affiliation, due to either changing sectors at some point during their

career or having two roles. In order to be clear about educational background for each group, the Figure 4-3 excludes respondents who listed more than one affiliation (2% of respondents within the academia and NGO groups).

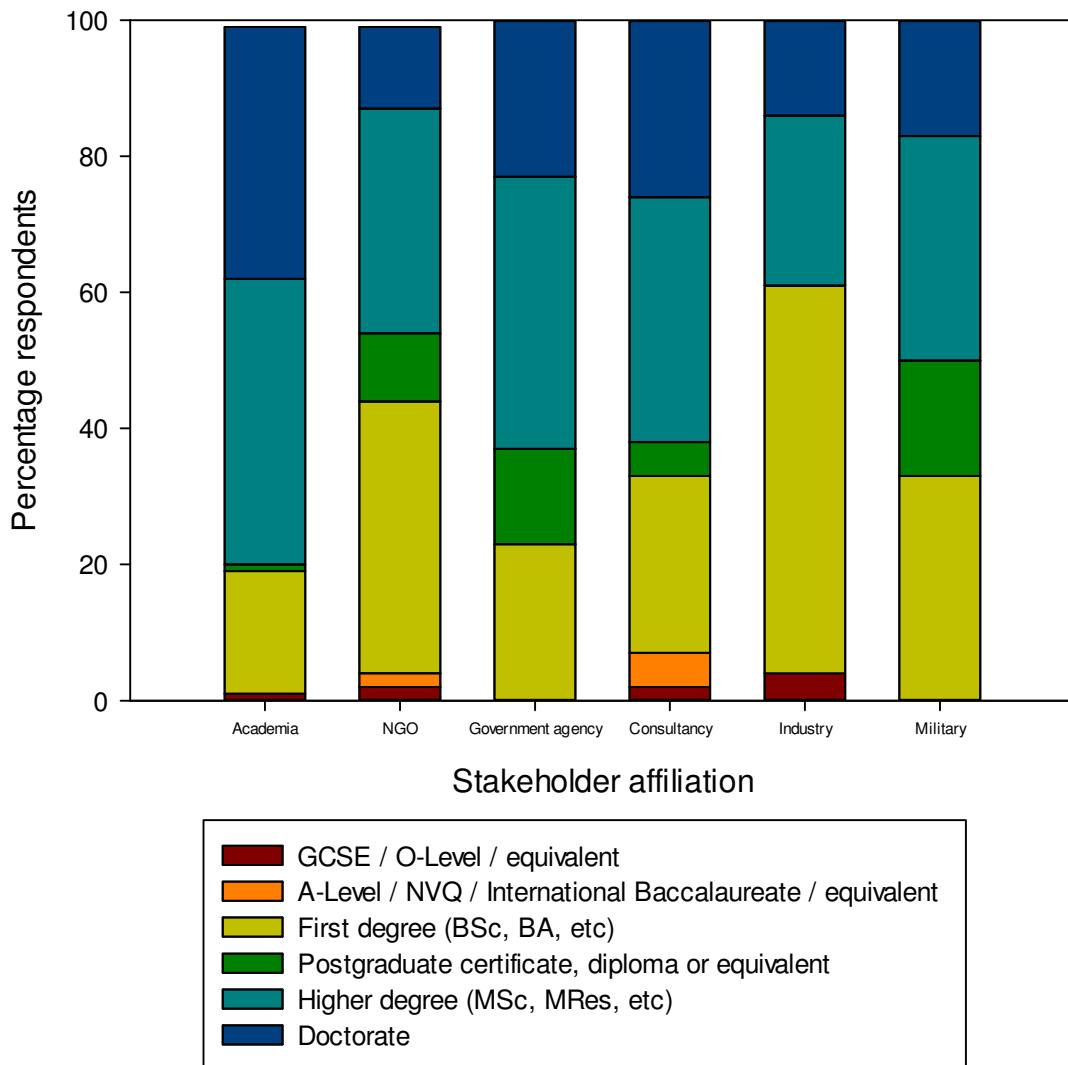


Figure 4-3; Educational background of each stakeholder group, showing the percentage of respondents categorised by their highest qualification.

In terms of subject area, the overwhelming majority of respondents (43%) listed 'Life sciences – Marine Biology' as the subject area of their highest qualification. A total of 41 respondents felt that the categories of subject area

were insufficient, and specified their subject by selecting the 'Other' option for that question. The subjects detailed within these responses are summarised in Table 4-1. Figures 4-4 to 4-6 show the breakdown of subject area by stakeholder group. Figure 4-4 shows that the life sciences are represented in the backgrounds of respondents from all stakeholder groups, though notably less so from Industry and the Military groups.

Table 4-1; Subject specialisations detailed by respondents selecting 'other'.

Stakeholder group	Subjects recorded with numbers of respondents in parentheses
Academia	<i>Experimental psychology (1), Law (1), Signal Processing (1), Wildlife and Fisheries Science (1), Wildlife Conservation and Management (1), Zoology (1)</i>
NGO	<i>Law (1), Zoology (1)</i>
Government Agency	<i>Zoology (1), Geophysics (1), Geology (1), Linguistics (1), Speech and Hearing Science (1), Earth and Planetary Science (1)</i>
Consultancy	<i>Wildlife and Fisheries Science (1), Acoustics (1), Fisheries (1), Marine Mammal Science (1), Marine Environmental Protection (1), Veterinary Medicine (1), Not specified (1)</i>
Industry	<i>Zoology (1), Geophysics (2), Marine Science (1)</i>
Military	<i>None recorded</i>

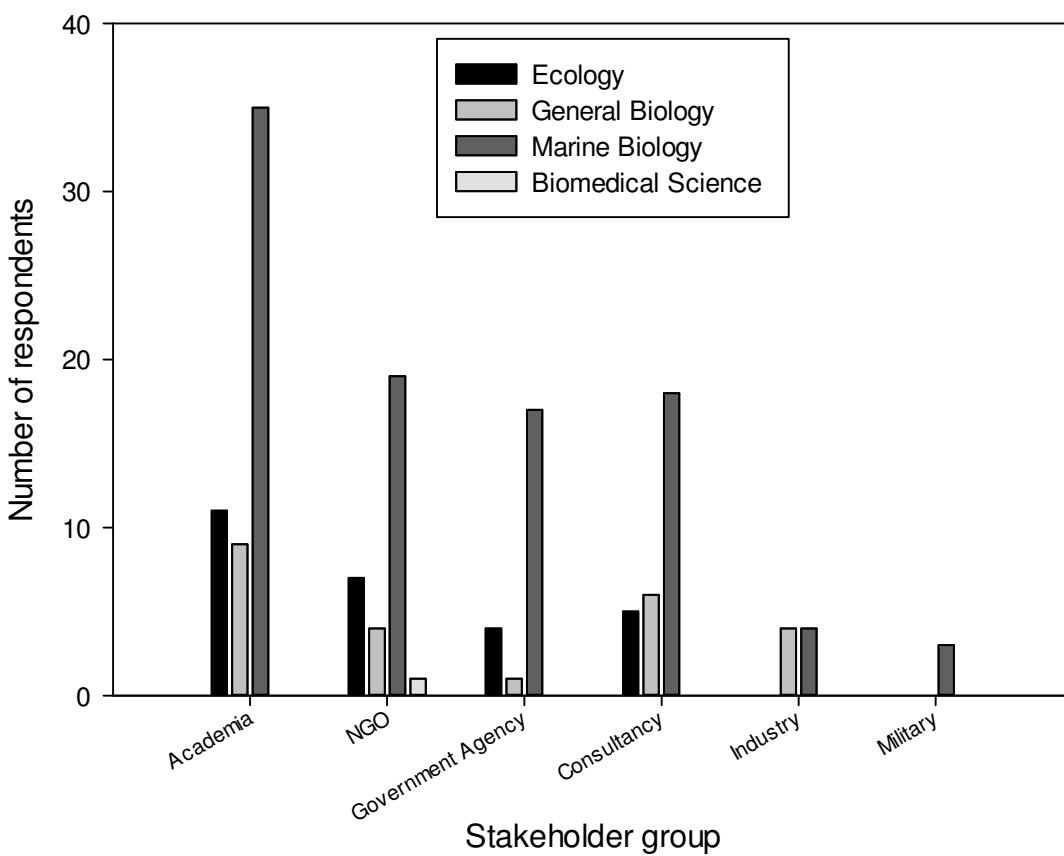


Figure 4-4; Number of respondents with a life sciences educational specialisation categorised by stakeholder group

Other science subjects are also well represented across the stakeholder groups, as shown in Figure 4-5, with the notable exception of the military group, though the number of respondents from this group was low, making assessment of the educational background for this group difficult. Notable differences are the higher number of oceanographers within the academia group, and the higher number of engineers within the industry group.

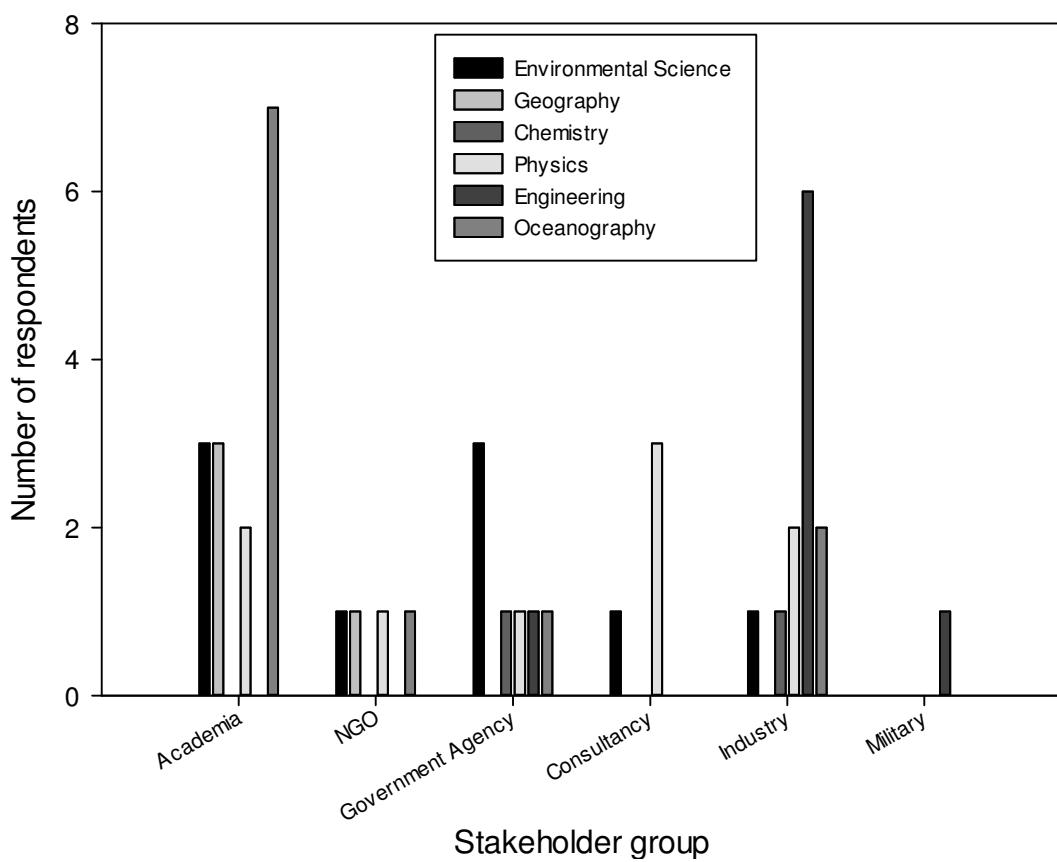


Figure 4-5; Number of respondents with a science or engineering educational specialisation, categorised by stakeholder group

Non-science subjects (when considering computer science and social science as not ‘traditional’ science subjects), are not well represented across the stakeholder groups. NGOs have a wider spread of respondents with non-science backgrounds, but only in very low quantities. Of note is that Industry has a higher number of respondents with a business specialisation. No government agency respondents had an educational specialisation from the listed non-science subjects.

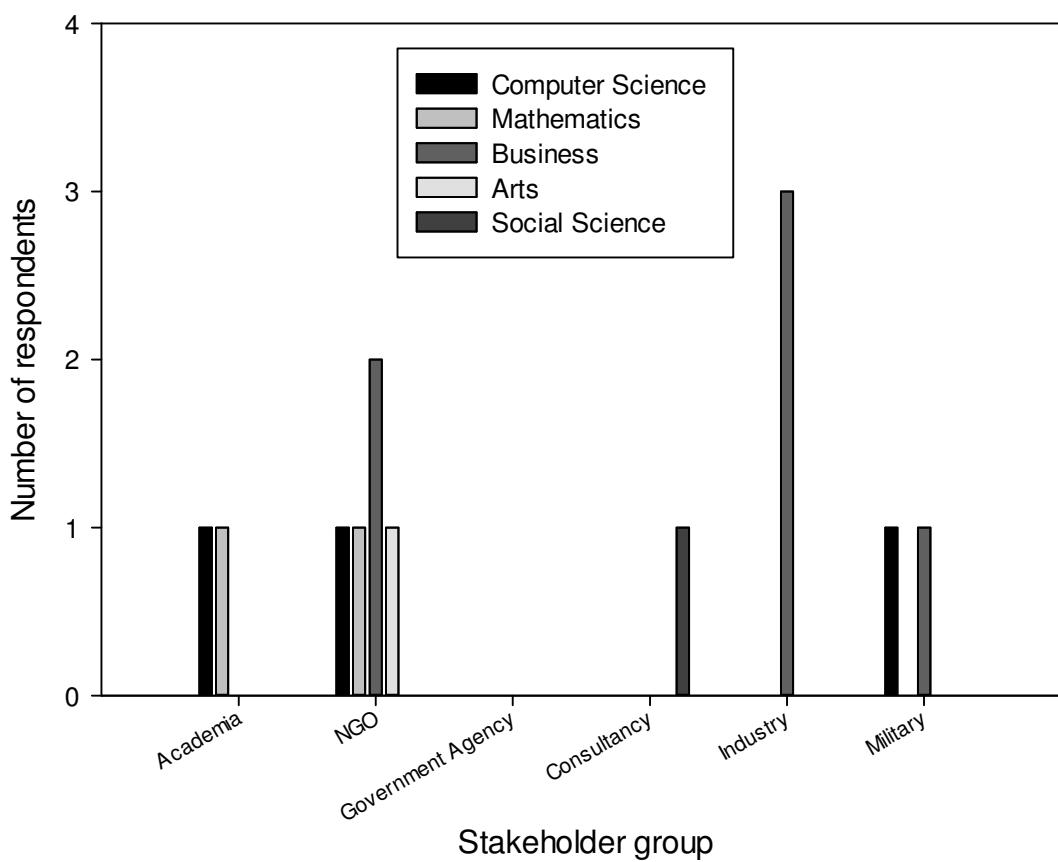


Figure 4-6; Number of respondents with a non-science educational specialisation, categorised by stakeholder group

Respondents recorded a wide variety of ‘other’ educational specialisations, also in low numbers, as with the listed ‘non-science’ subjects. The majority of responses under “other” represent what could be considered a division or related subject to some of those that were listed for respondents to select from, while others are very specialised, such as signal processing, or represent relevant additional categories that were not considered in the original question.

When asked about the nature of the core business of their current employer, the majority of respondents selected ‘life sciences’ research. Those working within ‘marine survey (seismic exploration)’ were the second largest group of respondents. Most categories of business type were represented by very low numbers of respondents. The largest category of respondents chose ‘other’ and listed a further range of core business areas, which included clarification of the stakeholder affiliation from the previous question, but also other areas such as ‘industry advocacy’, ‘marine tourism’ and ‘seismic equipment manufacturing’.

4.3.2 Underwater sound and marine life

Respondents were asked to rank a number of issues of concern for marine life, including underwater sound. Table 4-2 summarises the rankings given to the 11 issues. Underwater sound was ranked joint 4th overall with chemical pollution, with all respondents ranking ‘over-fishing’ as the most important issue. Issues that have a direct potential impact upon marine mammals only, were ranked in the last three places; whaling, collisions with ships and whale-watching. A number of minor differences are evident between stakeholder groups, including NGOs ranking underwater sound as the third most important issue, which is higher than any other group, and the military and industry ranking it as less important than other groups. Industry ranks whaling more highly than academia and NGOs, while rankings from the military stakeholder group show the greatest difference from the other groups. Broadly, there is consensus evident between groups, with all agreeing on both the most

and least important issues of concern to marine life. This is confirmed by statistical analysis, with no significant difference between stakeholder groups identified (one-way ANOVA, $F = 0.29$, 5 d.f., $p = 0.917$).

Table 4-2; Average ranks assigned to issues of concern to marine life for all respondents, and then by stakeholder grouping. Issues are ranked by importance with low numbers representing the most important, and high numbers the least important.

Issue of concern	All	Academia	Consultancy	Government agency	Industry	Military	NGO
Fisheries by-catch	2	2	2	3	3	2	2
Over-fishing	1	1	1	1	1	1	1
Global environmental change	3	3	5	2	2	6	4
Chemical pollution	4	5	3	5	4	4	5
Marine litter	6	6	6	9	7	3	6
Invasive species	8	7	8	8	9	10	10
Whaling	9	10	9	10	6	8	8
Marine mammal collisions with ships	10	9	10	7	10	9	7
Whale-watching	11	11	11	11	11	11	11
Marine recreational development	7	8	7	6	8	5	9
Underwater sound	4	4	4	4	5	7	3

Respondents were also asked to consider the potential impacts of underwater sound on a range of species groups. Table 4-3 summarises the responses by stakeholder affiliation. From this it can be seen that there is general consensus that the likelihood of cetaceans (both baleen and toothed whales) being impacted is generally considered high for all stakeholder groups. However, there are some exceptions to draw out. The military differ, with a significantly lower proportion of respondents categorising the potential impacts upon mysticetes as high, and a higher proportion categorising the potential impacts as being medium. The sample size for this stakeholder group is very in

comparison with the other however. NGOs differ significantly in the number of respondents categorising the potential impacts upon odontocetes as high only, whereas there is more of a spread for the other stakeholder groups.

Marine mammals that are not completely aquatic (e.g., polar bears) are seen as less likely to be impacted (generally scoring medium to low), with a similar pattern emerging for the groups of fish. A significantly greater number of respondents within the consultancy group have categorised the potential impacts on sea otters as being low, with a similar result for the military when responding regarding fin fish. Uncertainty is evident for groups such as coral and diving birds, where respondents have stated 'don't know' relatively often.

Table 4-3; Summary of the likelihood of different groups of marine species being impacted by underwater sound, broken down by respondent stakeholder affiliation. Values in the same row not sharing the same subscript differ significantly at p<0.05 using a two-sided z-test of equality for column proportions. Zero values were not included within the test.

		Stakeholder affiliation					
		Academia	Consultancy	Government agency	Industry	Military	NGO
Mysticetes (baleen whales)	High	46 _a	29 _a	18 _{a,b}	15 _{a,b}	1 _b	23 _a
	Medium	5 _a	3 _a	3 _a	3 _{a,b}	4 _b	1 _a
	Low	1 _a	2 _a	2 _a	2 _a	0 ¹	1 _a
	Don't know	0 ¹	0 ¹	2 _a	0 ¹	0 ¹	0 ¹
Odontocetes (toothed whales)	High	46 _{a,b}	28 _{a,b}	18 _{a,b}	13 _{a,b}	2 _a	24 _b
	Medium	5 _a	4 _{a,b}	3 _{a,b}	5 _{a,b}	3 _b	0 ¹
	Low	1 _a	2 _a	2 _a	2 _a	0 ¹	1 _a
	Don't know	0 ¹	0 ¹	2 _a	0 ¹	0 ¹	0 ¹
Pinnipeds (seals and sea lions)	High	27 _a	13 _a	14 _a	8 _a	1 _a	17 _a
	Medium	22 _a	15 _a	6 _a	7 _a	4 _a	6 _a
	Low	1 _a	6 _a	3 _a	4 _a	0 ¹	1 _a
	Not at all	1 _a	0 ¹	0 ¹	1 _a	0 ¹	1 _a
	Don't know	1 _a	0 ¹	2 _a	0 ¹	0 ¹	0 ¹
Sirenians (Dugongs and manatees)	High	27 _a	18 _a	11 _a	10 _a	0 ¹	19 _a
	Medium	15 _{a,b}	7 _{a,b}	5 _{a,b}	4 _{a,b}	4 _a	4 _b
	Low	8 _a	6 _a	2 _a	2 _a	1 _a	0 ¹
	Not at all	0 ¹	0 ¹	0 ¹	1 _a	0 ¹	1 _a

	Don't know	2 _a	3 _{a,b}	7 _b	3 _{a,b}	0 ¹	1 _{a,b}
Sea otter – Medium	High	16 _a	8 _a	4 _a	2 _a	0 ¹	8 _a
	Medium	22 _a	6 _a	8 _a	6 _a	3 _a	10 _a
	Low	11 _a	19 _b	6 _{a,b}	6 _{a,b}	2 _{a,b}	3 _a
	Not at all	1 _a	0 ¹	1 _a	1 _a	0 ¹	1 _a
	Don't know	2 _a	1 _a	6 _a	5 _a	0 ¹	3 _a
Polar bears	High	9 _a	5 _a	4 _a	3 _a	0 ¹	7 _a
	Medium	18 _a	6 _a	5 _a	4 _a	1 _a	6 _a
	Low	20 _a	20 _a	7 _a	6 _a	4 _a	8 _a
	Not at all	1 _a	2 _a	2 _a	4 _a	0 ¹	1 _a
	Don't know	4 _a	1 _a	7 _a	3 _a	0 ¹	3 _a
Sea turtles	High	12 _a	10 _a	4 _a	4 _a	0 ¹	7 _a
	Medium	21 _a	11 _a	6 _a	7 _a	2 _a	8 _a
	Low	13 _{a,b}	11 _{a,b}	1 _a	5 _{a,b}	3 _b	4 _{a,b}
	Not at all	3 _a	0 ¹	1 _a	2 _a	0 ¹	2 _a
	Don't know	3 _a	2 _a	13 _b	2 _a	0 ¹	4 _{a,b}
Fin fish	High	16 _a	10 _a	4 _a	2 _a	0 ¹	9 _a
	Medium	19 _a	15 _a	8 _a	3 _a	3 _a	8 _a
	Low	12 _a	7 _{a,b}	9 _{a,b}	12 _b	1 _{a,b}	2 _a
	Not at all	1 _a	1 _a	0 ¹	0 ¹	1 _a	1 _a
	Don't know	4 _a	1 _a	4 _a	3 _a	0 ¹	5 _a
Elasmobranchs (sharks and rays)	High	14 _a	7 _a	4 _a	2 _a	0 ¹	10 _a
	Medium	19 _a	13 _a	7 _a	5 _a	1 _a	7 _a
	Low	12 _a	10 _a	8 _a	9 _a	2 _a	4 _a
	Not at all	0 ¹	1 _a	0 ¹	1 _a	0 ¹	0 ¹
	Don't know	7 _a	3 _a	6 _a	3 _a	2 _a	4 _a
Shellfish	High	1 _a	2 _a	0 ¹	0 ¹	0 ¹	3 _a
	Low	19 _a	11 _a	9 _a	5 _a	1 _a	6 _a
	Medium	7 _a	3 _a	0 ¹	1 _a	1 _a	5 _a
	Not at all	15 _a	9 _a	2 _a	9 _a	1 _a	5 _a
	Don't know	10 _a	9 _{a,b}	14 _b	5 _{a,b}	2 _{a,b}	6 _{a,b}
Cephalopods (Squid, octopi etc)	High	7 _a	5 _a	2 _a	4 _a	0 ¹	9 _a
	Medium	14 _a	7 _a	10 _a	2 _a	1 _a	6 _a
	Low	12 _a	10 _a	7 _a	7 _a	3 _a	3 _a
	Not at all	5 _a	3 _a	0 ¹	2 _a	0 ¹	1 _a
	Don't know	14 _a	9 _a	6 _a	5 _a	1 _a	6 _a
Coral	High	1 _a	2 _a	0 ¹	1 _a	0 ¹	1 _a
	Medium	6 _a	2 _a	0 ¹	0 ¹	0 ¹	5 _a
	Low	22 _a	8 _a	9 _a	5 _a	3 _a	6 _a
	Not at all	10 _a	12 _a	2 _a	9 _a	1 _a	3 _a
	Don't know	13 _a	10 _a	14 _a	5 _a	1 _a	10 _a
Diving birds (e.g. gannets)	High	7 _a	1 _a	0 ¹	2 _a	0 ¹	4 _a
	Medium	13 _a	10 _a	4 _a	1 _a	0 ¹	4 _a
	Low	23 _a	19 _a	12 _a	9 _a	4 _a	10 _a
	Not at all	4 _a	1 _a	4 _a	5 _a	0 ¹	1 _a
	Don't know	5 _a	3 _a	5 _a	3 _a	1 _a	6 _a

4.3.3 Underwater sound; principles, measurement and sources

The vast majority of respondents (71.6% of 183 answering this question) considered the decibel to be the most appropriate unit to characterise and compare underwater sounds. Interestingly though, the majority of respondents also gave high importance to every factor listed for the characterisation of a sound. Of particular importance were the frequency and amplitude of the sound, and the duration of the operation in question. Factors seen as less important were the ambient noise levels, the combination of sound sources in use and the site characteristics.

Of the respondents that did not consider the decibel appropriate for characterising and comparing underwater sounds, the ‘dB ht (species)’ received the highest number of responses (12 from 53 answering this question). However, a greater number of respondents selected ‘other’, and provided in some cases detailed qualifications suggesting that the dB may be appropriate, as long as it is fully qualified with the reference pressure, and other appropriate descriptors to characterise the sound.

4.3.4 Guidelines and policies

When asked to consider the effectiveness of current mitigation guidelines, the majority of respondents (68.9% of 122 answering this question) considered them to be ‘somewhat’ effective. Only 4.1% considered them highly effective. Interestingly, it was respondents from the industry group that classed the effectiveness of guidelines as ‘highly’ significantly more than other groups, though the sample size is low. The consultancy group had least spread among

answers, with a significantly higher proportion of this group classifying the effectiveness of guidelines as ‘somewhat’, which was the most common answer across all groups.

Table 4-4; Summary of how each stakeholder group views the effectiveness of current mitigation guidelines. Values in the same row not sharing the same subscript differ significantly at $p<0.05$ using a two-sided z-test of equality for column proportions. Zero values were not included within the test.

	Stakeholder affiliation					
	Academia	Consultancy	Government agency	Industry	Military	NGO
Highly	1 _a	0	1 _{a,b}	3 _b	0	0
Generally	3 _a	6 _a	3 _a	2 _a	1 _a	5 _a
Somewhat	22 _a	22 _b	12 _{a,b}	8 _{a,b}	3 _{a,b}	17 _{a,b}
Not at all	5 _a	0	0	1 _a	0	3 _a
Don't know	2 _a	1 _a	0	0	0	1 _a

With regard to how respondents measure effectiveness (summarised in table 4-5), there were no statistically significant differences between stakeholder groups. The most popular answer was the ‘reduction of noise in the environment’, with 35% of respondents selecting this.

Table 4-5; Summary of stakeholder choices regarding an appropriate measure of the effectiveness of mitigation guidelines. Values in the same row not sharing the same subscript differ significantly at $p<0.05$ using a two-sided z-test of equality for column proportions. Zero values were not included within the test.

	Stakeholder affiliation					
	Academia	Consultancy	Government agency	Industry	Military	NGO
High compliance levels	6 _a	7 _a	1 _a	0	0	1 _a
Application of 'best practice' measures by operators	8 _a	7 _a	4 _a	3 _a	2 _a	3 _a
Uptake of guidelines in non-regulated areas	4 _a	4 _a	1 _a	2 _a	0	3 _a
Reduction of noise in the environment	12 _a	6 _a	6 _a	7 _a	1 _a	14 _a
Don't know	0	0	0	0	0	1 _a
Other	3 _a	5 _a	4 _a	2 _a	1 _a	4 _a

Respondents were asked about the effectiveness and practicality of the 500 m mitigation zone around the seismic source that is implemented in the UK, and many other locations, with responses summarised in table 4-6. Industry differed significantly from other stakeholder groups by responding that the 500 m mitigation zone is 'highly' effective, though the sample size is low. The majority of respondents (57%) answered that the 500 m zone is 'somewhat' effective. In terms of practicality, a significantly higher proportion of respondents from the consultancy group viewed the 500 m as practical to implement, but again the overall view from stakeholders was that the zone is 'somewhat' practical, with a majority of 38% selecting this answer.

Table 4-6; Summary of responses regarding the effectiveness and practicality of the 500 m mitigation zone. Values in the same row not sharing the same subscript differ significantly at p<0.05 using a two-sided z-test of equality for column proportions. Zero values were not included within the test.

		Stakeholder affiliation					
		Academia	Consultancy	Government Agency	Industry	Military	NGO
Effectiveness	Highly	1 _a	1 _{a,b}	0	3 _b	0	0
	Generally	1 _a	5 _a	1 _a	3 _a	1 _a	2 _a
	Somewhat	21 _a	18 _a	9 _a	7 _a	1 _a	14 _a
	Not at all	6 _a	4 _a	4 _a	1 _a	1 _a	6 _a
	Don't know	4 _a	1 _a	2 _a	0	1 _a	4 _a
Practicality	Highly	3 _a	6 _a	2 _a	4 _a	1 _a	1 _a
	Generally	6 _a	12 _b	5 _{a,b}	3 _{a,b}	1 _{a,b}	9 _{a,b}
	Somewhat	17 _a	8 _a	5 _a	4 _a	1 _a	11 _a
	Not at all	4 _a	2 _a	3 _a	3 _a	0	1 _a
	Don't know	3 _a	1 _a	1 _a	0	1 _a	4 _a

Respondents were asked to comment on what might improve both the effectiveness and practicality of the mitigation zone, with the results summarised in table 4-7. Few respondents felt that one improvement in isolation would be enough, with most selecting multiple answers. The only difference between stakeholder groups is that a higher proportion of industry respondents have shown a preference for a combination of mitigation zones based upon sound emission characteristics combined with a full suite of mitigation tools. This is also the most popular answer overall, with 24% of respondents selecting this combination, though 22% also selected these two responses in addition to simply 'larger mitigation zones'.

Table 4-7; Summary of stakeholder responses regarding ways to improve the effectiveness and practicality of the mitigation zone. Values in the same row not sharing the same subscript differ significantly at p<0.05 using a two-sided z-test of equality for column proportions. Zero values were not included within the test.

	Stakeholder affiliation					
	Academia	Consultancy	Government Agency	Industry	Military	NGO
Larger mitigation zones	2 _a	0 ¹	1 _a	2 _a	0 ¹	1 _a
Mitigation zones based upon sound emission characteristics	3 _a	2 _a	2 _a	1 _a	0 ¹	5 _a
Full suite of mitigation tools (e.g. visual plus acoustic)	2 _a	2 _a	2 _a	2 _a	1 _a	2 _a
Larger mitigation zones AND mitigation zones based upon sound emission characteristics	1 _a	0 ¹	0 ¹	0 ¹	0 ¹	0 ¹
Larger mitigation zones AND a full suite of mitigation tools	0 ¹	0 ¹	1 _a	0 ¹	0 ¹	0 ¹
Larger mitigation zones, mitigation zones based upon sound emission characteristics AND a full suite of mitigation tools	10 _a	7 _a	3 _a	1 _a	0 ¹	3 _a
Larger mitigation zones, mitigation zones based upon sound emission characteristics, a full suite of mitigation tools AND 'other'	1 _a	1 _a	0 ¹	0 ¹	0 ¹	1 _a
Larger mitigation zones, a full suite of mitigation tools AND 'other'	0 ¹	0 ¹	0 ¹	0 ¹	0 ¹	1 _a
Mitigation zones based upon sound emission characteristics AND a full suite of mitigation tools	4 _a	8 _{a,b}	5 _{a,b}	6 _b	1 _{a,b}	2 _{a,b}
Mitigation zones based upon sound emission characteristics AND 'other'	1 _a	0 ¹	1 _a	0 ¹	0 ¹	0 ¹
Mitigation zones based upon sound emission characteristics, a full suite of mitigation tools AND 'other'	3 _a	3 _a	0 ¹	1 _a	0 ¹	1 _a
Don't know	0 ¹	2 _a	1 _a	0 ¹	1 _a	0 ¹
Other	1 _a	3 _a	0 ¹	1 _a	0 ¹	2 _a

In isolation or in combination with other answers, a large proportion (20%) of respondents selected the ‘other’ category and made suggestions for how to improve the effectiveness and practicality of the mitigation zone. Answers included having a shutdown procedure for marine species entering the mitigation zone, mitigation based on the species likely to be encountered and what may be more appropriate to those species and the use of mitigation measures not based on detection such as geographic exclusion.

In relation to the ‘grey areas’ that are inherent in most guideline documents due to wide ranging survey types, technologies and therefore operational constraints faced within projects, most respondents (32.8%) felt that a broader range of mitigation guidelines and operational specificity would be of most value. Few felt that decisions in the field, rapid responses of regulators or at project start-up were the appropriate ways or times to resolve issues. A further 17% of respondents provided ‘other’ answers, with most suggesting that a combination of the pre-defined answers would be appropriate, as well as emphasising the need for clear and open communication between stakeholders. There were no significant differences between the views of stakeholders.

Table 4-8; Summary of responses regarding how ‘grey’ areas within guideline documents should be overcome. Values in the same row not sharing the same subscript differ significantly at p<0.05 using a two-sided z-test of equality for column proportions. Zero values were not included within the test.

	Stakeholder affiliation					
	Academia	Consultancy	Government Agency	Industry	Military	NGO
Increased consultation between regulators and industry at consent phase	6 _a	7 _a	2 _a	4 _a	1 _a	6 _a
In the field, between MMO/PAM personnel and the client/contractor	3 _a	1 _a	0	2 _a	1 _a	4 _a
At start-up, by liaison with all parties and the regulator	6 _a	2 _a	3 _a	1 _a	0	1 _a
Rapid response of regulator to issues during operations	3 _a	1 _a	0	0	0	0
Broader range of mitigation guidelines and operational specificity	9 _a	11 _a	6 _a	5 _a	1 _a	8 _a
Don't know	2 _a	0	2 _a	0	1 _a	2 _a
Other	4 _a	7 _a	3 _a	2 _a	0	5 _a

The majority of respondents (43.8%, of 160 answering) saw PAM as ‘somewhat’ effective as a mitigation tool, with only 14.4% seeing it as highly effective, with results summarised in table 4-9. The consultancy group differed from other stakeholder groups in responding significantly more often that PAM is ‘somewhat’ effective, while other groups had a greater spread of answers.

Table 4-9; Summary of responses regarding the effectiveness of PAM as a mitigation tool.

Values in the same row not sharing the same subscript differ significantly at $p<0.05$ using a two-sided z-test of equality for column proportions. Zero values were not included within the test.

	Stakeholder affiliation					
	Academia	Consultancy	Government Agency	Industry	Military	NGO
Highly	6 _a	3 _a	2 _a	1 _a	0	3 _a
Generally	9 _a	10 _a	5 _a	6 _a	1 _a	11 _a
Somewhat	11 _a	14 _b	6 _{a,b}	7 _{a,b}	3 _{a,b}	10 _{a,b}
Not at all	1 _a	2 _a	0	0	0	0
Don't know	6 _a	0	3 _a	0	0	2 _a

All of the potential ways of improving the effectiveness of PAM as a mitigation tool were selected by at least 30% of the respondents. There were no significant differences between the stakeholders with regard to suggested improvements, with the responses shown below in figure 4-7. 20.6% of respondents suggested 'other' measures including integrating PAM into seismic equipment, suggesting 'all of the above' would be useful, as well as highlighting issues that limit the performance of PAM regardless of improvements. For example, it cannot detect non-vocalising animals, so suggestions based on this included emitting whale sounds to trigger a response from animals and ensuring PAM is not used in isolation from visual observations. Several respondents pointed out that the low frequency capability of systems is low, and that it is essential to improve this, perhaps by locating the PAM array further from the seismic source. The low frequency capability of systems is low due to the high levels of low frequency ambient noise in the immediate environment systems are placed within (vessel engine noise, seismic source and so on), and the limited spacing of hydrophone sensors that do not capture the long wavelength of a low frequency sound.

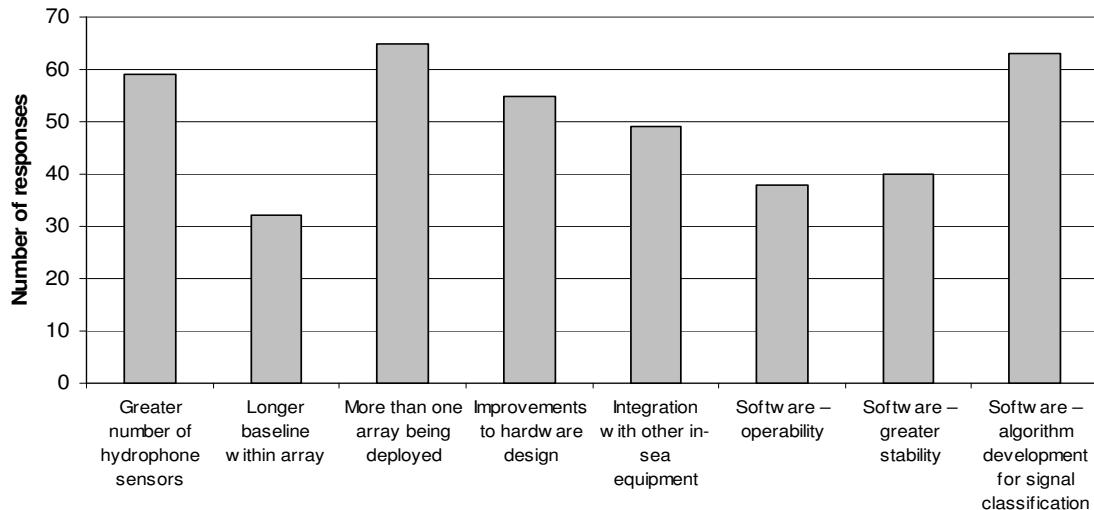


Figure 4-7; Summary of responses on ways to improve PAM as a mitigation tool.

4.3.5 MMO and PAM training

41 respondents identified themselves as MMOs. Of those, the majority had undertaken JNCC approved MMO training. When asked what minimum standard of training people look for, the largest group of respondents (36.2% of a total of 94 answering) stated JNCC training. From those that answered ‘other’, most responses indicated that although the training was important, all were looking for appropriate experience among MMO personnel.

In terms of whether MMO and PAM training is seen as adequate, the largest group of respondents (38.6%) felt that for MMO training, it was only ‘somewhat’ adequate. For PAM training the largest group of respondents (37%) stated that they ‘didn’t know’, though the next largest group of respondents (34.5%) also felt that training was only ‘somewhat’ adequate. There were some differences among stakeholders, as shown in table 4-10, with the consultancy group responding significantly more often that MMO training was ‘generally’ effective. For PAM training, the consultancy group responded significantly more often that the training was ‘somewhat’ effective.

Table 4-10; Summary of responses regarding the effectiveness of MMO and PAM training.

Values in the same row not sharing the same subscript differ significantly at p<0.05 using a two-sided z-test of equality for column proportions. Zero values were not included within the test.

		Stakeholder affiliation					
		Academia	Consultancy	Government agency	Industry	Military	NGO
MMO training	Highly	1 _a	1 _a	0 ¹	1 _a	1 _a	1 _a
	Generally	3 _a	11 _b	3 _{a,b}	3 _{a,b}	1 _{a,b}	3 _{a,b}
	Somewhat	4 _a	7 _{a,b}	5 _{a,b}	5 _{a,b}	0 ¹	11 _b
	Not at all	3 _a	2 _a	0 ¹	2 _a	0 ¹	2 _a
	Don't know	9 _a	0 ¹	3 _a	1 _a	1 _a	0 ¹
PAM training	Highly	3 _a	0 ¹	0 ¹	0 ¹	0 ¹	1 _a
	Generally	0 ¹	2 _a	3 _a	3 _a	1 _a	3 _a
	Somewhat	4 _a	12 _b	2 _{a,b}	2 _{a,b}	1 _{a,b}	8 _{a,b}
	Not at all	3 _a	1 _a	0 ¹	4 _a	0 ¹	0 ¹
	Don't know	10 _a	6 _a	6 _a	3 _a	1 _a	5 _a

To improve MMO training, there were no significant differences between stakeholders, or particular subjects that stood out, as shown in figure 4-8. Few felt any need for further HSE training of any kind. 21.4% of respondents suggested ‘other’ ways to improve MMO training, including on the job training, the use of better qualified (minimum BSc in a relevant discipline) personnel as MMOs, and a greater level of acoustic theory.

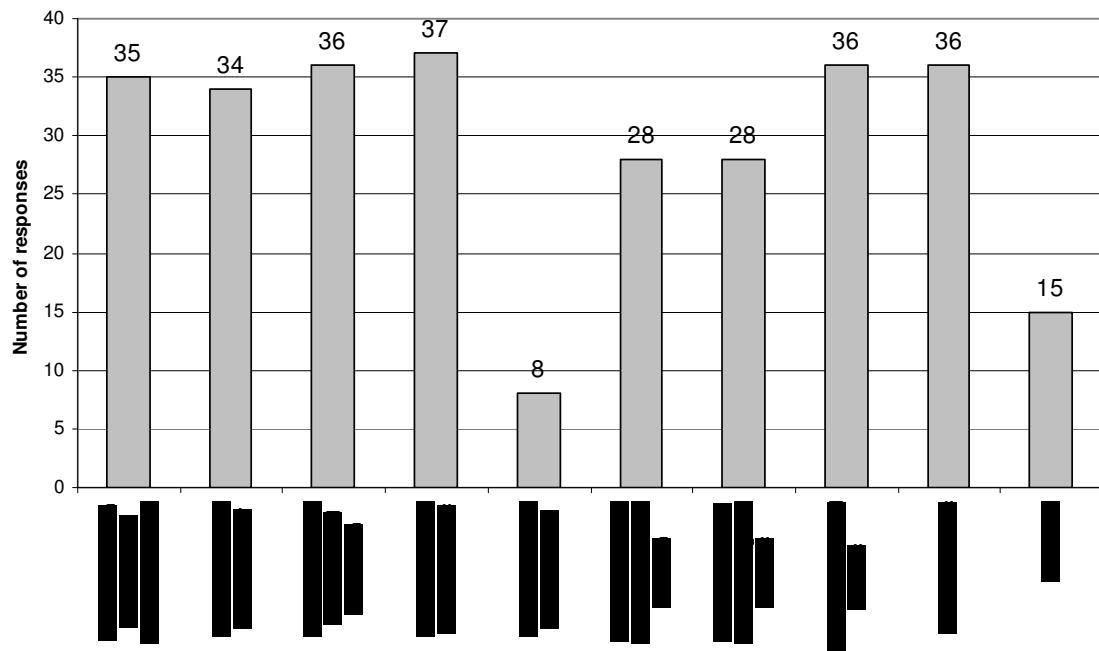


Figure 4-8; Summary of responses regarding ways to improve current MMO training.

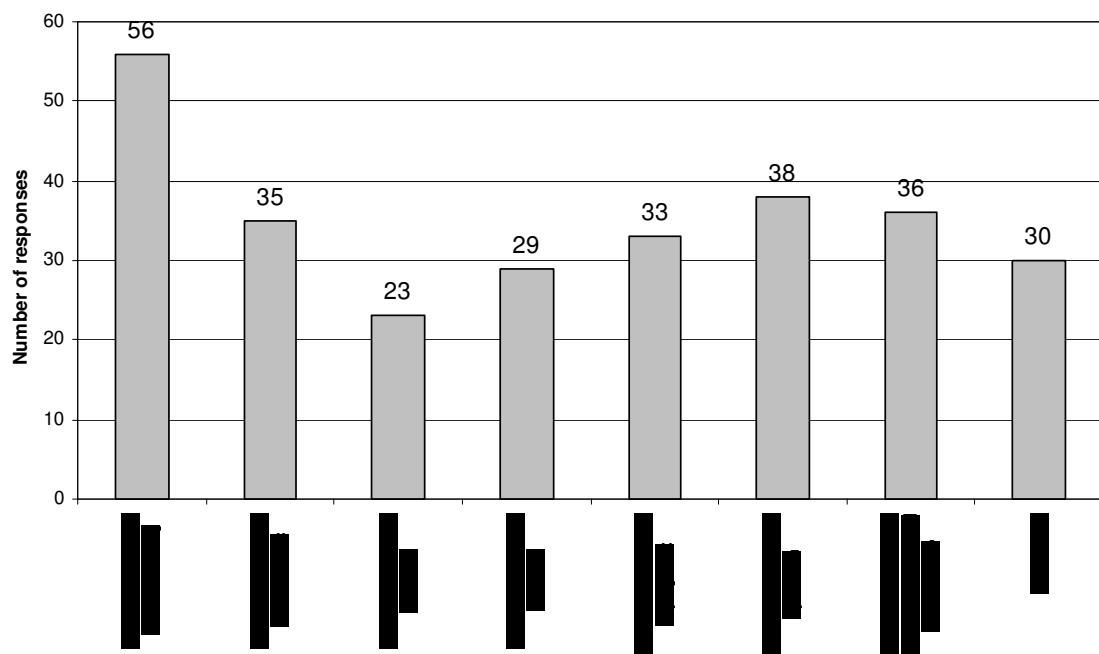


Figure 4-9; Summary of responses regarding ways to improve current PAM training.

Additional training on acoustic theory was the most frequent response with regard to improving MMO training, with other subjects scoring similarly. Lastly, the vast majority of respondents (85.3% of 116 answering) stated that a unified, internationally recognised training course for MMOs / PAM Operators would be of benefit.

4.3.6 Data usage

The majority of respondents (84.2% of 114 answering) felt that not enough is done to utilise the data collected by MMOs and PAM Operators. When asked to select a potential way forward, the largest group of respondents (43.2% of 95 answering) suggest that the best way to tackle this would through an international, collaborative research project. In terms of what MMO data should be used for, there was consensus that the data could be used for determining compliance levels, assessing impacts upon marine mammal behaviour and adding to our general knowledge of marine mammal distribution. The data was clearly not thought of as being useful for real-time decision making, as shown in figure 4-10.

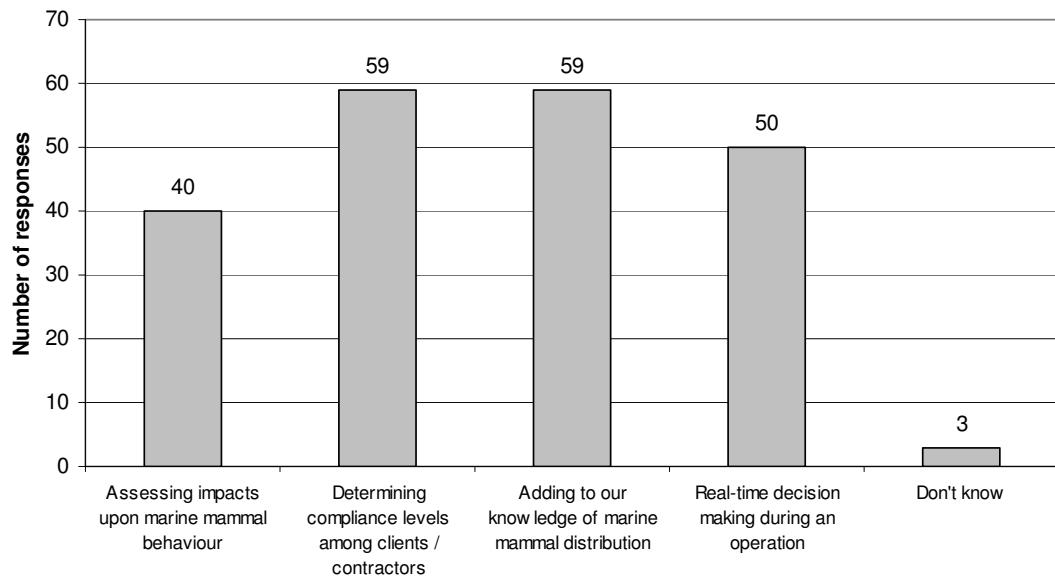


Figure 4-10; Summary of responses regarding ways in which MMO data could be utilised.

4.3.7 General feedback

A total of 56 respondents left additional comments about the survey, as well detailed responses regarding particular areas where the respondent wanted to expand on issues raised. Most criticism was focused on questions where additional options would have been useful to the respondent, such as question 23, asking whether respondents were MMOs or PAM Operators, but not giving an option for those that are both. Another perceived flaw was perceived simplicity or ambiguity within some of the questions.

Detailed responses highlighted areas where respondents believe there should be greater focus from stakeholders, such as developing all aspects of PAM to increase its effectiveness as a mitigation tool, the limitations of MMO data usage due to varying capability and motivations among those carrying out this work, and concern over a perceived lack of scientific basis for aspects of mitigation. A number of respondents stated that mitigation and monitoring should be separate, in order to enable greater detail to be collected on subjects

such as behaviour and facilitate more consistency in data collection. Reducing sound levels and spatial / temporal avoidance of certain areas were suggested as more effective ways of mitigating.

4.4 Discussion

The questionnaire succeeded in reaching the intended target audience, with a broad range of stakeholders represented within the respondent group, including academia, NGOs and industry. The group has been shown to be highly educated (majority to at least undergraduate degree level), and although varied in terms of educational background and career specialisation, there is a bias towards the life sciences within the group. This might be expected in terms of gaining responses for a topic focused on an aspect of life sciences. The overall sample size was high, though a relatively small percentage answered every question, with the sample sizes for individual stakeholder groups being low, particularly for the military.

In terms of how the different stakeholder groups view the importance of underwater noise and other issues of concern to marine life, what is interesting is the degree of consensus between groups. There were no significant differences between the rankings given by the six stakeholder groups, disproving the original hypothesis. All stakeholders agreed that overfishing is of the greatest concern, and that whale-watching is of the least concern. Overfishing has been demonstrated as having wide reaching ecological impacts such as trophic cascading (Scheffer et al., 2005) as well as long term impacts on the populations of target species such as cod (Hutchings, 2000). In light of such clear impacts, it is perhaps no surprise that this issue was seen as most

important, broadly followed by a closely related issue; fisheries by-catch. Fisheries by-catch is widely attributed as a major factor in exacerbating over-fishing due to direct impacts on non-target species, as well as physical impacts on benthic communities due to fishing methods such as beam trawling (Philippart, 1998).

Whale-watching could well be seen as a benign activity, due to potentially wide socioeconomic benefits, and the variety of guidelines and codes of conduct that have been implemented in most regions to mitigate potential disturbance from whale-watching vessels (Garrod and Fennell, 2004). It is not an activity likely to have wider ecological impacts such as over-fishing, though it has been demonstrated as resulting in short-term behavioural impacts similar to those demonstrated in relation to seismic survey activities (Magalhães et al., 2002). Of more concern is the decline in abundance over long periods as whale-watching activity increases (Bejder et al., 2006), which is a concern for industrial operations, but not something that is evident from current research.

Broadly, the issues have been ranked with those that have clearly demonstrable and wide ranging impacts being seen as most important, and those that have either the least tangible impacts or impacts restricted to few species as the least important (see Table 4-2). As hypothesised, there are differences between how some stakeholders view the importance of underwater sound, with industry and the military ranking it 5th and 7th respectively, while NGOs ranked it 3rd (higher than all other stakeholders). This could be a reflection of attitudes within those stakeholder groups, but also a reflection of the educational backgrounds too, as the respondents with a life science background are not as common within industry or the military, and NGO respondents were noted as having a wider spread of non-science backgrounds.

Therefore there is a potential lack of fundamental understanding of key aspects such as biology within industry, and physical sciences within NGOs. However, it must also be pointed out that the sample size of respondents for the military was low, and the rank placement of underwater sound by the industry and NGO groups only differed from the average for the group by one place, suggesting there is not a large difference of opinion regarding the overall importance of this issue in the wider context of those other issues listed.

When considering the potential impacts upon individual groups of species, there is again broad agreement between the stakeholder groups. For cetaceans, the majority of respondents for all stakeholders except the military have answered that there is a high likelihood of both mysticetes and odontocetes being impacted by underwater sound. Proving part of the hypothesis that industry and the military would view the potential impacts from underwater sound as less likely, the military were significantly different in responding that there would be a ‘medium’ likelihood of impact on mysticetes and odontocetes. This may reflect a deeper understanding of that group regarding the technology being used and its real potential to impact upon marine life, though may also downplay the many unknowns with regard to behavioural reactions and physiological impacts upon different species. No groups responded that there would be no likelihood of impact at all. This is not consistent with the hypothesis, as one might expect those stakeholders inputting sound into the ocean, and with lower marine biological expertise than academia, to have lower expectations regarding the likelihood of sound resulting in impacts upon marine species.

Considerable uncertainty regarding the likelihood of impacting upon other groups of species such as corals, polar bears and cephalopods is evident. This reflects to some degree the lack of research into the potential effects upon these other species. It also reflects the clear difference in how these species or groups are likely to have more limited exposure to anthropogenic underwater sound due to living semi-aquatic lifestyles such as polar bears, or not have the potential to suffer impacts like auditory trauma, such as corals. There is however, research indicating coral larvae respond to sound (Vermaij et al., 2010) and acoustic trauma within the sensory organs of cephalopods (André et al., 2011), highlighting the need for further work to understand the potential impacts on these other species.

Current guidelines and mitigation policy were seen as generally effective by the respondent group as a whole. However, industry differed in that they saw the guidelines as ‘highly’ effective, rather than NGOs viewing mitigation as ineffective, as hypothesised. This may be indicative of industry not wishing to have further restrictions placed upon it, when those that exist already impact upon operations. JNCC guidelines, on which the questionnaire focused, have previously been the subject of criticism due a range of perceived deficiencies, including a lack of scientific basis for the 500 m mitigation zone (Parsons et al., 2009). When compared to mitigation guidelines from other countries, as shown in Chapter 2, the JNCC guidelines are far more pragmatic in terms of operations than other examples such as those that implement larger mitigation zones and shutdown policies due to protected species proximity.

Reduction of noise in the environment was seen as the best measure of effectiveness by the respondent group, though this is presently not measured. Compliance levels and the extent to which mitigation practices are implemented

more generally can be easily assessed, and while regulators such as the JNCC may aim to reduce the level of noise in the environment, there is no clear indicator of whether this is achieved. The hours of source operation are reported by the MMO/ PAM team on board vessels, so information is available about the overall sound input over time, but this is more dependent on where and when surveys may take place at the request of operators, rather than any drive to limit hours of exposure at present.

Looking at the often used 500 m mitigation zone in particular, most respondents saw this as generally effective, while again the industry group saw this as ‘highly’ effective, disproving the hypothesis that all stakeholders would see the 500 m mitigation zone as ineffective and impractical. Practicality of the implementing and monitoring the 500 m zone was viewed as being ‘somewhat’ or ‘generally’ practical by most stakeholders, with the consultancy group standing out as seeing it as generally practical. Most respondents suggested a combination of measures to improve upon the effectiveness and practicality of the zone, with industry suggesting that mitigation zones should be based upon sound emission characteristics and monitored with a full suite of mitigation tools. That industry would wish for mitigation zones to be based on sound emission characteristics is consistent with the view that there is a lack of scientific basis to some elements of current mitigation practice (Streever et al., 2008). A mitigation zone can only be effectively monitored when provided with the necessary tools with which to do so.

A broader range of mitigation guidelines and operational specificity was seen as the best way to overcome grey areas that are present within current mitigation guidelines. Often there is a lag between developments with survey techniques and technology, and how mitigation policy fits those new

developments. For example, guidelines are based on surveys conducted as a series of grid lines, whereas many companies are now acquiring data between survey lines or in coil/ spiral configurations. There are also changes to survey technology that enable contractors to acquire data in weather conditions that previously wouldn't have been possible, and are non-optimal in terms of visual observation by MMOs. The formulation of clear guidelines for different operations has been begun by the JNCC with differing protocols for seismic surveys, construction piling and the use of explosives. Continuing this process for different survey types, such as VSPs, site surveys, wide azimuth surveys and so on would be beneficial, and also require a greater level of cooperation between regulators and industry.

PAM was seen as a 'somewhat' effective mitigation tool, rather than ineffective as hypothesised. Current systems are easily capable of detecting a range of species, particular those utilising mid to high frequencies, where the system is less limited by the seismic source array and general noise from the vessel. This means odontocete species are more readily detected than the larger mysticetes species. A wide range of improvements have been suggested by the respondents, with increasing the number of sensors within arrays, as well as deploying more arrays being popular answers. These improvements make a great deal of sense in terms of system capability, but lack practicality due to the congested area behind a typical seismic vessel where systems are deployed amongst seismic source and receiver equipment. Development such as those by seismic contractor *WesternGeco* have potential to implement these improvements while also being practical in terms of integration with existing equipment (Groenaas et al., 2011).

MMO training was seen as generally effective, particularly by the consultancy group. This stakeholder group will encompass those that work as and supply MMOs, as well as potentially those responsible for training, so it is perhaps little surprise that this group has confidence in the training. The effectiveness of PAM training was more of an unknown by the respondent group as a whole, with most respondents selecting ‘don’t know’. One of the main improvements to training for PAM was seen as being more acoustic theory training. Respondents felt that a unified course dealing more generally with mitigation policy, rather than focusing on individual jurisdictions such as the JNCC guidelines would be of value. The industry is international, and working to a variety of regulations within differing marine habitats, so a broader view for both MMO and PAM personnel as well as managers would be a useful undertaking.

As hypothesised, the vast majority of respondents did not think enough is being done with MMO data. The data was seen of least value for assessing the behavioural impacts upon marine mammals, with the greatest potential for both compliance monitoring with regard to how operators have conducted operations and adding to our general understanding of species distributions.

4.4.1 Limitations of the survey

While an attempt was made to get an accurate picture of the educational background and stakeholder affiliation of respondents, the current questionnaire limited the ability of respondents to report their cross-sector experience and expertise. This was highlighted by the number of respondents who recorded more than one affiliation. This shows respondents may have a multi-disciplinary

educational background and that at different times during their career may have changed sectors. These people potentially have a high level of expertise in a range of subjects of benefit when dealing with issues such as underwater sound and marine life, which are naturally multi-disciplinary in nature. It is perhaps not surprising that this is the case, when one considers the range of social and environmental impacts the energy sector in particular must consider while developing their business.

The requirement to carefully mitigate the potential effects of sound upon marine life has economic costs associated with it for those involved with offshore operations, which ultimately contribute to the price of energy or hydrocarbon products. Though direct monetary benefits to mitigating the potential effects upon marine life are hard to quantify, there is an indirect benefit in maintaining healthy populations and therefore ecosystem function. Protection is afforded by the stakeholders having a ‘willingness to pay’ (WTP) for the maintenance of ecological systems whether they have an intrinsic use in terms of resources or not (Martín-López et al., 2007; Christie et al., 2006). It would be of interest to establish, in light of how people view the importance of underwater sound as a potential threat to marine species, how much they may be willing to pay in order to ensure that those potential effects are mitigated against. This would require widening the target audience of any further questionnaire to include members of the public, as this stakeholder group would bear the main burden of increased costs. Similar studies have been conducted to establish the level of WTP and how it can vary between stakeholder groups, the perceived conservation status and the type of species, with marine mammals resulting in a high WTP (Loomis and White, 1996).

Respondents' concerns regarding simplicity or ambiguity within the questionnaire highlight that a greater complexity could have been incorporated within some subject areas. For example, question 15 asked respondents 'how effective do you consider current guidelines to be?', but was not specific about the ways in which the guidelines may or may not be effective. This was deliberate, in order to garner opinion from respondents who will have different ideas about what makes the guidelines effective in the first place, but is a simplistic approach. However, by making questions more complex and the survey potentially much longer, this may limit the type and number of respondents. The broad and relatively simplistic approach enabled a wide variety of respondents to answer regarding a suitable range of topics.

4.4.2 Summary

The questionnaire has served to highlight where differences of opinion but also consensus lie amongst key stakeholders involved with the underwater sound and marine life topic. The stakeholder group has been shown to be diverse in background and well educated. Stakeholders viewed underwater sound as something of moderate importance in comparison with other issues affecting marine species, with overfishing being ranked as the most important issue. Stakeholders felt that mysticete and odontocete cetaceans were the most likely species groups to be impacted by underwater sound. Considerable uncertainty regarding the potential impacts upon other species groups was evident, reflecting the broad lack of research across other species groups.

Current mitigation was deemed to be 'somewhat' effective overall, though seen by industry as 'highly' effective. The 500 m mitigation zone was also seen as generally effective overall, with industry again seeing it as 'highly' effective.

In order to make the mitigation zone more effective, respondents felt that a mitigation zone based on sound emission characteristics combined with a full suite of mitigation tools was the best way forward. The key measure of effectiveness was found to be the reduction of sound in the environment, which is currently not directly measured. Stakeholders agreed that more can and should be done with the data collected by MMOs, highlighting that its greatest potential is for it to enhance our understanding of the distribution of species sighted.

Chapter 5. Data collection, collation and dissemination

There is a large volume of data collected during the process of mitigating the potential effects of sound from offshore operations by MMOs (see Chapter 3). The majority of opinion from stakeholder analysis concluded that not enough is done to collate and analyse data collected by MMOs for the benefit of stakeholders (see Chapter 4). While these stakeholders may have different uses for this data, it has the greatest potential to add to our knowledge of marine mammal distribution. In this chapter, methods to enhance the data collection by using data validation techniques implemented by Global Positioning System (GPS) enabled smartphone technology are discussed. Utilising a Geographical Information System (GIS), marine mammal sightings are collated in order to demonstrate the benefit of viewing data in the context of environmental variables, marine administrative boundaries and industry infrastructure.

5.1 Introduction

The effective conservation of most species requires suitably detailed knowledge of its geographic occurrence and the availability/ quality of suitable habitat. It is well known that the biogeographical ranges of aquatic animals may be limited by environmental factors that define their ecological niche, such as temperature and bathymetry; because these factors can also define areas of high productivity and therefore prey availability (Kaschner et al., 2006). Human activity can also influence population sizes of aquatic animals at particular locations, for example, the depletion of offshore cod stocks near Canada due to fishing activity (Hutchings, 2000). Pollution is also known to impact population

dynamics, with examples such as nutrient excess in coastal waters, and oil spills impacting primarily on local scales (Gray, 1997). However, the situation with regards to the input of sound into the oceans is different, as there are multiple sources, many of which such as shipping and seismic surveying are also highly mobile. Similarly, marine mammals can cover long distances during migrations. Therefore, with larger distances and longer time scales, there is a need for a sensitive but broad method for mapping the locations of the sound, and of the animals around the oceans. In turn, it is vital to understand how species are affected behaviourally and/ or physiologically and whether such effects vary with the type of activity, duration and range from the source.

Biodiversity informatics is a sub-discipline of the general topic of 'Bioinformatics'. The latter is simply the use of computational methods and data bases of information in the life sciences. For ecologists, biodiversity informatics is the computer based management system that facilitates the archiving and analysis of biodiversity and related information (Costello and Vanden Berghe, 2006). GIS can be defined as a computerised inventory of geographically distributed features enabling geographic problems to be solved, and which comprises software, geographic datasets and both a user and developer community (Longley et al., 2001). It is a tool that can be used to effectively combine, archive, analyse, visualise and distribute georeferenced bioinformatic (biogeographic) data in order to aid the work of resource managers and policymakers (Stanbury and Starr, 1999; Su et al., 2006). GIS is an ideal system for the combination of data and analyses required in order to help understand species distributions in relation to their habitats, and how these may be impacted by natural and anthropogenic phenomena.

The use of GIS within the ocean sciences and the study of cetacean species has become commonplace. It is regularly used in order to plot species distributions (Reid et al., 2003), explore relationships between species occurrences and oceanographic variables (Moore et al., 2002), determine habitat preferences (Ersts and Rosenbaum, 2003), delineate potential MPAs (Hooker et al., 1999) and examine spatio-temporal effects upon marine species distribution due to anthropogenic activities (Jelinski et al., 2002).

There is an increasing trend towards the use of computer technologies in order to collate and disseminate biogeographic data relating to marine mammals and other species (Costello and Vanden Berghe, 2006). This should facilitate data access and analysis by the wider scientific community. Most notably the Ocean Biogeographic Information System – Spatial Ecological Analysis of Megavertebrate Animal Populations (OBIS-SEAMAP) combines georeferenced presence and absence data for marine mammal, seabird and turtle species, with remotely sensed oceanographic data (e.g., bathymetry and sea surface temperature) in a freely accessible web-based GIS (Halpin et al., 2006).

Observations collected by MMOs represent potentially important sightings data which can include rare species and sightings from poorly studied areas (as well as observations more generally available from shipping routes for example), and can enhance our understanding of where species occur. While such datasets cannot be utilised for absolute abundance estimates as the data collection is opportunistic rather than following a dedicated sampling strategy, and may have limitations regarding their further use for analyses of behaviours (Weir, 2008b), with the proper controls in place to ensure accurate species and location information, they have the potential to enhance the planning of marine

operations. Observations are collected in a broad range of locales relevant to marine operations, over long periods which may span seasonal variations in species occurrence within a given area (e.g. Stone and Tasker, 2006).

Combining historical species sighting data within a GIS and using temporal and spatial analyses to examine habitat suitability (HS) for different species can form the basis of an important planning tool for anthropogenic activity. The variety of mitigation guidelines, marine protected areas, as well as other temporal or spatial restrictions that exist within different jurisdictional areas are also of vital importance when planning activities at sea. This chapter describes the formulation of a GIS planning tool that encompasses a variety of data regarding marine mammal distributions, environmental factors, anthropogenic factors, administrative boundaries and regulatory guidelines. In tandem with this is the need to define a data collection process that standardises as far as possible the observations from the field, and ensure accurate metadata are produced to describe the context and parameters of the operation as part of which the observations are collected. The aim is to construct a planning tool that can inform those wishing to conduct activities offshore of the likelihood of encountering marine species and the regulatory framework at that location, as well as be updated regularly using information collected by mitigation personnel in order to improve the overall accuracy of the system.

The aims for this chapter were to;

- Summarise and critique current approaches to marine mammal data collation and use, focusing on data validation and quality control for subsequent use in GIS.

- Demonstrate the basis of a GIS data management and presentation system, with examples of data usage for modelling and feedback into the regulatory process with regard to anthropogenic activities.

5.2 GIS development

5.2.1 Field-based data collection

Data collection by MMOs in the field is a two-stage process, utilising paper recording forms completed by hand and PC based spreadsheet or database programmes for collation and later submission to the regulator and/or client. This method of working has the potential to introduce errors during data entry (Aanensen et al., 2009), is laborious and requires the user to utilise further software in order to produce distribution plots of species sighted which could play a role in real-time planning. GPS enabled mobile GIS have been developed in order to simplify, standardise and enhance field-based geospatial data collection (Briner et al., 1999; Poorazizi et al., 2008). For example, EpiCollect (Aanensen et al., 2009) was developed to enable field personnel collecting soil samples to enter data such as pH, temperature and moisture level data using GPS enabled smartphones which can then be synchronised to an internet based database, from which data can then be made available to others.

Prior to 2009, JNCC data forms had a header table that requested the user to fill in some basic details about the type of operation, the vessel and source. When reissued in 2009, the JNCC data recording forms included a summary ‘cover page’ for the first time, designed to capture this same basic

information regarding the operation and the sound source, but also observation methods and training of the observers present for the first time. This metadata is important to give context to the dataset being collected, in order that those data can be appropriately analysed and compared at a later date. Within the framework of a mobile GIS, such data is simple to capture prior to commencing data collection on the GIS/ GPS enabled device.

The manual recording of data can result in a wide range of errors that can be laborious to correct when collating in order to present results clearly. These can be simple spelling errors, where a GIS system for example would recognise records for a sighted marine mammal as different if recorded as 'sperm whale' and 'Sperm Whale' within the same spreadsheet, or may be the result of different terminology being used to describe the same animal behaviours, vessel activities or similar. For example, when a survey vessel moves from one survey line to the next, one person may record this as 'line change', whereas another may record this as 'line turn'. Such variations can be made worse if interpreted incorrectly by those responsible for transcribing data at a later date, and they impede automatic analysis. Ensuring the standardisation and quality of data collection would form a part of the International Organisation for Standardisation (ISO) 9000 quality management system that many public and private organisations implement.

Errors and variation of language need to be avoided in order to ensure data presentation and analysis is accurate, straightforward and as unambiguous as possible. By controlling the language of data collection in the first instance, errors are removed at the start and cannot be later compounded due to the removal of the transcription process. In order to achieve this, a GIS based data collection system using lists of options for items such as species names can

take the place of standard data collection forms. Examples of digital forms with this type of control are widespread both within scientific field data collection and in more common daily use within the growing usage of GPS enabled smartphone devices with applications ('apps') for a variety of functions, including those tailored to field data collection and interaction with a centrally stored database (Aanensen et al., 2009).

The standard JNCC recording forms are now issued with a spreadsheet version of the forms in addition to templates intended for printing and completion manually while working on deck. The manually completed data can be transcribed to the spreadsheet, with each worksheet having a number of data validation tools to control the data entry and reduce the potential for errors. This includes pop-up instructions for the completion of each column, with some containing drop-down lists of codes for data fields such as how the animals were first detected (see figure 5-1), the direction of travel of the animal and the status of the sound source.

The JNCC forms do not control data entry regarding species identification. This can lead to issues as already identified, with spelling errors and slight variations of species name leading to multiple entries that relate to the same species, leading to time consuming quality control once the data is collated for further use. Regulators in other areas have developed database systems to collate field data during the survey, which have far more control over data entry. For example, the Australian Department of Sustainability, Environment, Water, Population and Communities has developed a 'Cetacean Sightings Application' (CSA) for MMOs to complete which incorporates the standard forms for effort, operations and sightings as well as general survey information.

F	G	H	I	J	K	L
Time at start of encounter (UTC)	Time at end of encounter (UTC)	Were animals detected visually and/or acoustically?	How were the animals first detected?	Observer's/operator's name	Position degrees latitude	Position - minutes latitude
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						

Figure 5-1; An example of the data validation present within the JNCC data spreadsheets, depicting pop-up instructions and a column with a coded drop-down options list.

The CSA includes drop-down menus to select a ‘species category’, such as baleen whale, which then filters the next data entry field for species, such that the user then selects from a list of baleen whales, or whatever species category was first selected (see figure 5-2). Similar drop-down lists are present for behaviours, sighting cues and several other data fields where the range of entries needs to be controlled. This kind of validation removes many errors that may be associated with varied terminology and spelling mistakes when entering data manually, automating the quality control process and making the data import to GIS or statistical software much more straightforward.

Cetacean Sightings Application - Seismic - Version 3.0

Figure 5-2; The sighting data entry form of the Cetacean Sighting Application, illustrating data validation drop-down menus for species identification.

A database with mobile device data entry and synchronisation, called CheckPoint (© Copyright MidPoint Geo Limited 2012), has been developed for use by MMOs and other survey personnel, which is currently being field trialled. This system allows users to collect data manually in the normal way, entering data into a database utilising drop-down menus such as the CSA in order to ensure data are accurate. It also has the option to utilise a version of the database that is compatible with mobile devices running the iOS system (the Apple iPhone, iPod Touch and iPad), so data that is entered in this fashion is

automatically synchronised with a database on the local server (based on a survey vessel, for example) before being uploaded to databases held by clients or regulators.

The iOS data entry benefits from mobile devices that are GPS enabled, such that the position of the observer is automatically registered at the time a sighting is made (as shown in figure 5-3), and by using distance and bearing information, the position of the marine species being observed can also be calculated. All sightings are automatically plotted within a map viewer element of the graphical user interface (GUI), which can be augmented with data such as the survey line plan, bathymetry contours and so forth for context.



Figure 5-3; MMO data entry utilising iOS enabled device showing automatic geo-referencing, © Copyright MidPoint Geo Limited 2012.

5.3 Methodology

Improving the accuracy of data collection is important for maximising the usefulness of data when shared. The focus here is on the development of a GIS tool for sharing MMO data for the benefit of stakeholders involved with exploration.

5.3.1 Petroleum Exploration Protected Species Observation and Planning (PEPSOP)

The approach here has been to combine a number of vector and raster based data layers within ESRI ArcGIS 9.3.1 GIS software in order to demonstrate a proof of concept GIS planning tool (PEPSOP) that is adaptable to different marine operations, based on the input from accurately recorded information from MMOs. Raster data is a matrix of data in cells, with one data type completely filling each cell. The matrix must be given a coordinate pair for the top left cell, the number of rows and columns, a cell size (usually square) and an orientation. Vector data is defined by coordinate pairs, using one pair for a point, two or more for a line, and three or more for a polygon (where the last pair is the same as the first). The tool was constructed as worldwide in scope, utilising broad scale environmental and administrative data layers such as bathymetry and EEZ boundaries, while drawing out specific examples such as the UK where there are a wide variety of fine scale data layers available. In this way the effectiveness for broad information gathering for worldwide operations such as geophysical surveys can be demonstrated, as well as the more fine

scale planning required for operations within a complex marine environment utilised by a wide variety of stakeholders and subject to a more developed regulatory framework.

Spatial scales are important when considering the type of operations being undertaken. For example, a 2D geophysical survey is a transient operation covering hundreds of square kilometres, most likely in an offshore, deep-water environment. A site survey for locating a new marine installation is smaller scale (tens of square kilometres) and may be in a more congested area in terms of existing marine infrastructure, though this will also change as deep-water exploration and exploitation increases. The installation of a marine renewable development represents a permanent fixture within a given environment, most likely a relatively high use, shallow coastal environment. For each of these and other operations, there are very different potential impacts on the environment to consider, and so data requirements will also vary in order to understand how best to plan to mitigate those impacts. For example, while there is potential disturbance to consider from a seismic survey, such an operation is transient. A marine renewable development will result in sound input during the installation phase, but then have a variety of further potential impacts over its lifespan associated with the structures, the trenching of cabling, maintenance and eventual decommissioning.

Data layers as described in Table 5-1 (below) were combined within a GIS. A common spatial reference was used for all layers (World Geodetic System (WGS) 1984). While other spatial reference systems may be more appropriate on a national level, WGS 1984 provides an accurate worldwide reference system that is the default for most commercial GPS devices.

Table 5-1; Summary of data within the proof of concept PEPSOP, detailing the type of information, data type (whether raster or vector) and the data category.

Data layer	Data type	Category
Marine mammal observer records	Vector, point	Marine species
Bathymetry	Raster	Environmental
Exclusive Economic Zones (EEZs)	Vector, polygon	Administrative
Marine Protected Areas (MPAs)	Vector, polygon	Administrative
Marine Industry Assets – Pipelines, platforms, tidal and wind energy devices	Vector, point and line	Infrastructure

5.3.2 Marine species

In order to demonstrate the use of the GIS for the collation of marine species sighting data, data collected by MMOs and presented within chapter 3 is utilised, as shown in figure 5-4.. The data features marine mammal sightings collected during seismic operations, using JNCC recording forms, or adapted versions thereof. Each sighting is represented by a data point within a vector point shapefile (a vector shapefile uses vector data stored and manipulated in the format of the GIS software manufacturer, ESRI). Attribute data including the date and time of the sighting, position (decimal degrees to four decimal places), species, distance from the vessel, behaviour and details of the industrial activity taking place are all contained within the shapefile.

5.3.3 Environmental variables

The global bathymetry dataset ETOPO1 was utilised within the GIS (Amante and Eakins, 2009). This dataset is of 1 minute resolution, providing a global coverage of water depth, but which is relatively imprecise at local scales,

where additional sources of higher resolution data would be of use. Similar global datasets are available for variables including sea surface temperature, which would need to be assessed for their appropriateness to the sightings data in terms of temporal scale.

5.3.4 Administrative data – global

In order to delineate the EEZ of each country, within which a given a set of environmental guidelines and national legislation apply, the EEZ boundary shapefile developed by the Vlaams Instituut voor de Zee (VLIZ, Flanders Marine Institute) of Oostende, Belgium was utilised (VLIZ, 2011). The website includes a full description of how the dataset was created.

The World Database on Protected Areas was utilised to show all current MPAs or protected areas with a marine component (IUCN and UNEP, 2010). This database is itself the basis of an online biogeographic information system, enabling users to download GIS compatible files of protected areas which include a variety of attributes.

5.3.5 Administrative data – national

At local scales, national administrative marine boundaries are of relevance, as marine species may be occurring within zones used by varying stakeholder groups, such as licence blocks leased by oil and gas operators. Within the UK, the EEZ is divided into a series of quadrants and blocks, within which leases for exploration are managed by the DECC.

5.4 Results

5.4.1 Global overview

The marine mammal sightings were concentrated in the margins of the Atlantic Ocean, as shown in figure 5-4. The data cover a variety of deep-water and shallow habitats, with sightings coincident with both survey areas (which are not defined) and periods of transit by vessels between areas. The data have been collected in areas with mitigation guidelines in place (UK, Ireland etc), and a number where none exist, but where JNCC guidelines have clearly been implemented by the operator and the data returned to the JNCC, including Mauritania, Gambia and Senegal. When viewing the global dataset, it is combined with data layers that provide context including land masses, global bathymetry in raster format, worldwide EEZ boundaries and the global MPA dataset. The geographic location of the groups of sightings can clearly be seen at this scale, before selecting groups of data on a more regional basis in order to examine fine scale information such as water depth and proximity to MPAs or marine infrastructure.

Scales were set in order that as the user enlarges areas of the map, the context changes to provide more detail where datasets allow. For example, when viewing the UKCS, the EEZ layer is no longer visible, but licence quadrants, blocks, hydrocarbon fields and infrastructure become visible. This same process was used to aid in viewing the marine mammal sightings, which when viewed on a global scale all have the same symbol. When a region is enlarged within the map, the symbols change in order in order that species or species groups can be differentiated.

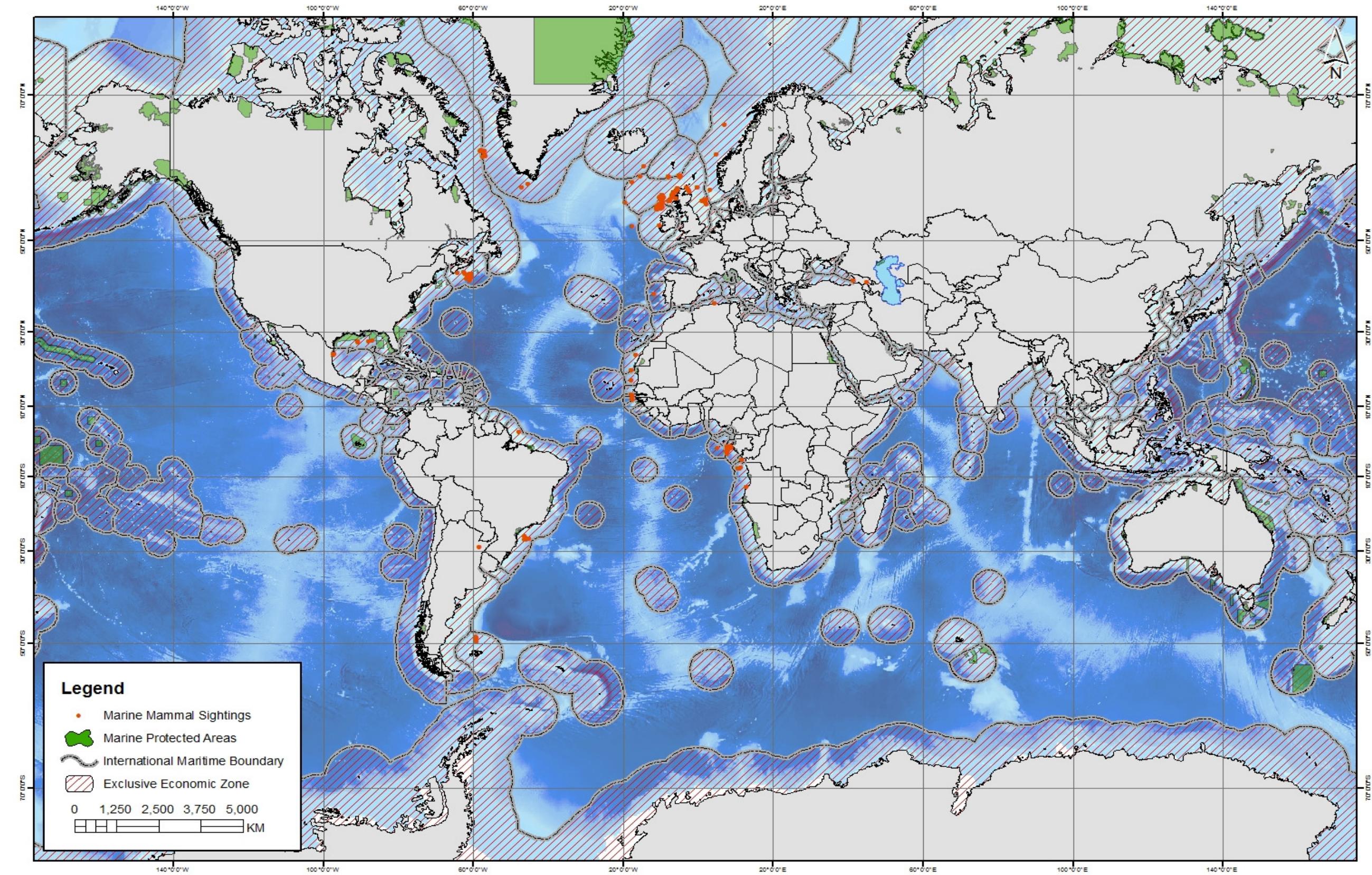


Figure 5-4; Global overview of a GIS planning tool depicting marine mammal observations with global administrative data and bathymetry. (Author).

The marine mammal sighting data can be queried by selecting a single sighting in order to review all attribute data that was recorded in the original JNCC recording sheets such as the date, observer, species, behaviour and so on, as shown in figure 5-5. These attributes can be utilised to filter and query the data in a variety of ways offered within the GIS software in order to show sightings by species, within particular date ranges, water depths and so on, depending on the interests of the user.

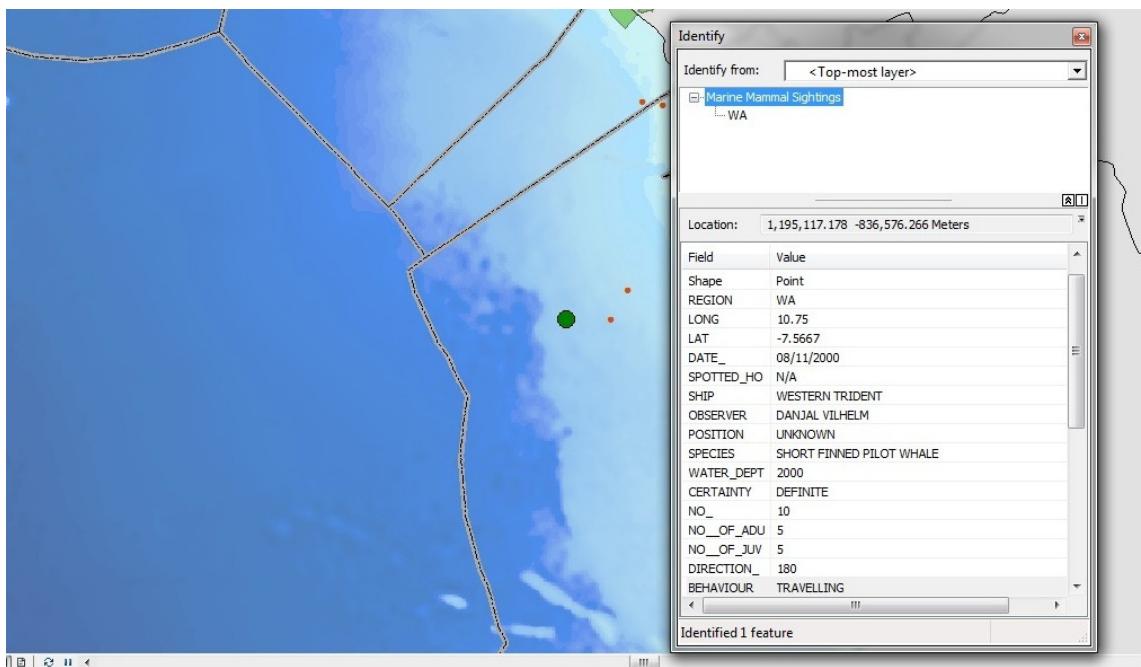


Figure 5-5; Illustration of the selection of an individual marine mammal sighting within the GIS showing the list of attributes available for each point within that data layer. (Author).

The geographical position of the sighting is evident in the list of attributes, and can be displayed as UTM coordinates as well. Without being plotted, the location coordinate is relatively meaningless, but when plotted with contextual data layers such as those shown here, issues with positional accuracy are easily highlighted, as the example in figure 5-6 shows. Within a

GIS, this data is easily filtered and removed, though would be absent altogether if data were collected using a GPS enabled device, such as a smartphone or personal digital assistant (PDA) as the user would not be responsible for recording the position.

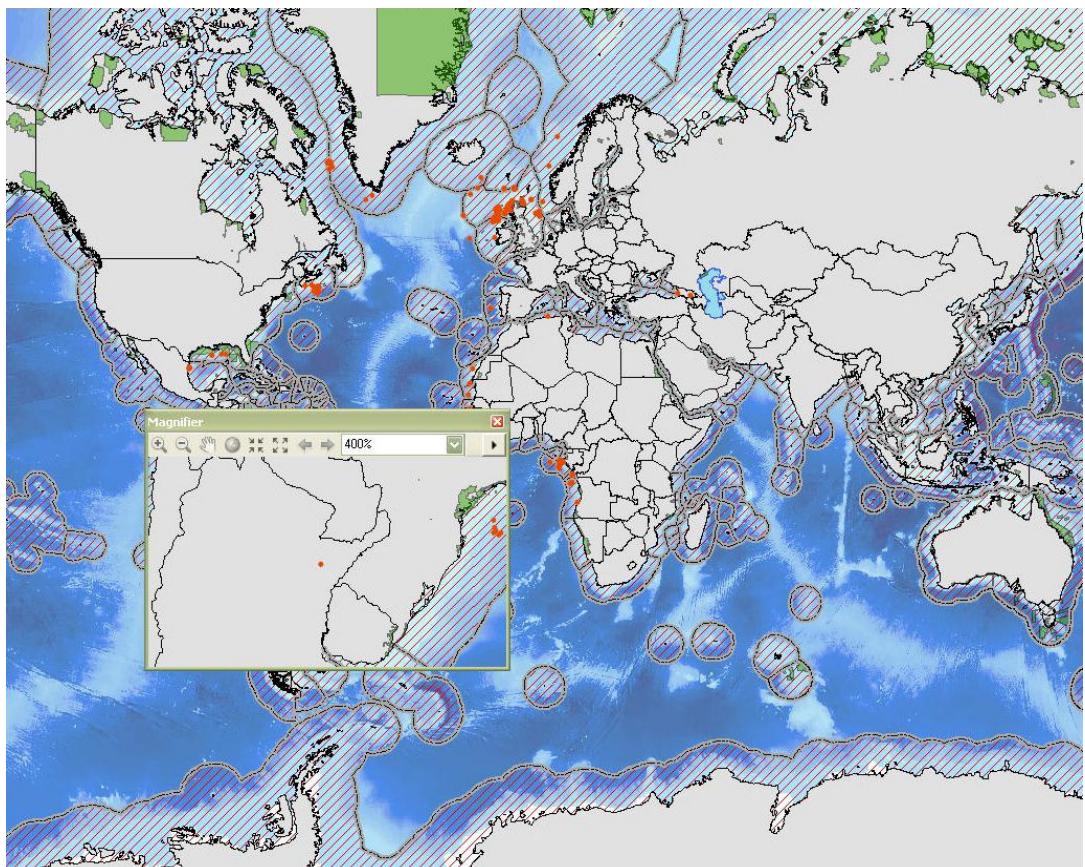


Figure 5-6; Overview of marine mammal sighting data collected during geophysical operations. The magnified area highlights a sighting event with low positional accuracy, resulting in a data falsely occurring over land. (Author).

Drawing upon the example of the UK in order to aid planning at the national/ regional level, there are a variety of datasets available relating to marine industries. As detailed in Table 5-1, these include oil and gas platforms, pipelines (also shown in figure 5-7) and offshore wind farm locations. These

data all require periodic updates, as new areas are designated for wind farm developments, for example, as well as installations being completed or decommissioned.

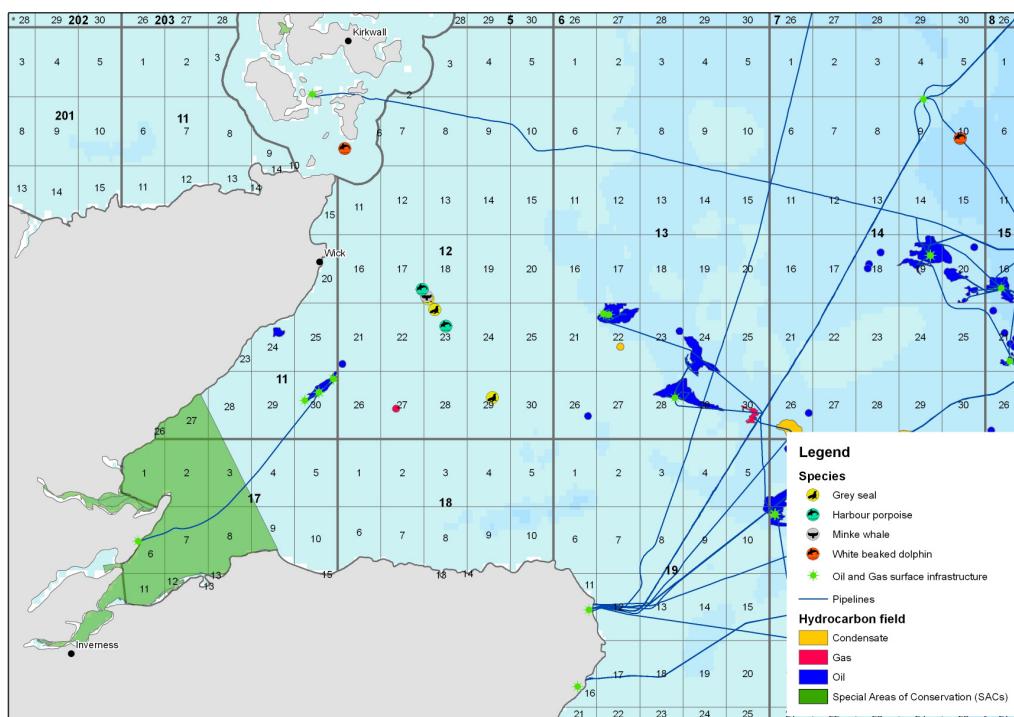


Figure 5-7; Local scale view of the GIS depicting marine mammal sightings in the outer Moray Firth, UK. The numbered blocks show the quadrants (outlined in bold) and individual licence blocks used to licence areas to oil and gas operators. Also shown are hydrocarbon fields, surface installations and pipelines. (Author).

As well as the attributes of individual shapefiles, the GIS makes further information available to the user, based on requirements such as mitigation guidelines within a particular jurisdiction, such as UK waters. Using the ‘hyperlink’ tool within the GIS allows the user to view a variety of guideline documents when selecting the EEZ of countries with guidelines, including the UK, USA, Canada, Greenland and so on. This can work locally too, for example where there are differing requirements based on the presence of a protected

area. The user can access official documentation, or summary information prepared in order to simplify information for particular locales or scenarios. This may include such information as strategic environmental impact assessments, mitigation guidelines, or even legislation that is relevant.

Figure 5-8 demonstrates an example for the UK sector where the polygon for the EEZ of the UK has been linked to JNCC documentation for mitigation of disturbance from seismic surveys, construction piling and the use of explosives. Any number of documents can be linked in this manner, enabling the user to pick from a list as shown. The example shows documents from 2004 and 2009 as guidelines have been updated. It may be of most benefit to include the most recent guidance only, along with any forms or procedures for data collection, assuming no move towards automation of data collection. Other examples of hyperlinked information include the ability to include photographs of species sighted, which may be of further utility for confirming species identification.

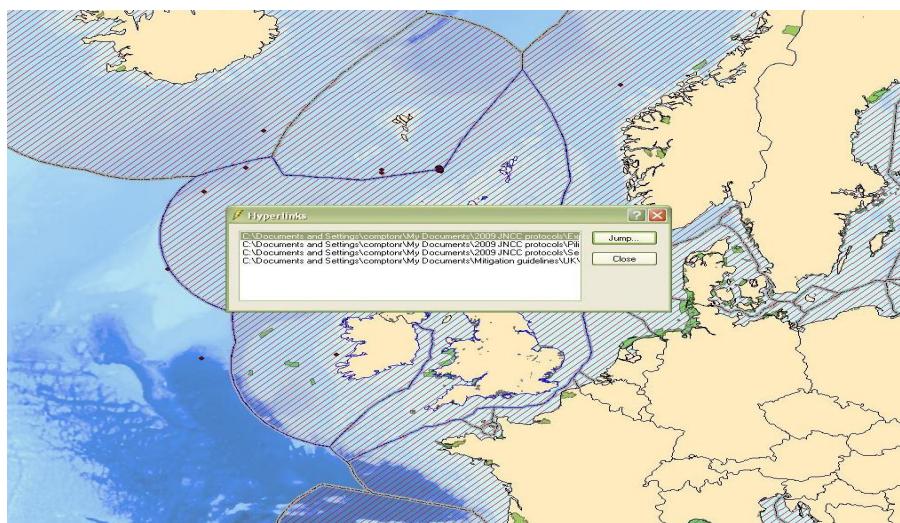


Figure 5-8; Screenshot illustrating a 'picking-list' of documentation that has been linked to the polygon of the UK EEZ (outlined in blue), allowing the user to select from a range of documents relating to mitigation within that area.

5.4.2 Derived data

Presence data for any given species can be further utilised by modelling the distribution of that species using a variety of techniques such as General Linear Modelling (GLM) and General Additive Modelling (GAM) (Guisan and Zimmermann, 2000; Hirzel et al., 2002). The example provided here is of HS calculated for the northern bottlenose whale from a dataset of 2,103 sighting and whaling records in the Northwest Atlantic Ocean, using Ecological Niche Factor Analysis (ENFA) (Compton, 2004). The data layer shows how suitable the habitat is for the northern bottlenose whale based on the ecological niche identified at sighting locations based on the factors depth, slope, aspect and sea surface temperature. Sightings of northern bottlenose whales collected during a geophysical survey correlate well with areas identified as being of high habitat suitability for that species shown in figure 5-9.

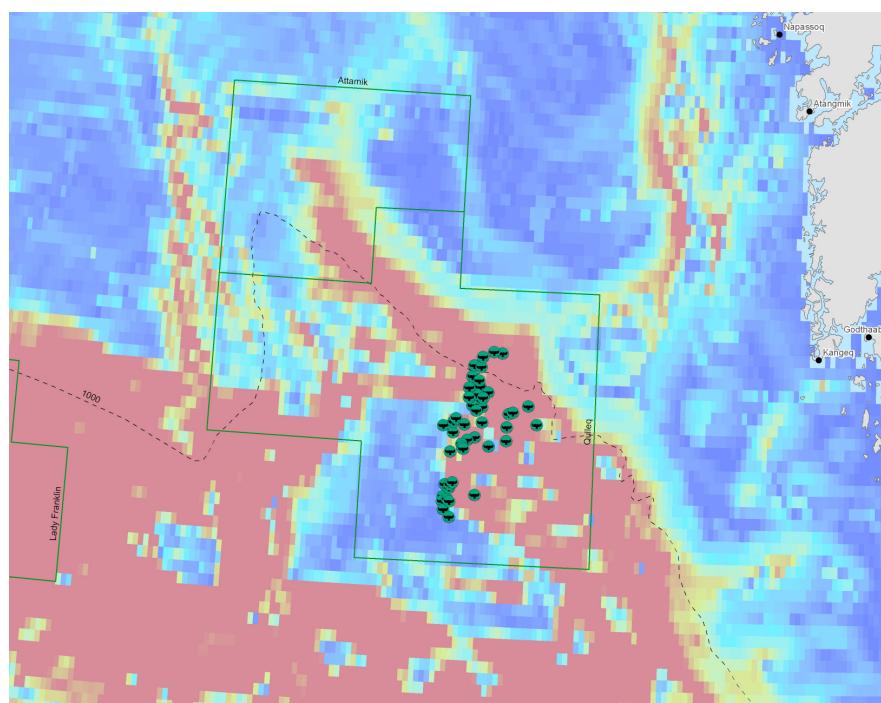


Figure 5-9; Northern Bottlenose whale sightings from a geophysical survey offshore Greenland, overlaid on to a habitat suitability map calculated from previous sighting and whaling data for that species. The sightings occur over areas of high habitat suitability (in red). (Author).

5.5 Discussion

The GIS development described here has a number of advantages over existing data uses. By placing data in a spatial context, they are more easily compared with existing sighting data from dedicated surveys where such exist, and facilitate analyses to model potential species distributions. With simple visuals, it enables the user to identify where areas of exploration activity are coincident with areas of species occurrence and diversity. Stakeholder engagement would be facilitated by making PEPSOP internet based, in the same way as the OBIS-SEAMAP and similar systems (Halpin et al., 2006). This would enable stakeholders to see the outcome of the mitigation that has become a part of operations, and enable all greater use of the information for planning purposes. Automating the data collection in the field by utilising GPS enabled devices would be a technological advancement to streamline the system and increase data quality, which would maximise stakeholder confidence in the system as a whole.

Enhancing the collection and use of species distribution data has the ability to help stakeholders manage potential risk by reducing the exposure to operations. Over time and with appropriate access to data collected by all stakeholders, marine mammal observations can enhance the quality of EIAs, and provide planners within regulatory bodies and energy companies with spatial and temporal information relating to marine species that may assist in further mitigating the potential impacts of operations. Effective Marine Spatial Planning (MSP) needs to combine data regarding natural resources that may be impacted by anthropogenic activities along with appropriate information relating

to the activities of stakeholders which may include marine installations or geological maps describing areas for potential exploration and/ or development (St. Martin and Hall-Arber, 2008).

5.5.1 Habitat preferences and distribution modelling

The example presented in section 5.4.2 highlights the potential use of distribution modelling techniques, with sightings collected during a recent geophysical survey correlating well with previously modelled data for the occurrence of the northern bottlenose whale (Compton, 2004). Marine mammal distributional data is collected in a variety of forms. Research institutions and NGOs around the world carry out dedicated surveys either independently or as part of consortia, often yielding the most comprehensive and reliable datasets which may in turn feed into biogeographic storage systems such as the OBIS-SEAMAP. Further data comes from sources such as historical whaling reports, fishery observer reports and opportunistic sightings surveys conducted aboard ships of opportunity (Reeves et al., 1993; Evans and Hammond, 2004). A simple use of such data is to plot sighting distributions with features such as bathymetry contours, which can be an informative display. However, as a wide range of fine scale remotely sensed oceanographic data such as sea surface temperature has become available, multivariate analysis within a GIS environment has made it possible to extract detailed information about which environmental factors may drive the distribution of a species and begin to describe a species' fundamental niche (Hirzel et al., 2002). Examples of work to identify the habitat associations of cetacean species include Moore et al. (2002) who found a seasonal association between blue whale (*Balaenoptera*

musculus) distribution and chlorophyll-a concentration, and Laidre et al. (2004), who showed bottom temperature to be the most important factor in describing the movements and behaviour of narwhals (*Monodon monoceros*).

Having identified the habitat requirements of a given species, this information can be extrapolated further using logistic regression and similar techniques in order to produce HS and predicted distribution maps (Guisan and Zimmermann, 2000; Hirzel et al., 2002; Gibson et al., 2004). Such methods have been applied to a range of species, including the northern right whale (*Eubalaena glacialis*) (Moses and Finn 1997), humpback whale (*Megaptera novaeangliae*), blue whale (*Balaenoptera musculus*), sperm whale (*Physeter macrocephalus*), fin whale (*Balaenoptera physalus*) (Gregr and Trites, 2001) and the beaked whales (*Mesoplodon* spp. and *Ziphius cavirostris*) (Waring et al., 2001). Work by Kaschner et al. (2006) developed an approach known as relative environmental suitability (RES) modelling to assign suitability values to map cells based on the published information regarding habitat usage for 115 cetacean and pinniped species, producing broad scale predicted distribution maps. This suite of predicted distribution maps has become the basis of a module within the Environmental Risk Management Capability (ERMC) system developed by BAE Systems, for use by the Royal Navy in order to assess any potential impact to marine fauna of planned sonar operations (Kaschner, pers. comm.).

Detailed knowledge of the habitat requirements and consequent distribution of a species is a central theme within ecology and a key factor in delivering effective conservation and management (Hirzel et al., 2001, Gurnell et al., 2002). This application represents an important use of any marine mammal sighting location data that may be collected by observers on board

seismic vessels, in order to identify which species may be encountered within a potential geophysical prospect area, as well as likely areas of high cetacean density and/ or diversity that may require particular care in terms any mitigation methods employed.

5.5.2 Integrated data collection and management

Field data collection utilising GPS enabled devices, database collation and web-based GIS tools can each be implemented in isolation, but the maximum benefit to stakeholders would be gained from having an integrated approach. Doing so would speed the collation and dissemination of sighting data such that stakeholders have more instant access in order to inform current and future operations. Figure 5-10 shows an example of the data flow.

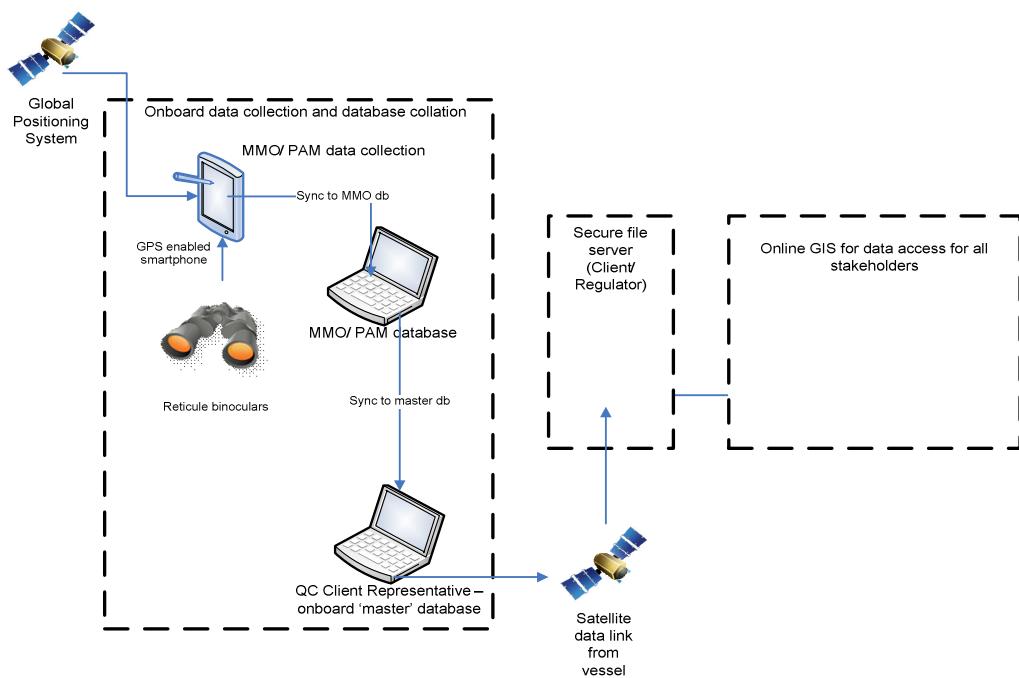


Figure 5-10; Data flow from a single operation, depicting data collection by MMOs, synchronisation to onboard databases prior to upload to databases held by regulators and transfer to a web based system accessible to all stakeholders in order to view, query and download data.

In practice, such a system would have multiple inputs from multiple operations. There are multiple regulatory databases, as well as those held by clients in regions where there is no depository for the data collected in the field by MMO and PAM personnel during operations. The databases can be brought together in the web based system, allowing stakeholders to view sightings and perform simple queries in order to identify where mitigation has been implemented for example. With little lag time between when the data is collected and when it is made available via the web based GIS, the system could facilitate near real-time planning in that surveys can adapt to any high density of sightings being encountered. Longer term planning is facilitated by building up data that can inform the EIA process, allowing stakeholders to manage risk based on any need to adapt mitigation protocols. This is of particular importance in areas where there is a general lack of information about what species are present and when, and where operators plan long term developments following successful early exploration phases that may lead to more intensive surveying, prior to potential drilling and hydrocarbon field development.

5.5.3 Summary

Utilising a GIS based system can enhance the accuracy of data collection and archiving. It enables real time plotting of sighting distributions in order to enhance survey planning during operations, by highlighting to managers where particular species are being encountered and so may be avoided by potentially changing survey acquisition plans. Dissemination of data can be facilitated by the development of website based GIS, enabling further analyses to be

undertaken by academic institutions, and provide planners and operators with detailed information about the occurrence of species in areas where other sources of information regarding marine species may be lacking. This would inform the lifecycle of exploration from the initial survey phases to drilling and extraction, enabling regulators and operators to more accurately assess the potential risks and impacts in any given area.

Chapter 6. General discussion

Underwater sound from anthropogenic sources such as marine geophysical surveys and the potential impacts upon marine life is a wide ranging research topic as demonstrated in Chapter 1. It is, by its very nature, multi-disciplinary, requiring research not only into topics as diverse as the many facets of underwater sound (propagation, measurement and characterisation), but also bioacoustics, marine animal physiology, behaviour, temporal and spatial aspects of population ecology, marine policy, environmental economics, to name a few. The combination of these research themes is necessary to examine such a complex issue, involve all stakeholders and develop effective management techniques to reduce the likelihood of resulting in the potential impacts identified.

6.1 A best practice framework

The aim here has been to develop a framework of best practice measures relating to mitigation of the potential effects of underwater sound on marine mammals during offshore exploration and development operations, focusing on the collection, use and dissemination of accurate marine fauna sighting data. Drawing upon chapters two to five, the stages of this framework are discussed below and summarised in figure 6-1. A key factor is the intention that the implementation of mitigation should be seen as separate from dedicated research, which is required in order to inform the basis of the necessity and extent of mitigation, but which cannot be carried out by personnel responsible for implementing mitigation protocols in isolation.

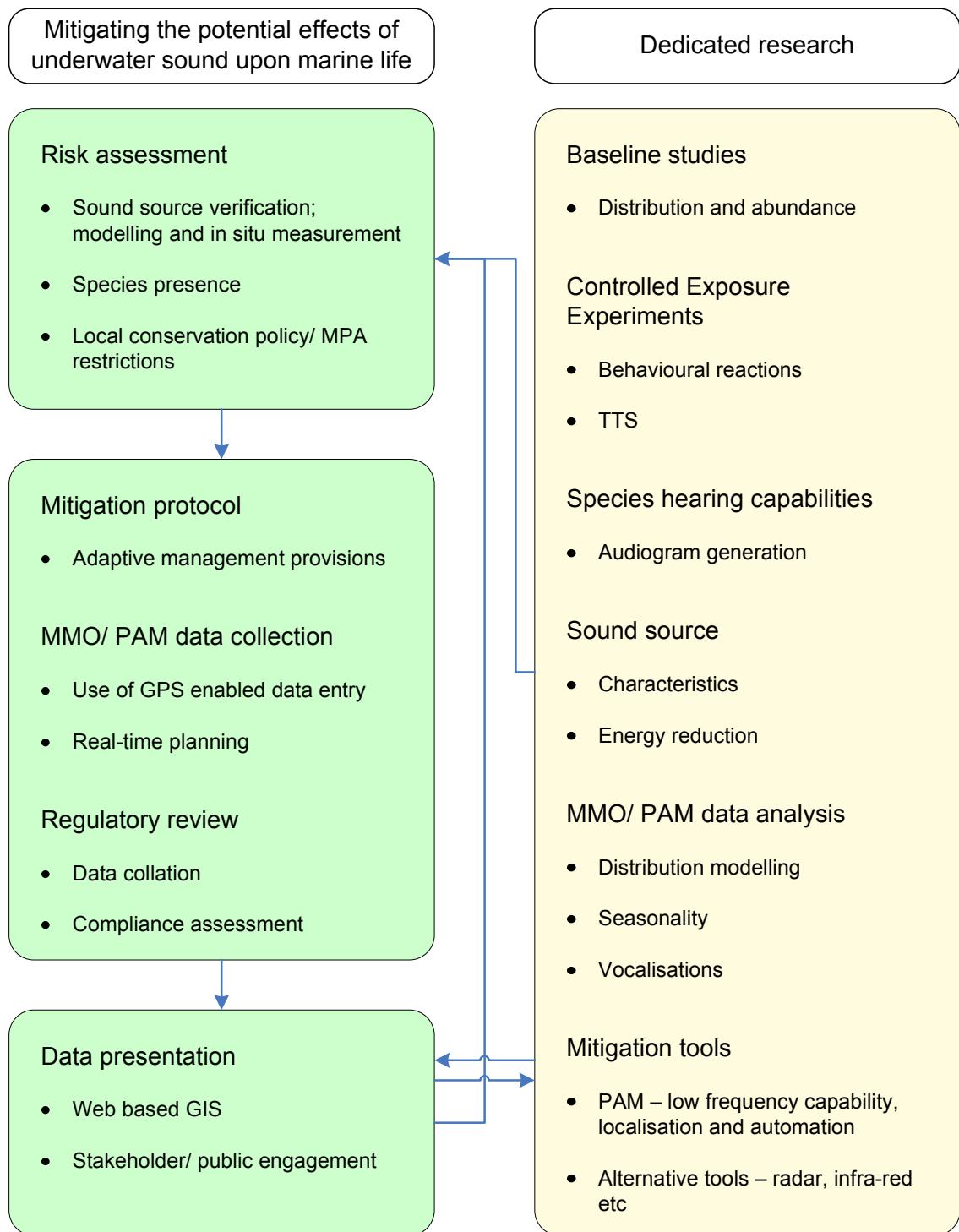


Figure 6-1; Summary of a best practice framework for the mitigation of the potential effects of underwater sound upon marine mammals.

Within Chapter 2 it was identified that the scope and practice of mitigation for marine species is varied, but rooted in a number of common techniques widely seen as best practice for reducing the chance of injury to marine species

and/ or minimising disturbance altogether. The efficacy of individual measures remains a further topic of debate, with some regulatory jurisdictions placing greater emphasis on precautionary measures in light of uncertainties than others.

While behavioural changes have been demonstrated for a range of species, the question of what potential there is for resulting in physical harm and significant long term impacts from activities such as seismic surveying and other offshore industrial activities remains unanswered and hotly debated by stakeholders (Boyd et al., 2011). Further collaborative research is required to establish what the true impacts are from the individual level to populations, and at varying temporal scales. This should include efforts to establish baseline information about populations in poorly studied regions. As our understanding improves, the mitigation process can be informed and refined in order to ensure that appropriate and practical measures are being implemented. The application of the precautionary principle in terms of mitigation of underwater sound is a way of managing a risk that is in many respects unknown (Gillespie, 2007). The degree to which we apply that principle can challenge the practicability of those mitigation measures, where one might argue that mitigation zones of 500 m are too small to effectively minimise disturbance, whereas mitigation zones that are in the thousands of metres cannot effectively be monitored. A balance needs to be struck between effectively minimising the potential impacts upon marine species, and enabling activities essential to the economies and energy securities of nations to continue in a safe and responsible manner.

A common baseline protocol for mitigating the potential effects of underwater sound upon marine mammals was discussed in chapter 2, and can be summarised as;

- Protocol to cover all cetacean species, other megafauna protected in any given jurisdiction, and a precautionary approach with regard to other species for which an understanding of the potential effects of underwater sound is lacking. This is supported by consistent findings both here and in previous studies that all cetacean groups have been found to exhibit lateral spatial avoidance (Stone and Tasker, 2006; Barkaszi et al., 2012), that the seismic pulse contains energy in a frequency range with the potential to impact upon small cetacean species (Goold and Fish, 1998), and that precaution is an accepted management tool in the face of uncertainty (Gillespie, 2007).
- Commitment to the appropriate staffing on projects in order to ensure that there enough MMO and PAM personnel to adequately cover both daylight and periods of darkness or poor visibility.
- The continued application of the ‘soft-start’ procedure, in the absence of evidence that it does not serve as an acoustic warning to proximal marine species that may then move away from an operation where the sound level may result in harm.
- Application of mitigation zones based on the sound source in use, applying exposure criteria set by Southall et al. (2007). A dual zone approach should be applied, with an outer zone being 500 m beyond that applied subsequent to sound source verification relating to the sound exposure criteria. This zone should be used to improve communication with the seismic crew by warning

personnel when marine species are within it, which may soon impact upon the zone within which further mitigation must be implemented.

- The implementation of a shutdown during seismic acquisition if the mitigation zone is breached by cetaceans or other marine species being mitigated for.
- Adaptive management, to allow for amendment to the protocol based on a local risk assessment in order to account for the proximity of MPAs, local regulations and the presence of species with enhanced protection provisions due to unfavourable conservation status. Risk assessment is common either as a full EIA, or in the permit application within some jurisdictions, but should be a compulsory undertaking prior to any operation.

The use of MMOs during seismic surveys and other offshore activities facilitates the implementation of mitigation protocols, and as demonstrated within Chapter 3, provides regulators with critical information to do three things. Firstly, the degree of compliance with the relevant guidelines by operators can be determined. Secondly, sighting information provides a valuable resource relating to the occurrence and distribution of marine mammal species, allowing stakeholders to assess the potential level of interaction with marine species in an area, which may assist with operational and regulatory decisions. Thirdly, the data collected attempts to characterise behavioural reactions in relation to operations. However, it has been highlighted that MMOs in general are not adequately trained to make informed decisions about the behavioural state of marine mammals during their observations, with behavioural observations often

lacking or inconsistent (Weir, 2008a; Barkaszi et al., 2012). As such, behavioural analyses should not be carried out using current MMO data. The data are adequate for distributional analyses to help inform stakeholders of the temporal and spatial patterns of marine mammal populations. Some data from MMOs has been demonstrated to be fit for this purpose, but as shown in Chapter 3 it is subject to wide variation in quality and ease of integration due to data requirements varying between regions, and manual recording techniques resulting in errors that can limit data usage or at the very least increase the difficulty of data integration and subsequent analysis.

The stakeholder questionnaire of Chapter 4 highlighted some consensus and differences between the views of stakeholders on a number of issues. Interestingly, there was no significant difference between the views of stakeholders with regard to the importance of underwater sound in relation to other marine environmental issues. Industry and the military viewed the subject as slightly less important than others, while NGOs viewed it as more important, in part reflecting the differing understanding of themes surrounding the issue. This highlights the need for information sharing between groups. There was broad consensus on some items including the perceived environmental issue of greatest threat to marine life (over-fishing), but also those groups of species most likely to be impacted by underwater noise; odontocetes and mysticetes. Stakeholder opinion on the potential threats to a variety of other species such as corals and cephalopods was varied, highlighting the lack of research and knowledge regarding these groups. A central point highlighted by the questionnaire was that the key measure of the effectiveness of mitigation guidelines is the reduction of noise in the environment. While the overarching aim of guidelines may be to reduce sound in the environment by using the

lowest practicable seismic source volume for example (JNCC, 2010), there is no mechanism in place to measure either sound input or any potential reduction.

Stakeholders confirmed the view discussed in Chapter 3 regarding data usage, with the majority of those responding confirming that the data can add to our knowledge of species distribution, but far fewer felt that it could be used for determining behaviour. It was also revealed that stakeholders do not feel enough is done to utilise data collected during mitigation, and that a collaborative approach to its use and dissemination would be of benefit.

Chapter 5 builds on these points in order to present a method of data collection, collation, use and dissemination. This is based on utilisation of electronic, GPS enabled media to record information in the field which is automatically georeferenced and uploaded to local databases, which can then be added to regulatory databases. Wider dissemination and use of the data can be achieved by pooling information by way of an internet based mapping resource, such as the non web-based proof of concept PEPSOP. Both mitigation and data collection can be enhanced by simplification, allowing personnel to focus on operational needs and the central task of reducing the risks of protected species being within the given mitigation zone of the operation. Removing the need for behavioural observation and its associated inaccuracies resulting from a non-specialist and varied observer group, and increasing the control over the terminology and data field entries has the potential to provide a focused and accurate dataset on which to establish risk profiles for both areas and seasons, in relation to any planned marine operations. The risk profile would be based on an increasing knowledge of the level of occurrence, diversity and distribution of species, combined with

increasing knowledge from empirical studies of behavioural responses and investigations into the physiology of species in relation to potential impacts from underwater sound. This is shown within the feedback loop within figure 6-1, whereby mitigation is carried out based on a common protocol that may or may not be adapted subsequent to risk assessment. Data is then collected and collated utilising improved tools for field personnel and managers, before being made available to the wider stakeholder community in order to then further inform both research priorities and the risk assessment and mitigation phases.

Chapter 7. Conclusion

Mitigating the potential effects of anthropogenic underwater sound on marine life is an emotive issue, with many unresolved questions and a great deal of uncertainty. The wide range of documented behavioural changes in relation to sound and concern for potential physical effects, such as TTS which can be demonstrated experimentally (Finneran et al., 2005) has led to the development and implementation of common sense measures to try to minimise the disturbance and potential for injury to cetaceans and a range of other marine species. These protocols and the way they are implemented vary between jurisdictions, and in some cases have been noted as lacking a scientific basis (Parsons et al., 2009). Our developing understanding of what levels of sound may result in injury presents an opportunity to update mitigation protocols and focus the efforts of personnel who implement mitigation and collect valuable information regarding the spatial and temporal occurrence of a range of species.

Improving the way in which data is both collected and disseminated affords stakeholders an opportunity to better plan the timing and location of operations in order to further limit the exposure of marine species to operations. The only guaranteed method of minimising the risk of disturbance or injury to marine species is by not being carrying out an operation where those species occur. While we strive to exploit our natural resources such as hydrocarbons or physical spaces for installations (oil rigs, renewable energy devices and so on), a level of impact is unavoidable. By balancing precaution and pragmatism, and utilising the information gathered to guide stakeholders, we can ensure that significant, long term harm or disturbance to marine life is avoided, while

ensuring that marine operations essential to global economies and individual nation's energy securities are facilitated. The outcome here provides a method of capitalising on existing methodologies in order to improve the quality and use of information being gathered in the field, as well as recommendations for a common precautionary protocol on which to base mitigation.

The initial chapters contained a critical review of current mitigation measures designed to minimise the potential effects of underwater sound on marine species. The review of data collection found that the quality of sightings data varied, with trained MMOs more likely to record data fully and accurately. Example analyses identified that some sighting distances was greater for some species when the seismic source was active but that the behaviour of species was difficult to establish. This established that the data is not well suited to behavioural analyses. There was a distinct weakness in the quality of the data and the difficulty in recording behavioural observations.

Stakeholder opinion was gathered using a questionnaire, highlighting differences of opinion and some consensus. A total of 346 people attempted the survey, from a potentially very large target audience across all stakeholders identified. They were diverse in background and well educated. Stakeholders viewed underwater sound of moderate importance in comparison with other issues affecting marine species such as overfishing; mysticete and odontocete cetaceans were the most likely species groups to be impacted by underwater sound. Mitigation was deemed to be 'somewhat' effective overall by the majority of stakeholders but industry classified it as 'highly' effective. Favoured improvements included better estimates of sound and its overall reduction. Stakeholders agreed that more should be done with the data collected by MMOs to improve our understanding of the distribution of those species sighted.

A purpose-built Geographical Information System was created populated with 300 paper sightings transposed into digital form. The associated data relating to anthropogenic activities and administrative boundaries established a planning tool to inform spatio-temporal mitigation. The author's analysis of the original data identified recording, positioning, typology and classification errors and incomplete data. Analysis in the GIS highlighted further positioning errors not originally clear from the raw data.

The GIS based, digital data gathering system offers enhanced data accuracy through improved collection and archiving. It enables real time plotting of sighting distributions in order to enhance survey planning during operations, by highlighting to managers where particular species are being encountered and so may be avoided by potentially changing survey acquisition plans. The dissemination of data can be facilitated by the development of the GIS, enabling further analyses to be undertaken.

Thus, the study has developed a framework of best practice measures which relate to the mitigation of potential effects of underwater sound on marine mammals.

7.1 Recommendations

A common baseline for mitigation protocols has been suggested, which should be implemented in order to benefit all stakeholders. The companies involved often have global exploration activities, such that moving between areas can create confusion regarding which rules apply where. It is also important to highlight that species may migrate between jurisdictions, where

current protection levels will vary. The use of a worldwide standard should not preclude the use of adaptive management techniques in relation to sensitive habitats and/ or species where there may be particular conservation concerns. Any common guidelines must recognise that each region will be different in the specific needs that must be met by an effective mitigation plan for industrial operations, and a risk assessment to help identify any potential adaptation and additional conditions is a key part of the suggested protocol. However, with a standard core set of measures, mitigation will be simplified and standardised.

Mitigating the potential effects of underwater noise from seismic surveys and other operations is a task that has been overcomplicated by combining it with trying to monitor those effects. The task should be simplified by focusing on mitigation, and directing more effort into ensuring the sighting data being collected is as accurate as it can be. In turn that data can be collated and disseminated, building on the existing knowledge of species distributions within given areas, and allowing stakeholders to plan operations based on an understanding of what species are likely to be present and when. Understanding the potential effects upon those species or populations remains a fundamental requirement, but is better kept separate from operations, with focused research efforts employing scientific rigour to experimental design and data collection in order to avoid the weaknesses of data collected by non-specialists with varied training.

7.2 Future work

The stakeholder questionnaire could be developed further to enable further detail to be gathered regarding respondents cross-sector expertise,

which was not well captured within the present questionnaire. It would also be of benefit to question stakeholders regarding their willingness to pay for mitigation, in order to see how this may vary between stakeholders, as well as identify any potential effect on WTP by species or species group, as previously identified by Loomis and White (1996).

Provided with access to data by both industry and regulators, the main area of future work identified here is to populate a web-based spatial database with data collected by MMOs as described in Chapter 5. Bringing this data together, with data validation and quality control procedures established under a management system such as ISO9000 would enable comparison with academic sources of sighting data, and the implementation of statistical modelling in order to identify areas of high species diversity and work towards identifying critical habitat. In this way the potential risk to species within a given space and/ or time can be more accurately assessed, and therefore assist in reducing exposure to potential stressors.

The use of GPS enabled smartphones, tablet PCs and PDAs along with associated databases for field data collection and collation is currently being trialled within industry. It is hoped that this will streamline the process of data collation, and ensure that validation for data entries can be fully implemented. Given positive results from the use of such technology, this approach should be adopted across the industry as a standard. Ideally it would be implemented with a more common approach to mitigation as suggested, though in the short term could be implemented for varying protocols and data requirements depending upon the regulatory requirements in a given region.

Appendix 1 – Stakeholder questionnaire

Underwater sound and the mitigation of disturbance to marine life

The subject of underwater sound and its potential impacts upon marine life is an important area of scientific research. Concern over potential effects upon marine mammal species in particular has led to the development and implementation of guidelines for the offshore industries. The key example is the 'Guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys', issued by the UK's Joint Nature Conservation Committee (JNCC). Similar protocols exist for piling and the use of explosives in the marine environment.

Similar guidelines have been developed around the world, primarily for geophysical survey operations. Each set of guidelines has common features relating to how operations should be monitored, delayed and in some cases temporarily suspended due to the proximity of protected marine species. The implementation of such guidelines has, and continues to be a contentious issue for stakeholders due to the costs incurred and differing views regarding the scientific basis for the varying features of the guidelines, as well as the effectiveness in terms of the conservation of species.

This questionnaire is designed to gather opinions on;

- 1) the scientific basis of the guidelines
- 2) the practicalities and issues relating to current practice

The survey consists of six groups of questions. The first set of questions is simply to identify your background in terms of stakeholder grouping (industry, academia, etc) and identify any areas of expertise. The questionnaire then focuses on the areas mentioned above. The survey should take approximately 15 minutes to complete. All submissions are anonymous.

The survey is being conducted as part of postgraduate research conducted by Ross Compton; an MPhil / PhD candidate of the University of Plymouth. For any queries, please contact; ross.compton@plymouth.ac.uk

Underwater sound and the mitigation of disturbance to marine life

Section 1; About You.

***1. Are you male or female?**

- Male
- Female

***2. Which category below includes your age?**

- 17 or younger
- 18-20
- 21-29
- 30-39
- 40-49
- 50-59
- 60 or older

Underwater sound and the mitigation of disturbance to marine life

***3. Please indicate the highest level of qualifications you have from the following list;**

- GCSE / O-Level / equivalent
- A-Level / NVQ / International Baccalaureate / equivalent
- First degree (BSc, BA etc)
- Postgraduate Certificate, Diploma or equivalent
- Higher degree (MSc, MRes etc)
- Doctorate

***4. If you have a degree or postgraduate degree, please indicate the subject area that best describes your highest qualification from the following list, or detail 'other' as appropriate;**

- Computer science
- Arts
- Life sciences – Marine Biology
- Chemistry
- Social science
- Geography
- Oceanography
- Engineering
- Physics
- Life sciences – General Biology
- Life sciences – Biomedical Sciences
- Mathematics
- Business studies / commerce
- Life sciences – Ecology
- Environmental science
- Other (please specify)

Underwater sound and the mitigation of disturbance to marine life

***5. With which of the following stakeholder groups would you consider you currently work within. Please select one by indicating the length of time in years you have worked within that general role.**

Academia	<input type="text"/>
Non-governmental organisation	<input type="text"/>
Government agency	<input type="text"/>
Consultancy	<input type="text"/>
Industry	<input type="text"/>
Military	<input type="text"/>

***6. What is the nature of the core business of your current employer?**

- Deep sea fishing
- Environmental Impact Assessment
- Fish farming
- Health and Safety
- Inshore fishing
- Marine construction
- Marine survey (hydrographic)
- Marine survey (Seismic exploration)
- Oil and Gas Exploration
- Oil and Gas producer
- Regulator
- Renewable Energy
- Research – Computer Sciences
- Research – Life sciences
- Research – Oceanography
- Research – Other
- Research – Petroleum Geology
- Research – Physics / Engineering
- Other (please specify)

Underwater sound and the mitigation of disturbance to marine life

Section 2; Underwater Sound & Marine Life

***7. To what extent are you directly involved (via research, implementation of policies or similar) with the general subject area of underwater sound marine and marine life?**

- Not at all
- Passing knowledge
- General knowledge of the broad topics
- Technical competence and working knowledge
- Expert

Underwater sound and the mitigation of disturbance to marine life

***8. How would you rank the issue of underwater sound in relation to other issues of concern for marine life? Please rank the following in order of importance, where 1 is the issue you believe is most important.**

Chemical pollution	<input type="text"/>
Global environmental change	<input type="text"/>
Over-fishing	<input type="text"/>
Fisheries by-catch	<input type="text"/>
Marine litter	<input type="text"/>
Whale-watching (professionally guided trips)	<input type="text"/>
Whaling	<input type="text"/>
Marine recreational development (e.g. growth of marinas and associated impacts on coastal environment, including increase in number of small vessels)	<input type="text"/>
Invasive species	<input type="text"/>
Marine mammal collisions with ships	<input type="text"/>
Underwater sound	<input type="text"/>

Underwater sound and the mitigation of disturbance to marine life

***9. What do you consider to be the likelihood of the following groups of marine species being affected in some way by underwater sound?**

	Don't know	Not at all	Low	Medium	High
Cephalopods (Squid, octopi etc)	<input type="radio"/>				
Coral	<input type="radio"/>				
Diving birds (e.g. gannets)	<input type="radio"/>				
Elasmobranchs (sharks and rays)	<input type="radio"/>				
Fin fish	<input type="radio"/>				
Mysticetes (baleen whales)	<input type="radio"/>				
Odontocetes (toothed whales)	<input type="radio"/>				
Pinnipeds (seals and sea lions)	<input type="radio"/>				
Polar bears	<input type="radio"/>				
Sea otter	<input type="radio"/>				
Sea turtles	<input type="radio"/>				
Shellfish	<input type="radio"/>				
Sirenians (Dugongs and manatees)	<input type="radio"/>				

Underwater sound and the mitigation of disturbance to marine life

Section 3; Underwater sound – principles, measurement and sources.

***10. To what extent are you knowledgeable with the general principles of underwater sound; in particular its measurement, propagation and the characteristics of underwater sound sources?**

- Not at all
- Passing knowledge
- General knowledge of principles
- High level of knowledge of principles, theory and sources
- Expert

Underwater sound and the mitigation of disturbance to marine life

* 11. The decibel is the most common unit used to quantify the amplitude of a sound.

Do you believe this to be appropriate when trying to characterise and compare underwater sounds, sounds in general, and the potential impacts upon marine life?

- Yes
- No

Underwater sound and the mitigation of disturbance to marine life

***12. What do you consider to be an appropriate unit of measurement, if not the decibel?**

- Pascal (Pa)
- Newtons per square metre (N/m²)
- Watts per square metre (w/m²)
- dB ht (species)
- Other (please specify) _____

Underwater sound and the mitigation of disturbance to marine life

*** 13. In terms of trying to understand the potential impacts of underwater sounds, how do you rate the importance of each of the following characteristics of a sound?**

	Don't know	Not at all	Low importance	Medium importance	High importance
Frequency	<input type="radio"/>				
Bandwidth	<input type="radio"/>				
Amplitude	<input type="radio"/>				
Type of sound (e.g. whether pulsed or tonal)	<input type="radio"/>				
Duration of operation	<input type="radio"/>				
Spatial scale of operation	<input type="radio"/>				
The combination of sound sources being used	<input type="radio"/>				
Site characteristics (sound speed profile etc)	<input type="radio"/>				
Ambient noise levels	<input type="radio"/>				
Other (please specify)	<hr/>				

Underwater sound and the mitigation of disturbance to marine life

Section 4; Guidelines and policies.

***14. To what extent are you familiar with guidelines and policies relating to minimising the risk of injury and disturbance to marine species?**

- Not at all
- Passing knowledge of their intent
- General knowledge of the intent, methods and variation
- High level of knowledge
- Expert

Underwater sound and the mitigation of disturbance to marine life

***15. How effective do you consider current guidelines to be?**

Tick one	Don't know	Not at all	Somewhat	Generally	Highly
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***16. What do you consider to be a useful measure off 'effectiveness' for current guidelines?**

- High compliance levels
- Application of 'best practice' measures by operators
- Uptake of guidelines in non-regulated areas
- Reduction of noise in the environment
- Don't know
- Other (please specify)

***17. To what extent do you consider the 'standard' source mitigation zone of 500 metres to both a) effective and b) practical?**

	Don't know	Not at all	Somewhat	Generally	Highly
Effective	<input type="radio"/>				
Practical	<input type="radio"/>				

***18. What, in your opinion, would improve both the effectiveness and practicality of the mitigation zone (the standard assumed as being 500m around the sound source)? Tick all that apply.**

- Larger mitigation zones
- Smaller mitigation zones
- Mitigation zones based upon sound emission characteristics
- Full suite of mitigation tools (e.g. visual plus acoustic)
- Don't know
- Other (please specify)

Underwater sound and the mitigation of disturbance to marine life

***19. Mitigation guidelines have been based largely on 'standard' 2D and 3D seismic operations. As survey methodologies develop, increasingly there are 'grey' areas where there is a lack of clarity as to how guidelines should be applied depending upon operational constraints, weather, hours of darkness (particularly around dawn and dusk) and so on. How should these grey areas be resolved?**

- Increased consultation between regulators and industry at consent phase
- In the field, between MMO/PAM personnel and the client/contractor
- At start-up, by liaison with all parties and the regulator
- Rapid response of regulator to issues during operations
- Broader range of mitigation guidelines and operational specificity
- Don't know
- Other (please specify)

***20. Passive acoustic monitoring (PAM) is increasingly used as a mitigation tool to augment the visual observers on board. To what extent do you consider it to be an effective mitigation tool?**

Tick one	Don't know	Not at all	Somewhat	Generally	Highly
	<input type="radio"/>				

***21. What, in your opinion, would improve the effectiveness of PAM? Tick all that apply.**

- Greater number of hydrophone sensors
- Longer baseline within array
- More than one array being deployed
- Improvements to hardware design
- Integration with other in-sea equipment
- Software – operability
- Software – greater stability
- Software – algorithm development for signal classification
- Further training for operators
- Further training for vessel crews
- Don't know
- Other (please specify)

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Section 5; Marine Mammal Observer (MMO) & Passive Acoustic Monitoring (...)

*** 22. To what extent are you familiar with training for Marine Mammal Observers (MMOs) and Passive Acoustic Monitoring (PAM) Operators?**

- Not at all
- Passing knowledge of the courses
- General knowledge of the courses, content and variation
- High level of knowledge of most aspects of training
- Expert

Underwater sound and the mitigation of disturbance to marine life

***23. Are you an MMO and / or PAM Operator?**

- MMO
- PAM Operator
- Neither

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***24. Which training have you undertaken? Select all that apply by indicating the number of years since you undertook that training.**

JNCC

MMS / BOEMRE

MMO training for Irish waters

In-house (non accredited)

***25. Are you involved with hiring MMOs or PAM Operators?**

Yes

No

***26. What is the minimum standard of MMO training you look for?**

- JNCC
- MMS / BOEMRE
- MMO training for Irish waters
- In-house (non accredited)
- Other (please state)
- Other (please specify)

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*27. To what extent do you consider MMO training to be adequate?

Tick one	Don't know	Not at all	Somewhat	Generally	Highly
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*28. What do you think could be done to improve MMO training?

- Additional detail on marine operations
- Greater context with other environmental regulation
- Wider discussion of worldwide mitigation guidelines
- Don't know
- Additional detail on marine mammal anatomy/physiology
- Additional detail on animal behaviour
- Compulsory practical elements
- Additional detail on health and safety
- Additional detail on marine mammal identification
- Refresher courses
- Other (please specify)

*29. To what extent do you consider PAM training to be adequate?

Tick one	Don't know	Not at all	Somewhat	Generally	Highly
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*30. What do you think could be done to improve training for PAM Operators?

- Additional detail on acoustic theory
- Additional detail on bioacoustics
- Additional detail on hardware
- Additional detail on software
- Practical exercises – deployment
- Practical exercises – operation
- Practical exercises – troubleshooting and maintenance
- Don't know
- Other (please specify)

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* 31. Would a unified, internationally recognised training course for MMOs / PAM Operators be benefit?

Yes

No

Underwater sound and the mitigation of disturbance to marine life

Section 6; Data usage.

***32. To what extent are you familiar with the use of MMO / PAM data for compliance monitoring and research?**

- Not at all
- Passing knowledge
- General knowledge of uses
- High level of knowledge of research literature and findings
- Expert

Underwater sound and the mitigation of disturbance to marine life

***33. Is enough done to collate and analyse MMO / PAM data for the benefit of stakeholders?**

- Yes
- No

Underwater sound and the mitigation of disturbance to marine life

***34. How should MMO / PAM data be collated to maximise its use?**

- On a national level, by individual regulatory agencies
- Internationally, by an NGO
- Internationally, through a collaborative research project
- Internationally, by an industry body (e.g. Oil and Gas Producers Association)
- By an international organisation, such as UNESCO
- Don't know
- Other (please specify) _____

***35. MMO data is periodically analysed for the purposes of assessing whether operations are impacting marine mammal behaviour, and for assessing compliance with guidelines. From the following list, tick all uses for which you consider the data to be adequate.**

- Real-time decision making during an operation (i.e. changing survey priorities depending upon marine mammal occurrence and potential for mitigation)
- Determining compliance levels among clients / contractors
- Don't know
- Assessing impacts upon marine mammal behaviour
- Adding to our knowledge of marine mammal distribution
- Other (please specify) _____

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Comments

36. Additional comments?

Many thanks for taking the time to complete this survey.

All answers are kept anonymous. However, should you wish to receive feedback subsequent to collation and analysis, please provide an email address for further correspondence. Output is estimated to be available within one year.

Appendix 2 – JNCC recording forms

MARINE MAMMAL RECORDING FORM - COVER PAGE

Regulatory reference number (e.g. DECC no., BOEM permit no., OCS lease no., etc.)	Country	Location	Ship/ platform name
Client	Contractor	Survey type	
		site	VSP
		2D	WAZ
		3D	piling
		4D	explosives
		OBC	other
		4C	

Number of source vessels	Type of source (e.g. airguns)	Number of airguns (only if airguns used)	Source volume (cu. in.)
Source depth (metres)	Frequency (range in which peak energy is emitted, in Hz)	Intensity (primary peak-to-peak amplitude in dB re. 1µPa or bar metres)	Shot point interval (metres)
Method of soft start			
increase number of guns	increase frequency (where permitted)	increase pressure (where permitted)	increase number and frequency and pressure other

Visual monitoring equipment used (e.g. binoculars, big eyes, etc.)	Magnification of optical equipment (e.g. binoculars)	Height of eye above water surface (metres)	How was distance of animals estimated?
			by eye with laser rangefinder with rangefinder stick/ callipers with reticle binoculars by relating to object at known distance other
Number of dedicated MMOs		Training of MMOs	

Was PAM used? <input type="checkbox"/> yes <input type="checkbox"/> no	Number of PAM operators	
Description of PAM equipment		
Range of PAM hydrophones from airguns (metres)	Bearing of PAM hydrophones from airguns (relative to direction of travel)	Depth of PAM hydrophones (metres)

MARINE MAMMAL RECORDING FORM - OPERATIONS

Regulatory reference number
(e.g. DECC no., BOEM permit no., OCS lease no., etc.)

Complete this form every time the airguns are used, including overnight, whether for shooting a line or for testing or for any purpose.
Times should be in UTC, using the 24 hour clock.

Ship/ platform name

MARINE MAMMAL RECORDING FORM - EFFORT

Regulatory reference number
(e.g. DECC no., BOEM permit no., OCS les-

Record the following for all watches, even if no marine mammals are seen

Ship/ platform name

Record the following for all watches, even if no marine mammals are seen.

Visual watch or PAM:
Source activity:

V = visual watch; p = PAM
f = full power; s = soft start;

g = glassy (like mirror); s = slight (no/ few white caps); c = choppy (many white caps); r = rough (big waves, foam, spray)

0 = low (< 2 m); m = medium (2-4 m); l = large (> 4 m)

β = poor (< 1 km); m = moderate (1-5 km); g = good (> 5 km)

p = poor (< 1 km); m = moderate ($1-2$ km); g = good (> 2 km)

m = none; wf = weak forward; sf = strong forward; vf = variable forward; wb = weak behind; sb = strong behind; vb = variable behind

MARINE MAMMAL RECORDING FORM - SIGHTINGS

Regulatory reference number (e.g. DECC no., BOEM permit no., OCS lease no., etc.)	Ship/ platform name		Sighting number (start at 1 for first sighting of survey)	Acoustic detection number (start at 500 for first detection of survey)
Date		Time at start of encounter (UTC, 24hr clock)		Time at end of encounter (UTC, 24hr clock)
Were animals detected visually and/ or acoustically? visual acoustic both		How were the animals first detected? visually detected by observer keeping a continuous watch visually spotted incidentally by observer or someone else acoustically detected by PAM both visually and acoustically before operators/ observers informed each other		
Observer's/ operator's name		Position (latitude and longitude)		Water depth (metres)
Species/ species group		Description (include features such as overall size; shape of head; colour and pattern; size, shape and position of dorsal fin; height, direction and shape of blow; characteristics of whistles/ clicks)		
Bearing to animal (when first seen or heard) (bearing from true north)	Range to animal (when first seen or heard) (metres)			
Total number	Number of adults (visual sightings only)	Number of juveniles (visual sightings only)	Number of calves (visual sightings only)	Photograph taken yes no
Behaviour (visual sightings only)				
Direction of travel (relative to ship)			Direction of travel (compass points)	
towards ship away from ship parallel to ship in same direction as ship parallel to opposite direction to ship crossing perpendicular ahead of ship	variable milling stationary other unknown		N NE E SE S SW	W NW variable stationary unknown
Airgun (or other source) activity when animals first detected full power not firing soft start reduced power (other than soft start)		Airgun (or other source) activity when animals last detected full power not firing soft start reduced power (other than soft start)	Time animals entered mitigation/ exclusion zone (UTC, 24hr clock)	Time animals left mitigation/ exclusion zone (UTC, 24hr clock)
		Closest distance of animals from airguns (or other source) (metres)		Time of closest approach (UTC, 24hr clock)
If seen during soft start give: First distance Closest distance Last distance during soft start (metres)	What action was taken? (according to requirements of guidelines/ regulations in country concerned) none required delay start of firing shut-down of active source power-down of active source power-down then shut-down of active source		Length of power-down and/ or shut-down (if relevant) (length of time until subsequent soft start, in minutes)	Estimated loss of production (if relevant) due to mitigating actions (km)

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A critical examination of worldwide guidelines for minimising the disturbance to marine mammals during seismic surveys

Ross Compton^{a,*}, Lissa Goodwin^b, Richard Handy^{c,1}, Victor Abbott^{d,2}

^aResearch and Innovation, 17a Portland Villas, University of Plymouth, Plymouth, Devon PL4 8AA, UK

^bSchool of Biological Sciences, Portland Square A 402, University of Plymouth, Drake Circus, Plymouth, Devon PL4 8AA, UK

^cSchool of Biological Sciences, Davy Building, Room 406, University of Plymouth, Drake Circus, Plymouth, Devon PL4 8AA, UK

^dSchool of Earth, Ocean and Environmental Science, Portland Square A 423, University of Plymouth, Drake Circus, Plymouth, Devon PL4 8AA, UK

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Abstract

Marine seismic exploration has potentially detrimental effects upon marine life and marine mammals in particular. Potential effects range from disturbance that may lead to displacement from feeding or breeding areas, to auditory damage and potential mortality. Nations including the USA, Canada and Brazil have followed the example set by the United Kingdom by introducing guidelines to minimise acoustic disturbance to marine mammals. This paper describes the mitigation measures central to the guidelines currently in place, and identifies the similarities, differences and deficiencies within them. A need for further review by some nations is identified, with a recommendation that an international standard should be produced, benefiting both the geophysical exploration industry and the conservation community.

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1. Introduction

There is an increasing level of interest in the effects of anthropogenic sound on the marine environment, particularly the potential effects of widespread marine geophysical exploration upon marine mammals [1–3]. Marine geophysical or seismic exploration typically involves the use of airgun arrays (the seismic source) to produce low frequency impulsive sounds at intervals of 10–15 s, with broadband source levels of 220–255 dB re 1 μPa at 1 m (all decibel levels [dBs] are referenced to 1 μPa unless otherwise stated in the text) [3]. The dominant frequencies of airgun pulses lie within the 0–120 Hz range, though there are significant levels of high-frequency sound up to 20 kHz also produced by the pulses [4]. The dominant frequencies overlap with

those used by baleen whales (10 Hz–1 kHz), with the high-frequency component also overlapping with the frequency range used by many odontocetes (10–150 kHz) [3].

Despite correlations between cetacean stranding events and seismic activity being demonstrated [5]; a causal link between cetacean stranding and seismic exploration is disputed due to lack of clear data [6]. There is however, a growing body of evidence detailing a host of behavioural effects caused by a variety of underwater noise sources, as well as the potential for physical damage [2,3,7–10]. Physical damage includes damage to body tissues resembling decompression sickness ('the bends') and auditory damage. Symptoms resembling decompression sickness may result from the initiation of bubble growth caused by sound, or from hypothesised behavioural changes to normal dive profiles (such as a faster ascent rate) [11,12].

Auditory damage is the physical reduction in hearing sensitivity due to exposure to high intensity sound and can be either temporary (temporary threshold shift—TTS), or permanent (permanent threshold shift—PTS) depending on the exposure level and duration [3]. Other than physical

*Corresponding author. Tel.: +44 1752 232769; fax: +44 1752 233505.

E-mail addresses: ross.compton@plymouth.ac.uk (R. Compton), lissa.goodwin@plymouth.ac.uk (L. Goodwin), r.handy@plymouth.ac.uk (R. Handy), v.abbott@plymouth.ac.uk (V. Abbott).

¹Tel.: +01752 232959.

²Tel.: +01752 232424.

damage, the key auditory effect is the increase in background noise levels, such that the ability of an animal to detect a relevant sound signal is diminished, which is known as ‘auditory masking’ [3,13]. Masking marine mammal vocalisations used for finding prey, navigation and social cohesion may compromise the ecological fitness of populations [14].

Seven nations where there are high levels of geophysical activity have recognised the potential for such impacts, and as seismic exploration increases [15]; guidelines and regulations that aim to minimise disturbance and potential damage to marine mammals during seismic surveys have been formulated. The UK’s ‘*Guidelines for minimising acoustic disturbance to marine mammals from seismic surveys*’ produced by the joint nature conservation committee (JNCC) [16] were the first such guidelines to come into effect. Introduced in 1995, developed from a draft produced by the sea mammal research unit (SMRU), these guidelines have been used as a model by other countries when producing their own mitigation guidelines. The Brazilian guidelines for example, used both the UK and USA guidelines. In addition to this, the USA guidelines allow for the use of JNCC recording forms for all sightings. Building on this initial work, nations such as Brazil and New Zealand have recognised the need for further or enhanced mitigation methods [17,18].

This paper examines the mitigation measures central to the various guideline documents, in order to identify the similarities, differences and deficiencies within them. Specific deficiencies for further consultation between industry, government and the environmental lobby are highlighted. Considered here are guidelines and regulations from the UK, USA (Gulf of Mexico–GoM and California), Canada, Australia, New Zealand, Brazil and Sakhalin. It is recognised that guidelines in other regions such as Alaska are currently being developed, but were not sufficiently advanced prior to preparation of this manuscript. Additionally it is noted that many countries are yet to formulate guidelines.

2. Scope of guidelines

Cetaceans form the primary focus for each of the guidelines described here, reflecting the quantity of evidence describing deleterious effects of sound upon this group of marine animals. There is however, variation between the countries, with some not covering all cetaceans and others covering a much broader range of marine life including seals, turtles and finfish [16,18,20]. The only guidelines that are cetacean specific, are those set out by Environment Australia. Table 1 summarises these and other key differences.

Despite the knowledge that seismic exploration produces high frequency sound [4], which may affect small cetaceans, with hearing in this range, some guidelines fail to include adequate mitigation measures. Canadian and Australian guidelines omit actions for dolphins or porpoises.

New Zealand requires mitigation measures to be taken when in proximity to Hector’s (*Cephalorhynchus hectori*) and Maui’s dolphins (*Cephalorhynchus hectori maui*), due to specific conservation concern for those species, but does not include others. Both Hector’s and Maui’s dolphins are listed as ‘species of concern’, a designation that includes all whales and other species that may be recommended as concern arises [18].

Each set of guidelines is put in place in order to implement national and/or international environmental policies. On a national basis there are acts of government such as the Marine Mammal Protection Act in the USA and the Countryside and Wildlife Act in the UK which variously protect species against capture, harm or harassment. The guidelines discussed here fulfil the aims of such legislation (the full details of which do not warrant discussion here), as well as work towards fulfilling aspects of international treaties such as the 3rd United Nations Convention on the Law of the Sea, internationally effective since 1994, which imposes a broad obligation on states to prevent and reduce *all* sources of pollution, including ocean noise.

3. Mitigation methods

3.1. Minimising sound output

The ocean environment is a noisy place for marine mammals to inhabit, with significant background noise in the 1–1000 Hz frequency range stemming from natural sources as well as increasing anthropogenic input [3]. In order to limit the additional input from the seismic airgun sources, some guidelines emphasise the use of the lowest practicable volume throughout operations [16,17]. Other recommendations include seeking to reduce the level of high frequency sound output [16], and configuration of the airgun array to maximise the proportion of sound energy directed downwards rather than horizontally [21].

3.2. Safety zones

To reduce the chance of causing physical damage to cetaceans, safety zones or exclusion zones around the sound source have become a key mitigation tool within any given set of guidelines. This is due to the recognition that the potential for temporary or permanent hearing impairment in marine mammals is greatly increased within a few hundred metres of the sound source [3]. The safety zone is generally defined as the radius where received sound levels are believed to have the potential for at least temporary hearing impairment [22]. The safety radius common to the UK, USA and Canadian guidelines and regulations is 500 m, which is deemed to be the distance at which cetaceans may be reliably observed [16].

While this distance may be sufficient to prevent physical injury, the potential for TTS, behavioural disturbance and auditory masking is likely to extend beyond this zone [23].

Table 1
Matrix of key similarities and differences between the national guidelines for the mitigation of acoustic disturbance to marine mammals

Country/region	UK	USA ^(GoM)	USA ^{(California)a}	Canada	Australia	New Zealand	Brazil	Russian Fed. ^(Sakhalin)
Year introduced/updated	2004	2007	1999	2004	2001 ^b	2005	2005	2003
Cetacean specific?	No	No	No	No	Yes	No	No	No
All cetaceans included?	Yes	No ^c	Yes	No ^d	No ^e	Yes ^f	Yes	Yes
Safety zone distance	500 m	500 m	180 dB ^g	500 m	3 km	1–1.5 km ^h	0.5–1 km ⁱ	180 dB ^j
Sighting-free period ^k	20 min	30 min	30 min	30 min	30 min	30 min	30 min	?
Soft-start?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Shut-down during firing?	No	Yes	Yes	Yes ^l	Yes ^m	Yes	Yes	Yes
Poor/no visibility soft-start?	Unrestricted	Requires PAM	Unrestricted	PAM preferred	Night vision obs.	Unrestricted	Prohibited	Unrestricted
Status of PAM	Encouraged	Required ⁿ	Not recommended	Encouraged ^o	Encouraged ^p	Encouraged	Encouraged	?
Info. on 'sensitive' areas?	Yes	Yes	Yes	No	Yes	Yes	No	Yes

^aThese guidelines were implemented on a case by case basis for specific projects. California is no longer an important area for geophysical exploration activity.

^bUnder review.

^cShut-down procedures are for whale species only.

^dDolphins and porpoises excluded.

^eSmall cetaceans excluded.

^fCentral measures are for 'species of concern' only.

^gDistance of safety radius calculated using transmission loss modelling on a case by case basis.

^h1.5km observation zone. Further mitigation may be introduced at 1.5km for groups with calves, 1km for groups without calves and at 200m for species not classed as 'species of concern'.

ⁱA distance of 1 km is termed the 'area of guard' which should be monitored at all times and is an area that if animals are within, the soft-start must be delayed. An area of 500 m within this is termed the 'area of security', within which seismic production must cease if animals enter it.

^jDistance for cetaceans calculated by transmission loss modelling and verified in the field, 190 dB safety zone for pinnipeds.

^kThe period of time after a sighting within the safety zone which must be free of animal sightings in order to allow commencement of the soft-start.

^lIf species encountered is listed on schedule 1, 2 or 3 of the Species at Risk Act.

^mReduce to minimum firing.

ⁿRequired in order to initiate soft-start during hours of darkness of times of poor visibility.

^oInsufficient development for recommendation, but its use for detecting species such as sperm whales is recognised and therefore may be recommended for surveys in areas where sperm whales are known to be present.

^pMay be stipulated as part of survey license, depending on the area and season.

A range of startle and avoidance responses have been reported for pinnipeds and both toothed and baleen whale species, including ranges of many kilometres for bowhead whales in the Beaufort Sea [3]. Comprehensive summaries of the documented disturbance reactions to airgun sources include Richardson et al. [3] and Gordon et al. [2]. It seems clear that with significant responses occurring beyond the fairly arbitrary mitigation zone of 500 m, guidelines that include this zone are failing to 'minimise disturbance'.

The United States national marine fisheries service (NMFS) has identified safety radii defined by sound pressure levels likely to cause behavioural disturbance (level B harassment) and potential physical harm (level A harassment) [19]. An isopleth of 160 dB rms (root mean squared) has been identified for the induction of behavioural responses, and between 180 (for cetaceans) and 190 dB rms (for pinnipeds) for the likely induction of auditory damage and other physical injury [19,22]. Depending on the capacity of the seismic source and the site-specific attenuation of sound, a sound pressure level of 180 dB rms is achieved at distances varying from less than 200 m to over 1 km [24]. The NMFS has required the application of propagation loss models in order to identify

where the 180 dB rms isopleth occurs, in order for the implementation of this as the safety radius for project specific use off California [22]. Although not included in the Canadian guidelines, the Department of Fisheries and Oceans in the Pacific region issue letters to applicants, recommending the use of the 160 and 180 dB isopleths as safety radii (M. Joyce, pers. comm.). The guidelines from Sakhalin also require the provision of safety radii based on sound pressure levels; 180 dB for cetacean and 190 dB for pinnipeds [21].

Environment Australia requires that a safety zone of 3 km is monitored. Such an area should easily extend beyond the distance at which a sound pressure level of 180 dB is reached, but represents an enormous challenge in terms of reliable detection, identification and range estimation, either visually or with the aid of acoustic monitoring. Yet, it is claimed that up to 70% of animals are detected by 'experienced' observers (R. McCulloch, pers. comm.), with only a forward facing 210° sector monitored. Focusing observations forward and to the sides of the seismic source does not allow for animals that may surface behind the vessel, and is at odds with all other guidelines that require 360° around the seismic source to be monitored.

The guidelines from New Zealand request that a safety zone of 1.5 km be monitored at all times, with this distance being the critical pre-firing distance in terms of implementing further mitigation methods for all species identified as ‘species of concern’ [18]. During seismic production, further mitigation is initiated within 1 km of the source, with the exception of groups that include calves, in which case the 1.5 km radius remains. The 1 km radius is based on the sound pressure level of 180 dB re 1 µPa, assuming the use of a gun array of 2000–3000 in³ capacity [18]. This is an oversimplification given site-specific differences resulting from water depth, temperature and salinity that will affect the distance at which that sound pressure level is reached. Additionally, no information is provided within the document for contractors who may operate a larger capacity array. The increased distance of 1.5 km is based on evidence that suggests groups containing calves may be more vulnerable to disturbance [25]. For those marine species not listed as ‘species of concern’, a distance of 200 m is specified.

The Brazilian guidelines recommend a similar dual zone approach. An area of 1 km, termed the ‘area of guard’ is monitored at all times, and acts as a restraint to the start of production if this zone is breached. If the ‘area of guard’ is breached during production, the seismic crew are to be kept updated by the marine mammal observer (MMO) in case the animals sighted move within the second mitigation zone. The inner zone is termed the ‘area of security’, and is a 500 m source exclusion zone, which if breached results in the shutdown of production until the ‘area of guard’ can be declared clear again for a period of least 30 min [17].

There is a clear need for case by case calculation of where a safe sound pressure level is achieved based on site specific sound speed profiles and airgun parameters, in order to identify safety radii that are appropriate, precautionary and that can be effectively monitored. The calculation of safety radii based on sound pressure levels represents a far more scientific way forward than the arbitrary designation of a 500 m radius. The 180 dB rms radius set by the NMFS is termed the level A harassment zone, representing the sound pressure level above which physical damage may occur. However, given the inherent uncertainty over its application to all species and the goal to minimise the *disturbance* rather than simply physical harm to marine mammals, the application of the 160 dB rms sound pressure level as the safety zone boundary represents a more precautionary solution. It may be difficult to implement such a boundary in the field however, due to the distance from the source at which this level would be reached.

3.3. Soft-start

The term ‘soft-start’ or ‘ramp-up’ refers to the gradual build up of energy released from the seismic source from a basal level (firing of a single airgun, generally the smallest) with subsequent activation of additional sources in ascending size order over a period of 20–45 min, in order

to allow animals to move away [16–18,20,21,26,27]. The California guidelines alone provide operational instruction as to the level of volume increase at each stage of the soft-start, requiring a 6 dB/min increase [22].

The soft-start procedure is based upon the assumption that animals will move away from the seismic source as the sound builds and becomes potentially more aversive, thus limiting the chance of auditory or other physiological damage, though this has not been shown experimentally [3]. Each of the guidelines includes a soft-start procedure, and is required to be carried out each time the guns are to begin firing, with the exception of breaks in firing of less than 30 min under Canadian guidelines [20]. The guidelines from Sakhalin and Brazil prohibit the commencement of the soft-start during hours of darkness or poor visibility. Under the GoM guidelines, a passive acoustic system is required in order to ensure that no cetaceans are present before the soft-start can commence [26]. Under each of the other guidelines, the soft-start procedure can commence at these times with no form of confirmation that the safety zone is clear of cetaceans.

The effectiveness of the soft-start method is likely to vary between species and circumstances [24], and there is concern that this procedure may lead to habituation, as has been reported with regards to the use of acoustic harassment devices (AHDs) to keep marine mammals away from fishing gear, and whale-watching vessels [28]. AHDs have typical source levels of 185–195 dB re 1 µPa at 1 m, and emit variable waveforms at varying time intervals in order to reduce the potential for habituation to occur [28]. However, seals have been shown to alter behaviour by lifting their heads out of the water away from the sound field in response to such devices, and harbour porpoises have been demonstrated to habituate to similar deterrent devices within two weeks [29,30]. Habituation leading to long-term exposure to high sound levels may lead to chronic auditory damage [24].

A further potential problem with the ramp-up method is the possibility of attracting animals by initially weak sounds [24]. This has been illustrated experimentally by Shapiro et al. [31], who exposed sperm whales to a received sound level below 160 dB rms, resulting in the individuals orienting towards the sound source rather than moving away from it. The soft-start/ramp-up has become a standard mitigation tool, but its effectiveness in light of such findings should be the focus of further research. Controlled exposure experiments (CEEs) such as the above example represent a controversial but powerful technique for determining the response of animals to anthropogenic sound and define the real risks associated with offshore operations [32].

3.4. Visual observations

This is the most commonly used method of monitoring the mitigation zone, and should be carried out by suitably trained MMOs [10,16,17,26]. The role of an MMO is to

monitor, detect and identify marine mammals during daylight hours within the given safety zone. Additional monitoring during hours of darkness is required within Australian waters using night-vision binoculars, with a minimum of 10 min/h [27]. The standard procedure is for an observer(s) to keep watch from a suitable location which allows a clear 360° view of the sea surface (with the exception of under Australian guidelines), beginning no less than 30 min prior to commencement of the soft-start. The number of observers used varies between countries and the circumstances of a particular survey. In the UK, one observer is the norm, but two are required between April 1st and September 30th due to the longer daylight hours, particularly in northerly latitudes [16]. IBAMA require at least three observers to be aboard, in order that at least two can divide the 360° visual field, and allow rotation of duty to avoid excessive fatigue [17].

If a marine mammal is detected within the safety zone, it is the responsibility of the MMO to advise the seismic crew that further mitigation is necessary, so it is essential that an effective communication line between the MMO and party manager is established [10,16–18,26]. There are two mitigation procedures that the MMO can request:

1. If a marine mammal is detected within the safety zone within the pre-watch period, the soft-start must be delayed until the zone has been clear of cetaceans for 30 min.
2. For all areas except the UK, the source array must be shut down if the safety zone is breached by the species covered under the given guideline document.

The JNCC guidelines in their current form do not require source shutdown during operations; a key mitigation measure is included within the guidelines from all other countries as well as the voluntary guidelines of some companies. This represents a lack of precaution given the uncertainty over habituation [3] and the possibility that animals surfacing near the vessel have been undetected due to a deep dive and have already been subjected to a high sound pressure level.

MMOs working within UK and GoM waters have to undergo a short training course and follow a particular method of reporting for the observations. The JNCC and MMS specify the MMO syllabus for the UK and GoM, respectively. Each syllabus contains an overview of the relevant legislation, an overview of seismic operations, a description of the role of an MMO, instructions about data recording and reporting mechanisms, and finally some tips and information about the detection and identification of marine mammals [16,26]. Both syllabi lack training in the field and require no pre-requisites. There is currently no equivalent course for other areas, so training is often ad-hoc, and the expertise of MMOs depends upon their background resulting in high variability. Since the observation techniques and mitigation tools are the same the world over (with the exception of details identified here,

and easily conveyed during training), it would seem prudent to improve and standardise observer training, such that an observer trained in the UK is equally qualified to work offshore Canada for example, and vice versa.

3.5. Passive acoustic monitoring (PAM)

Visual monitoring has a number of problems besides human error. Visual monitoring is not reliable at night (even with night-vision, due to reduced field of view), and during the day may be compromised by adverse weather conditions such as increasing sea state and precipitation [3,22,33,34]. In addition, cetaceans spend a large proportion of their time underwater, with an example of male sperm whales demonstrated to spend approximately 80% of their time submerged [35].

PAM technology for mitigation purposes currently takes the form of a series of hydrophones towed in a linear array behind the seismic vessel, which have varying abilities at providing the operator with range and bearing estimates to any vocalising cetacean. PAM represents an important way to overcome the issue of not being able to reliably use visual observations during hours of darkness and poor visibility. It can also augment visual observations, increasing both the likelihood and range of detection for all vocalising cetacean species, particularly deep-divers such as sperm whales and members of the Ziphidae [24,36,37]. Comparison of visual and acoustic detection rates has shown that the combination of the two methods can increase the number of animals detected by between five and eight times, with significant numbers of animals heard but never seen [38].

At the present time, the use of PAM technology is widely encouraged [16–18,20,26]. The New Zealand Department of Conservation for example, state that operations within areas identified as being of ecological importance should consider the use of PAM before operating at night [18]. Within the GoM only, PAM is a requirement during hours of darkness and poor visibility, a soft-start may *only* commence if a PAM system is deployed and no cetaceans have been detected for a period of at least 30 min [26]. In this context, PAM facilitates seismic production which otherwise could not commence. Making the use of PAM a requirement in this manner encourages industry to invest in its development, such that systems become more reliable and effective, in turn supporting the wider uptake of PAM.

3.6. Temporal and spatial restrictions

The wealth of research activities in some locations has aided the identification of areas of ecological importance, based on the presence of endangered species, high cetacean and/or marine biodiversity, or regular aggregations of cetaceans for feeding, breeding or migrating. The key recommendation for these areas is that work be avoided at such times of the year when aggregations are known to occur. The New Zealand Department of Conservation for

example have identified six permanent and two seasonal ‘areas of ecological importance’ with details of their location and particular species of concern listed in the reference document that accompanies the DoC’s guidelines [18].

The JNCC splits the UK sector into three areas with differing cetacean sensitivities. The Moray Firth, Cardigan Bay and the West of Britain are listed as being of highest cetacean sensitivity, and as such are subject to particular requirements in terms of using experienced MMOs and a strong recommendation to use PAM [16].

The Australian guidelines include a large number of maps displaying feeding and breeding areas and migration paths for humpback, blue and southern right whales [27]. Permits are required for work within all of these areas, with additional mitigation methods recommended on a case by case basis which may include aerial or guard vessel observations of the area [27].

The guidelines from Sakhalin require that seismic surveys be carried out during July, August or September. This is due to avoidance of western grey whales, which during those times are aggregated at feeding grounds to the north of Sakhalin [21].

Areas and species of ecological importance will clearly vary in terms of extent and temporal duration, and it is the responsibility of government agencies and research institutions to continue research in order to identify the best ways in which to further limit the potential impacts of acoustic disturbance on those areas and species. Agencies such as the JNCC have already begun to use the wealth of data that can be collected using MMOs to look in detail at the potential effects of acoustic disturbance as well as marine mammal distributions [9]. This should continue, however there is far more potential for data collection and use through collaboration with the oil and gas and geophysical exploration industries, as many companies already allow the use of data collected by MMOs for academic study, for example; Repsol (R. Koemans, pers. comm.).

The further designation of marine protected areas (MPAs), in order to delineate areas that are of seasonal or continual importance for a range of species represent the simplest and most effective way of ensuring that no disturbance is caused to the regular inhabitants of these areas. Further, to limit the influence of marine operations in the vicinity of closed areas, it would be advisable to apply an exclusion zone to the perimeter that is of a width equivalent to the mitigation zone employed by the largest source operating in the area for each given operational season [39,40].

3.7. Aerial and dedicated research vessel surveys

The use of aerial surveys or surveys carried out using dedicated research vessels can be recommended on a case by case basis under the Australian, Californian and Sakhalin guidelines [21,22,27]. The goals are generally to monitor before, during and after operations, in order to obtain real-time information concerning the locations of

cetaceans in relation to the seismic activity, as well as to identify important areas and any detectable changes in distribution or numbers due to the operations [22]. Aerial surveys are limited in their usefulness during seismic surveys due to the requirement to fly at approximately 300 m altitude in order to avoid causing direct disturbance themselves, as well as the logistical constraints and high costs that are involved [24].

4. Voluntary methods

As seismic exploration expands into frontier areas, where there may be no guidelines in place, many industrial clients are taking the initiative to implement similar mitigation protocols on a voluntary basis. For example, Repsol YPF requires survey contractors to mitigate for cetaceans and pinnipeds using a 500 m safety zone, and for turtles using a 125 m safety zone. The standard pre-firing watches, soft-starts and delays in firing are implemented, with the addition of voluntary shutdown during acquisition if either safety zone is breached [41].

Following the advice of environmental impact assessments (EIAs), many clients voluntarily use the JNCC guidelines in areas that have nothing in place. For example, Amerada Hess recently required the use of JNCC guidelines working offshore Libya (M. Attree, pers. comm.). Similarly, clients working offshore Angola have implemented JNCC guidelines amended for the particular conditions of the area (C. Weir, pers. comm.). Angolan waters have been identified as a seasonal calving ground and a migration route for humpback whales as well as a year round nursery for sperm whales and other large species. Again, based on evidence that calves may be more vulnerable to disturbance [25], a shutdown of production is ordered if any whale calf (excluding blackfish) breaches the 500 m source safety zone (C. Weir, pers. comm.).

5. Discussion

The summary presented here has clearly identified that the various mitigation guidelines that have been formulated have more similarities than differences between them. For example, the use of a soft-start/ramp-up is not only ubiquitous, but adheres to almost the same time constraints between nations. This is not surprising, given the common goal of mitigating disturbance to marine mammals and the limited ways of ensuring their absence during seismic production. What is surprising is the ways in which simple and common mitigation techniques such as the source safety zone vary. There has been a clear progression from distances defined by what is relatively easy to visually monitor, to zones based more on the distance at which certain sound pressure levels are achieved. However, at this stage it is still unclear what sound pressure level is most appropriate to define as a boundary, and it is clear that within a varying survey area it may be problematic to agree an appropriately sized zone.

This paper has identified a number of areas where further research should be directed, as well as points for discussion in enhancing mitigations guidelines;

- Our understanding of the specific effects of noise upon small cetaceans is lacking and requires further research. Until it is clear that underwater noise associated with seismic surveys does not cause damage and disturbance to these species, *all* species should be mitigated for.
- Greater collaboration with academic institutions, regulators and industry in order to make more use of the data collected by MMOs and PAM operators from around the world. Analysis may help to delineate areas that may be suited to management as MPAs.
- Soft-start procedures should not be initiated during times of poor visibility or darkness without the use of existing PAM technology to confirm that no cetaceans are present.
- Use of practical source safety zones with the need for further research into mitigation zones based on safe sound pressure levels.
- Where monitoring is required during all daylight hours, two and preferably three MMOs should be present in order to allow efficient rotation of duties and maintain full coverage.
- Greater attention needs to be paid to training needs in terms of identifying marine mammals, accurate range estimation, the use of PAM technology and crew integration.

The clear recommendation to come out of this discussion is that an international consensus in terms of the mitigation techniques to be employed would be of benefit to all stakeholders in the offshore environment. Having clear mitigation methods based on the best advice of the scientific community, the core measures of which do not differ between nations will make it simple for geophysical exploration companies to adhere to guidelines and have confidence that any decisions to initiate mitigation are necessary and expedient.

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