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# Comparative Review of the Regional Marine Mammal Mitigation Guidelines Implemented during Industrial Seismic Surveys, and Guidance Towards a Worldwide Standard

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## 1. INTRODUCTION

Marine mammals rely on sound for all of the fundamental biological and ecological aspects of their lives including navigation, prey location and capture, predator avoidance, and communication (including during migration and reproduction). There is increasing concern regarding the potential effects of the airgun sound produced during geophysical seismic surveys on marine mammals. Airgun arrays typically produce high amplitude sound with source levels in the region of 220–248 dB re. 1 $\mu$Pa @ 1 m.[2] The acoustic output has highest energy at relatively low frequencies of 10–200 Hz, which overlaps extensively with the low frequency sound produced by baleen whales in the 12–500 Hz bandwidth.[3] Airgun arrays may alsoproduce significant high

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[2] Charles R. Greene, Jr. & W. John Richardson, *Characteristics of Marine Seismic Survey Sounds in the Beaufort Sea Canada USA*. J.ACOUST. SOC. AM., 83 (1988); W. John Richardson & Bernd Würsig, *Influences of Man-Made Noise and Other Human Actions on Cetacean Behaviour*. MARINE AND FRESHWATER BEHAVIOUR AND PHYSIOLOGY, 29 (1997); Gulland, Jim A. & C.D.T. Walker, *Marine Seismic Overview*, *in:* Mark L. Tasker, & C.R. Weir (eds.), PROCEEDINGS OF THE SEISMIC AND MARINE MAMMALS WORKSHOP, London, 23–25 June 1998 (2001).

[3] Thompson, T.J., Winn, H. E., & Perkins, P. J. *Mysticete Sounds, in Behaviour of Marine Animals*, VOLUME 3: CETACEANS, (H.E. Winn & B. J. Olla, eds. (1979); W. John Richardson *et al*. MARINE MAMMALS AND NOISE. (1995).

frequency sound energy, with airgun sound dominating frequencies up to 22 kHz within a few kilometres of the source.[4]

Since small odontocete species utilise and are sensitive to sound in the 0.5–20 kHz range,[5] both odontocete and mysticete species may potentially be adversely affected by airgun sound. Reviews have identified several potential levels of impact on marine mammals from seismic airgun sound, including physical injury (such as tissue damage, temporary and permanent hearing loss), indirect physical damage (e.g., "the bends"), physiological effects (e.g., stress), masking of echolocation signals, behavioural impacts (including displacement from migratory, feeding, and breeding habitat), and indirect effects from displacement of prey species.[6]

Although the oil and gas industry conducts seismic surveys throughout the world, the potential acoustic impact upon marine mammals from seismic airguns has not yet been addressed on a worldwide scale. However, the last decade has seen the regulatory agencies of several countries introduce marine mammal mitigation guidelines for use during industrial seismic surveys, aimed at reducing the impacts from seismic airgun sound. In 1998, the UK's Joint Nature Conservation Committee (JNCC) was the first regulatory body to issue statutory marine mammal mitigation measures for use during industrial seismic surveys in their national waters.[7] Australia's Department of Environment and Heritage (formerly Environment Australia) followed in 2001,[8] and a number of other countries have since developed guidelines (or are in the process of doing so). Most of these guidelines are statutory and are included by the regional industrial regulatory bodies within their oil and gas licensing agreements.

Limited seismic surveys are also carried out annually for academic research purposes, and the legislation governing these surveys is less specific and often managed on a case-by-case basis. In some regions, particularly in the US, the marine mammal mitigation procedures utilised during research seismic surveys have a more stringent permitting procedure, are prepared

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[4] John C. Goold & P.J. Fish. *Broadband Spectra of Seismic Survey Air-Gun Emissions, with Reference to Dolphin Auditory Thresholds*. JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA, 103 (1998).

[5] Arthur N. Popper. *Sound Emission and Detection by Delphinids* in CETACEAN BEHAVIOUR: MECHANISMS AND PROCESSES, (L.M. Herman, ed. 1980); W. John Richardson, Charles R. Greene, Jr., Charles I. Malme & Dave H. Thompson. *Effects of Noise on Marine Mammals*. OCS Study MMS 90–0093. LGL Rep. TA834-1. Report from LGL Ecological Research Associates Inc., Bryan, TX for U.S. Minerals Management Serv., Atlantic OCS Reg., Herndon, VA. NTIS PB91-168914 (1991).

[6] Jonathon C.D. Gordon *et al*. *The Effects of Seismic Surveys on Marine Mammals,* in Tasker, M.L. & Weir, C.R., eds, PROCEEDINGS OF THE SEISMIC AND MARINE MAMMALS WORKSHOP, London, 23–25 June 1998 (1998); W. John Richardson *et al., supra* note 2 and 4.

[7] JNCC*, Guidelines for Minimising Acoustic Disturbance to Marine Mammals from Seismic Surveys*. Joint Nature Conservation Committee, Peterborough, UK (1998).

[8] Environment Australia*, Guidelines on the Application of the Environment Protection and Biodiversity Conservation Act to Interactions Between Offshore Seismic Operations and Larger Cetaceans* (2001).

specifically on a site basis and are considerably more precautionary than the standard industrial guidelines.[9] However, some research seismic surveys, for example in Antarctic waters, are apparently conducted with less protection for marine mammals than the standard industrial guidelines.

This article reviews the types and effectiveness of marine mammal mitigation measures presently used during industrial seismic surveys worldwide. We do not review the various levels of mitigation used during research-based seismic surveys, since they are less standardised in nature. Many of the protocols discussed here, however, apply to both types of survey. While many developed countries now enforce statutory industrial guidelines within their own national waters, the numerous seismic surveys occurring in the waters of developing countries or elsewhere worldwide may not include marine mammal mitigation measures. We make suggestions towards a minimum worldwide mitigation standard, for use in unlegislated areas. The development of each region's statutory guidelines is a continually evolving process, and this comparative review is based on the best information available for each region at this time. We also acknowledge that, although not available at present, guidelines are currently being developed in several other geographic areas (e.g., Alaska).

## 2. EXISTING MITIGATION MEASURES

There are three main methods currently used to mitigate the potential impacts on marine mammals during seismic surveys: (1) implementation of operational procedures (e.g., 'soft start'—where sound levels are gradually increased over time); (2) detection of animals close to airguns and implementation of real-time mitigation measures (e.g., shut-down), and (3) time/area planning of surveys to avoid marine mammals. Detection of animals via real-time monitoring, while not a mitigation measure per se, is an essential component of marine mammal mitigation during seismic surveys and is therefore discussed throughout this article in a mitigation context.

The mitigation measures in use worldwide are summarised in Table 1 on page 26 (which also identifies the sources of information used in this chapter).

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[9] Examples include *NMFS Small Takes of Marine Mammals Incidental to Specified Activities; Seismic Reflection Data off Southern California*. Federal Register, 67, 42541–42547 (2002); *NMFS Small Takes of Marine Mammals Incidental to Specified Activities; Oceanographic Surveys in the Hess Deep, Eastern Equatorial Pacific Ocean*. Federal Register 68, 17909–17920 (2003); LGL Ltd. *Marine Mammal Monitoring During Lamont-Doherty Earth Observatory's Acoustic Calibration Study in the Northern Gulf of Mexico, 2003*. LGL Rep. TA2822–12. Report from LGL Ltd. To Lamont-Doherty Earth Observatory, Columbia University and the National Marine Fisheries Service, Silver Spring, MO (2003).

## 2.1. Avoidance of Sensitive Areas

Most regional guidelines loosely define sensitive areas as breeding, feeding, or migration habitat for marine mammals. While many guidelines request more stringent mitigation procedures within such areas and suggest planning surveys to avoid sensitive times/areas, the only regions for which seismic survey closed seasons appear to be clearly defined and implemented are Brazil where prohibited areas exist for breeding humpback *Megaptera novaeangliae* (Jul–Nov) and southern right whales *Eubalaena australis* (Jun–Dec), nesting areas for marine turtles (Oct–Feb) and manatee habitat (Sep–May, some areas permanently closed) (reported in Brazilian Environmental Licensing Guide),[10] and Australia where the Marine Mammal Protection Zone in the Great Australian Bight is permanently closed due to the sensitivity of southern right whales and Australian fur seals *Arctocephalus pusillus*.[11]

## 2.2. Operational Procedures

### *2.2.1. Soft Start*

Common to mitigation guidelines worldwide (Table 1) is the requirement for a soft start or "ramp-up." Soft start incorporates a gradual build-up of airgun sound level over time, with the aim of warning marine mammals and allowing them to depart the area of a seismic survey before sound levels peak. In most regions it is stated that soft start should have at least 20 min duration and, in some regions, an upper limit of 40 to 45 min is also provided to attempt to minimise airgun disturbance.

### *2.2.2. Minimising Airgun Sound Propagation*

The guidelines for the UK, Brazil, California, Sakhalin, and New Zealand emphasise the requirement to use airgun arrays of lowest practicable volume throughout. In the UK and New Zealand it is also requested that operators minimise unnecessary high frequency sound and in Sakhalin it is required that operators configure the airgun array to minimise horizontal sound propagation.

### *2.2.3. Restrictions on Airgun Use*

Due to the ineffectiveness of visual monitoring at night there are varying requirements for using airguns during darkness. These range from the continued use of airguns with no mitigation measures (UK), the use of night-vision binoculars to carry our short-range visual monitoring (Australia and California), the use of passive acoustic monitoring in sensitive areas (Canada) and the use of a "warning" small volume airgun throughout night-time

[10] IBAMA, Brazilian Environmental Licensing Guide. *Atividades de Sísmica Marítima na Costa Brasileira, available at* http://www.anp.gov.br/ibamasismica/ (Last viewed May 2006) (2005a).

[11] Sarah J. Dolman. *Noise Pollution and International Best Practise*. J. INT. WILDLIFE LAW & POL'Y (In press).

line changes (Gulf of Mexico, California, Brazil, and New Zealand). The Californian guidelines include the possibility that airguns may operate only during daylight hours. In most regions it is stated that airguns should be shut-down completely (and a visual watch maintained) during daylight line changes. In New Zealand and California, however, it is recommended that a small airgun is active throughout all line changes.

#### *2.2.4. Operational Shut-Downs*

Seismic vessels occasionally need to stop firing airguns for operational reasons including noise recordings, maintenance and repairs. In most regions a period of acceptable shut-down has been stated, for which a full soft start would not be required. In the UK and Brazil the permitted period is five minutes. The Gulf of Mexico and New Zealand permit a 20 minutes shut-down, while Canada allows the longest shut-down at 30 minutes. The California and Sakhalin guidelines state that soft start is required following every power down of the source.

### 2.3. Detection and Real-Time Mitigation Procedures

#### *2.3.1. Visual Detection*

Visual monitoring is the primary (and usually sole) method of animal detection in all regions (Table 1). Notwithstanding external influences (such as weather conditions), the efficacy of visual detection depends on factors including the number of marine mammal observers (MMOs) present, their experience, the regularity of their breaks, their dedication, their objectivity (crew member or independent consultant), their enthusiasm, and their level of training. The guidelines vary in their stated requirements for MMOs. Those with stated shut-down procedures should require several MMOs to ensure effective monitoring throughout all daylight hours. This is the case in California, Brazil, the Gulf of Mexico, and Sakhalin (Table 1) where at least two dedicated and trained MMOs must be on watch throughout the day. Australia and Canada, however, do not require an MMO to be on watch all daylight hours despite the prevailing shut-down policy.

Most regions accept the use of trained crew members to carry out MMO duties, with the exception of sensitive areas where experienced biologists are requested. The only regions where it is stated that a professional, experienced, dedicated and trained MMO is required for all surveys are California and Brazil. While most regions require a visual watch 360° around an airgun source prior to use, Australia appears to require visual observations only forward and abeam of the survey vessel.

#### *2.3.2. Species for Which Mitigation Applies*

The UK, California, Brazil, New Zealand, and Sakhalin include all marine mammal species within the mitigation measures (to varying extents).

In Australia, the Gulf of Mexico, and Canada, mitigation measures apply only to whale species and exclude dolphins, porpoises, and pinnipeds.

#### *2.3.3. Exclusion Zone*

The exclusion zone (EZ) (or 'safety zone') is usually defined as the radius around an airgun source within which real-time mitigation measures are implemented if animals are detected. The UK, the Gulf of Mexico, and Canada designate a 500 m EZ for all mitigation measures. Australia has the largest designated EZ at 3000 m. In Brazil, the 500 m EZ is used for airgun shut-down, but a more precautionary 1000 m EZ is used for delays to soft start. In New Zealand, a 200 m EZ is used to delay soft start for most marine mammals, but for stated species of concern a 1500 m EZ is used for delays and a 1000 m EZ for shut-downs. In Sakhalin a 250 m EZ has been designated for pinnipeds, while a standard 1000 m EZ is used for cetaceans. However where feeding groups of western gray whales *Eschrichtius robustus* are observed, an EZ of 6–7 km may be implemented.[12] In California the EZ is defined as the "radius of received sound levels believed to have the potential for at least temporary hearing impairment," and is calculated on a survey-specific basis according to the calculated radius of the 180-dB re 1 $\mu$Pa (rms) radius around the source[13] (all sound levels reported in this article are rms re 1$\mu$ Pa unless otherwise stated).

#### *2.3.4. Pre-Shoot Watch*

The pre-shoot watch (the watch carried out for marine mammals prior to starting up the airgun source) is required to be at least 30 min in all regions, with the exception of Australia where a 90 minute pre-shoot watch is required (Table 1).

#### 2.3.5. Soft Start Delay

A delay to commencement of airgun operation if relevant marine mammal species are observed within the EZ during the pre-shoot watch is a standard mitigation measure applied in all regions. In Australia, the Gulf of Mexico, and Canada, mitigation measures apply only to whales and airgun use is permitted when dolphins, porpoises, or pinnipeds are within the EZ. After implementing delays, it is generally stated that airguns may not be activated until the animal is observed to depart the EZ (It is unclear in some guidelines,

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[12] SEIC, *Western Gray Whale Environmental Impact Assessment*. Draft 1. Chapter 7.2.4. Produced by LGL Ltd for Sakhalin Energy Investment Company (2005).

[13] HESS, *(High Energy Seismic Survey) Review Process and Interim Operational Guidelines for Marine Surveys Offshore Southern California*. REPORT FROM THE HIGH ENERGY SEISMIC SURVEY TEAM FOR THE CALIFORNIA STATE LANDS COMMISSION AND THE US MINERALS MANAGEMENT SERVICE PACIFIC OUTER CONTINENTAL SHELF REGION, California (1999).

however, whether a further clearance delay is required or whether the soft start can commence immediately that animals depart the EZ) or, if it submerges and is not detected again, until a designated time after it was last observed within the EZ (30 min in most regions).

### *2.3.6. Shut-Downs (Stop Work Procedure)*

Most regions require a shut-down of the airguns whenever designated species approach within the EZ. The exception is the UK, where no shut-down procedure is required on the basis that animals "choose" to approach active airguns of their own accord.[14] In Brazil, California, and Sakhalin shut-down occurs for all marine mammal species, while only whales warrant shut-down in Australia and the Gulf of Mexico. In Canada and New Zealand, shut-downs are requested only for stated species of concern. New Zealand is the only region for which a larger shut-down EZ is designated when species of concern are accompanied by calves. When shut-downs occur, all regions request a 20–30 min delay in gun use following the observation, or a delay until the animal is observed outside of the EZ (again it is often unclear whether airguns can then resume immediately or whether a further 30 min clearance period is required). Most regions also require a full soft start procedure following marine mammal shut-downs. It is unclear whether subsequent soft start is a requirement in all guidelines, particularly in regions where airgun operations are permitted to resume immediately that an animal departs the EZ and the total shut-down period may be relatively short. For example, Canada states that a soft start is only required for marine mammal shut-downs exceeding 30 min, and this may also be the case in other areas.

### *2.3.7. Passive Acoustic Monitoring (PAM)*

Although most guidelines acknowledge the potential value of real-time passive acoustic monitoring (listening for vocalising animals) for mitigation, it is not yet a mandatory procedure in any region. However, PAM may be recommended by the regulating body as a back up to visual observation in some sensitive areas, particularly deep water areas where sperm whales *Physeter macrocephalus* are expected to occur (e.g., west of Scotland in the UK).[15] There are some specific mitigation measures relating to PAM in the UK, the Gulf of Mexico, and Canada. In the UK, a delay to airgun use is required if marine mammal sounds are detected within 500 m of the source based on (a) software estimates or (b) judgement of the PAM operator. Canada implements a similar delay to soft start when PAM is used, but applied only to selected whale species. In the Gulf of Mexico, the use of PAM at night

[14] JNCC, *Guidelines for Minimising Acoustic Disturbance to Marine Mammals from Seismic Surveys*. Joint Nature Conservation Committee, Peterborough, UK (2004).

[15] Id.

(or poor visibility) allows soft start to commence when it would otherwise require visual monitoring or the continued use of a small airgun.

## 3. SEISMIC GUIDELINE LIMITATIONS

### 3.1. Operational Procedures

#### *3.1.1. Soft Starts*

Although the soft start procedure is the most widely used seismic mitigation measure and, in some areas, comprises the sole measure used at night, its effectiveness for at least some species has been the subject of considerable debate. Beyond this basic shortcoming, the practice is also limited by certain limitations in its application. The existing guidelines on how to operate a soft start are ambiguous and state only that power should be built up slowly over time, e.g., starting with the smallest airgun in the array and gradually adding in others over 20 min. Only in the Gulf of Mexico, Canada, and Brazil, is it stated that the smallest airgun means in terms of energy output (dB) and volume ($in^3$). The exact energy output requirement for the first stage of soft start is not provided by any regional guidelines and nor is there guidance on the level of acoustic output that should be added-in during each subsequent stage of soft start, with the exception of the California guidelines which request an energy increase of 6 dB per min.[16]

Soft starts are currently conducted in a variety of ways, varying from add-ins of individual guns every 30 sec to add-ins of several guns simultaneously every few minutes. The required minimum soft start duration of 20 min is predetermined in all regional guidelines, and makes no allowance for variation in airgun volume. Since the airguns used during modern 2D/3D/4D seismic surveys vary from a few hundred to over 10,000 $in^3$, the designation of single soft start duration may be inappropriate. The requirement for soft start during periods of gun testing (when only one sub-array might be active) is also poorly defined in all guidelines.

Independent monitoring of the soft start procedure in the field is challenging since it is operated from the vessel's instrument room and there is no automated record. On most vessels soft starts are carried out manually (with each gun(s) added in by switch at an appropriate time), and the precision of the soft start procedure therefore relies entirely on the aptitude and interest of individual seismic crew. On a minority of vessels the soft start is computer automated (each gun(s) automatically added in at predetermined shot points), providing a more reliable method of increasing sound level than manual operation. Logging of soft starts (as required to ensure compliance with the

[16] HESS, *supra* note 13.

20 min duration) is also carried out by seismic crew and cannot therefore be independently monitored by an MMO who is required to be on watch for the soft start.

### *3.1.2. Airgun Use*

Some regional guidelines require airguns to be active 24 hr throughout a survey (e.g., Department Of Conservation, New Zealand),[17] while others require a small gun to be active throughout the night.[18] It is unclear how such measures minimise acoustic impact on the environment, and in particular there is no evidence that continual firing of a small gun acts as a deterrent to marine mammals. In contrast, some studies suggest that some species such as humpback whales may actively approach small volume airguns.[19] Importantly, although some guidelines suggest using airguns of "lowest practicable level" during seismic surveys, it is unclear how or even whether this is regulated. It is not stated that airgun use should be restricted to the allocated survey prospects. In some regions weather downtime and maintenance may result in seismic vessels straying far from their licensed prospect area (and sometimes into more sensitive habitat), where airgun testing might occur. There are concerns over the cumulative impact of time-sharing (two or more vessels operating in adjacent areas, which take turns firing airguns to avoid interference with one another), which may produce 24 hr airgun sound when one vessel commences soft start as another ends a line.

### *3.1.3. Monitoring in Adverse Conditions*

All of the current guidelines depend solely on visual monitoring to detect animals at the surface. This means that effectively no mitigation is in place for seismic surveys occurring at night. While JNCC "encourage all seismic survey operators to ensure that, as far as possible, soft starts occur during daylight hours,"[20] this would greatly restrict seismic operation production time and to our knowledge has not been implemented. Currently none of the guidelines have an outright restriction on airgun use at night. Although airgun start-up is not allowed during darkness in some regions, operations are allowed to continue at full volume providing that a small gun is kept active during line

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[17] Department of Conservation, *Reference Document: Guidelines for Minimising Acoustic Disturbance to Marine Mammals from Seismic Surveys*. DEPARTMENT OF CONSERVATION, Wellington, New Zealand (2005).

[18] MMS, NTL No. 2004-G01. *Implementation of Seismic Survey Mitigation Measures and Protected Species Observer Program*. UNITED STATES DEPARTMENT OF THE INTERIOR, MINERALS MANAGEMENT SERVICE (2004).

[19] Rob D. McCauley *et al*. *The Response of Humpback Whales* (Megaptera novaeangliae) *to Offshore Seismic Survey: Preliminary Results of Observations about a Working Seismic Vessel and Experimental Exposures*. APPEA JOURNAL (1998). Rob D. McCauley *et al*. *Marine Seismic Surveys—A Study of Environmental Implications*. APPEA JOURNAL (2000).

[20] JNCC, *supra* note 14.

changes. In Australia and California airgun operations continue at night with visual monitoring via infra-red/night vision binoculars, despite an effective range of only around 100 m.

With the exception of reduced visibility (which is treated the same as night operations), the guidelines do not address adverse weather conditions. It is well documented, however, that detection of marine mammal species decreases significantly with increasing sea state (particularly porpoises, *Kogia* whales, beaked whales, minke whales *Balaenoptera acutorostrata*).[21] Environment Australia notes that the "upper limit for practical whale observation is sea state 5, corresponding with the operational weather limit for most seismic vessels."[22] But sea state 5 is not conducive to the detection of many cetacean species. Furthermore, advancing seismic technology (e.g., OBC, solid streamers) means that some seismic surveys frequently operate in sea states greater than 5 with swell height representing the more usual operational constraint. In the California guidelines there is some indication that when weather deteriorates such that the MMO cannot effectively monitor the EZ and there are known to be concentrations of animals in the area, a halt to gun use might be imposed.[23]

### 3.2. Detection and Real-time Mitigation Procedures

#### *3.2.1. Visual Detection*

In addition to the limitations described above, visual detection is also currently hindered by the lack of appropriate training programs for, and independence of, MMOs. The regional guidelines vary considerably in their requirements for MMOs, but none define the frequently used terms "trained," "experienced," and "qualified." At present the MMS guidelines are the only ones to state the criteria for a "trained" MMO via the content of training courses. Where stated, training involves attendance of a one-day theoretical course,[24] which does not include marine mammal field experience. It is not a prerequisite to have any practical experience of marine mammals to work as a MMO, and use of crew members is permitted in most areas. There is no feedback or assessment of those MMOs working in the industry.

A further concern is the lack of independence of MMOs. This is most apparent where MMOs are crew members or otherwise employed directly by the seismic contractor, presenting a clear conflict of interests. Even when this is not the case, provision of "independent" MMOs to the oil and gas industry

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[21] Clarke, R. *An Index of Sighting Conditions for Surveys of Whales and Dolphins*. REPORT OF THE INTERNATIONAL WHALING COMMISSION, 32 (1982).

[22] Environment Australia, *supra* note 8.

[23] IBAMA, Guide for Monitoring Marine Biota During Seismic Data Acquisition Activities. IBAMA, Brazil (2005b).

[24] JNCC, *supra* note 14; MMS, *supra* note 18.

is usually controlled by industry-specific employment agencies, which does not necessarily ensure that the most appropriate MMOs are used on each survey. Direct reports from the MMO to the regulating body are a stated requirement only in Brazil.[25] In most regions it is usual for MMO reports to be submitted to the regulator via the employment agency and oil/gas company, thus compromising the independence of the reporting procedure.

Australia's policy of visually monitoring for only 10 min every hour cannot ensure adequate detection of cetacean species or effective implementation of the stated mitigation measures, particularly given the large exclusion zone stated for this region.

### *3.2.2. Species Included*

All marine mammals utilise sound and are potentially affected by seismic surveys. Although some regions currently offer no protection to dolphins and porpoises (Table 1), there is good evidence that small odontocetes experience disturbance from seismic surveys.[26] Emission of higher frequency sound increases concern of the potential impact on toothed whales.[27] All species of marine mammal should therefore be included in seismic survey mitigation measures.

### *3.2.3. Exclusion Zone*

Defining an EZ is clearly a fundamental component of the real-time mitigation measures used during seismic surveys. However, the basis for defining EZs remains unclear in most cases. Some of the regional guidelines attempt to provide a scientific basis for the determination of these EZs. For example, the Canadian guidelines suggest that behavioural and harmful effects may be produced in marine mammals by 160 dB re 1 $\mu$Pa and 180 dB re 1 $\mu$Pa respectively,[28] while the existing Sakhalin guidelines calculate EZs according to received levels of 190 dB re 1 $\mu$Pa for pinnipeds and 180 dB re 1 $\mu$Pa for cetaceans.[29] We note, however, that a received level of 120 dB re 1 $\mu$Pa was recently identified at a scientific workshop as the appropriate EZ standard for protecting critically endangered Western gray whales during construction

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[25] HESS, *supra* note 13.

[26] For example, John C. Goold. *Acoustic Assessment of Populations of Common Dolphin* Delphinus Delphis *in Conjunction with Seismic Surveying*. JOURNAL OF THE MARINE BIOLOGICAL ASSOCIATION OF THE UNITED KINGDOM, 76 (1996); Caroline J. Stone. *The Effects of Seismic Activity on Marine Mammals in UK Waters, 1998–2000*. JNCC REPORT NO. 323. Joint Nature Conservation Committee, Aberdeen, UK (2003).

[27] Peter T. Madsen *et al*. *Quantative Measures of Air Gun Pulses Recorded on Sperm Whales* (Physeter macrocephalus) *Using Acoustic Tags During Controlled Exposure Experiments*. PAPER PRESENTED TO IWC SCIENTIFIC COMMITTEE (2006).

[28] Department of Fisheries and Oceans. *Statement of Canadian Practice: Mitigation of Seismic Noise in the Marine Environment* (2005).

[29] SEIC, *Supra* note 12.

activities off Sakhalin Island.[30] The New Zealand guidelines state that, "It is generally accepted that noise levels below 180 dB re 1 $\mu$Pa (rms) are unlikely to cause any loss of hearing (temporary or permanent) or physiological damage to cetaceans".[31]

The HESS panel was the first to introduce a scientific basis for the EZ in 1999, defining the EZ by the 180-dB radius since this was the received sound level believed to have potential for auditory injury.[32] The safety of this level remains unverified, however, and recent evidence suggests that physical injury and strandings may be induced at received sound levels far lower than 180 dB re 1 $\mu$Pa.[33] Except in California, none of the guidelines that use an isopleth-based standard provide information on the distance that the isopleth extends from the source, and none of the guidelines that use a radius-based standard take into account the properties of individual survey areas (water type, depth), or airgun arrays (volume) when determining the EZ.

Rather, the same generic value for EZ (from 200 m for some species in New Zealand to 3000 m for whales in Australia) applies regardless of whether airgun array volume is 10 $in^3$ or 10,000 $in^3$, or the survey area in deep, shallow or shelf edge waters. For example, the New Zealand guidelines state that, "based on vessels operating 2000–3000 $in^3$ arrays at full power, several studies indicate that the 180 dB re 1 $\mu$Pa (rms) threshold correlates well with a 1 km distance in most scenarios."[34] If 1 km has been calculated as the 180 dB EZ for this region, then the basis for the 500 m EZ designated by the UK, Gulf of Mexico and Canada should be questioned. And given that airgun arrays reach volumes four times larger than the 2000–3000 $in^3$ quoted in this statement, there is clearly a need to incorporate the effect of varying airgun volume on EZ calculations.

Only in California is a considered evaluation of the basis for the EZ provided, where a site-specific EZ is calculated during the survey application process based on the specific survey parameters provided by the operator. The mitigation guidelines implemented during some research-related seismic surveys do take into account the variation in airgun volume on the EZ. For example, modelling has shown that the 180 dB re 1 $\mu$Pa (rms) EZ for a relatively small 210 $in^3$ airgun array is expected to extend to only 50 m around the source, but may comprise a 950 m radius around an 8600 $in^3$ airgun

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[30] IUCN. 2006. Report of the interim independent scientists group (IISG) on mitigation measures to protect Western gray whales during Sakhalin II construction operations in 2006. Workshop convened by the IUCN, Vancouver, British Columbia, 3–5 April 2006.

[31] DOC. 2005. Draft Guidelines for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations. Department of Conservation, Wellington, New Zealand. November 2005.

[32] HESS, *supra note* 13.

[33] Dolman, S.J. and Simmonds, M.P. 2005. Noise pollution—some thoughts on mitigation and wider protection. Paper SC/57/E9 presented to the Scientific Committee of the International Whaling Commission.

[34] DOC, *supra note* 31.

array.[35] Models and subsequent field measurements in the Gulf of Mexico clearly showed that the EZs for the received sound levels relevant to current marine mammal mitigation (160 to 190 dB) increase markedly with airgun volume.[36] The effect of variation in water depth on received sound levels from airgun arrays has also been studied using modelling and field verification, indicating that the EZ for a 20-gun array at a measured precautionary sound level of 160 dB re 1 $\mu$Pa (rms) may be around 2.5 km in deep water ($\sim$3200 m) but extends to over 12 km in a shallow water ($\sim$30 m) area.[37] Clearly, the use of a single standard EZ value for all seismic surveys regardless of airgun volume or water depth is inappropriate.

Although these field calibrations were conducted during a research-related seismic survey,[38] both the California and Sakhalin mitigation guidelines recognise that exact sound levels can be relatively easily measured in the field using existing industrial seismic equipment, and the EZs subsequently revised according to measured sound levels. A recent study of sperm whales exposed to seismic pulses found that the received sound level of the first pulse was similar at ranges of 2 to 12 km from a seismic array, with secondary pulse arrivals having higher received levels at 5 to 12.6 km from the source than at closer range.[39] This emphasises a need for measurements to be made at extended distances from the source vessel and appropriate EZs designated.

### *3.2.4. Pre-Shoot Watch*

The 30 min pre-shoot watch was originally defined by the JNCC for the UK's continental shelf (<200 m) waters. Only Australia has designated a longer pre-shoot watch period (90 min), with all other areas retaining the 30 min watch regardless of water depth. Although 30 min might be adequate for detecting shallow-diving shelf species, it is not necessarily appropriate in deep water areas where the known dive times of some species (e.g., sperm whale, beaked whales) regularly equals or exceeds this duration.

### *3.2.5. Soft Start Delays*

The soft start delay for animals observed within the EZ is now standard practice within the seismic industry and there are relatively few problems with its implementation. However some of the regional guidelines remain unclear on the required duration of the delay, and whether soft start can commence immediately after animals depart the EZ or whether a 30 min clearance period is required. Some operators now commence soft start much earlier in a line

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[35] LGL, *supra* note 8.
[36] Tolstoy, M. *et al*. *Broadband Calibration of R/V Ewing Seismic Sources*. GEOPHYSICAL RESEARCH LETTERS, 31 (2004).
[37] Id.
[38] Id.
[39] Madsen, *supra* note 27.

change than is required operationally, in order to allow for potential delays due to marine mammals and avoid circling. This tactic results in increased airgun noise in the environment and should be prohibited.

### *3.2.6. Shut-downs*

Only Brazil, California, and Sakhalin implement shut-downs for all marine mammals. Given the evidence that small odontocetes may be sensitive to disturbance from seismic surveys,[40] it is appropriate for all regions to apply shut-down for all cetaceans. As in New Zealand, specific shut-down procedures should be considered for calves, which might be more sensitive to anthropogenic sound than adults. While shut-down is a straightforward mitigation technique, it is only possible to implement the procedure during daylight as it relies upon visual detection. Following a shut-down procedure, it is unclear in many of the regional guidelines whether airgun use can resume immediately that the animals depart the EZ or whether a further 30 min clearance period is required. While most guidelines stipulate that a full soft start is required following shut-down for marine mammals, Canada requires a soft start only if the shut-down exceeds 30 min duration. Potentially, this means a temporary pause in airgun use simply as an animal passes through the 500 m EZ, with the guns suddenly activated again at full volume. This does not appear to be a precautionary use of airguns given that animals may be only 500 m from the guns when they are activated again at full power. Similarly, the period of accepted shut-down for "operational reasons" currently ranges from 5 to 30 min according to region.

While the UK and Gulf of Mexico guidelines specify that operational shut-down periods are only permitted if a visual watch is maintained, the other guidelines omit this clause and therefore allow such shut-downs at night when no monitoring can occur. Where shut-down procedures are required, it is logical that several dedicated MMOs are used to cover all daylight hours and to ensure detection and species identification of animals out to the required EZ ranges of up to 3000 m. Australia's policy of monitoring for only 10 min every hour cannot allow effective implementation of the shut-down procedure.

### *3.2.7. Passive Acoustic Monitoring*

Although passive acoustic monitoring is recognised as a potentially valuable detection technique within most of the regional guidelines, its full potential use in seismic mitigation is not yet realised. There are a variety of PAM systems that can be used to detect cetaceans (e.g., towed arrays, bottom-mounted hydrophones, sonobuoys). The system usually employed during seismic surveys is the towed array, since airguns are mobile and require a mobile mitigation system.

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[40] Goold, *supra* note 26; Stone, *supra* note 26.

The essence of existing seismic survey mitigation is to detect animals within the EZ and implement the relevant measures, and PAM will become more successful as a mitigation tool if it is able to: (a) reliably detect a significant number of vocalising marine mammal species within the EZ, (b) reliably identify each marine mammal species (where guidelines are species selective), and (c) provide a reliable range measurement to the animal. Use of PAM as a seismic mitigation tool is currently limited by the fact that animals are not always vocal, the seasonality in vocal activity of some species (e.g., baleen whales), lack of knowledge regarding sounds produced by some species (e.g., beaked whales), difficulty in species identification, the variable detection range between species, lack of accurate range estimation (currently often based on operator interpretation) and the regular masking of lower frequencies (those used by baleen whales) by vessel noise. To date PAM towed arrays have usually been deployed from the chase (guard) vessel which is often positioned over 1 km ahead of the seismic vessel itself so that PAM monitoring occurs too far from the airguns to be effective.

The use of PAM is also constrained by the lack of guidance for its implementation and the lack of training programmes in its use. Establishing whether a marine mammal is within 500 m of the airgun array often depends on the judgement of the PAM operator rather than on objective software.[41] As pointed out by Barlow and Gisiner,[42] acoustic detection improves tremendously if an observer knows what to listen for, and the development of training programs for the use of PAM should be a priority.

## 3.3. General Issues

### *3.3.1. Sensitive Areas*

All of the regional guidelines recognise sensitive areas for marine mammals, but there is little rigorous definition of these areas and how they apply to seismic survey applications. Only Brazil (reported in Environmental Licensing Guide)[43] and Australia[44] have allocated defined prohibited areas for seismic surveys due to marine fauna. Avoidance of seismic surveys in sensitive habitat is the most effective and straightforward mitigation measure that can be applied to protect marine mammals and more regions should define this option.

### *3.3.2. Other Sources of Disturbance*

Seismic surveys often incorporate a range of vessels, including chase (guard) vessels, supply boats, undershoot vessels, workboats, and crew boats.

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[41] JNCC, *supra* note 14.

[42] Jay Barlow & R. Gisiner. *Mitigating, Monitoring and Assessing the Effects of Anthropogenic Sound on Beaked Whales*. JOURNAL OF CETACEAN RESEARCH AND MANAGEMENT 7 (2006).

[43] IBAMA, *supra* note 10.

[44] Dolman, *supra* note 11.

These vessels also have the potential to disturb marine mammals, and guidelines for minimising impact to marine mammals need to address all activities related to seismic surveys and not simply airgun noise. Only the Brazilian guidelines state that it is prohibited to attempt to deliberately move animals out of the EZ,[45] a matter that has arisen in other areas.

### *3.3.3. Ineffectiveness of Existing Mitigation Techniques*

While visual detection is a reasonable method for detecting some marine mammals in the vicinity of a seismic survey (given favourable weather and daylight), it remains ineffective for certain species such as beaked whales[46] and small inconspicuous animals such as *Kogia* whales and porpoises. These same species may be difficult to detect acoustically, for example the vocalisations of beaked and *Kogi*a whales are poorly known. All marine mammal species are currently poorly protected at night. Where visual observations do occur at night[47] they are only realistically likely to detect bow-riding dolphins due to limitations of night vision equipment. The use of acoustic monitoring at night will detect only vocalising animals and is therefore very limited for species that are largely non-vocal or which aren't vocalising at the time. The use of the currently available acoustic equipment is also hindered by ship-produced noise.

A further inefficiency of the existing mitigation methods is that the MMO must visually observe the marine mammal entering the EZ before mitigation can be requested. This does not adequately mitigate for deep-diving species such as sperm and beaked whales that may dive ahead of the survey on the vessel's trackline. For example, since sperm whales typically dive vertically during the first portion of their dive,[48] animals seen to fluke and commence a dive ahead of the ship may remain submerged on the trackline and enter the EZ without being visually detectable within the EZ by the MMO. No mitigation measures could be applied to probable submerged animals under the present regional guidelines. The MMS guidelines alone define the EZ as "the area at and below the sea surface within a radius of 500 meters surrounding the centre of an airgun array and the area within the immediate vicinity of the survey vessel." Mitigating for animals below the sea surface is clearly limited using only visual methods.

### *3.3.4. Enforcement of Mitigation Methods*

While the mitigation measures outlined within the guidelines in Table 1 are a licensing requirement for operators working in those particular regions, there is little obvious enforcement by the regulating bodies. There appears

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[45] IBAMA, *supra* note 23.
[46] Barlow, *supra* note 42.
[47] For example, Environment Australia, *supra* note 8.
[48] Hal Whitehead. SPERM WHALES: SOCIAL EVOLUTION IN THE OCEAN. (2003).

to be no onboard monitoring (or feedback system) of the effectiveness of guidelines, no evaluation of the mitigation procedures and no repercussions for operators that fail to comply with the guidelines, e.g., soft starts below the required duration. This is partly a result of the reporting procedure in most regions, whereby MMO reports are relayed via the contractor/agency before reaching the regulating body. Mitigation measures would be better enforced if the regulating body (or equivalent independent body) was responsible for providing MMOs to industry, and if those independent MMOs were required to report directly to the regulating body, as is the case in Brazil.

#### *3.3.5. Regional Application of Guidelines*

Although the guidelines summarised in Table 1 are now being used within those particular geographic regions, the majority of the world's oceans are still open to seismic surveying without any marine mammal mitigation procedures in place. Some of the regional guidelines are selective regarding inclusion of their own waters, for example in most of the Gulf of Mexico the MMS guidelines apply only to water depths greater than 200 m[49] providing no protection for marine mammals in shelf waters. In regions where no statutory legislation exists for the protection of marine mammals, many seismic surveys occur within sensitive habitats without any consideration of marine fauna.

## 4. ADDITIONAL MITIGATION MEASURES

Although there are a number of mitigation measures (e.g., acoustic deterrent devices, bubble screens) currently used to mitigate the effects of other anthropogenic sound sources on marine mammals, many of these are unsuitable for use during seismic surveys due to the mobility of the airguns. There are several other technologies/measures, however, that could be developed for seismic surveys in the future.

### 4.1. Closed Areas

The simplest way to mitigate the effects of seismic surveys on marine fauna is to avoid animals either in space or time. This measure requires knowledge on the distribution, density and seasonal occurrence of cetaceans in an area, which is lacking for many parts of the world. In some regions the occurrence of marine mammals is well documented, and simple closed (temporary or permanent) areas could be implemented to ensure protection. For example, humpback whales are a predictable species that return annually to traditional breeding and feeding grounds. Brazil is the only country for which designated closed areas are clearly defined, and a seasonal closed area to protect breeding humpback whales exists between July and November. There are other areas

[49] MMS, *supra* note 18.

worldwide where similar breeding humpback whale populations are currently offered little or no protection from seismic surveys, notably on the west coast of Africa where the Angola and Gulf of Guinea breeding grounds overlap with an area of increasing seismic survey activity.

The designation of closed areas is most effectively implemented at the government level in each region as part of standard statutory guidelines, where the legislation applies to and is adopted equally by all licensees. Regional authorities can also recommend closed areas (e.g., regional seas agreements), though their recommendations may have only limited force of law. In some regions worldwide there is little awareness of the potential effects of seismic activity on marine mammals, and such countries should be strongly encouraged to consider marine mammal issues during the licensing procedure.

### 4.2. Passive Acoustic Monitoring

Although various types of acoustic monitoring are available, only the towed array is currently used during seismic surveys due to the mobility of the source. The limitations of the current towed array equipment have been considered above, but with advancing technology it is likely that PAM will provide improved detection ability in future years. Both the UK and Canadian guidelines note that improvements in technology are likely to make PAM a requirement in the future. It has been suggested that marine mammal PAM equipment could eventually be incorporated into the standard seismic cables towed behind a seismic ship to solve current deployment problems.

### 4.3. Active Sonar

Active sonar comprises emission of a sound signal that reflects off submerged objects and back to a signal receiver to produce a 3D image of the water column. There is potential for the use of high-frequency active sonars for the detection of marine mammals within a short distance of an airgun array. But the system requires further work to reduce false triggers and increase species identification, and there are important concerns over the potential adverse effects from this additional sound energy on cetaceans.

### 4.4. Equipment Modification / Development

The development of new technology as an alternative to airgun sound should be encouraged. For example, there is a marine vibrational device being developed as an alternative to airgun arrays, which has a lower peak amplitude, slower rise time and significantly less energy above 100 Hz.[50] Operators should aim to reduce unnecessary output of incidental high frequencies from airguns, and

[50] Smith, J.G. & M.R. Jenkerson. *Acquiring and Processing Marine Vibrator Data in the Transition Zone*. Mobil Exploration and Producing Technical Centre (1998).

ensure that airguns are configured so that horizontal propagation of sound is minimised.[51] Equipment to improve visual monitoring during night and poor visibility should also be developed, with potential uses of infrared equipment and millimeter waves radar.[52] While some engineering modifications have been encouraged for years in some regions (e.g., baffling of higher frequency sound requested by the JNCC), there have been no statutory requirements to do so or to conduct relevant research.

### 4.5. Additional Monitoring Platforms

The Californian, Australian, and Sakhalin guidelines mention the use of aerial surveys before, during, and after seismic surveys in sensitive areas to monitor for concentrations of whales. This information can subsequently be used in real-time planning of seismic data acquisition and assessing marine mammal responses to the sound source. The use of additional, dedicated research vessels may also be useful to survey the areas ahead of seismic vessels and provide advice on the occurrence of animals.

## 5. GUIDANCE TOWARDS A WORLDWIDE INDUSTRIAL STANDARD

As reviewed above, the statutory marine mammal mitigation guidelines in use during industrial seismic surveys worldwide show significant variation in most parameters between regions. This lack of consistency needs to be addressed so that a minimum "best practice" with a scientific basis offering adequate protection to all marine mammal species is adopted worldwide. Guidance is also needed for the management of industrial seismic surveys in waters where no statutory guidelines currently exist, for example in the Indian Ocean and off West Africa. In the absence of standard international guidelines, industrial seismic surveys in such areas are presently carried out: (a) without any mitigation measures in place, or (b) using guidelines from other countries. The UK guidelines are often perceived as incurring least disruption to a survey,[53] and are most commonly adopted by operators in those regions without statutory guidelines (e.g., West Africa). However, the JNCC guidelines do not constitute best practice for protecting marine mammals, since they have no scientific basis and were developed for the UK's shallow continental shelf area[54] which may not be appropriate for deep-water areas or for marine mammals (and turtles) found in other regions.

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[51] JNCC, *supra* note 14.
[52] HESS, *supra* note 13.
[53] IAGC Statement of Principles. *Marine Mammal Protection* (2006).
[54] JNCC, *supra* note 14.

The marine mammal mitigation procedures implemented during some research-related seismic surveys are prime examples of exemplary adaptive management, involving a rigorous application process and developing a variety of mitigation measures specific to the survey site, adopting a precautionary approach, based on scientific data and embracing the full range of mitigation procedures and technologies available.[55] This process certainly comprises current "best practice" for mitigating the potential effects of airgun sound on marine mammals. This multi-faceted approach however, is not implemented for industrial seismic surveys anywhere in the world; nor is it applied to research seismic surveys in some areas. For example, Article 7 of the Protocol on Environmental Protection to the Antarctic Treaty bans all mineral resource activities in Antarctica,[56] yet despite the sensitivity of the region, research seismic surveys are permitted with only ad hoc marine mammal mitigation in place that depends predominantly on the awareness and interest of the individual operator.

In the absence of comprehensive mitigation procedures for many standard industrial seismic surveys and some research seismic surveys (particularly in regions where statutory guidelines do not exist), the following points are recommended for inclusion as a minimal "best practice" mitigation procedure.

### 5.1. Avoiding Densities of Animals

- Surveys should be planned so that entire habitats or migration paths are not blocked, cumulative seismic sound is limited within any particular area, and time-sharing is prohibited. In some areas there are considerable scientific data supporting the occurrence of vulnerable species and/or key marine mammal breeding/feeding/migratory habitat. Where such evidence exists, closed areas (seasonal and/or year-round as appropriate) should be designated similar to those existing in Brazil (e.g., the Abrolhos Bank).[57] Research should be prioritised in those areas where the distribution, density and seasonality of cetaceans in an area are not known.
- Closed areas should be surrounded by appropriate buffer zones. They should be managed so that use of airguns is completely prohibited within and adjacent to key habitats (spatial areas or water depths) during particular seasons or on a year-round basis so that damaging or disturbing noise levels are not created. Theycould also be managed

[55] NMFS, *supra* note 9; LGL, *supra* note 9.

[56] Protocol on Environmental Protection to the Antarctic Treaty (1991) available at http://www.cep.aq/apa/legal_docs/protocol.html (last visited 2/24/07)

[57] Marcia H. Engel *et al*. *Are Seismic Surveys Responsible for Cetacean Strandings? An Unusual Mortality of Adult Humpback Whales in Abrolhos Bank, Northeastern coast of Brazil*. Paper SC/56/E28 Presented to the Scientific Committee of the International Whaling Commission (2004).

so that only very low noise output surveys (e.g., High Resolution, site surveys) can be considered to occur within sensitive areas during key seasons.
- Closed areas and buffer zones need to be defined clearly in the regional mitigation guidelines, so that all operators and companies are equally subject to and aware of restrictions.

### 5.2. Onboard Mitigation Procedures

- Mitigation measures should apply to all marine mammal species (and turtles).
- At least one dedicated MMO should be on watch 24 hr (max 4 hr shift), requiring at least two (and preferably three) dedicated and qualified MMOs on every seismic vessel. While visual watches at night are clearly limited in range, there are no other mitigation methods available and visual observers would still detect those animals closest to the ship where they are most vulnerable. Equipment including high quality infra-red and night-vision binoculars should be provided to the MMO for night time observations. Studies into their effectiveness would be useful.
- Every seismic operator (irrelevant of geographical area and local conditions) should implement a soft start procedure for every use of the airguns. Soft start should commence with a small, individual gun (i.e., $<70$ in$^3$), and increase by stages of approximately 6 dB per minute. Total soft start duration will therefore be proportionate to airgun volume, with larger volume arrays taking longer to complete soft start than small arrays. This procedure can be applied in an easily interpreted manner to all gun testing. All soft starts should be automated, to reduce potential operator inaccuracy. All soft starts should commence as close to start of line as practical to minimise airgun noise during line change.
- The use of the lowest practicable airgun volume should be defined and enforced. Small airguns should not be kept active during line changes (to avoid habituation or positive approach), and airgun use should be prohibited outside of the licensed prospect area.
- There should be a scientific basis for the exclusion zone rather than an arbitrary designation. Although a received level of 180 dB re 1 $\mu$Pa (rms) is generally considered to be the likely injurious sound level for marine mammals, this may not be adequately precautionary and protective.[58] Marine mammal behavioural responses have occurred at

[58] Sarah J. Dolman & M.P. Simmonds, *Noise pollution—some Thoughts on Mitigation and Wider Protection*. Paper SC/57/E9 Presented to the Scientific Committee of the International Whaling Commission (2004).

received sound levels of at least 160 dB, and it is therefore recommended that a precautionary received level of no more than 160 dB re 1 $\mu$Pa (rms) is used to calculate the EZ (this sound level may need to be revised in the future should research indicate that animals are more sensitive to sound than indicated at the present time). For some endangered populations/species in important habitat that has not been effectively closed (e.g., Western gray whales on their feeding grounds off Sakhalin Island), a more precautionary lower sound level should be used and EZs may be correspondingly greater. EZ values should be calculated by the operator prior to the application process, using site-specific transmission loss modelling based on airgun array parameters and the bathymetry, water properties and sound velocity profiles of the water column within the prospect area. The EZ value should be verified in the field at the start of the survey. During long duration surveys, the EZ should be regularly recalculated. We also recommend that the criteria used to calculate exclusion zones should regularly be reviewed.

- There should be a dedicated pre-shoot watch of at least 30 min. In areas where water depths exceed 200 m, the watch should be at least 60 min to help increase the probability that deep-diving species are detected.
- There should be a delay to commencement of soft start for all marine mammal species (and marine turtles) observed within the 160-dB EZ. Soft start may not begin until 30 min after the animals depart the EZ or 30 min after they are last seen.
- There should be a shut-down of the airguns whenever a marine mammal (or marine turtle) is seen to enter the 160-dB EZ. Constant radio communication is required between the MMO and the Instrument Room to ensure shut-downs are instantaneous. Following a shut-down, a full soft start is mandatory. Soft start should not begin until 30 min after the animals depart the EZ or 30 min after they are last seen. The permitted shut-down of airguns for operational purposes should be no longer than 5 min without requiring full soft start.
- Extra mitigation measures should be applied in deep water areas for sperm and beaked whales seen diving on the vessel trackline. Assuming an average survey speed of 4.5 kts and a 15 min mean vertical descent period for sperm whales,[59] a whale diving within 2 km ahead of the airgun source may remain on the vessel trackline until the ship draws level before it commences horizontal movement. It is therefore recommended that for sperm and beaked whales, soft start

[59] Whitehead, *supra* note 48.

delays and shut-down procedures are applied to animals seen diving within 2 km ahead of the source, even if outside of the EZ at the time of last visual confirmation.

- Ideally, airgun use should be prohibited at night since current mitigation techniques are inadequate to detect marine mammals. Restricting airgun use to daylight hours should certainly be considered in particularly sensitive areas (breeding, feeding and migratory zones). However there is a trade-off between allowing continual 24 hr airgun use and completing the survey earlier, or restricting airgun use to daylight only and having a much longer survey duration and possibly greater impact on the region. To ensure that seismic surveys have minimal overall duration within an area, airgun use should be permitted at night (outside of sensitive areas) on condition that visual watches are maintained using night-vision / infra-red binoculars. PAM should also be used as an additional night time mitigation measure in areas where species suitable for acoustic monitoring occur (e.g., deep-water areas inhabited by sperm whales). Soft starts remain mandatory, and periods of extra gun use (such as testing) should be restricted to daylight hours.
- Because of the impact of adverse weather conditions on the visual detection of marine mammals, airgun use during unfavourable conditions (at least Beaufort sea state $\geq 4$, swell $\geq 2$ m, visibility $\leq 1$ km) should be restricted (both night and day). This measure is particularly important at night when visual observations are already hindered. In relatively more sensitive areas, gun use should be prohibited altogether, but especially in unfavourable detection conditions. In other areas, gun use should be permitted only if animal density in the region is low and at least two MMOs maintain visual watch. PAM should be used as an additional adverse weather mitigation measure, particularly in deep-water areas.
- Disturbance from other vessels associated with the seismic operation (e.g., guard vessels, supply boats, work boats, undershoot vessels etc) should be minimised. In particular, vessels should be prohibited from directly approaching cetaceans with the aim of 'herding' them away from the area of seismic operations to avoid mitigation. Those vessels free to manoeuvre should aim to provide at least 300 m clearance around cetaceans, in consistency with standard recommendations elsewhere.[60]
- MMOs should report directly to the regulating body throughout and on completion of each survey to ensure that reports are received without other involvement(i.e. reports should not go via a third party or be

[60] Carole Carlson. *A Review of Whale Watch Guidelines and Regulations Around the World*. International Fund for Animal Welfare (2004).

subject to any editing prior to receipt). Standardised reporting should also be a requirement.

### 5.3. Other Recommendations

- Marine mammal mitigation guidelines should be adopted by all oil and gas companies and contractors, to ensure that marine mammals are protected worldwide and not simply in those (usually developed) countries where adequate resources and structure are available to implement protection as a licensing requirement.
- A system of automated logging of gun use should be developed so that soft starts and use of the small gun at night can be independently monitored. At present the onboard observer cannot properly assess these key measures.
- MMOs must be qualified, dedicated and experienced. As a minimum this should require that an MMO has no other role on the ship, that they have field experience of the relevant marine mammal species in an area and that they have completed an appropriate training scheme. Training courses should incorporate an eye test, practical field training, extensive theoretical training (including seismic survey, underwater acoustics, marine mammal identification, and passive acoustic monitoring modules), and assessments. Establishment of an independent MMO body should be encouraged, with MMOs reporting directly to regulating bodies during and after a survey.
- Seismic PAM towed array technology should be further developed so that accurate ranges can be determined to vocalising animals, and official PAM guidelines should be developed (and continually revised according to data available) for implementing mitigation measures based purely on acoustic detection. A PAM training scheme is required, particularly since mitigation measures may be based on the PAM operators' judgement.
- Alternative seismic technology should be developed, such as low sound intensity replacements for airgun arrays and suppressor devices to eliminate unwanted high frequency sound. Such research could be required as a condition of permit.
- There should be improved and ongoing biological monitoring before, during and after seismic surveys, to provide information on species occurrence, seasonal/temporal distribution, and reaction to airgun sound. Long-term research programmes are recommended in those areas particularly prone to industrial activities.
- A commitment to investigate the effectiveness of mitigation measures undertaken is long overdue. Effort should be also be made to measure

the efficacy of commonly used mitigation measures, particularly soft start and the deterrent success of small guns.

## 6. CONCLUSIONS

The marine mammal mitigation measures currently in use worldwide show considerable variation in parameters such as the exclusion zone radius, the marine mammal species included in mitigation, and delay/shut-down procedures. Relatively few aspects of current mitigation have a firm scientific basis and proven efficacy in the field, and there remains a total lack of effective mitigation during night and adverse weather. This review highlights a number of shortcomings in the existing mitigation guidelines and makes recommendations towards a standardised set of guidelines applicable worldwide. Marine mammal mitigation measures should be utilised as standard procedure during all worldwide seismic surveys, and not simply where regional legislation requires them. Area closures and avoidance of key marine mammal habitat remain the most effective and precautionary mitigation against seismic noise and should be implemented in areas of importance for marine mammals.

TABLE 1. Statutory Marine Mammal Mitigation Measures Currently Used During Seismic Surveys Worldwide (Industrial Surveys Only, Not Including Site, Borehole or VSP Surveys)[61]

| Location | Species included | Observer requirement | Required observation technique | Soft start / ramp-up | Source exclusion zone (EZ) | Duration of pre-shoot watch | Soft start delay for animal(s) within EZ | Airgun shut-down for animal(s) within EZ | Night-time airgun use | Airgun use during line changes | Use of passive acoustics | Time/area closed zones? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UK[62] | All marine mammal species | 1–2 dedicated and trained MMOs (can be crew)<br>Experienced in sensitive areas | All 30 min pre-shoot watches<br>Other data collection optional | Compulsory. 20–40 min | 500 m | 30 min | At least 20 min delay after animal last seen | No | Permitted without monitoring | Discouraged. Shut-down completely between lines | Recommended in some sensitive areas | Seasonal limitations in some licence blocks |
| California[63] | All marine mammal species | Two dedicated and NMFS certified MMOs (Three MMOs for surveys >7 days) | One MMO on watch 24 hr (night and day)<br>Max. 4 hr watch | Compulsory. Time not provided.<br>Increase by 6dB per min | 180-dB radius (defined by transmission loss modelling)<br>Survey dependent | At least 30 min | Not stated | Yes for all marine mammals<br>No details provided | Permitted (with visual watches)<br>MMO can abort operations if visibility insufficient | Continue during turns but at lower level (in Appendix 5) | Not generally recommended unless sperm whales in area | Some prohibited areas, e.g., Channel Islands National Marine Sanctuary |
| Australia[64] | All whale species (except *Kogia*), plus pilot and killer whales | MMO should be trained, dedicated and preferably independent (compulsory in sensitive areas) | All 30 min pre-shoot watches. 10 min every hour or continual in sensitive areas | Compulsory. At least 20 min | 3000 m | 90 min | 30 min delay or until whale(s) seen outside EZ | Yes for whales<br>Soft start after 20 min delay or whale(s) depart EZ | Watches using Infra-Red / night-vision binoculars | Either leave small guns running, or shut-down completely and use soft start again. | Recognised as back-up to visual, but not required | Closed area in Great Australian Bight for southern right whales and Australian fur seals[11] |
| Gulf of Mexico[65] | Whale species only | Two dedicated MMOs on watch (can be crew)<br>MMO must be trained | All daylight hours (max. 4 hr on watch) | Compulsory. 20–40 min | 500 m | 30 min | Delay of at least 30 min after the whale(s) have been seen | Yes for whales<br>Soft start after 30 min 'all clear' delay | Permitted only if small gun (160 dB re 1 mPa-m) firing in line change | Daylight shut-down. Soft start at night permitted only if small gun kept active. | Encouraged Use of PAM allows ramp-up during darkness (adverse weather) | No |
| Brazil[66] | All marine mammals (turtles included) | Min. of three professional and dedicated—either experienced or trained | Two on watch continuously throughout daylight hours | 20–40 min | 1000 m for soft start 500 m for shut-down | 30 min | 30 min delay after animal seen outside EZ | Yes for all mammals / turtles 30 min delay after animal seen outside EZ, then soft start | Not allowed to *start* airguns at night unless a small gun (160 dB re 1 $\mu$Pa-m) is kept active | Shut-down during daylight Small gun can be kept active at night / poor visibility. | Not required Trials encouraged | Seasonal closed areas for breeding humpback and right whales, turtle nesting season and manatee areas |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Canada[67] | Whale species only (turtles included) | Use of a qualified and DFO approved MMO (qualification not stated) | All 30 min pre-shoot watches Other data collection optional | 20–40 min | 500 m | 30 min · | 30 min delay or until animal seen outside EZ | Yes for *some* whale/turtles of concern 30 min delay or until animal seen outside EZ. Soft start if shut-down >30 min | Not allowed to *start* the airguns at night / low visibility (can keep small gun active) | Either full shut-down or use of a single energy source | Strongly encouraged If vocalising whales are heard, soft start cannot commence for 30 min | Recommends planning surveys to avoid sensitive areas/times |
| New Zealand[68] | All marine mammals Extra measures for Species of Concern (SoC)[69] | Use of dedicated MMO (can be crew). Experienced and trained MMO in sensitive areas | Continuous throughout daylight hours | 20–45 min | 1500 m for SoC 200 m for other marine mammals | 30 min | 30 min delay or until animal seen outside EZ | Yes for SoC within 1000 m EZ (1500 m for calves) 30 min delay or until SoC seen outside EZ, then soft start | Small gun kept firing during night time line changes | Continued use of small guns during all line changes required | Recommended for poor visibility | Plan surveys to avoid sensitive areas/times Extra measures in sensitive areas |
| Sakhalin[70] | All marine mammals | 2–3 trained and dedicated MMOs | Two on watch continuously throughout daylight hours | 20 min | 250 m pinnipeds 1000 m cetaceans (6–7 km for gray whales in feeding areas) | Not reported | Yes—suspension of airgun activity until animals depart EZ. No details | Yes—suspension of airgun activity until animals depart EZ. Details not reported | Not allowed to *start* the airguns at night / low visibility. Details not reported. | Not reported | Not reported | Seismic prohibited within two gray whale feeding area 'protection zones' |
| Guidance for best practice | All marine mammals | 2–3 trained, experienced and dedicated MMOs | At least one (preferably two) on watch continuously 24 hr | Duration proportional to total airgun volume | 160-dB radius (defined by modelling) Survey dependent | 30 min, or 60 min in waters deeper than 200 m | Yes—30 min delay after last sighting / departure of animals from EZ | Yes for all species 30 min delay after animal seen outside EZ (or after last sighting), then full soft start | Permitted with visual watches (using night vision aids) and PAM. | Discouraged. Shut-down completely between lines | Required, especially in deep water areas. Implement mitigation measures based on acoustic detections | Required for breeding, feeding, migratory or other key habitats |

**61** Presented data are based on the best information available.

[62] JNCC 1998, 2004 *supra* note 6, 13.

[63] HESS, *supra* note 12.

[64] Environment Australia, *supra* note 7.

[65] MMS, *supra* note 17; MMS. *Implementation of Seismic Survey Mitigation Measures and Protected Species Observer Program*. United States Department of the Interior, Minerals Management Service (2003).

[66] IBAMA, *supra* note 22.

[67] DFO, *supra* note 27.

[68] DOC, *supra* note 16.

[69] Species of Concern refers to all whale species, pilot *Globicephala* sp. and killer whales *Orcinus orca*, Hector's *Cephalorhynchus hectori,* and Maui's dolphins *C. h. maui*.

[70] SEIC, *supra* note 11.