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ScienceDirect
Marine Policy 32 (2008) 255–262
MARINE POLICY
www.elsevier.com/locate/marpol

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

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Received 15 February 2007; accepted 22 May 2007

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.

Keywords: Underwater noise; Marine mammal; Mitigation; Seismic survey; Marine mammal observer

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

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0308-597X/$ - see front matter
doi:10.1016/j.marpol.2007.05.005

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

[a]These guidelines were implemented on a case by case basis for specific projects. California is no longer an important area for geophysical exploration activity.
[b]Under review.
[c]Shut-down procedures are for whale species only.
[d]Dolphins and porpoises excluded.
[e]Small cetaceans excluded.
[f]Central measures are for 'species of concern' only.
[g]Distance of safety radius calculated using transmission loss modelling on a case by case basis.
[h]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'.
[i]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.
[j]Distance for cetaceans calculated by transmission loss modelling and verified in the field, 190 dB safety zone for pinnipeds.
[k]The 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.
[l]If species encountered is listed on schedule 1, 2 or 3 of the Species at Risk Act.
[m]Reduce to minimum firing.
[n]Required in order to initiate soft-start during hours of darkness of times of poor visibility.
[o]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.
[p]May 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 inducement of behavioural responses, and between 180 (for cetaceans) and 190 dB rms (for pinnipeds) for the likely inducement 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 in^3 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 Ziphiidae [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.

Acknowledgements

The authors would like to thank the following people for contributing information; Mark Attree and Traci Demecs (Hess Corporation), Robin Koemans (Repsol YPF), Caroline Weir (Ketos Ecology), Helen McConnell and Daniel Brown (Department of Conservation, New Zealand), Robyn McCulloch (Environment Australia), Marilyn Joyce (Department of Fisheries and Oceans, Canada).

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