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Review of Mitigation Measures for Cetacean Species at Risk During Seismic Survey Operations

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Mitigation measures are required for seismic survey operations occurring in Canadian waters to reduce potential negative effects on marine mammals. Since 2008, the Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment (SOCP) has been used to guide the minimum standard mitigation measures recommended for seismic operations in Canadian waters. The objectives of this paper are to determine if the mitigation measures outlined in the SOCP are likely to avoid *Species at Risk Act* (SARA)-prohibited impacts on listed cetaceans, to identify potential gaps or issues, and to provide additional or modified mitigation measures that should be considered to further reduce potential impacts. Specific reference to endangered North Atlantic Right Whales (*Eubalaena glacialis*), Atlantic Blue Whales (*Balaenoptera musculus*) and Scotian Shelf Northern Bottlenose Whales (*Hyperoodon ampullatus*) are provided as case studies.

Examen des mesures d'atténuation pour les espèces de cétacés en péril lors d'activités de levés sismiques

RÉSUMÉ

Des mesures d'atténuation sont requises pour les activités de levés sismiques dans les eaux canadiennes afin de réduire les effets nocifs potentiels sur les mammifères marins. Depuis 2008, l'Énoncé des pratiques canadiennes d'atténuation des ondes sismiques en milieu marin [ci-après l'Énoncé de pratiques canadiennes] sert à orienter les normes minimales d'atténuation recommandées pour les activités sismiques dans les eaux canadiennes. Voici les objectifs du présent document : déterminer si les mesures d'atténuation décrites dans l'Énoncé de pratiques canadiennes permettront d'éviter les effets nocifs interdits par la *Loi sur les espèces en péril* (LEP) concernant les cétacés inscrits sur la liste de la LEP; cerner les lacunes et les problèmes potentiels; et fournir des mesures d'atténuation supplémentaires ou modifiées qui devraient être prises en compte pour réduire encore plus les effets potentiels. Des mentions précises d'espèces en péril sont données comme études de cas : baleine noire de l'Atlantique Nord (*Eubalaena glacialis*); rorqual bleu de l'Atlantique (*Balaenoptera musculus*); et baleine à bec commune (*Hyperoodon ampullatus*), population du plateau néo-écossais.

INTRODUCTION

BACKGROUND

Mitigation measures to reduce potential negative effects on marine mammals are required for seismic survey operations occurring in Canadian waters. Since 2008, the Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment (SOCP) has been used to guide the minimum standard mitigation measures recommended for seismic operations occurring in all non-ice covered marine waters in Canada (DFO 2008). However, with the updated interpretation of the *Species at Risk Act* (SARA), the generic recommendations provided in the SOCP need to be evaluated for their ability to ensure that prohibited impacts on threatened and endangered cetaceans are avoided.

Project specific Environmental Assessments (EAs), are reviewed by three regulatory boards (the Canada-Nova Scotia Offshore Petroleum Board, the Canada-Newfoundland Offshore Petroleum Board, and the National Energy Board) prior to seismic survey activities occurring in Canadian waters to determine if proposed mitigation measures are sufficient and to identify any additional measures needed. Fisheries and Oceans Canada (DFO), Environment Canada (EC), and other stakeholders provide advice within this process. Member companies of the Canadian Association of Petroleum Producers and their seismic contractors have often put into place additional mitigation measures identified during the EA process to further reduce potential negative impacts of seismic survey activities on vulnerable species and sensitive marine areas. Sections 13-15 of the SOCP outline criteria around required additional mitigation measures. Although additional mitigation measures for cetaceans have been used during past seismic surveys, little guidance exists on what measures should be considered to ensure that SARA-prohibited impacts are avoided.

SPECIES AT RISK ACT DEFINITIONS

The *Species at Risk Act* (SARA) provides legislation for the protection of Canadian species at risk. The goal of the SARA is to prevent the extinction of endangered and threatened wildlife, to promote the recovery of these species, and to manage species of special concern to prevent them from becoming endangered or threatened (SARA 2002). SARA prohibits the killing, harming, harassing, capturing or taking of endangered or threatened individuals, or the destruction of their critical habitat:

> *"Section 32.(1) No person shall kill, harm, harass, capture or take an individual of a wildlife species that is listed as an extirpated species, an endangered species or a threatened species.*
>
> *Section 58.(1) No person shall destroy any part of the critical habitat of any listed endangered species or of any listed threatened species — or of any listed extirpated species if a recovery strategy has recommended the reintroduction of the species into the wild in Canada." (SARA 2002)*

"Harm" is considered to be "*the adverse result of an activity where single or multiple events reduce the fitness (e.g., survival, reproduction, movement) of individuals*" (DFO 2014a). "Harass" is considered to be "*any act or series of acts which tend to disturb, alarm, or molest and individual or population, which by means of frequency and magnitude results in changes to normal behavior(s) that reduce an individual's ability to carry out one or more of its life processes which could jeopardize the survival or recovery of the species*" (most recent definition provided by DFO SARA Program, modified from the DFO (2010a) definition of "harass" to incorporate results of recent supreme court decisions – see Provincial Court of British Columbia

2012). There is not a formal SARA definition associated with the terms “capture” and “take”, but these are likely the least applicable to seismic survey activities.

SARA defines “critical habitat” as: “*the habitat that is necessary for the survival or recovery of a listed species and that is identified as the species’ critical habitat in the recovery strategy or in an action plan for the species*.” (SARA 2002). “Destroy” (or destruction of) critical habitat is “*determined on a case by case basis. Destruction would result if part of the critical habitat were degraded, either permanently or temporarily such that it would not serve its function when needed by the species. Destruction may result from a single or multiple activities at one point in time or from the cumulative effects of one or more activities over time*” (EC 2009). Thus, activities that prevent the function of critical habitat from being available when needed by the species would be considered to have destroyed critical habitat, even if the effect is temporary (e.g., masking caused by ensonification of the habitat). While critical habitat is defined as a geo-spatial area, the availability of prey and other resources important to the fitness of listed species can be defined as a feature of their critical habitat and impacts on such features must be managed to maintain the functions of critical habitat (DFO 2010a).

Because marine mammals utilize both the passive reception and active transmission of sounds for many important life functions, the ambient background noise levels of their habitat can enhance or reduce its suitability for these activities and changes in the acoustic environment of their critical habitat affect habitat quality and impact the fitness of listed species, thus the quality of the acoustic environment can be defined as a feature of critical habitat (EC 2009, DFO 2010a). Activities that adversely alter the acoustic environment of the critical habitat of listed cetaceans could result in destruction of critical habitat if its functions (e.g., providing foraging opportunities, supporting critical life history processes such as socializing, mating, giving birth to and rearing young) are either temporarily or permanently unavailable or compromised when needed. For example, if sounds produced during seismic surveys were to increase background noise within critical habitat known to be important foraging grounds for an at-risk species to levels at which individuals are no longer able to effectively forage (thus preventing them from accessing food within their critical habitat), then destruction of critical habitat would be considered to have occurred. It is therefore possible for sound-producing anthropogenic activities to alter the acoustic environment of the critical habitat to the extent that destruction of critical habitat occurs (DFO 2010a).

SARA has provisions that allows some activities (such as those related to scientific research) to proceed through the issuance of permits or agreements even if the activities would otherwise be prohibited under the *Act* (Sections 73 and 74). SARA also allows exceptions for otherwise prohibited activities as outlined in Section 83 (SARA 2002).

The recovery strategies for most SARA-listed cetaceans do not currently provide specific guidance on sound exposure criteria or thresholds for harm or harassment of individuals, or for destruction of critical habitat (for example, see Beauchamp et. al. 2009, DFO 2014b and 2016). Theriault and Moors-Murphy (2015) review the current state of knowledge on the potential effects/responses of sounds produced by seismic airgun arrays on marine mammals and linkages to SARA-prohibited impacts. One of their main conclusions was that due to broad SARA definitions and large knowledge gaps, thresholds well-supported by the scientific literature to avoid SARA-prohibited impacts could not be established. They recommended a number of priority research areas on which to focus future efforts.

SEISMIC SURVEYS AND CETACEANS

Sound is the primary sensory mode for marine mammals and they are highly adapted to sending and receiving acoustic signals within the aquatic environment (Richardson et al. 1995, Wartzok and Ketten 1999). Because marine mammals have sensitive acoustic sensory systems, changes in the natural ambient acoustic environment could potentially cause negative impacts on individuals and populations. It is widely recognized and accepted that underwater sounds from human activities have the potential to cause behavioral disturbance, physiological harm, and even death of marine mammals (Richardson et al. 1995).

Seismic surveys can produce a significant amount of sound underwater. These surveys measure the characteristics of reflected sound to determine the physical properties of geological structures underlying the seabed, such as oil and gas deposits. The sounds are commonly initiated using arrays of airguns. Airguns generate sound pulses by releasing high-pressure air into the water. An airgun-generated pulse is characterized by a sharp rise followed by a rapid fall in pressure (Caldwell and Dragoset 2000, OGP 2011). The acoustic spectrum is dominated by energy in the 10 to 120 Hz band, but contains significant energy up to 1000 Hz (Goold and Fish 1998), and in some cases, measurable energy to 150 kHz (Goold and Coats 2006). Seismic surveys tend to be episodic, lasting from days to months with pulses usually occurring every 10-15 seconds (Caldwell and Dragoset 2000). The frequency spectrum of seismic pulses overlaps the hearing range of many marine mammals and can be produced at sufficiently high levels to cause hearing damage. The potential impacts of seismic airgun sounds are thus of concern for listed cetaceans.

OBJECTIVES

The objectives of this paper were to determine if the mitigation measures outlined in the SOCP are likely to avoid SARA-prohibited impacts on listed cetaceans, to identify potential gaps or issues, and to provide additional or modified mitigation measures that should be considered to further reduce potential impacts. Specific reference to endangered North Atlantic Right Whale (*Eubalaena glacialis*), Atlantic Blue Whale (*Balaenoptera musculus*) and Scotian Shelf Northern Bottlenose Whale (*Hyperoodon ampullatus*) are provided as case studies. The questions addressed are as follows:

- Are the mitigation measures currently outlined in the SOCP likely to avoid the potential occurrence of SARA-prohibited impacts on listed cetaceans?
- Are there modifications to the current SOCP or additional mitigation and monitoring measures that could be implemented to further reduce the potential occurrence of SARA-prohibited impacts on listed cetaceans?
- What are the priority areas for future research that will further inform best practices for seismic survey operations?

REVIEW OF MITIGATION AND MONITORING MEASURES IN THE STATEMENT OF CANADIAN PRACTICE (SOCP)

A CONSERVATIVE APPROACH

The SOCP outlines the minimum mitigation requirements to be met during seismic surveys in non-ice covered Canadian waters. A review of factors affecting the efficacy of the mitigation measures as set out in the SOCP and guidance as to how the various mitigation measures should be applied to minimize the potential impacts of seismic sound on marine mammals is provided by DFO (2010b). DFO (2010b) recommends that the guidance provided should be revisited periodically to update as appropriate and ensure that current best practices reflect the full body of scientific and technical information available. The sections to follow examine specific mitigation measures outlined in the SOCP and consider the advice provided by DFO (2010b) as well as more recent information to determine if modified or alternative mitigation measures might be defined for listed cetaceans.

Within the SOCP, it is specified that all seismic surveys must be planned to avoid significant adverse effects on individuals of marine mammal species listed as endangered or threatened (DFO 2008; Section 4). Though not specifically stated, to meet the SARA requirements this would include avoiding the killing, harming and harassing of listed cetaceans and destruction of their critical habitat (as negative impacts on important habitat would undoubtedly impact individuals). Because of the significant knowledge gaps that exist on the effects of seismic airgun sounds on marine mammals in general, and specifically on listed cetaceans, it is difficult to determine the appropriate metrics and associated thresholds for avoiding such impacts. To date, no specific thresholds for acoustic-related mortality, harm or harassment of cetaceans or destruction of their critical habitat have been formally adopted in Canada (Theriault and Moors-Murphy 2015). Given the uncertainties around thresholds for meeting the SARA requirements, implementation of precautionary and reliable risk-reducing mitigation measures is the most effective approach for minimizing potential negative effects of seismic surveys on listed cetaceans. Thus, although quantitative thresholds to meet SARA requirements have yet to be determined, the current mitigation measures of the SOCP (including minimizing sound emissions, avoiding significant adverse effects, avoiding displacement of or diverting individuals, establishing a safety zone radius around the seismic source, visually or acoustically monitoring this safety zone, and source ramp-up and shut-down procedures), were reviewed below in a conservative manner to determine if they are likely to meet SARA requirements. Table 1 lists the generic mitigation measures of the SOCP and indicates which SARA-prohibited impacts are likely addressed by each.

It is also stated within the SOCP that “persons wishing to conduct seismic surveys in Canadian marine waters may be required to put in place additional or modified environmental impact mitigation measures, including modifications to the area of the safety zone and/or other measures as identified in the environmental assessment of the project to address species identified in an environmental assessment process for which there is concern” (DFO 2008; Section 13). Using this conservative approach, enhanced mitigation measures that could be put in place to further reduce potential negative effects on listed cetaceans were also discussed. Table 2 provides the mitigation measures from the SOCP being reviewed, indicates their likely effectiveness for avoiding SARA-prohibited impacts, and provides recommendations for additional or modified mitigation related to each measure.

When appropriate, relevant information on endangered North Atlantic Right Whales, Atlantic Blue Whales and/or Scotian Shelf Northern Bottlenose Whales is provided to demonstrate the level of effectiveness of the mitigation measures in the SOCP and additional or modified mitigation measures.

MINIMIZING SOUND ENERGY

Effectiveness

It is stated within the SOCP that seismic surveys must be planned to use the minimum amount of energy necessary for the survey, to minimize the proportion of energy that propagates horizontally, and to minimize the amount of energy at frequencies above those necessary for the survey (DFO 2008; Section 3). Minimizing the amount of energy projected into the water column may reduce the acoustic footprint of the survey and as a result, also reduce the number of animals exposed to the airgun sounds. While such mitigation is relevant for reducing potential SARA-prohibited impacts that occur both in close range of the airgun array and at greater distances from the sound source, implementation of this measure does not ensure that such impacts will be avoided (Table 1). Even the minimal airgun source levels required to effectively conduct seismic surveys are relatively loud and have the potential to cause mortality, harm, harassment and destruction of critical habitat. As this measure does not relate back to thresholds for avoiding SARA-prohibited impacts, its effectiveness is limited.

Additional Mitigation Measures for Consideration

In addition to minimizing the energy, horizontal propagation and frequencies used, seismic surveys should also be planned to minimize the area surveyed and survey duration to the extent possible (Nowacek et al. 2013; Table 2). This is standard industry best practice that further minimizes the acoustic footprint of the survey. Particular consideration should be given to avoiding critical habitat and other areas frequently used by listed cetaceans when they are expected to be present in these areas to minimize their exposure to airgun sounds (Table 2).

ADVOIDING SIGNIFICANT ADVERSE EFFECTS

Effectiveness

Section 4 of the SOCP states that all seismic surveys must be planned to avoid significant adverse effects on individuals of listed species (DFO 2008). Assuming the term "significant adverse effects" includes the killing, harming and harassment of individuals, when properly implemented this mitigation measure is one of the few in the SOCP that will not just reduce, but likely avoid SARA-prohibited impacts on individuals (Table 1). Additionally, avoiding SARA-prohibited impacts on individuals, which probably requires at least some degree of spatial and temporal avoidance of areas where listed cetaceans occur, also likely indirectly reduces potential destruction of critical habitat (Table 1).

Additional Mitigation Measures for Consideration

The term "significant adverse effect" is not defined in the SOCP (DFO 2008), and, therefore, it is not entirely clear if this mitigation measure meets SARA regulatory requirements. To make this measure more relevant for listed cetaceans, SARA terminology (e.g., "SARA-prohibited impacts") should be used. Seismic surveys should therefore be planned to avoid the killing, harming and harassment of individuals and destruction of critical habitat, or collectively, to avoid SARA-prohibited impacts (Table 2).

AVOIDING DISPLACEMENT/DIVERTING

Effectiveness

The SOCP states that for listed species, all seismic surveys must be planned to avoid displacing individuals from breeding, feeding or nursing activities, or diverting migrating individuals from known migration routes or corridors (DFO 2008; Section 5). The propagation of the airgun sound through the environment needs to be modelled and considered when implementing this mitigation measure. Implementation of this mitigation measure is likely to avoid SARA-prohibited impacts on individuals, and because it probably requires some degree of spatial and temporal avoidance of areas where listed cetaceans occur, it likely also indirectly reduces potential critical habitat destruction (Table 1).

Additional Mitigation Measures for Consideration

Spatial and temporal avoidance of areas where species of concern occur (or where they are known to most frequently occur) is the most effective way to avoid displacing or diverting individuals from important areas and activities (DFO 2010b, Nowacek et al. 2013). This preventative mitigation measure is especially important when planning surveys in areas that overlap the known distribution of listed cetaceans and can be implemented to varying degrees, some examples of which are discussed below.

Cetacean species often have widespread distribution and travel great distances on a daily basis (Bowen and Siniff 1999). In some cases, especially for 3D and 4D surveys, spatial avoidance of all areas where individuals may possibly or frequently occur is not practical, especially given that seismic surveys are site-specific with little flexibility in location (Nowacek et al. 2013). If spatial avoidance were to be implemented as a mitigation measure, avoiding specific areas where important life history functions are known to take place and where the probability of encountering individuals is high may be a more practical approach. Critical habitat are areas identified to be important to the survival and recovery of listed cetaceans (SARA 2002) as they provide the habitat necessary to carry out important life functions such as socializing, mating, giving birth to and rearing young and/or feeding (DFO 2014a). These areas are typically also areas with high species occurrence (e.g., DFO 2014b, DFO 2016). Avoiding identified critical habitat of listed cetaceans when they are expected to be present in these areas is a logical approach for reducing/avoiding SARA-prohibited impacts (Table 2).

Avoiding areas where species most frequently occur does not eliminate the possibility of encountering them elsewhere, especially when operating in areas adjacent to known important habitat. Compton et al. (2008) recommend applying a buffer zone to the perimeter of areas being avoided equivalent to the width of the safety zone employed to further reduce potential impacts. A buffer zone the width of the safety zone around identified critical habitat would provide an additional measure of precaution for reducing near-field impacts on listed cetaceans (though this would not completely address impacts that likely occur at greater ranges from the sound source such as harassment and destruction of critical habitat).

Because low frequency airgun sounds propagate so efficiently underwater, it is possible that SARA-prohibited impacts such as harassment and destruction of critical habitat may occur at long range. A larger buffer zone around areas of occurrence (e.g., a buffer zone around critical habitat equivalent to a distance based on the sound-level threshold for harassment or destruction of critical habitat) would reduce these potential impacts on listed cetaceans that occur at long range. However, such thresholds have yet to be established and require further research (Theriault and Moors-Murphy 2015).

Surveys can also be designed to orient shot lines so that the least amount of energy possible is projected towards areas of occurrence (Lawson and McQuinn 2004). Though the sounds produced by airguns are typically projected towards the ocean bottom, significant amounts of sound energy also propagate horizontally through the water column, particularly from the broadsides of the array (OGP 2011). Often the pattern or starting point in which a given block is surveyed can be altered so that energy radiated outside the survey area in a given direction is minimized (Lawson and McQuinn 2004).

If distribution of a species varies seasonally, coordinating seismic surveys to occur when the fewest number of individuals are present in the survey area (i.e., temporal avoidance) is another mitigation approach that can be employed (Nowacek et al. 2013). This requires information on the seasonal variation in species distribution.

If important habitats cannot be completely avoided, temporal restrictions on the use of seismic airguns in these areas (e.g., limiting the number of hours/day or days/month, specifying a maximum percentage of time over a certain period that seismic airgun operations may occur within an area) could be considered to reduce potential SARA-prohibited impacts. For example, ensonifying important feeding grounds or migration routes for weeks or months at a time could have serious long-term impacts on individuals and populations, while operating in the same areas for a few consecutive hours or days is not as likely to have significant long-term effects. The European Union has developed a noise indicator that incorporates temporal elements to assess the acoustic suitability of the environment (the proportion of days and their distribution within the calendar year that anthropogenic sounds exceed levels likely to impact marine animals; Van der Graaf et al. 2012). Species biology and life history are important factors to consider when determining the appropriate temporal restrictions to effectively implement this approach. Alternatively, temporal restrictions in high-use areas aimed at increasing the detection of any animals present could also be applied. For example, in the Canadian Arctic, when operating in important bowhead whale aggregation areas seismic surveys were restricted to only operating airguns during periods when the full safety zone was visible (i.e., only during daylight hours with good visibility; Harwood et. al. 2009).

Planning seismic surveys to avoid areas used by listed cetaceans during the times that they are there requires detailed knowledge of when and where the species occurs. Furthermore, knowledge on distribution is required to determine the importance of avoidance measures for a species as such measures may be more important for resident species in comparison to transient or migratory species. While information on broad-scale distribution patterns is typically available, fine-scale distribution patterns and knowledge of how these patterns vary temporally is often limited. When large knowledge gaps exist (which is currently the case for most cetacean species occurring in the Scotian Shelf region; Hurley 2013), further studies of abundance and distribution are required to inform and enhance spatial and temporal avoidance measures. If a seismic survey overlaps the distributional range of a listed cetacean species but fine-scale distribution within the area of operation is not known, then timely pre-survey studies at the appropriate temporal and spatial scales should be conducted to assess species occurrence, provided that their distribution is not expected to drastically change over short time scales (Table 2). For example, density surveys conducted a short time before seismic operations (such as within a week before the survey) can be used to determine what species are present in the area of operation and where listed cetaceans are most likely to be encountered before seismic operations begin (e.g., Harwood et al. 2009).

Avoidance of spatial and temporal overlap can only be successful if there is flexibility in the exact location where and time when seismic surveys can occur or when listed cetaceans are not resident year-round in the proposed area of interest. Spatial and temporal avoidance measures are not likely to be effective when the distribution of year-round resident species overlap areas of interest for oil and gas exploration. In that case, alternative source-based mitigation (see “Other Considerations”) may be the most effective approach for reducing potential SARA-prohibited impacts on listed cetaceans, and such measures should be used whenever feasible.

Species Case Studies

North Atlantic Right Whales have a widespread distribution and undergo extensive annual migrations, appearing in waters off eastern Canada primarily during summer and fall to feed (DFO 2014b). Most sightings have occurred off Nova Scotia and in waters further south, with occasional sightings reported in the Gulf of St. Lawrence or off Newfoundland and Labrador. Their known distribution spans from near-shore to offshore, though they appear to prefer waters between 100-150 m deep over steep slopes where dense concentrations of calanoid copepods occur (DFO 2014b). The Grand Manan Basin in the Bay of Fundy and Roseway Basin on the western Scotian Shelf have been identified as critical habitat for Right Whales and individuals have been observed socializing, suckling and feeding in these areas. These two areas encompass 90% of reported Right Whale sightings in the Bay of Fundy and the majority of reported sightings on the Scotian Shelf. Sightings have also been documented in other areas of the Scotian Shelf, in the Gulf of St. Lawrence and in waters off Newfoundland and Labrador (DFO 2014b). To avoid areas and times when there is a reasonable probability of encountering Right Whales off eastern Canada, operators would have to avoid conducting seismic surveys in Scotian Shelf waters, particularly in waters off southwestern Nova Scotia, from June-October. To avoid operating in areas and times when there is the highest probability of encountering Right Whales, operators would have to avoid conducting seismic surveys in and around the Grand Manan and Roseway Basin over this same period.

Atlantic Blue Whales also have a widespread distribution and are thought to undergo seasonal migrations, though their winter distribution is unknown (Beauchamp et al. 2009). The majority of Blue Whale sightings have occurred in the Gulf of St. Lawrence from April to November, in waters off Nova Scotia primarily during summer months (including in canyons of the eastern Scotian Shelf; Whitehead 2013), and along the southwest and eastern coast of Newfoundland in late winter and early spring. Blue Whales inhabit both coastal and pelagic waters, often aggregating in areas along the continental slope where concentrations of euphausiids occur. No critical habitat for the population has been identified in Canadian waters (Beauchamp et al. 2009). To avoid areas and times when there exists a reasonable probability of encountering Blue Whales off eastern Canada, operators would have to avoid conducting seismic surveys on the Scotian Slope and in the Gulf of St. Lawrence from April-November, and in waters off Newfoundland and Labrador from late winter to early spring. To avoid operating in areas and times when there is the highest probability of encountering Blue Whales, operators would likely have to avoid conducting seismic surveys along the eastern Scotian Slope and in the Gulf of St. Lawrence from April-November.

Northern Bottlenose Whales are only found in the North Atlantic Ocean, occurring from the Scotian Shelf to Spitsbergen (DFO 2016). The Scotian Shelf population is found at the extreme southern limit of the species range and is genetically distinct from populations further north (Dalebout et al. 2006). The boundaries of the Scotian Shelf population are considered to extend from the Northeast Channel southwest of Nova Scotia to the Flemish Cap (COSEWIC 2011). Sightings of individuals have occurred in deep waters along the continental slopes throughout this range with the majority of sightings occurring in the Gully, Shortland and Haldimand canyons of the eastern Scotian Slope (COSEWIC 2011, Harris et al. 2013). Waters greater than 500 m deep within these three canyons have been identified as critical habitat for the population. Northern Bottlenose Whales are considered year-round residents of these areas, which provide important foraging, breeding and calving grounds for the population (DFO 2016). It is also known that individuals regularly travel between these canyons and acoustic studies indicate that Northern Bottlenose Whales feed in slope waters adjacent to the canyons throughout the year (Moors 2012). To avoid areas and times when there is a reasonable probability of encountering Northern Bottlenose Whales off eastern Canada, operators would have to avoid conducting seismic surveys in slope waters greater than 500 m deep throughout the year. To avoid operating in areas and times when there is the highest probability of encountering Northern Bottlenose Whales, operators would have to avoid conducting seismic surveys in and around the eastern Scotian Shelf canyons throughout the year.

The buffer zone around identified critical habitat or areas of known occurrence that should be applied to avoid far-field impacts on right, blue or Northern Bottlenose Whales is not currently known and requires further studies of the far-field impacts of seismic surveys on these species.

SAFTEY ZONE RADIUS

Effectiveness

The SOCP requires that a safety zone around the center of the airgun array(s)[1] of at least 500 m must be established (DFO 2008; Section 6). A specific objective or rationale for establishing a safety zone is not provided; however, such safety zones (also called mitigation or exclusion zones or safety radii) are generally established to prevent direct physical harm (i.e., injury or death) or significant adverse behavioral responses in close proximity to the sound source (DFO 2010b). The establishment of a safety zone is aimed at reducing impacts most likely to occur in close range of the airgun array and is thus most relevant for reducing mortality and, to some extent, harm to listed cetaceans. However, because the 500 m radius is not related to thresholds for preventing these SARA-prohibited impacts, mortality and harm might not be altogether avoided (Table 1). This mitigation measure also does not fully address harassment of individuals, which likely occurs out to distances beyond 500 m from the airgun array (Theriault and Moors-Murphy 2015), nor does it address impacts on habitat (Table 1).

Additional Mitigation Measures for Consideration

Fixed-distance safety zones, such as the 500 m safety zone radius specified in the SOCP, are not directly related to thresholds for physiological impacts, significant behavioral responses or SARA-prohibited impacts. As discussed by DFO (2010b) and Lawson (2009), the actual radius to which any given effect occurs will vary depending on the characteristics of the airgun array and local environmental conditions that impact sound propagation. Ideally, it is more appropriate to use sound propagation models based on a relevant acoustic threshold and exposure criteria for avoiding SARA-prohibited impacts to establish the safety zone radius (DFO 2010b; Table 2). While thresholds for avoiding SARA-prohibited impacts do not currently exist (Theriault and Moors-Murphy 2015), other thresholds have been used to establish more conservative safety zones in Canadian waters (e.g., LGL 2013, 2014).

Received sound-level thresholds are a standard industry practice used to predict zones of potential impact and a variety of biologically relevant metrics have been used to establish safety zones. For example, for impulsive sound the US National Marine Fisheries Service (NMFS) has previously used a received level threshold of 180 dB re 1µPa rms received Sound Pressure Level (SPL) over an interval enclosing 90% of the pulse energy to predict marine mammal injury (Level A harassment), and a 160 dB re 1µPa rms SPL threshold to predict marine mammal behavioral effects (Level B harassment) (NOAA 2000). Southall et al. (2007) provide more recent scientific recommendations for noise exposure criteria for marine mammals which incorporate frequency-weighted marine mammal hearing curves (m-weighting) to correct sound-level measurements for the frequency-dependent hearing functions that vary between different marine mammal functional hearing groups. They then propose injury criteria (peak pressure and m-weighted SEL) for several different marine mammal functional hearing groups for single-pulsed sounds, multiple-pulsed sounds, and non-pulsed sounds (Southall et al. 2007). NMFS has recently extended the Southall et al. (2007) recommendations to propose thresholds for Temporary and Permanent Hearing Threshold Shifts (TTS and PTS, respective; peak pressure and cumulative SEL) for the different marine mammal functional hearing groups for impulsive and non-impulsive sounds (NOAA 2013, 2015). Establishing a safety zone based on a PTS

[1] The SOCP uses the term air source array(s) as opposed to the more common term airgun array(s) used here.

threshold would reduce the likelihood of physiological effects resulting in mortality and harm (though it is not clear if TTS also constitutes harm; Theriault and Moors-Murphy 2015). Theriault and Moors-Murphy (2015) provide a more detailed discussion of these various thresholds and their relevance for avoiding SARA-prohibited impacts.

In addition to the uncertainties in received sound-level thresholds for predicting SARA-prohibited impacts, the modeling exercise used to predict the radius of a safety zone presents another source of uncertainty. There are many potential approaches to modeling and predicting received sound levels, all associated with numerous assumptions that can impact model accuracy to varying degrees. The modeling recommendations discussed by DFO (2010b) and Lawson (2009), such as incorporating magnitude and frequency characteristics of the seismic source output, geometry of the airgun array, distribution of biological receivers in space and time, and geophysical and oceanographical data; considering the effects of the variation in these variables over time; and using information on the species and conditions present in the area of operation; should be incorporated into any sound propagation model used (Table 2). Because of the highly-variable sound transmission conditions, there are often discrepancies between modeled sound propagation and measured received levels (Lawson 2009, Pecknold and Osler 2011). In-field verification is essential for assessing model accuracy and standardized verification methods should be established and implemented, particularly when listed cetaceans are present within the area of operations (DFO 2010b, McQuinn and Carrier 2005; Table 2).

The ability to effectively monitor a specified safety zone also needs to be considered. For example, as an impact criteria threshold decreases, the size of the safety zone increases and it could become difficult to monitor the entire safety zone using the methods traditionally employed during seismic surveys (Theriault and Moors-Murphy 2015). Visual detection rates of marine mammals decrease with increasing distance from the observation platform (Barlow 2015) and, therefore, the ability to monitor the full range of the safety zone becomes problematic as size of the safety zone increases. Monitoring for cetaceans from an accompanying guard vessel or through concurrent aerial surveys may increase the ability to monitor large safety zones (Wright 2014). In the Candian Arctic, TTS-based safety zones of manageable sizes ranging from 500-2500 m have been established and monitored (Harwood et. al. 2009).

Species Case Studies

Due to significant knowledge gaps, received sound level thresholds for avoiding SARA-prohibited impacts on listed cetacean species in general have yet to be established (Theriault and Moors-Murphy 2015) and thresholds for avoiding SARA-prohibited impacts for right, blue or Northern Bottlenose Whales specifically are not known.

The quantitative impact thresholds for TTS and PTS calculated based on latest scientific reviews and guidance (i.e., Southall et al. 2007, NOAA 2013 and 2015) vary between different marine mammal functional hearing groups as frequency-weighted hearing curves are applied. For example, the thresholds suggested for low frequency cetaceans (such as Blue and Right whales) vary from those for mid-frequency cetaceans (such as Northern Bottlenose Whales). The safety zone radius calculated for blue and Right Whales will, therefore, differ (and in the case of seismic airgun sounds be larger) from that calculated for Northern Bottlenose Whales.

In areas where multiple species from different functional hearing groups are expected to occur such as on the Scotian Shelf, it is logistically easier to use the lowest of the thresholds calculated for the marine mammal functional hearing groups expected to occur in the survey area to determine the safety zone radius (Theriault and Moors 2015), thereby establishing one safety zone radius applicable to all listed cetaceans in the area.

MARINE MAMMAL OBSERVERS

Effectiveness

The SOCP requires that during seismic survey operations, a qualified Marine Mammal Observer (MMO) must continually visually observe the safety zone for the presence of marine mammals for at least 30 minutes prior to starting the airgun array and during all other times that the airgun array is active to detect the presence of marine mammals within the safety zone (DFO 2008; Sections 6 and 10). Mitigation measures related to the establishment and monitoring of a safety zone are aimed at reducing close-range impacts and are most relevant for reducing mortality and to some extent harm to listed cetaceans but do not altogether avoid these SARA-prohibited impacts (Table 1). Unless the safety zone is established based on thresholds to avoid harassment of individuals, mitigation related to monitoring the safety zone (including use of MMOs, PAM and the 30 minutes pre ramp-up watch period) will not address harassment, nor will they address impacts on critical habitat (Table 1). Additionally, monitoring of the safety zone for the pre ramp-up observation period requires some clarification as typically MMOs monitor the area around a moving vessel for 30 minutes and not the actual area where ramp-up will begin. To effectively detect marine mammals in the area where ramp-up is to commence, the area would need to be monitored from a stationary platform or other alternative means of monitoring the ramp-up area (e.g., aerial platforms).

Additional Mitigation Measures for Consideration

As the success of any mitigation measures related to visual observations are dependent on the ability of an observer to detect marine mammals present within the safety zone, measures designed to maximize an MMO’s ability to detect listed cetaceans should be implemented (Table 2). As outlined by DFO (2010b), the ability of an MMO to effectively detect cetaceans is influenced by human, environmental and biological factors. All of these factors need to be considered to ensure that the probability of detecting listed species within the safety zone is acceptable.

Human factors impacting the visual detection of cetaceans include the training and experience of MMOs; MMO protocols such as the number of MMOs on watch, watch rotation, watch period, data collection, recording and reporting methods; and the platform and equipment used including observer location, area visible from the observer location, height of observer, and use of binoculars. MMO experience has been found to be a highly significant factor in explaining differences in sightings rates between individual observers (Barlow et al. 2006). Though the SOCP specifies that observations must be made by a qualified MMO, the term “qualified” is not defined. MMO training and qualifications should be standardized; however, such standardization has yet to be put in place within Canada. Baker et al. (2013) provides recommendations for the Protected Species Observer and Data Management Program for marine geological and geophysical surveys in the United States of America (US), including recommendations for a standardized training program and MMO qualifications. The Joint Nature Conservation Committee (JNCC) has developed similar guidelines for seismic operations occurring in the United Kingdom (UK) (JNCC 2010). Development of a similar standardized MMO training and qualification program (or a standardized approach to assessing the training and qualification of MMOs) in Canada would enhance the effectiveness of MMOs and therefore the probability of detecting listed cetacean species within the safety zone. Additionally, such a program would ensure that high-quality data is collected to support further research on the seismic survey impacts on cetaceans and the efficacy of the mitigation measures used (Lawson and McQuinn 2004).

The MMO protocols employed during seismic operations often vary between surveys and there is currently no standardized approach in Canada. Development of standardized MMO protocols in Canada would provide guidance on how MMOs should perform their duties to maximize the effectiveness of any visual detection methods employed. For example, it is known that observer fatigue negatively impacts detection rates; consequently, a maximum shift length of four hours is recommended (Lawson and McQuinn 2004, Weir and Dolman 2007). DFO (2010b) also recommends setting a maximum total duty time per day in addition to a maximum shift length. It is very difficult for a single observer to cover 360° around a vessel reliably (Harwood and Joynt 2009), therefore, maximizing the number of observers on watch simultaneously is recommended (DFO 2010b). Higher vantage points increase the range to which MMOs can detect animals and it has been recommended that the highest safe lookout with 360° visibility should be made available to MMOs (DFO 2010b). Use of high-power binoculars increase the range to which MMOs can detect marine mammals (Barlow et al. 2001) and high-quality optical equipment (e.g., reticule binoculars with at least 25x magnification) should be used when visually monitoring the safety zone (DFO 2004, 2010b; JNCC 2010). Estimated distance to a sighting may vary between observers and use of reticule binoculars or range finders could help MMOs make more consistent and accurate distance measurements. Having a guard vessel(s) survey the area ahead of the seismic vessel during shooting would aid in early detection of marine mammals (Lawson and McQuinn 2004), and could also help address the issue of monitoring the actual area where ramp-up will begin rather than the area around a moving vessel.

Environmental factors that impact visual detection of cetaceans include the time of day, sea state, swell height, weather and sun glare. Harwood and Joynt (2009) present examples from the Canadian Arctic demonstrating that seismic operations often proceed when MMO mitigation measures are compromised due to environmental conditions. Taking into account the role of environmental conditions on the ability to visually detect marine mammals within the safety zone, Nichol (2009) suggests that the range of environmental conditions during which seismic surveys can occur need to be specified, particularly in areas where listed cetaceans are likely to occur. Past studies have shown that increasing sea state clearly impacts the ability to detect cetaceans, with sighting rates decreasing more than 10-fold in some cases when sea state changes from a Beaufort 0-1 to a Beaufort 5 (Barlow et al. 2001, Barlow 2015). The percentage of cloud cover also impacts detection, with sighting rates increasing during overcast conditions in comparison to clear conditions (Nichol 2009). This is related to glare (the reflection of sunlight off the water), which negatively affects visibility and detection of cetaceans (Barlow et al. 2001). An additional point to consider is that environmental conditions often affect the distance to which cetaceans can be detected (Barlow et al. 2001, Nichol 2009); therefore, the size of the safety zone needs to be taken into account when determining environmental conditions under which MMOs can effectively monitor the safety zone. Parsons et al. (2009) suggest that for surveys relying on visual observers as a mitigation measure, seismic operations should not be conducted in sea states greater than a Beaufort 5, during fog or heavy precipitation, or at night. Such restrictions would offer a precautionary approach for minimizing potential harm to individuals when operating in areas used by listed cetaceans.

Biological factors that impact detection are species specific and include the size of animals, blow size, visual cues, surface behavior, swimming behaviour, dive duration and group size. Typically, large whales are much easier to visually detect than smaller cetaceans because of their large blows (which are more conspicuous than other cues used for detecting marine mammals such as a flash of body or splashes) and larger body size presenting a more discernible visual cue (Barlow et al. 2001, Nichol 2009). Group size is positively correlated to detection rate and larger groups of individuals are more likely to be seen than smaller groups (Barlow et al. 2001). Behaviour while at the surface also impacts detectability as animals that undergo a wider range of behaviours at the surface may present multiple visual cues making them easier to detect (Nichol 2009). In addition to behaviour at the surface, dive duration also needs to be considered. Deep-diving species spend less time at the surface, narrowing the window for detection (Barlow and Gisiner 2006). When operating in areas where deep-diving species are likely to occur, the 30 minute pre-survey detection window would have to be increased to account for the longer times spent underwater by deep-diving species. JNCC (2010) suggests that a 60 minute pre-survey detection window in areas where deep-diving species occur (Table 2). Again, ideally this would need to be implemented from a stationary platform rather than from a moving vessel.

The use of other detection methods/technologies in combination with traditional MMO monitoring methods should be considered to enhance the detection of listed cetaceans in the safety zone. Other detection methods/technologies include Passive Acoustic Monitoring (PAM; discussed in the next section), night-vision binoculars, flood-lights, image intensifiers, radar, LiDAR, infrared or thermal detectors, and sonar (Watkins et al. 1993, Lawson and McQuinn 2004, Simrad 2007, Bernasconi et al. 2009, Pyc et al. 2015). Limitations of these alternative technologies include issues with species identification and false detections (e.g., Simrad 2007). In the case of active sonar detection, which operate at higher frequencies (but at lower levels) than seismic airguns, there is also a concern that the increased amount of sound released into the marine environment could negatively impact cetaceans (Barlow and Gisiner 2006). However, as the systems would operate at frequencies where the acoustic absorption is much higher (Mellen et al. 1987) than for an airgun array, the associated impact zone would be much shorter than for the airgun array. Further studies on the effectiveness of alternative detection methods and the behavioral response of cetaceans to these systems need to be conducted. There is general agreement that the ability to detect marine mammals at night or in conditions of poor visibility is greatly reduced regardless of the technologies used, as most of these technologies have been shown to have only limited effectiveness (Lawson and McQuinn 2004, Nowacek et al. 2013). However, the use of multiple detection methods still likely increases the ability to detect cetaceans as compared to any one measure on its own, thus a combination of detection methods/technologies to maximize the ability to detect listed cetaceans should be considered (Table 2). Additionally, to ensure that the safety zone is effectively monitored, combined monitoring capabilities should be designed to maximize the probability of detecting listed cetaceans to achieve some target probability of detection (e.g., detection function estimate) within the safety zone consistent with SARA requirements (Table 2). Such a “target probability of detection” has yet to be established and further work is needed to provide guidance on the probability of detection that can be achieved for each species.

Species Case Studies

North Atlantic Right Whales are large animals that produce large blows. Because of the unique v-shaped pattern of its blow, it is also possible to identify this species by the blow alone (DFO 2014b) thus the blow itself provides a good sighting cue for this species. When present in northern feeding areas in the Bay of Fundy and on the Scotian Shelf, Right Whales primarily spend their time foraging, mainly at depth though sometimes at the surface (Baumgartner and Mate 2003). The mean duration of foraging dives is 12 minutes (ranging between 8-16 minutes), while the mean depth is 121 m (ranging between 79-174 m). The average time that individuals spend at the surface between foraging bouts ranges from 2-7 minutes, with females with calves spending longer times at the surface than animals without calves. Time spent at the surface becomes more variable during other activities such as travelling, socializing and searching (Baumgartner and Mate 2003). When socializing at the surface, Right Whales are often observed in large surface active groups, characterized as groups of up to 35 whales interacting at the surface with frequent physical contact (Kraus and Hatch 2001). These large groups of whales are easy to detect visually. If using a stationary platform to observe the area where ramp-up will commence, the 30-minute pre ramp-up observation period should be adequate for Right Whales. When conducting seismic surveys in Right Whale habitat, limiting seismic operations to good sea-state conditions and daylight hours would maximize probability of detection within the safety zone.

Blue Whales are also large animals that produce large, highly conspicuous blows. Blue Whales have been sighted from seismic vessels during past seismic survey activities occurring on the Scotian Shelf (e.g., Moulton and Miller 2005, RPS 2014). Similar to Right Whales, Blue Whales spend much of their time foraging when in waters on the Scotian Shelf or in the Gulf of St. Lawrence (Beauchamp et al. 2009). Blue Whales often dive for approximately 5-15 minutes, surfacing 50 seconds to 5 minutes between dives to breathe 6-20 times (COSEWIC 2002). They are typically observed alone or in pairs, though groups as large as 40 individuals have been observed (Sears et al. 1990, Sears and Calambokidis 2002, Beauchamp et al. 2009). The 30 minute pre-survey observation period should be adequate for Blue Whales when using a stationary platform. When conducting seismic surveys in Blue Whale habitat, limiting seismic operations to good sea-state conditions and daylight hours would maximize probability of detection.

The ability to detect Northern Bottlenose Whales within the safety zone during seismic survey activities is limited. Beaked whales, such as Northern Bottlenose Whales, are notoriously the most difficult group of cetaceans to detect and visually identify (Barlow and Gisiner 2006). The deep-diving behavior of these animals' results in them spending most of their time at depth and very little time at the surface (Barlow and Gisiner 2006). Northern Bottlenose Whales regularly dive to depths exceeding 800 m every 80 minutes with maximum depths of 1450 m and maximum dive durations of 70 minutes reported (Hooker and Baird 1999). Tagged individuals were found to spend 62-70% of their time at depths exceeding 40 m (Hooker and Baird 1999) - the proportion of time spent at the surface is much less than this. Additionally, Northern Bottlenose Whales (and beaked whales in general) have relatively small blows and a low profile at the surface further limiting the ability to visually detect them. Barlow and Gisiner (2006) found that even in the best of circumstances, using experienced observers and during good weather conditions, the probability of visually detecting beaked whales when they are present and near the vessel was in the range of 20-50% at best. The probability of detection decreases substantially with inexperienced observers, and as sea state increases and visibility decreases (e.g., rain, fog, reduced light levels); under these conditions the probability of sighting a beaked whale is estimated to decrease to as little as 1-2%. For this reason, most estimates of beaked whale density performed from vessel-based surveys only include data collected in excellent to good conditions, Beaufort 0-4 (Barlow and Gisiner 2006). The sighting rates of inexperienced observers were approximately half those of experienced observers (Barlow and Gisiner 2006). During past seismic surveys on the Scotian Shelf, Northern Bottlenose Whales have been detected from seismic vessels (Moulton and Miller 2005). When conducting seismic surveys in Northern Bottlenose Whale habitat, an extended pre-survey observation period (e.g., 60 minutes) from a stationary platform, limiting seismic operations to good sea-state conditions, and employing MMOs with experience in beaked whale detection would maximize the probability of detecting Bottlenose Whales within the safety zone. It should be noted, however, that even with these measures in place a significant proportion of the individuals that occur within the safety zone are likely to be visually missed.

PASSIVE ACOUSTIC MONITORING

Effectiveness

Under low visibility conditions (when the full extent of the safety zone cannot be visually observed), the SOCP requires that alternative cetacean detection technology such as PAM must be used for at least 30 minutes prior to starting the airgun source array and during all other times that the airgun source array is active to detect the presence of marine mammals within the safety zone (DFO 2008; Sections 11 and 12). The SOCP does not specify the technical or operational performance for PAM. Hence, the effectiveness may be highly variable. As discussed above, mitigation measures related to the establishment and monitoring of a safety zone including PAM and the 30 minute pre ramp-up observation period are aimed at reducing impacts in close range and are thus most relevant for reducing mortality and to some extent harm to listed cetaceans but likely do not address harassment or impacts on critical habitat (Table 1). As described above, to be most effective, PAM should be applied to the safety zone area where ramp-up will begin from a stationary platform or some other equivalent means (e.g., aerial platforms) for the duration of the pre ramp-up observation period, rather than the area around a moving vessel.

Additional Mitigation Measures for Consideration

The effectiveness of PAM is dependent on the ability to acoustically detect marine mammals present within the safety zone, thus measures designed to maximize the acoustic detection of listed cetaceans should be implemented (Table 2). The ability to acoustically detect marine mammals present within the safety zone is influenced by a number of variables including human, biological and environmental factors.

Human factors include the training and experience of PAM operators; the PAM protocols used such as data analysis, collection, recording and reporting methods; and the platform and equipment used including the recording equipment specifications, placement of the recording equipment relative to the airgun array and ship engines, and the analysis software used (Mellinger et al. 2007, Simard 2009, DFO 2010b). Currently, there are no existing standardized PAM operator training or qualification programs (or a standardized approach to assessing the training and qualification of PAM operators) in Canada, nor is there an existing standardized PAM protocol (DFO 2010b). The International Association of Geophysical Contractors (IAGC) recently developed guidance on the use of PAM during oil and gas operations including minimum performance criteria and technical and operational requirements (IAGC 2014). An Acoustical Association of America Working Group (ANSI S3/SC1WG3) is developing new standards for "recording and reporting underwater acoustic data, including minimum capabilities of passive acoustic monitoring hardware and recommendations for monitoring activity." (Thode 2015). Such standardized programs and protocols would enhance the effectiveness of PAM during seismic surveys, particularly if operations are being conducted during periods of low visibility and at night. PAM protocols should outline required recording equipment specifications (e.g., receivers with a capability of recording a wide range of frequencies so that all species of interest can be detected, directional receivers to aid in locating an animal), recording equipment setup (e.g., reducing anthropogenic noise by towing the array from a guard vessel, use of multiple receivers to increase localization ability) and signal processing requirements (e.g., ability to effectively monitor both low and high-frequency data, detection algorithms, localization software) (DFO 2010b, IAGC 2014). While acoustic localization of vocalizing animals is possible with the appropriate recording equipment and analysis software, determining the distance or location of an animal relative to the safety zone may not be feasible using the PAM approach implemented during some seismic operations (DFO 2010b). Localization generally requires tracking the same sound source over time, which may not be feasible during seismic surveys when airguns are firing (Simard 2009). While PAM technology continues to advance, few systems are available which can accurately detect, classify and locate marine mammal signals in real-time. Signal processing and display systems such as PAMGUARD (Gillespie et al. 2008) provide a basic capability to detect, classify, and localize marine mammals when combined with appropriate sensor systems.

Biological factors that impact acoustic detectability include vocal behavior of the species such as vocalization rate, proportion of time spent vocalizing and how vocal behaviour changes with activity, as well as species vocalization characteristics such as the source level, timing and frequency of their calls. PAM will only be effective for vocal species and effectiveness will vary depending on vocalization rate and call characteristics. For example, low frequency vocalizations can be masked by ship noise and airgun sounds that occur in the same frequency band, limiting the range to which they can be detected. These low-frequency anthropogenic noise sources may have less impact on the ability to detect high-frequency vocalizations; however, higher frequency calls attenuate faster (and are more susceptible to acoustic ducting) and therefore the range to which they can be detected is limited (Simard 2009). The effectiveness of PAM methods will also be negatively impacted if marine mammals stop vocalizing in response to airgun sounds (Lawson and McQuinn 2004). Identification of a vocalizing species can be difficult due to unknown (or the broad range of) vocalization characteristics, detection of somewhat similar unidentified sounds, and distinguishing between similar sounding species, all of which pose problems for automated call-classification algorithms as well as PAM operators (DFO 2010b). Marine mammal vocalizations cover a broad frequency band, from infrasonic sounds of a few Hz to ultrasonic sounds exceeding 100 kHz (Richardson et al. 1995) and familiarity with the vocal repertoire of species in the area of operation is important for developing an appropriate PAM protocol.

Environmental factors that may impact acoustic detection of listed cetaceans include sea state, precipitation, acoustic propagation conditions, environmental noise, and noise produced by the vessel and airgun array. Ambient background noise levels and noise produced during survey operations (e.g., vessel noise and airgun sounds) will interfere with the ability to detect marine mammal signals (Simard 2009, DFO 2010b). The modelling results of Simard (2009) suggest that the full potential of PAM technology may be difficult to implement during seismic surveys due to the loud acoustic environment that exists within the safety zone where towed arrays are often placed. Rather, PAM may be much more beneficial for monitoring larger areas in front of or around the safety zone to track cetaceans and assess their probability of entering the safety zone. This could also assist visual observers by providing early detection and tracking of individuals (Simard 2009). Additionally, monitoring the behaviour of whales in the far-field, potentially from supporting escort or guard vessels, could contribute to studies of the potential impacts of seismic airgun sounds on cetaceans at greater ranges (Simard 2009).

Species Case Studies

North Atlantic Right Whales produce vocalizations when feeding (Schevill et al. 1962, Schevill and Watkins 1962), and when socializing in surface active groups (Parks and Tyack 2005). They produce a variety of call types including screams, warbles, upcalls, downcalls, blows and gunshots. The frequency of their vocalizations varies between 20 Hz to 22 kHz, while the mean peak frequency ranges between 0.19-1.64 kHz, depending on call type (Parks and Tyack 2005). The proportion of time Right Whales spend vocalizing when in waters of the Scotian Shelf has not been assessed. Using modeling techniques, Simard (2009) suggests that using a towed array behind a large seismic vessel, low-frequency baleen whale moan calls (similar to Right Whale calls) could likely be detected up to 1.7 km away when the airguns are turned off, and likely less than 300 m away with airguns operating. As well, masking from ships' radiated noise is an issue because of frequency overlap (Richardson et al. 2005). Additionally, if the receiver does not have a high enough dynamic range, the airguns could overload the front end of the array for a short time after the airgun shot further reducing the quality of acoustic data received. There may be alternative acoustic array technologies and configurations that can be used to help address these issues; however, if the PAM configuration is that typically employed during seismic surveys consisting of a towed array behind the seismic vessel, then the use of PAM for detecting Right Whales when airguns are firing may not be an effective mitigation measure as the ability to monitor the entire safety zone is likely restricted. In such cases, visual detection may be more reliable for detecting Right Whales within the safety zone and surveys should thus be restricted to daylight hours and good visibility when the probability of visual detection is maximized. Alternate hydrophone configuration, such as towing the array outside of the safety zone where background noise levels are less likely to mask the signals of Right Whales, would increase the effectiveness of PAM.

In the North Atlantic, Blue Whales produce low frequency infrasonic moans and arch calls. The frequency range of these calls is 9-69 Hz with fundamental frequencies ranging between 15.7-18.5 Hz (Mellinger and Clark 2003). Worldwide, the fundamental frequency of Blue Whale calls ranges between 15.7-122 Hz (Mellinger and Clark 2003). The function of these infrasonic calls is not well known. It has been speculated that these calls may be communication signals, used to investigate the environment, or to locate feeding grounds (Richardson et al. 1995, Stafford et al. 1998, McDonald et al. 2001, Stafford et al. 2007). These low-frequency sounds are difficult to detect when ambient noise levels are high (Stafford et al. 2007, Simard and Roy 2008, Simard et al. 2008). When using a towed array behind a large seismic vessel, infrasonic Blue Whale calls could likely be detected from distances up to 3 km away with airguns off (limited by noise generated by the ship itself). When airguns are firing, the predicted detection range reduces to 17 m, i.e., essentially zero (Simard 2009). Again, airguns overloading the front end of the array could also create issues with data quality. Similar to the case of Right Whales, the use of PAM for detecting Blue Whales within the safety zone when airguns are firing is likely to be limited if the PAM configuration used consists of a towed array behind the seismic vessel. In such cases, visual detection is likely to be more reliable for detecting Blue Whales within the safety zone and surveys should thus be restricted to daylight hours and good visibility conditions when the probability of visual detection is maximized. Alternate hydrophone configuration, such as towing the array outside of the safety zone where background noise levels are less likely to mask the signals of Blue Whales, would increase the effectiveness of PAM.

Northern Bottlenose Whales undergo deep dives to forage and produce echolocation clicks during deep dives (Hooker and Baird 1999, Wahlberg et al. 2011). Clicks (or Frequency Modulated (FM) pulses) are the only type of vocalizations that have been described in any detail for Northern Bottlenose Whales. Three types of click vocalizations have been described: surface clicks, deep-water clicks or regular pulses, and buzz clicks. Discrete frequency whistles, sweep-frequency chirps and possible burst-pulsed tones similar to the sounds made by pilot whales and dolphins were also recorded in the presence of Northern Bottlenose Whales, but pilot whales or dolphins were often sighted within half an hour of these recordings thus these types of vocalizations could not be unequivocally attributed to Northern Bottlenose Whales (Winn et. al. 1970, Hooker and Whitehead 2002). The clicks or bisonar pulses produced by Northern Bottlenose Whales are broadband impulsive vocalizations, with spectral content from 0.5 to at least 26 kHz and dominant frequency bands greater than 10 kHz. Hooker and Whitehead (2002) report a mean peak frequency of 24 kHz, while Wahlberg et al. (2011) recorded at a higher sampling rate and report a centroid frequency of 47 kHz (range = 32-51 kHz). Deep-water clicks/regular pulses have a frequency upswept structure typical of echolocation pulses produced by other beaked whale species, while buzz clicks have no frequency upsweep

(Wahlberg et. al. 2011). PAM using fixed bottom-mounted sensors has been successfully used to detect Northern Bottlenose Whales to study their foraging behavior over various spatial and temporal scales (Moors 2012). However, because of their high frequency and directionality, PAM is only effective at detecting Northern Bottlenose Whale clicks over relatively short ranges, likely around a kilometer (Moors 2012). Simard (2009) suggests that ultrasonic echolocation clicks produced by odontocetes are likely only detectable up to a few hundred meters range due to the attenuation of high frequencies and that ship noise or seismic airgun sounds are not as likely to impact the detection range for ultrasonic clicks as they do not overlap in frequency (although propeller cavitation noise can extend into higher frequencies). However, if the airgun shots overload the receiver electronics, detection of even high frequency sounds will be difficult. Also problematic is that Northern Bottlenose Whale clicks may potentially be confused with delphinid clicks. There are ways of distinguishing between the clicks produced by Bottlenose Whales and delphinds, but this involves careful examination of waveforms and spectrograms (Wahlberg et al. 2011), likely requiring an experienced PAM operator or acoustic classification algorithms. Potter et al. (2005) detected Northern Bottlenose Whales visually or acoustically (but not both concurrently) during seismic surveys on the Scotian Shelf, demonstrating that a combination of visual and acoustic detection methods will help increase detection rates. A combination of PAM and visual observation likely offers the greatest probability of detecting Northern Bottlenose Whales and both detection methods should be concurrently used when operating in areas where Northern Bottlenose Whales are expected to occur.

RAMP-UP PROCEDURES

Effectiveness

The SOCP requires that a gradual ramp-up (also known as a “soft start”) of the airgun array(s) be conducted over a minimum of 20 minutes at the beginning of seismic survey operations, or when the array(s) have been shut-down for more than 30 minutes. Ramp-up may only commence if cetaceans have not been detected within the safety zone for at least 30 minutes. It is recommended that ramp-up begin with the activation of a single source element of the airgun array(s) (preferably the smallest source element in terms of energy output) and additional source elements of the airgun array(s) are gradually activated until the full operating level is obtained (DFO 2008; Sections 7 and 12). The goal of the ramp-up is to allow marine mammals in close proximity to the airgun array to move away before they are exposed to the full output of the array thereby minimizing potential hearing damage (Compton et al. 2008, DFO 2010b). The use of ramp-up is a standard mitigation measure used worldwide for mitigating the impacts of airgun sounds and military sonar on marine mammals (Compton et al. 2008, Dolman et al. 2009). Ramp-up as a mitigation measure is logic-based but its effectiveness has not yet been confirmed by empirical evidence (DFO 2010b).

The effectiveness of ramp-up is based on the assumption that animals will move away from the sound source as the sound builds (Compton et al. 2008); however, marine mammals do not always avoid sound sources and their motivation to leave an area may vary (DFO 2010b). The possibility of attracting animals by initially weak sounds has been identified as a potential problem (Compton et al. 2008). Shapiro et al. (2006) demonstrate that sperm whales exposed to a received sound level below 160 dB rms re 1 μPa/m oriented towards the sound source rather than away. Weir (2008a) documented varying responses of short-finned pilot whales to airguns in operation during a ramp-up period including sharply turning away from the sound source, logging at the surface and orienting towards the sound source, and eventually swimming away in the opposite direction of the seismic survey vessel. Atlantic spotted dolphins were observed veering away from a ship during the early stages of a ramp-up off Angola (Weir 2008b). No difference in the distance of cetaceans from airguns during ramp-up as compared to when the airguns were either turned off or when they were turned on full volume was observed by Stone and Tasker (2006). Moulton and Holst (2010) found that mysticetes were observed significantly further from the array during ramp-up periods as compared to when airguns were quiet, while distances of odonotocetes did not vary between ramp-up and quiet periods. The response of cetaceans to airgun sounds produced during ramp-up procedures thus appears to be inconsistent and likely variable between species. The effectiveness of ramp-up for avoiding SARA-prohibited impacts is thus unknown (Table 1).

It is important to note that ramp-up is designed to elicit a behavioral (avoidance) response by cetaceans, and thus the ramp-up mitigation measure itself in some circumstances could actually constitute harassment or destruction of critical habitat under SARA (e.g., if ramp-up diverts animals away from their critical habitat).

Additional Mitigation Measures for Consideration

There is large variation in the actual ramp-up procedure that may be used. Use of a 20 minutes (or more) ramp-up period as required by the SOCP allows the ramp-up to be tailored to a specific project depending on the species expected to be present in the area and the likelihood of detecting them (DFO 2010b). For example, longer ramp-ups could be used if longer diving species may be present. Alternatively, ramp-up procedures could include limiting the rate of increase of the number of airguns in the array up to full operational strength (DFO 2010b) or the rate of source level increase up to full operational strength (e.g, some guidelines require that the rate of ramp-up be no more than 6 dB/5 minute period). Mitigation guidelines often specify that a build in source level should occur in uniform stages to provide a constant increase in output over time (e.g., JNCC 2010). Some guidelines also specify a limit on the maximum duration of time over which ramp-up should occur to minimize additional noise being emitted into the marine environment (e.g., ramp-up should be no longer than 40 minutes; JNCC 2010, BOEM 2012).

Modelling studies by von Benda-Beckmann et al. (2013) provide some useful information about ramp-up effectiveness. The study results indicate that ramp-up procedures of only a few minutes in duration with relatively short pulses may reduce the risk of harm to animals (von Benda-Beckmann et al. 2013). Effectiveness of ramp-up increases as animal responsiveness increases (i.e., as animals elicit a response to lower noise thresholds). Ramp-up duration also affects ramp-up effectiveness. Reduction in the area affected by ramp-up occurred mostly in the first five minutes, with only a negligible benefit of extending ramp-up beyond this. A reduction of ship-speed also increased the effectiveness of ramp-up. In the case of unresponsive animals, long ramp-up durations should be avoided (von Benda-Beckmann et al. 2013).

The effectiveness of ramp-up will depend on the nature and level of the animal's responsiveness, which may vary by individual, species and context. A detailed literature review and possibly additional field or modeling studies will be required to determine the effectiveness of this measure for avoiding SARA-prohibited impacts (Table 2). Future research should focus on evaluating the effectiveness of ramp-up (Compton et al., 2008), such as the work being undertaken in Australia as part of the Behavioral Response of Australian Humpbacks Whales to Seismic Surveys (BRAHSS) project (Cato et al. 2013) and the Sea mammals and Sonar Safety 3S/3S2 project being conducted in Norwegian waters (Miller et al. 2011, Kvasheim et al. 2015). Weir (2008a) outlines the importance of extensive observations before commencing ramp-up to allow for sufficient time to determine the behavior and movement of animals in relation to the ramp-up procedure so that changes in behavior if or when they occur, can be detected. Weir (2008a) also highlights the importance of recording behavioral data in detail (and specifically in much greater detail than standard MMO reporting forms currently allow) before, during and after ramp-up in order to study the potential effect of ramp-up procedures (and of airgun arrays in general) on marine mammals. MMOs should also have appropriate scientific background and relevant field experience for assessing and recording behavioral and directional changes made by animals (Weir 2008a). Behavioral Response Studies (i.e., Controlled Exposure Experiments) are a controversial but potentially powerful technique that could be used to increase knowledge of the response of animals to airgun sounds (Compton et al. 2008).

A possible alternative method to ramp-up of eliciting a behavioral avoidance response is playback of predator vocalizations. Some species exhibit avoidance behavior to predator vocalizations (e.g., Tyack et al. 2011, Miller et al. 2014) and it is possible that predator playbacks could elicit more consistent and predictable responses from some species, though this has never been tested as a mitigation measure and the biological repercussions of using such a method are unknown. As well, predator playbacks could also constitute harassment under SARA. Behavioral Response Studies such as those performed by Tyack et al. (2011) and Allen et al. (2014) would be needed to determine the effectiveness of predator playbacks.

Species Case Studies

Given the limited knowledge about the effectiveness of ramp-up procedures or behavioral observations of these specific species to airgun ramp-up activities, no species-specific advice can be provided.

SHUT-DOWN CRITERIA

Effectiveness

It is specified within the SOCP that the airgun array must be immediately shut down if an individual of a listed marine mammal species is observed within the safety zone, including when the array has been reduced to a single source element (DFO 2008; Sections 8 and 10). Shutting down of the airgun array when individuals are observed within the safety zone will reduce potential mortality and harm, but because individuals can enter the zone undetected, it does not necessarily avoid these SARA-prohibited impacts, nor does this measure address lower-level impacts such as harassment or destruction of critical habitat (Table 1).

Additionally, the array must be shut down completely or reduced to a single source element when data collection ceases during line changes, for maintenance, or for other operations (DFO 2008; Section 9). The effectiveness of this measure for reducing SARA-prohibited impacts is not known (Table 1).

Additional Mitigation Measures for Consideration

The immediate shutdown of the airgun array when a listed cetacean is detected within the safety zone should apply when detection occurs by any monitoring method or technique used. Shut-down should also occur before the animal enters the safety zone if it is anticipated, by any monitoring technique, that the animal will enter the safety zone based on its movement patterns (Table 2).

During line changes or operational maintenance the airgun array should only be reduced to a single source element if the safety zone cannot be effectively monitored before ramping back up; otherwise, the airgun array should be reduced to a single source element or operations should be delayed until the safety zone can be effectively monitored (Table 2). Continuing to emit regular but lower-source-level pulses during these sorts of activities will continue to alert cetaceans of the presence of the seismic operations in the area, although such continued operation results in more sound energy being emitted into the marine environment. Shut-down criteria other than the occurrence of listed cetaceans in the safety zone could also be considered for shut-down requirements during line changes or maintenance operations. For example, JNCC guidance suggests that if a line-change is expected to be greater than some a specified period of time (for example, 30 minutes), then airgun firing should be ended at the end of the line and the typical pre-shooting search and ramp-up should be undertaken before the next line to minimize the amount of noise in the marine environment (JNCC 2010). A similar approach has been used in bowhead whale feeding grounds in the Canadian Arctic where complete shut downs are required during line changes to minimize sound input into the marine environment (GX Technology Canada 2011). Ramp-up should be conducted as appropriate, including when recommencing the survey after the airgun array has been reduced to a single source element. The effectiveness of reducing the airgun array to a single source element during line changes or operational maintenance will depend on the nature and level of the animal's responsiveness, which may vary by species and context. A detailed literature review and possibly additional field or modeling studies will be required to determine the effectiveness of this measure for avoiding SARA-prohibited impacts.

OTHER CONSIDERATIONS

Consideration of Indirect Impacts

Seismic airgun sounds may indirectly result in SARA-prohibited impacts on listed cetaceans through several different pathways. For example, the potential effects of seismic surveys on prey species may indirectly negatively impact listed cetaceans and critical habitat (Theriault and Moors-Murphy 2015), and such effects should be taken into consideration when planning surveys (Nowacek et al. 2013). This requires evaluation of information on prey distribution and sensitivity to airgun sounds. Temporal and spatial avoidance of prey species sensitive to airgun sounds would decrease indirect impacts on listed cetaceans related to a reduction of quantity and quality of prey.

Alternative Energy Sources

There are alternative methods to traditional airgun arrays that can be used to generate and record sound waves used for geological exploration, such as marine vibroseis (CSA Ocean Sciences 2014). Marine Vibrators (MarVibs) use hydraulic or electrical power to drive an actuating plate or piston that generates vibrations from 10-250 Hz (LGL 2011). Vibrator technology spreads the energy out over long periods, reducing the peak acoustic source level in comparison to impulsive systems (Weilgart 2009, LGL 2011). The bandwidth, rise time and duration of MarVib signals are expected to be substantially different from those produced seismic surveys, and may result in significantly reduced acoustic energy being broadcast into the marine environment, particularly at the higher frequencies. It is therefore expected that MarVib will have significantly less environmental impact than airguns (LGL 2011). However, this technology is still in development and there have been no direct studies on the biological effects of MarVib thus their impacts on cetaceans are not known. While it is important to consider and encourage the development of such technologies, evaluating the use of or mitigation measures for MarVib is beyond the scope of this document.

Cumulative Effects

The cumulative effects of multiple noise sources occurring in the marine environment as well as other threats to cetaceans need to be considered when assessing the impact of seismic surveys on cetaceans, particularly for species which have shown substantial reactions to seismic sounds. Such effects should be taken into consideration when planning seismic survey activities (DFO 2010b).

DISCUSSION AND RECOMMENDATIONS

EVALUATION OF MITIGATION MEASURES

The majority of the mitigation measures in the SOCP are aimed at reducing physical injury to marine mammals in close proximity of the airgun array. The SOCP is therefore most relevant for reducing potential mortality and to some extent harm to listed cetaceans. The ability of the SOCP to address potential harm or harassment of individuals or destruction of critical habitat that may occur at greater ranges from the sound source (i.e., beyond the safety zone) is limited (Table 1). The only mitigation measures within the SOCP that currently address such far-field impacts are those applied at the planning stage where it is specified that all seismic surveys must be planned to avoid significant adverse effects and to avoid displacing or diverting listed marine mammal species (Table 1).

Most mitigation measures in the SOCP could reduce potential SARA-prohibited impacts, but to varying degrees of effectiveness (Table 1). The combination of the multiple measures outlined in the SOCP as a whole is more effective than any one measure on its own. Most importantly, the SOCP states that operators may be required to put in place additional or modified mitigation measures for listed species (DFO 2008; Section 13), and thus provides flexibility for enhancing mitigation measures to meet SARA requirements.

The extent of information on distribution, abundance and behavior of a species, or the specific manner in which a mitigation measure is conducted, will impact its effectiveness. For example, using marine mammal observers (MMOs) to monitor the safety zone will only be effective for highly-visible species during times of good visibility. Similarly, use of PAM to monitor the safety zone will only be effective for highly vocal species, species known to continue vocalizing during seismic activity, or species whose vocalizations are not masked by the airgun sound. Supplementing visual observations made by MMOs with concurrent PAM and/or other proven detection technologies (a measure not specifically outlined within the SOCP) would likely increase the ability to detect some species within the safety zone not only during conditions of poor visibility, but in almost all circumstances. Use of additional observation platforms ahead of the seismic survey vessel(s) would also increase the ability to detect marine mammals both visually and acoustically. In particular, it is not clear in the SOCP how monitoring of the safety zone during the pre ramp-up observation period should be conducted; however, to be effective this measure requires monitoring the zone where ramp-up is to commence from a stationary observation platform or other alternative means of monitoring the actual ramp-up area (e.g., aerial platforms), rather than monitoring the area around a moving seismic vessel.

Gradual ramp-up procedures are required during seismic surveys (DFO 2008), but the effectiveness of this procedure as a mitigation measure is not fully understood, nor is the effectiveness of reducing the airgun array to a single source element during line changes or operational maintenance rather than shutting down completely. Since the effectiveness of these measures is unclear, their ability to avoid SARA-prohibited impacts is unknown (Table 1).

As understanding and interpretation of SARA continues, revisiting the SOCP within the SARA context is recommended.

ADDITIONAL OR MODIFIED MITIGATION MEASURES

Substantial scientific knowledge gaps on the effects of sound from airgun arrays used for seismic surveys on marine mammals make determining appropriate acoustic thresholds to avoid SARA-prohibited impacts difficult. Given the uncertainty around establishing acoustic thresholds for avoiding impacts prohibited by SARA, emphasis is placed on reducing potential impacts on at-risk cetacean species through implementation of reliable and conservative mitigation measures. Most of the mitigation measures outlined in the SOCP contribute to reducing potential negative impacts on at-risk species to some extent, but with some caveats. The recommendations made by DFO (2010b) for increasing the effectiveness of the mitigation measures outlined in the SOCP are still relevant and could help reduce potential impacts on listed cetaceans. Table 2 provides specific recommendations for modifications and/or additions to the measures currently outlined in the SOCP that have been discussed above.

PRIORITY RESEARCH AREAS

Some of the mitigation measures identified in Table 2 are not likely to be easily or feasibly implemented in the immediate future as additional work or research is required before they can be employed. There are several areas of research that will contribute to successful implementation of these measures.

Studies to enhance our knowledge of the distribution and abundance of listed cetaceans, particularly in areas of interest for offshore oil and gas activities are needed. Information on species occurrence is required to assess the extent of the potential impacts of seismic survey activities on listed cetaceans and to enable spatial and temporal avoidance measures to effectively be applied. The scale of studies required may vary from strategically planned region-wide surveys to project-by-project data collection in specific areas of interest, depending on the current state of knowledge on species occurrence. Visual sightings and acoustic detection data obtained during seismic surveys and other industry operations (by MMOs or otherwise) may be useful for enhancing our collective understanding of the seasonal distribution of cetaceans and should be made available to develop this knowledge base. Development of a national sightings database easily accessible to managers, regulators and industry would provide a resource to collect, store and share data in common formats on marine mammal occurrence. Increasing knowledge of when and where species occur, as well as the nature of their activities in specific areas (i.e., feeding, mating, calving), through long-term monitoring programs in known areas of interest to the offshore petroleum industry should be a research priority.

The appropriate threshold to be used for establishing the safety zone radius rather than using a fixed distance of 500 meters will need to be determined. This will involve conducting a review of Southall et al. (2007), NOAA (2015) and additional new scientific literature on PTS/TTS in marine mammals to determine the most appropriate metric (Theriault and Moors-Murphy 2015).

The appropriate probability of detection for each listed cetacean species which seismic survey operators would be expected to achieve when operating in certain areas needs to be determined. A scientific literature review including an investigation of detection function estimates from research surveys and how different environmental factors (e.g., sea state, weather, visibility) and human-related factors (e.g., experience, protocols used) and equipment (e.g., survey platform, binoculars) may influence detectability of a species would help to inform this discussion. Developing a framework for evaluating how the various additional mitigation measures would influence the probability of detection would also be useful for both regulators and operators when developing mitigation strategies.

To address knowledge gaps and better understand the impacts of seismic surveys on listed cetaceans, continued research efforts by the international science community aimed at increasing our understanding of the behavioral and physiological response of cetaceans to airgun sounds, and the consequences of such responses on the habitat use, health, reproduction, survival and recovery of impacted individuals is needed. Designing and implementing effective monitoring programs with rigorous data collection protocols will be an important component of these efforts. Such monitoring programs should allow for detection and quantitative analysis of the potential negative impacts on listed cetaceans out to all ranges from the sound source where harm, harassment or destruction of critical habitat may occur, including beyond a defined safety zone. Such environmental effects monitoring programs have previously been conducted during seismic surveys in Canadian waters (e.g., Lee et al. 2005), and will be an important source of information for ensuring that the mitigation implemented is effective at avoiding SARA-prohibited impacts during future operations.

CONCLUDING REMARKS

The mitigation measures of the SOCP were reviewed and it was concluded that while most mitigation measures of the SOCP decrease the probability of SARA-prohibited impacts (to varying degrees of effectiveness), the majority of the measures are aimed at reducing impacts in close range of the airgun array but do not adequately address impacts that may occur at greater ranges from the source (outside the safety zone). Several additional/modified mitigation measures were thus recommended, as well as several priority research areas to enhance the development and evaluation of effective mitigation measures. To fully evaluate the effectiveness of mitigation measures that have been implemented for reducing the impacts of seismic survey activities on listed cetaceans, it will be necessary to implement explicitly designed research studies with rigorous data collection protocols and adequate statistical power and sensitivity to allow for the detection and quantitative analysis of potential SARA-prohibited impacts. This includes monitoring beyond the defined safety zone at ranges from the source where harm, harassment and destruction of critical habitat may occur.

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TABLES

Table 1. Mitigation measures of the SOCP that likely avoid the occurrence of a specific SARA-prohibited impact (√), reduce the likelihood of a specific SARA-prohibited impact from occurring but may not fully meet the SARA requirements (~), likely does not address a specific SARA-prohibited impact (x), or the ability to address a specific SARA-prohibited impact is unknown (?). Relevant sections of the SOCP are indicated for each mitigation measure provided.

Mitigation Measure	Kill	Harm	Harass	Destroy Critical Habitat
Use the minimum amount of energy necessary, minimize the horizontal propagation of energy, minimize the amount of energy at frequencies above those necessary for the survey (Section 3).	~	~	~	~
Avoid significant adverse effects on an individual[2] or population (Section 4).	√	√	√	~
Avoid displacing a breeding, feeding or nursing individual[2] or displacing a migrating individual[2] (Section 5).	√	√	√	~
Establish a safety zone of a 500 meter radius (Section 6).	~	~	x	x
Using a qualified Marine Mammal Observer, continuously monitor the safety zone 30 minutes prior to start-up of the airgun array and maintain a regular watch of the safety zone at all other times during the survey (Section 6) including when the airgun array is reduced to a single source element (Section 10).	~	~	x	x
Only start or restart the airgun array if the full extent of the safety zone is visible and an individual[2] has not been observed within the safety zone for at least 30 minutes (Section 7).	~	~	x	x
Gradually ramp-up the airgun array to operating level over a minimum of a 20 minute period (Sections 7 and 12).	?	?	x	x
Immediately shut down the airgun array if an individual[2] is observed within the safety zone (Section 8) including when the airgun array is reduced to a single source	~	~	x	x

[2] The term "individual" means an individual marine mammal species listed as endangered or threatened on Schedule 1 of the *Species at Risk Act*.

Mitigation Measure	Kill	Harm	Harass	Destroy Critical Habitat
element (Section 10).				
Shut down completely or reduce the airgun array to a single source element when data collection ceases during line changes, for maintenance or for other operational reasons (Section 9).	?	?	x	x
Use alternative cetacean detection technology such as passive acoustic monitoring to detect individuals[2] in the safety zone 30 minutes prior to ramp-up when the full extent of the safety zone is not visible and the survey is an area identified as critical habitat or where an individual[2] is expected to be encountered (Sections 11 and 12).	~	~	x	x

Table 2. Review of mitigation and monitoring measures of the SOCP and their likely effectiveness/ability to avoid SARA-prohibited impacts when properly implemented ("avoid" = measure likely to help avoid prohibited impacts, "reduce" = measure likely to reduce likelihood but not altogether avoid prohibited impacts, "unknown" = effectiveness not known), and recommended modifications or additional mitigation measures to be considered.

PLANNING

Mitigation Measure (from the SOCP)	Effectiveness	Recommendations for Modifications/Additions
Section 3. Each seismic survey must be planned to (a) use the minimum amount of energy necessary to achieve operational objectives; (b) minimize the proportion of the energy that propagates horizontally; and (c) minimize the amount of energy at frequencies above those necessary for the purpose of the survey.	reduce/avoid	Seismic surveys should also be planned to minimize the area surveyed and duration of the survey to the extent possible, with particular consideration given to avoiding identified critical habitat of threatened and endangered cetacean species when such species are expected to be present in the area.
Section 4. All seismic surveys must be planned to avoid: (a) a significant adverse effect for an individual marine mammal or sea turtle of a species listed as endangered or threatened on Schedule 1 of the *Species at Risk Act*; and (b) a significant adverse population-level effect for any other marine species.	avoid	Seismic surveys should also be planned to avoid harm and harassment of individuals and destruction of critical habitat of threatened and endangered marine mammals.
Section 5. Each seismic survey must be planned to avoid: (a) displacing an individual marine mammal or sea turtle of a species listed as endangered or threatened on Schedule 1 of the *Species at Risk Act* from breeding, feeding or nursing; (b) diverting an individual migrating marine mammal or sea turtle of a species listed as endangered or threatened on Schedule 1 of the *Species at Risk Act* from a known migration route or corridor; (c) dispersing aggregations of spawning fish from a known spawning area; (d) displacing a group of breeding, feeding or nursing marine mammals, if it is known there are no alternate areas available to those marine mammals for those activities, or that if by using those alternate areas, those marine mammals would incur significant adverse effects; and (e) diverting aggregations of fish or groups of marine mammals from known migration routes or corridors if it is known there are no alternate migration routes or corridors, or that if by using those alternate migration routes or corridors, the group of marine mammals or aggregations of fish would incur significant adverse effects.	avoid	If a seismic survey area overlaps the distributional range of a SARA-listed species but finer-scale distribution patterns within the area of interest are not well known, then timely pre-survey studies at the appropriate temporal and spatial scales should be conducted prior to the survey to assess species occurrence and increase understanding of the likelihood of displacing or diverting individuals.

SAFETY ZONE AND START-UP

Mitigation Measure (from the SOCP)	Effectiveness	Recommendations for Modifications/Additions
Section 6. Each seismic survey must: (a) establish a safety zone which is a circle with a radius of at least 500 meters as measured from the center of the air source array(s); and for all times the safety zone is visible, a qualified Marine Mammal Observer must continuously observe the safety zone for a minimum period of 30 minutes prior to the start-up of the air source array(s), and (b) maintain a regular watch of the safety zone at all other times if the proposed seismic survey is of a power that it would meet a threshold requirement for an assessment under the *Canadian Environmental Assessment Act*, regardless of whether the Act applies.	reduce	(a) The safety zone radius should be the most conservative of 500 meters or a radius determined using propagation models based on the best available data and science for a pre-determined acoustic threshold (which has yet to be established), taking into account to the extent possible the species, environment and sound source context, and which should be validated with field measurements. (b) Combined monitoring capabilities should be designed to maximize the probability of detecting SARA-listed species to achieve a target probability of detection within the safety zone consistent with SARA requirements (which has yet to be established). A combination of detection methods/technologies (not limited to MMOs and PAM) may be required to achieve the target probability of detection. When operating in areas overlapping the distribution of deep-diving SARA-listed cetaceans, the pre start-up (or restart-up) observation period should be extended to a minimum of 60 minutes to increase the probability of detecting deep-diving species, and ideally should be determined based on the maximum duration of at least one deep-dive cycle.
Section 7. If the full extent of the safety zone is visible, before starting or restarting an air source array(s) after they have been shut-down for more than 30 minutes, the following conditions and processes apply: (a) none of the following have been observed by the Marine Mammal Observer within the safety zone for at least 30 minutes: (i) a cetacean or sea turtle, (ii) a marine mammal listed as endangered or threatened on Schedule 1 of the *Species at Risk Act*, or (iii) based on the considerations set out in sub-section 4(b), any other marine mammal that has been identified in an environmental assessment process as a species for which there could be significant adverse effects; and (b) a	(a) reduce (b) unknown	(a) See 6(b) above. (b) Effectiveness is likely to be dependent on the nature and level of the animals' responsiveness, which may vary by species and context. A review of available literature and additional studies is required to fully understand effectiveness.

Mitigation Measure (from the SOCP)	Effectiveness	Recommendations for Modifications/Additions
gradual ramp-up of the air source array(s) over a minimum of a 20 minute period beginning with the activation of a single source element of the air source array(s), preferably the smallest source element in terms of energy output and a gradual activation of additional source elements of the air source array(s) until the operating level is obtained.		

SHUT-DOWN OF AIR SOURCE ARRAY

Mitigation Measure (from the SOCP)	Effectiveness	Recommendations for Modifications/Additions
Section 8. The air source array(s) must be shut down immediately if any of the following is observed by the Marine Mammal Observer in the safety zone: (a) a marine mammal or sea turtle listed as endangered or threatened on Schedule 1 of the *Species at Risk Act*; or (b) based on the considerations set out in sub-section 4(b), any other marine mammal or sea turtle that has been identified in an environmental assessment process as a species for which there could be significant adverse effects.	reduce	The immediate shutdown of the airgun array should apply when detection occurs within the safety zone by any monitoring method or technique used, and should also occur before the animal enters the safety zone if it is anticipated, by any monitoring technique, that the animal will enter the safety zone based on its movement pattern

LINE CHANGES AND MAINTENANCE SHUT-DOWNS

Mitigation Measure (from the SOCP)	Effectiveness	Recommendations for Modifications/Additions
Section 9. When seismic surveying (data collection) ceases during line changes, for maintenance or for other operational reasons, the air source array(s) must be: (a) shut down completely; or (b) reduced to a single source element.	(a) reduce (b) unknown	(a) During line changes or operational maintenance the airgun array should only be shut-down completely if the safety zone can be effectively monitored (i.e., the target probability of detection can be obtained) before ramping back up; otherwise, the air source array should be reduced to a single source element or operations should be delayed until the safety zone can be effectively monitored. (b) During line changes or operational maintenance the airgun array should only be reduced to a single source element if the safety zone cannot be effectively monitored before ramping back up. Effectiveness is likely to be dependent on the nature and level of the animals' responsiveness, which may

Mitigation Measure (from the SOCP)	Effectiveness	Recommendations for Modifications/Additions
		vary by species and context. A review of available literature and additional studies is required to fully understand effectiveness.
Section 10. If the air source array(s) is reduced to a single source element as per subsection 9(b), then: (a) visual monitoring of the safety zone as set out in section 6 and shut-down requirements as set out in section 8 must be maintained; but (b) ramp-up procedures as set out in section 7 will not be required when seismic surveying resumes.	(a) reduce (b) unknown	(b) Ramp-up should be conducted as appropriate even when the airgun array is reduced to a single source element.

OPERATIONS IN LOW VISIBILITY

Mitigation Measure (from the SOCP)	Effectiveness	Recommendations for Modifications/Additions
Section 11. Under the conditions set out in this section, cetacean detection technology, such as Passive Acoustic Monitoring, must be used prior to ramp-up for the same time period as for visual monitoring set out in section 6. Those conditions are as follows: (a) the full extent of the safety zone is not visible; and (b) the seismic survey is in an area that (i) has been identified as critical habitat for a vocalizing cetacean listed as endangered or threatened on Schedule 1 of the *Species at Risk Act*, or (ii) in keeping with the considerations set out in sub-section 4(b), has been identified through an environmental assessment process as an area where a vocalizing cetacean is expected to be encountered if that vocalizing cetacean has been identified through the environmental assessment process as a species for which there could be significant adverse effects.	reduce	See 6(b) above.
Section 12. If Passive Acoustic Monitoring or similar cetacean detection technology is used in accordance with the provision of section 11, unless the species can be identified by vocal signature or other recognition criteria: (a) all non-identified cetacean vocalizations must be assumed to be those of whales named in sections 8(a) or (b); and (b) unless it can be determined that the cetacean(s) is outside the safety zone, the ramp-up must not commence until non-identified cetacean vocalizations have not been detected for a period of at least 30 minutes.	reduce	(b) See caveat about deep-diving species on 6(b) above.

ADDITIONAL MITIGATION MEASURES AND MODIFICATIONS

Mitigation Measure (from the SOCP)	Effectiveness	Recommendations for Modifications/Additions
Section 13. Persons wishing to conduct seismic surveys in Canadian marine waters may be required to put in place additional or modified environmental mitigation measures, including modifications to the area of the safety zone and/or other measures as identified in the environmental assessment of the project to address: (a) the potential for chronic or cumulative adverse environmental effects of (i) multiple air source arrays (e.g., two vessels on one project; multiple projects), or (ii) seismic surveys being carried out in combination with other activities adverse to marine environmental quality in the area affected by the proposed program or programs; (b) variations in sound propagation levels within the water column, including factors such as seabed, geomorphologic, and oceanographic characteristics that affect sound propagation; (c) sound levels from air source array(s) that are significantly lower or higher than average; and (d) species identified in an environmental assessment process for which there is concern, including those described in sub-section 4(b).	reduce	
Section 14. Variations to some or all of the measures set out in this Statement may be allowed provided the alternate mitigation or precautionary measures will achieve an equivalent or greater level of environmental protection to address the matters outlined in sections 6 through 13 inclusive. Where alternative methods or technologies are proposed, they should be evaluated as part of the environmental assessment of the project.	reduce	
Section 15. Where a single source element is used and the ramping up from an individual air source element to multiple elements is not applicable, the sound should still be introduced gradually whenever technically feasible.	reduce	