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Review of the Potential Hydrophysical-related Issues in Canada, Risks to Marine Mammals, and Monitoring and Mitigation Strategies for Seismic Activities

Revue des problématiques potentielles liées à l'hydrophysique au Canada, leurs risques pour les mammifères marins, et des stratégies de monitorage et d'atténuation dans le contexte d'activités sismiques

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Abstract

To outline the elements of the physical environment that will effect seismic sound propagation, we subdivided Canadian waters into five hydrophysical areas based on a number of broadly-defined physical features such as depth, bottom type, weather patterns, and surrounding land masses: Enclosed Continental Shelf, Narrow and Broad Continental Shelves, Arctic Shelf, and Coastal Canyons. These characteristics overlap among the areas, and the characteristics effect underwater acoustic environments. The prediction of underwater acoustic propagation is a critical parameter in determining the detection range of acoustic signals by marine mammal receivers.

There are few studies of (1) marine mammal hearing sensitivity (especially for baleen whales), (2) physical structure and underwater sound propagation characteristics of many marine areas in Canada, and (3) the effects of seismic sounds on marine mammal hearing sensitivity or behaviour, both on an individual and population level. How reliably these effects occur, the magnitude of these effects, the range of "recovery times" after effects are detected, and the factors which seem to influence probability, magnitude, and time course of effects are all types of data that remain limited for almost all marine mammals.

Marine mammal reactions to seismic sounds are variable, and fixed exposure criteria for behaviour may be impractical given these variable reactions and the variable nature of sound propagation.

Study of issues related to potential impacts of seismic sound on marine mammals are needed:

(1) What are the best sound propagation models for areas likely to host seismic exploration?

(2) There is a need for better and more accurate information on naturally-occurring and man-made noise in the ocean.

(3) There is a need for significantly more information regarding the reactions of marine mammals (and their prey) to underwater sound from seismic arrays.

(4) Is ramp-up an effective mitigation method?

(5) Is passive and/or active acoustic monitoring of marine mammals from the source vessel an effective monitoring and/or mitigation strategy?

(6) The spatio-temporal distribution, and physiological needs of marine mammal populations.

We have underlined the complexities involved in developing protocols and standards for seismic exploration among the diverse physical environments making up the Canadian marine environment. However, ultimately the Department wants to understand the effects of seismic exploration on individuals and populations of living organisms that exploit these hydrophysical regions so as to find ways to minimise the impacts of this sound source. Due to the complex patterns of sound propagation in these diverse regions, some marine mammals may not necessarily encounter the average sound exposure conditions predicted for a seismic survey. Therefore we must determine and be sensitive to the worst-case conditions that can be encountered to ensure that we do not underestimate the impact upon a particular segment of a marine mammal population.

Especially when dealing with SARA-listed species, detrimental effects suffered by one individual can translate into detrimental effects on the population; in critical situations (e.g., the northern right whale and blue whale), the reduced fitness or loss of a single individual becomes a concern for the health and productivity of the population. The onus falls on DFO to provide the necessary precautionary regulations and mitigation measures to ensure that no additional pressure is exerted on populations already at risk. This may entail extraordinary measures when endangered species are involved in critical behaviours (e.g., calving, feeding, and migration), which might include areas and seasons closed to seismic, or operational shut downs when detection probabilities fall below certain standards due to sub-optimal observation conditions.

The validity of any assessment regarding potentially harmful impacts of seismic sound on marine mammals will depend crucially on the accuracy and applicability of acoustic propagation models and the data used in this process. DFO will have to regulate within a precautionary framework as it is unlikely there will ever be direct hearing sensitivity measures for the large whales, and marine mammals' behavioural reactions to seismic sounds will always be variable.

Résumé

Dans le but d'identifier les éléments de l'environnement physique affectant la propagation des sons sismiques, nous avons subdivisés les eaux canadiennes en cinq aires hydrophysiques en se basant sur un certain nombre de caractéristiques physiques telles que la profondeur, le type de substrat, les patrons climatiques et les terres environnantes: Plateau Continent Intérieur, Plateaux Continentaux Large et Étroit, Plateau Arctique, et Canyons Côtiers. Ces caractéristiques se chevauchent entre les régions et affectent l'environnement acoustique sous-marin. La prédiction de la propagation acoustique sous-marine constitue un paramètre critique dans la détermination de la distance de perception des signaux acoustiques par les mammifères marins.

Il n'existe que peu d'études concernant (1) la sensibilité auditive des mammifères marins (particulièrement les baleines à fanons), (2) la structure physique et les caractéristiques de propagation sonore sous-marine dans les différentes aires marines du Canada, et (3) les effets des impulsions sismiques sur la sensibilité auditive des mammifères marins ou leur comportement, autant au niveau des individus que des populations. La constance de ces effets, leur magnitude, l'étendue des 'temps de récupération' après que de tels effets soient survenus, et les facteurs qui semblent influencer la probabilité, la magnitude et la durée de ces effets sont autant d'exemples d'informations qui demeurent présentement limitées pour la presque totalité des mammifères marins.

Les réactions des mammifères marins aux impulsions sismiques sont variables, et l'utilisation de critères d'exposition fixes au niveau du comportement peut s'avérer impraticable étant donné la variabilité des réactions et la nature changeante de la propagation du son.

Une étude des problématiques liées aux impacts potentiels des sons de nature sismique sur les mammifères marins est nécessaire:

(1) Quels sont les modèles de propagation de sons les plus appropriés pour les aires qui feront vraisemblablement l'objet d'exploration sismique?

(2) Il existe un besoin pour une connaissance plus approfondie et plus précise des bruits naturels et anthropiques dans les océans.

(3) Il existe un besoin d'acquisition de beaucoup plus d'information concernant les réactions des mammifères marins (et leurs proies) aux sons sous-marins générés par les appareils de levés sismiques.

(4) L'augmentation progressive de la puissance de la source constitue-t-elle une mesure efficace d'atténuation des effets?

(5) Le monitorage acoustique passif et/ou actif des mammifères marins à partir de la plate-forme générant le bruit constitue-t-il une stratégie efficace de monitorage ou d'atténuation des effets?

(6) Il existe un besoin criant de mieux connaître la distribution spatio-temporelle, les besoins physiologiques des populations de mammifères marins.

Nous avons souligné la complexité de développer des protocoles et des standards s'appliquant à l'exploration sismique pour les divers environnements physiques constituant l'environnement marin du Canada. Toutefois, le Ministère désire ultimement comprendre les effets de l'exploration sismique sur les individus et les populations d'organismes vivant et exploitant ces aires hydrophysiques de manière à adopter des manières de faire minimisant les impacts de cette source de bruit. La complexité des patrons de propagation des sons dans ces diverses régions peut faire en sorte que certains mammifères marins ne soient pas nécessairement exposés aux conditions moyennes prédites pour les levés sismiques. Conséquemment, nous devons déterminer et demeurer sensibles aux conditions des scénarios extrêmes qui peuvent être rencontrées de manière à nous assurer de ne pas sous-estimer les impacts sur un segment particulier d'une population de mammifères marins.

Particulièrement dans le contexte des espèces considérées En Péril (Loi sur les Espèces en Péril), les effets négatifs subits par un individu peuvent se répercuter au niveau de la population; dans le cas de situation critiques (p. ex., la baleine franche noise et le rorqual bleu), la réduction des performances ou la perte d'un seul individu devient une préoccupation pour la santé et la productivité de la population. La responsabilité de dicter des mesures de gestion et d'atténuation adéquates et prudentes revient au MPO

de manière à s’assurer qu’aucune pression additionnelle n’est imposée aux populations déjà à risque. Ceci peut nécessiter des mesures extraordinaires lorsque des espèces en danger de disparition sont impliquées dans des comportements critiques (p. ex., reproduction, alimentation et migration), incluant possiblement la fermeture saisonnières ou de certaines zones aux levés sismiques, ou l’interruption des opération lorsque les probabilités de détection de mammifères marins chutent sous certains seuils suite à des conditions de monitorage sub-optimales.

La validité de l’évaluation des effets potentiellement dommageables des sons de nature sismiques sur les mammifères marins dépendra de façon cruciale de l’exactitude et l’applicabilité des modèles de propagation acoustique et de la qualité des données qui y sont introduites. Le MPO devra agir en adoptant une approche prudente compte tenu qu’il est peu probable qu’aucune mesure directe de la sensibilité auditive des grands cétacés ne puisse être effectuée, et que les réactions comportementales des mammifères marins aux bruits de nature sismiques demeureront toujours variables.

Introduction

This paper provides a baseline for scientific advice on the potential effects of seismic activities on marine mammals in Canadian waters. Many review documents have been written within the last five years that have addressed the issue of seismic impacts on marine mammals; they are cited in this document as sources for readers wanting to investigate this topic beyond the scope of this review.

This baseline may later be augmented once the U.S. National Marine Fisheries Service (NMFS) underwater sound exposure criteria document is released to the public. Canadian scientists may review the NMFS criteria and adopt them if they are deemed suitable within the Canadian context.

The authors contend that DFO draw its conclusions on seismic exposure criteria for marine mammals within Canadian waters after reviewing the new noise impact criteria that NMFS is fostering for the United States. As stated in LGL Ltd. (2004):

> *Those [NMFS] criteria are designed to identify exposure thresholds above which one could expect (a) injurious effects, and (b) biologically significant behavioural effects, taking into account the best scientific information presently available. A committee of specialists concerning acoustic impacts on marine mammals, convened by NMFS, has been reviewing the available information in considerable detail, and developing recommendations for consideration by NMFS. Unlike presently-existing criteria, the new criteria will take account of recently-acquired data on TTS thresholds of marine mammals, and their dependence on exposure duration, among other sources of information. The draft recommendations regarding injury criteria are now fairly well defined, and specific information about them may be available soon. (Preliminary recommendations about injury criteria were described at a workshop on 29 April 2004.) The recommendations regarding behavioural disturbance criteria are still being developed and it is likely to be a few months before those recommendations are finalized. Although it would be premature to judge whether Canada should adopt these new criteria, it would be appropriate to use those proposed criteria (when available) as a starting point for consideration. (p. 47)*

In the present review document we:

1. describe the issues for marine mammals as they relate to seismic activities and potential acoustic characteristics of five major hydrophysical categories in Canadian waters,
2. identify the risks associated with each of these issues,
3. briefly discuss the usefulness of current (Canadian and international) monitoring and mitigation strategies in reducing or eliminating those risks, and
4. provide recommendations for monitoring and mitigation protocols for seismic operations in Canadian waters, coupled with advice on what types of data should be collected during DFO's continued scientific studies of the potential impacts of seismic exploration on marine mammals and other fauna.

In this interim review we do not extensively address the potential risks from seismic on particular marine mammal species, populations, or stocks. This is mainly due to a paucity of information for most marine mammal species, although what information is available have been reviewed recently elsewhere (Austin et al. 2004, Gordon et al. 2004). What really limits our ability to address the question of potential risks from seismic on marine mammals is the lack of fundamental knowledge on their distribution, their reactions to manmade sounds such as seismic airguns, and what habitat might be critical for them based on feeding or other life history processes. We discuss these knowledge gaps and suggest approaches for the Department to move forward on the seismic sound issue.

Major Hydrophysical Areas in Canadian Waters

Water column and seafloor characteristics can significantly affect sound propagation directly or indirectly through variations in temperature and salinity with depth (these influence sound speed), and seafloor slope and composition. The level of sound that can be detected is also dependent on the ambient noise characteristics at the location of the receiver, whether that is a hydrophone or a marine mammal. Finally, physical characteristics and variability in prey distribution and abundance influence the distribution of marine mammal receivers.

Information on geology, seabed characteristics, sediment properties, and bathymetry are critical in determining acoustic propagation losses and received sound pressure levels. To simplify the discussion initially, we describe potential impacts within the context of five broadly-defined hydrophysical areas. This approach highlights the concept that sound propagation and ambient noise conditions are highly variable within and among areas, and serve to illustrate that a pan-regional "one-criteria-fits-all" regulatory approach is likely ill-advised. (A particular seismic operation might be acceptable in one area, but not in another based on the sound propagation or biological characteristics of the area.)

We subdivided Canadian waters into five hydrophysical areas based on a number of broadly-defined physical features such as depth, bottom type, weather patterns, and surrounding land masses (Figure 1). On a fine scale there is certainly overlap in these characteristics among these areas, and they have an impact on their underwater acoustic environments. The prediction of underwater acoustic propagation is a critical parameter in determining the detection range of acoustic signals by marine mammal receivers. For instance, in the relatively shallow waters of the continental shelves the acoustic properties of the seabed become the dominant factor (Duncan and McCauley 2000), but there are only a few locations where the relevant substrate properties have been adequately determined.

A. Enclosed Continental Shelf (e.g., Gulf of St. Lawrence, Bay of Fundy, Hudson Bay)

This category is characterised by a broad continental shelf (approximately 60 m deep) bordered by landmasses, and the presence of marine canyons or channels (Figure 2). The shallow depth combined with the presence of canyons and channels (maximum 350 m deep; see E below), fresh-water inflow, energetic tides and high stratification of the water column will have significant influences on the propagation characteristics of seismic sounds in these areas. Sound propagation on enclosed or semi-enclosed shelves can thus be very complex given the varying bathymetry and seabed types, and the vertically structured water density profile. The relative contribution of the various anthropogenic sound sources to the total ambient noise will be significant given these areas' abundant commercial vessel traffic (shipping and fishing), and various underwater construction activities (e.g., pile driving, employing underwater explosions, and drilling), especially in the proximity of inhabited regions. The various enclosed shelf areas within Canadian waters all have particular (unique) physical characteristics, and thus it is difficult to make generalisations about their sound propagation properties. Therefore, to illustrate the complexities involved, the Gulf of St. Lawrence (GSL) will be examined in detail as a case study, since it is the enclosed shelf for which the most information is currently available. The principal physical features of the GSL that define this hydrophysical category are summarised in Table 1.

The GSL is a semi-enclosed sea of approximately 2.4×105 km^2 (Figure 2). The northern portion of the GSL is characterised by a fan of deep submarine glacial channels, the most extensive of these being the Laurentian Channel. Measuring 1000 km long and between 300 and 500 m deep, the Laurentian Channel runs from the continental shelf through the Cabot Strait to the mouth of the Saguenay River, separating the Gulf north-south into two basins. Water inflow into the GSL is dominated by deep Atlantic water through the Cabot Strait in the southeast, Labrador water through the Strait of Belle Isle from the north, and the continental fresh water runoff from the St. Lawrence River watershed. Upwelling of deep ocean water occurs at the head of the major channels, notably around the mouth of the Saguenay River near Tadoussac (Laurentian channel), near the Mingin Archipelago (Anticosti Channel), south of the Strait of Belle Isle (Esquiman Channel), and off Gaspé (Chaleur Trough). At the head of the Laurentian Channel, the mixing of the warmer and saltier deep bottom waters with the continental fresh waters produces lower-salinity and less-dense surface water, which is then returned to the GSL through the Gaspé current. In winter, the dominant physical oceanographic features are the cold mixed surface layer, the relatively stable bottom layer, and the widespread yet variable ice cover (from January to May). In summer, warming of the surface waters produces a stable surface layer, which gradually erodes the winter's cold surface layer resulting in a cold intermediate layer (CIL) wedged between surface layer and the bottom layer. The GSL thus goes through a clear annual cycle of vertical temperature and density structuring, the CIL extending to the surface in winter and becoming capped by the mixed surface layer in summer.

The strong summer watermass stratification results in a relatively thin and weak surface sound channel (0-30 m), a thicker and more effective intermediate sound channel in the CIL (30-150 m) and, given the irregular topography, a variable bottom sound channel (150+ m). In winter, the surface mixed layer (0-150 m) will produce a strong surface sound channel and again a variable bottom sound channel (150+ m). The CIL will therefore be the feature of most importance for propagation and channelling of seismic sound pulses, since the extensive and shifting winter ice cover will preclude most surveying activities in winter.

These dominant and dynamic summer oceanographic features make sound propagation predictions rather difficult for the GSL. Simple, single-term models assuming classical geometric spreading are invariably inaccurate for predicting sound losses due to the complex interaction of frequency-dependent sound propagation with a multiple-layered water mass structure. This is especially true around the heads of channels, where vertical water structure can change significantly within a tidal cycle. Sound waves can be focused to form sound "hot spots" or convergence zones under such conditions resulting in propagated sound levels significantly higher, even orders of magnitude higher (Gordon et al. 1998), than predicted by a simple and inappropriate sound propagation model. In addition, the effects of seabed characteristics (seafloor type and topography) become important factors in predicting sound levels within relatively shallow waters of the GSL. At distances greater than the water depth, a portion of the emitted sound must interact with the seabed, either by travelling through it or being reflected from its surface. Depending in the seabed type, i.e. from unconsolidated deposits to bedrock, the amount of sound that is reflected or absorbed will vary greatly. Hard bottom will result in more reflected sound than unconsolidated sediment. Also, sound propagation from deeper to shallower water will have more interactions with the seafloor, and will be absorbed to a greater degree in penetrable substrates. Thus the use of complex models verified with direct field measurements at different distances from the sound source is necessary to ensure adequate understanding of seismic propagation within a given area (Evans 1998).

When assessing the effects on marine mammals of noise produced by a seismic airgun array, the level of ambient noise will influence an animal's perception of the seismic noise. The distances at which a given sound is audible to a marine mammal receiver and to which the mammal may react will be shorter in areas where ambient noise is relatively higher. The GSL is a zone of relatively abundant shipping traffic. It is estimated that over 2,000 large commercial ships (tankers and cargo vessels) travel through the GSL per year, the vast majority of these passing through the St. Lawrence Estuary to Montreal, the remainder travelling along the north shore (Kelly 2002). The majority of these vessels can produce considerable if transient noise in the order of 169-198 dB re 1 µPa-m for the dominant tones (Richardson et al. 1995b) or 195 dB re 1 μPa^2/Hz-m for peak spectral densities (Hildebrand 2003). This traffic contributes significantly to the high background noise within the GSL (Zakarauskas et al. 1990b, Desharnais and Collison 2001b). Local shipping has the dominant impact in shallow waters, raising the ambient noise by up to 5 dB, while the ambient noise in deeper waters is overshadowed by more distant shipping sounds (Zakarauskas et al. 1990b). In addition, in the proximity of fishing ports and whale-watching activities, local recreational boat traffic can result in a significant increase in ambient noise. For example, at the head of the Laurentian Channel near Tadoussac, at times of peak whale-watching boat traffic, the ambient noise can be raised by 10 dB compared to low-traffic periods for the frequencies 500 and 1000 Hz (Scheiflele, unpubl. data). These field measured levels (148 dB re 1 μPa^2 at 1000 Hz) are considerably higher than typical ambient noise levels of <100 re 1 μPa^2/Hz (Zakarauskas et al. 1990b).

B. Narrow Continental Shelf (e.g., British Columbia, Scotian Shelf)

This hydrophysical category is characterised by a relatively narrow continental shelf (depths less than 200 m) populated with many islands and bordered by deeper water (Figure 3). These islands will also have significant influence on the propagation characteristics of seismic sounds in this type of area, as will the relatively warm oceanic conditions. The relatively shallow waters will result in seismic sounds having more interactions with the seafloor and the ocean surface. The properties of the seafloor will therefore strongly influence propagation, resulting in variable and hard-to-predict transmission losses (Richardson et al. 1995a). In areas of soft bottom, bottom losses through absorption will reduce sound transmission. However, if the sound is reflected or refracted upwards, especially in areas of hard bottom, sound transmission can be enhanced and may follow quite closely pure cylindrical spreading (Figure 4). Sound channelling through oceanographic stratification will be an issue mainly in the winter/spring (at least on the Scotian shelf) when the cold surface layer extends down to 150-200 m. Sound ducting through an intermediate channel may persist into summer/fall in areas where the CIL is formed from shallow, summer surface warming (e.g.,Sable Gully; see E Coastal Canyons). Sound propagation predicted from theoretical models will therefore be highly dependent upon input parameters pertaining to bottom type and sound speed profiles. Since these parameters are often not well known on the required spatial scales, especially before a seismic survey has been conducted, locally collected field measurements must be obtained to validate predictions (Richardson et al. 1995a).

Ambient noise in these areas can be considered low compared to enclosed shelves, but is nonetheless dominated by distant shipping, with higher levels in winter than in summer due to the high shipping density and improved propagation conditions (Zakarauskas et al. 1990a). In some areas, biological and wind-related noise can be major components of the background noise on the edges of the continental shelf (Desharnais and Collison 2001a).

C. Broad Continental Shelf (e.g., Newfoundland Grand Banks)

This category is characterised by a relatively broad continental shelf bordered by deeper water (Figure 5). The shallow water depth (maximum 200 m; minimum 40 m) and cold, lower salinity water will have significant influences on the propagation characteristics of seismic sounds in this type of area. Again, the shallow depths result in more reflection and refraction with the sea surface and ocean floor than in deeper waters, resulting in complex reflection and refraction tracing. However, sound propagation can be very different from other continental shelves (Figure 4). Here transmission losses can be substantially more than spherical spreading would predict, undoubtedly due to substantial bottom losses and shadowing in very shallow depths (Table 2).

The broad continental shelf hydrophysical area has generally lower ambient noise than narrow coastal continental shelves (Zakarauskas et al. 1990a) most likely due to the reduced propagation conditions and being farther offshore and away from the major shipping lanes.

D. Arctic Shelf (e.g., Beaufort Sea, Arctic Archipelago)

This hydrophysical category is characterised by a relatively broad continental shelf (depths less than 200 m) bordered by land masses and covered by ice for much of the year (Figure 6). A feature of such areas may also be sub-bottom permafrost left from the last glacial period, which is known to propagate sound over great distances and unpredictably. These characteristics will have significant influences on the propagation characteristics of seismic sounds in this type of area. Many of these characteristics are common throughout the Canadian Arctic Archipelago.

Seismic sound propagation may be enhanced by conduits of sub-seafloor permafrost (from last glacial period). There also may be sound waveguide effects caused by cold water sandwiched between seafloor and a thick ice surface (although a rough ice undersurface should cause quite a bit of scattering and attenuation).

It must be noted that the short open-water season restricts access to these areas for both marine mammals and seismic exploration operations.

E. Coastal Canyons (e.g., Sable Gully, Gulf of St. Lawrence canyons)

This hydrophysical category is characterised by steep-walled and deep gorges (depths more than 300 m) cutting into the margin of the continental shelf or within enclosed shelves. Their depth and steep borders will have significant influences on the propagation characteristics of seismic sounds in these locations. Examples of these canyons are the Sable Gully (SGC), Haldimand and Shortland Canyons along the Scotian Shelf (Figure 7), and the head of the Laurentian Channel in the GSL. Due to their contrasting topography with the surrounding shelf, oceanographic forcing will result in complex and, in some cases, dynamic vertical structuring of water masses. This is especially true with the Laurentian Channel where tidal mixing and upwelling results in significant vertical restructuring within a tidal cycle (Lavoie et al. 2000) — which is significantly different from surrounding shallower areas. For example, a line transect of temperature profiles taken in the Sable Gully revealed the presence of a CIL over the Gully which was much less developed offshore where the Marathon seismic survey was being conducted in the summer of 2003 (Figure 8). In this case, modelled sound propagation predictions based on sound speed profiles collected along the continental shelf would underestimate the ducting of sound within the CIL formed within the Gully.

Ambient noise can be quite variable in canyons, depending upon nearby vessel traffic, sea state and marine mammal vocalisations. Mean values ranged between 62-82 dB re 1 μPa^2 at 1000 Hz for the off-shore Sable Gully canyon (Desharnais and Collison 2001a), compared to 148 dB re 1 μPa^2 at 1000 Hz for the inland Laurentian Channel canyon with heavy vessel traffic (Scheifele unpub. data). For surveys conducted in and around canyons, reflections from the canyon walls will produce convergence and shadow zones in a complex and dynamic manner, given the mobile sound source. Sound propagated towards shallow shelf areas at the boundaries of the canyons will be attenuated, creating shadow areas beyond them where the noise is significantly reduced (Figure 9). In these areas, shallow shelves, islands and headlands can serve as acoustic buffers zones. Conversely, sound that is channelled into canyons will be reflected off the hard, vertical walls, facilitating the ducting of the sound vertically, just as thermal sound channels duct the sound horizontally. Since the sound source is mobile, sound will reflect off the canyon walls at varying angles, rendering modelling of propagation patterns quite dynamic. Differences between model-predicted and measured sound levels can be of the order of 10-15 dB in such canyons(Austin et al. 2004).

Identifying the Risks From Seismic Sounds Associated With Each of These Hydrophysical Areas

Even without the sounds from seismic exploration, the ocean in these areas is not quiet. There are many sources of natural and manmade sound that are carried through the ocean, which have been reviewed by many authors (e.g., Wenz 1962, Calderon 1964, Piggot 1964, Urick 1986, Desharnais et al. 1999, Desharnais and Collison 2001c, NRC 2003). The following subsections provide a very brief description of natural, shipping, and seismic exploration sounds within the context of their contributions to ambient noise.

A. Review of Non-Seismic Contributions to Sound in the Marine Environment

Even in the Arctic hydrophysical area, there are many sources of underwater noise.[1] Since these sounds can propagate great distances under certain conditions, it is difficult to determine which might contribute most to ambient sound measures in any one location.

That “ambient noise in the world’s oceans may have risen by as much as 10 dB[2] between 1950 and 1975...” (Urick 1986) may relate to the global increase in the number and sizes of vessels in the commercial shipping fleet, in addition to commercial fishing and offshore oil industry activities. At a number of locations in the world, measures of the quietest noise levels {e.g., Swift and Thompson’s (2000) estimates of noise levels in the 10-100 Hz low frequency bands in the UK offshore} have been much higher than the “typical” ambient noise levels listed in Urick (1983) and Wenz (1962). Large variations in ambient noise levels both within and among regions do exist however, and there are a variety of factors that account for this.

1. Wind-related Noise

In the ocean, ambient underwater noise related to wind is caused primarily by wave action and spray. The windrelated noise component depends strongly on wind strength, duration, and fetch, as well as water depth, bottom topography and proximity to features, such as islands and shorelines (see Figure 10).

For instance, wind related ambient noise increases at a rate of 5 to 6 dB per doubling of wind speed. Maximum 1/3rd octave band sound levels of approximately 95 dB re 1 μPa are frequently observed at

[1] This can include sources not usually considered, such as melting icebergs (Urick 1971).

[2] 1 Pa = 1 N m^{-2} = 10 dyn cm^{-2}; 1 lb in^{-2} = 196.8 dB re 1 μPa; 1 bar = 220 dB re 1 μPa.

about 1 kHz for sustained winds of 34 to 40 knots and about 82 dB also at 1 kHz when the winds are in the 7 to 10 knot range (Lawson et al. 2001).

In the context of this review, wind conditions at sea off Newfoundland are rarely calm and strong winds exceeding 27 knots can occur throughout the year (Colbourne et al. 1994, Colbourne 1997, Drinkwater et al. 1999). These winds contribute to the greater ambient noise values here than might be experienced in locations with lower average wind speeds such as the nearby Scotian Shelf, or the British Columbia shelf.

2. Sea State-related Noise

Since ambient noise related to wind is also a function of wave action, a sea state scale that summarises sea surface conditions as a function of wind is commonly used in categorising wind-related ambient noise. However, any such relationship is unreliable as relatively large differences between ambient noise levels and sea state can occur depending on factors such as bottom topography and proximity to a coast subject to heavy surf conditions (e.g., Vancouver Island and Newfoundland coasts). Surf noise may be prominent near shorelines even in calm wind conditions (Wilson Jr. et al. 1985, Richardson et al. 1995b). This may be particularly true for the western shores of British Columbia or the eastern shores of Newfoundland, which are exposed to large waves from long fetches of open ocean. As was the case for wind-related ocean noise, location with greater mean monthly waves heights are likely to have a greater component of ambient noise attributable to wave action than at locations with lower average sea states. Again, higher ambient noise levels will serve to mask seismic sounds to a greater degree.

3. Biological Sound Sources

Biological noise arises in all oceans from a wide variety of sources. While marine mammals are major contributors (Richardson et al. 1995b, Desharnais et al. 1999), the sounds from certain shrimp and fish can also be significant in some areas (Myrberg Jr. 1978, Geistdoerfer 1998) The frequencies of biological noises can extend from approximately 12 Hz for some blue whale (*Balaenoptera musculus*) calls (Weston and Black 1965, Gagnon and Clark 1993, McDonald et al. 1995, Clark and Charif 1998), to over 100 kHz. Biological noise can dominate narrow or even broad frequency ranges (Richardson et al. 1995b). If biological noise dominates a particular frequency band, it can interfere with detection of other sounds at those frequencies by marine mammals.

As examples of the contribution to ambient noise by marine mammals, large baleen whales are conspicuous. DRDC studies have demonstrated that there is large variation in the 20 Hz sound data recorded in continental shelf areas in the northwest Atlantic (Desharnais et al. 1999, Desharnais and Collison 2001c). This large variation is attributed to fin whale (*Balaenoptera physalus*) calls, which are audible in many underwater recordings. Fin whales can emit intense calls with frequencies centred near 20 Hz (Watkins et al. 1987, McDonald et al. 1995). The noise level in this frequency band can increase by as much as 25 dB if fin whales are in the area and calling (Desharnais et al. 1999). This increase in ambient noise at lower frequencies due to large whale calls corresponds to the lower frequencies present in seismic sounds. It is possible that the lower frequency components of seismic signals could mask (see §2, below) fin whales communication calls, but fin whale calls could also produce sufficient increases in ambient noise to mask distant seismic sounds as well.

4. Shipping Noise

Vessels are major contributors to the overall background noise in most areas of the ocean (Calderon 1964, Richardson et al. 1995b), given their large numbers, wide distribution and mobility. This is true even for remote areas such as the Canadian arctic where icebreaker operations can produce significant underwater sound (Cosens and Dueck 1993).

A relatively constant low frequency (10-200 Hz) component in ambient ocean noise has been observed for many years and has been linked to distant ship traffic (Wenz 1962). Low-frequency sound energy radiated primarily by propellers and by engine excitation of the ship hull is propagated efficiently in the deep ocean to distances of 100 km or more (Richardson et al. 1995b). Since mid-frequency sounds radiated by vessels, even those that are nearby, will frequently be masked by local wind- and wave-related noise (Desharnais et al. 1999), distant shipping contributes little or no ambient noise at middle or high frequencies. Low-frequency noise from distant ships, as for seismic sounds and large whale calls, incurs more attenuation when it propagates across continental shelf regions and into shallow nearshore areas than occurs in the deep ocean.

There are significant differences in the predominant frequencies and sound levels emitted by different vessels, with additional variability dependent on their speed and mode of operation (Richardson et al. 1995b). Tours boats are an increasingly important source of underwater noise in many coastal areas where marine mammals aggregate (such as the GSL and the BCS), and they do influence marine mammal behaviour (Watkins 1986, Au and Green 2000, Henry and Hammill 2001, Lelli and Harris 2001, Williams et al. 2002).

B. Review of Seismic Contributions to Sound in the Marine Environment

Given the differences in seismic arrays, their sound characteristics, and continued development, in this document we describe only the characteristics of generic, and perhaps worst-case seismic sources; there have been many descriptions and reviews of seismic sound sources (e.g., Avedik et al. 1993, Johnson 1994, Richardson et al. 1995b, Rayson 1997, Pierson et al. 1998, Caldwell and Dragoset 2000, Dragoset 2000, Fontana 2002, Ronen 2002, Bain 2004).

The wide assortment of seismic source types and configurations is of less importance to discussions of potential impacts on marine mammals than are the qualities of the sounds produced. In all likelihood, noise exposure criteria that might be adopted by DFO will be set relative to given frequency-dependent source levels — no matter what the source. It is not feasible to treat each airgun (or other noise source) configuration separately (Watkins 1986, Au and Green 2000, Henry and Hammill 2001, Lelli and Harris 2001, Williams et al. 2002) – particularly since the propagation of the sounds produced will vary depending on the marine context. Therefore we provide a general description of seismic airgun sounds as it relates to propagation properties.

Air-guns release a volume of compressed gas rapidly into the water. This action creates a bubble which expands quickly, and in the process emits an impulsive signal (the primary pulse). This pulse subsequently oscillates with decaying amplitude, creating a signal called the bubble pulse (Figure 11). An airgun signal is omni-directional, and can produce high acoustic source levels at the bubble pulse frequency (approximately 20 Hz), and at its harmonics up to at least 500 Hz (Verbeek and McGee 1995).

Airguns cannot operate at great depths as their efficiency decreases rapidly with increasing depth. Further, when operated at typical gun depths the direct and reflected (from the water's surface) source signals can interfere with each other, resulting in more energy directed downwards than laterally. The signature of a single airgun is too weak to produce a good signal-to-noise ratio at depth. Using a tuned airgun array, in which airguns of different, carefully selected volumes are fired, direct arrivals from individual airguns sum coherently below the array (Figure 12), thereby producing a sound louder than that from a single airgun (Dragoset 2000).

C. Potential Effects of Seismic Sounds on Marine Mammals

The potential effects of seismic sounds on marine mammals have been either documented or postulated in many published and grey literature reports. While many of these reports simply recite older information, there are more relevant and/or recent examples (e.g., Reeves 1992, Richardson et al. 1995b, Davis et al. 1998, Evans 1998, Gisiner [ed.], JNCC 1998, Pierson et al. 1998, Tasker and Weir 1998, Anonymous 1999, Erbe 1999, Ketten and Potter 1999, Caldwell 2000, Lawson et al. 2000, McCauley et al. 2000, Stone 2003, Gordon et al. 2004, LGL Ltd. 2004, Tyack et al. 2004, Wartzok et al. 2004).

The effects of seismic on marine mammals could range from no response, to small-scale behavioural changes, to auditory effects such as temporary or permanent changes in hearing sensitivity, to non-auditory injury such as haemorrhage and direct mortality (Figure 13). Even more difficult to document are the potentially more subtle, but for SARA-listed species[3] potentially important, impacts such as increased

[3] In this context a "SARA-listed species" includes marine mammals listed by COSEWIC as Endangered (e.g., Atlantic blue whales, Pacific and Atlantic northern right whales, Scotian Shelf northern bottlenose whales, western and eastern Arctic bowhead whales, northeast Pacific southern resident population of killer whales), Threatened (e.g., St. Lawrence Estuary beluga whales, north Pacific humpback whales), or of Special Concern (e.g., northwest Atlantic humpback whales). For a listing of marine mammals see http://www.cosewic.gc.ca/eng/sct0/index_e.cfm.

levels of physiological stress and its possible role in immune compromise or reduced fertility and fecundity should they exist.

1. Non-auditory Physical Effects

While this category of injury could include pulmonary haemorrhage (Goertner 1982), and other internal injuries leading to direct mortality (Hill 1978, Yelverton 1981, Young 1981, Goertner 1982, O'Keefe and Young 1984) these effects are unlikely to occur following exposure to seismic sounds. Also included in this category would be chronic or long-term effects such as immunosuppression and reduced reproductive output (e.g., Ames 1971, Dierauf 1990, Sapolsky 1990, Jansen 1991, Berglund and Hassmén 1996, Heathershaw et al. 1997, Calow and Forbes 1998, vonHolst 1998, Fair and Becker 2000).

To date, for seismic sound sources there is no evidence that either acute or chronic physical impacts have occurred – although studies of sublethal effects on wild marine mammals would be difficult to conduct. It is possible that these effects might only occur during unusual exposure events. These could include marine mammals exposed at close range for unusually long periods, or when the seismic sound is strongly channelled with minimal propagation loss (e.g., the Sable Gully and canyons in the GSL), or when the animals are unable to avoid being near the seismic sources due to features in the habitat such as shorelines (see LGL Ltd. 2004).

2. Auditory Effects

Seismic sound effects on marine mammal auditory performance could range from masking, through Temporary Threshold Shift (TTS) in the mammals' hearing sensitivity, to Permanent Threshold Shift (PTS)[4]. The latter will likely be documented only in experimental settings. For instance, there have been sound exposure experiments conducted by the Office of Naval Research (ONR) in the United States on captive cetaceans and pinnipeds (Finneran et al. 2000a, 2000b, Schlundt et al. 2000, Finneran et al. 2002a, 2002b). These laboratory studies, plus extrapolations from studies of human hearing damage and theoretical literature, suggest that sound exposure levels (as a function of either source level or distance to receiver)and durations would have to be relatively high to produce TTS, much less PTS.

In the field, it is very unlikely that reception of a single impulse from an airgun array would be sufficient to cause these auditory impacts; also, multiple near-field seismic signal exposures are unlikely given the mobile nature of the array and the marine mammal receiver (Richardson et al. 1995b, Fontana 2002, Austin et al. 2004, LGL Ltd. 2004). There are no documented cases of field-based seismic activity from airguns causing TTS, PTS, haemorrhage or direct mortality. Furthermore, where auditory effects have been investigated in captive marine mammals (e.g.,Ridgeway et al. 1997, Finneran et al. 2002), the zone from the sound source that TTS levels consistent with measured results could occur within would be extremely limited (less than 10's of meters). With the near-field short pulse duration of a seismic array the source level would have to be very high to induce TTS (Figure 14). Nonetheless there has been no field studies to discount such impacts, although such studies would be difficult to design and conduct, and justify from an ethical standpoint.

Single or occasional occurrences of mild TTS do not cause permanent auditory damage (e.g., PTS) in terrestrial mammals, and presumably do not do so in marine mammals. For sound exposures at or somewhat above the TTS threshold, hearing sensitivity recovers rapidly after exposure to the noise ends. At least in terrestrial mammals, the received sound level from a single noise exposure must be far above the TTS threshold for there to be any risk of PTS (Kryter 1985, 1994). Relationships between TTS and PTS thresholds have not been studied in marine mammals, but all of the TTS effects induced using marine mammals in laboratory studies were mild and reversible—there was no evidence of PTS.

Although the hearing abilities of many marine mammal species are not well known, it is probable that they can hear seismic and other manmade sounds at distances ranging to hundreds of kilometres underwater if propagation conditions are favourable (Richardson et al. 1995b). Such noise in the ocean can be loud enough that they can overshadow or "mask" biological sounds that are important for marine mammals; if these sounds are used to communicate, detect prey or predators, or navigate then such masking could

[4] A temporary shift in the hearing threshold of a marine mammal is termed "TTS", while an irreversible (permanent) change in the animal's hearing threshold is termed "PTS".

have significant[5] impacts for individual animals. Long range communication, as may be happening between large mysticetes such as the blue whale, may be very important in keeping cetacean groups together {Payne's (1995) concept of a 'heard' of whales: individuals that keep together because they can hear each other's vocalisations}. Given the loud source levels and low frequency ranges of their calls, baleen whales can potentially hear each other over tens or hundreds of kilometres, and sperm whales can probably do so at ranges of tens of kilometres (Gordon et al. 2004). Acoustic disturbance or masking caused by seismic sounds could disrupt social groups (or mothers and their young) or hamper their ability to find each other and keep in contact using vocalisations (Gordon et al. 2004). On the other hand, it is speculated that the seismic pulse duty cycle (at close range approximately 20 ms every 10-15 seconds) makes it unlikely to cause significant disturbance to whale communication; some large whales may not be able to process short duty cycle information such as this. Further studies, especially at greater distances from the seismic sources, are needed to determine if masking can and does occur.

<u>3. Behavioural Effects</u>

Behavioural effects are problematical to identify as it is difficult to measure and describe subtle changes based on only a few field studies. Observers can usually document only gross displacements or changes in surface interval. This is because marine mammals are almost always moving, and because they tend to spend most of their lives below the water's surface. Sound playback experiments offer a good potential approach for the study of these effects (e.g., Malme 1993, Clark et al. 1998, Frankel and Clark 1998, Kastak and Schusterman 1998b, Tyack and Clark 1998, Clark et al. 1999, Finneran et al. 2000a, Tyack et al. 2004), but there are the usual caveats regarding the importance of context (how a marine mammal reacts to stimulus may relate to what it is doing at the time of exposure) and individual variation (not all individual marine mammals react similarly to the same stimulus). An interesting avenue of study would be to compare behaviour responses of marine mammals in areas where they are exposed to manmade sounds regularly to areas where they are not; this might provide evidence of habituation, such as in heavy ship traffic areas, such that the marine mammals might no longer respond in the same way to seismic activities, or that they already have changes in their hearing sensitivities (e.g., in the relatively noisy underwater environment of the Gulf of St. Lawrence).

The conclusions to be drawn regarding effects of seismic sounds on marine mammal behaviour are inconsistent: some studies have shown that toothed and baleen whales, and pinnipeds react to seismic sounds (and other loud manmade sound) with changes in their behaviour patterns, but this is not always the case (for thorough reviews see Richardson *et al.* 1995b, Stone 2003, Gordon *et al.* 2004). If there are changes these can range from deflections around a seismic source during migration, to small increases in the distance between seals and the seismic source vessel when it is operating (Richardson et al. 1995b, Richardson (ed) 2000, Harris et al. 2001). These same studies have shown that these displacements are short-lived, lasting hours to a day, and the mammals soon return to their previous patterns. Other behaveoural changes, such as calling rates, diving patterns, and group behaviour also show short-term modification (see for example Richardson et al. 1995b). Some marine mammals react at relatively low received sound levels whereas other individuals or species do not overtly react even at relatively high received levels.

However, for many of these behavioural studies there is little long-term follow-up (not to mention baseline research), so it is difficult to assess anything but gross-level changes. For all of these effects, and particularly for behavioural effects, we must consider how to assess and describe issues of scale, duration, and cumulative impacts. For instance, displacement from, or deprivation of access to, preferred habitats

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[5] Defining and detecting "biologically significant effects" of seismic surveys on marine mammals will be difficult as usually scientists do not know what degree of interruption of physiological processes or life history features can be tolerated without a significant reduction in the survival or reproductive capacity of a marine mammal. Gordon et al. (2004) suggest that "none of the research projects that have been conducted so far have been capable of adequately testing for effects at this level. The fact that plausible cases can be made for some of the responses that have been observed, or are thought possible, resulting in biologically significant effects, is an indication that this is a potential problem that deserves be taken seriously." (An NRC panel has been established to examine how likely disturbances of behaviour translate into biologically significant effects.) Within the context of <u>all</u> anthropogenic impacts on marine mammals, non-seismic effects such as biological processes (adult survival is most critical), bycatch, hunting, and ship strikes may be more important.

(or food sources) of marine mammals, including information on the duration of deprivation of access, will be important to know for SARA-listed species.

Modelling the impacts of such behavioural changes will be required to better understand the potential impact of depriving large (such as blue whales) and small (such as harbour porpoises and seals) marine mammals access to food for several hours or days due to seismic activities. Such modelling would be extremely difficult given the paucity of information on biological requirements (energy, critical habitat) for SARA-listed marine mammals. For instance, there is an energy-based consumption model for harp seals (Hammill and Stenson 2000), but similar information for inputs to such a model do not exist for most other marine mammals. A simplistic energy requirement model could be built (e.g., Innes et al. 1987) for a particular species based on previous studies of captive marine and terrestrial mammals, but would suffer from limited information on distribution and prey availability.

D. Modelling Effects

Modelling the impacts of seismic sounds on marine mammals will be an extremely complex task – even for a generic location model and receiver model. However, this complicated process must occur before the issue of exposure criteria can be resolved. The Expert Panel on Science Issues Related to Oil and Gas Activities, Offshore British Columbia (Royal Society of Canada 2004) recommended that "Acoustic modelling of sound intensities (verified by field measurement) from seismic shooting at sensitive areas should satisfy criteria to limit disturbance to marine animals, especially marine mammals, at critical times."

We have already described a number of the factors that affect seismic sound transmission loss, with the most important being oceanography (sound speed profiles varies with season and area), seabed features (material composition, bathymetry, surface texture), and the sea surface (particularly for sound in shallow areas, and it relates to weather conditions). A marine mammals receiver will therefore have varying probabilities to perceive a seismic signal, and as described previously will likely exhibit individually- and context-dependent physiological and behaviour reactions.

Given the factors determining propagation loss of any underwater sound, the potential impacts of seismic will be strongly-related to the receiver's distance from the source — hence the scale of analysis will be critical. Many studies have focussed on impacts at relatively short range (in the order of a few kilometres), whereas seismic sounds (and their potential impacts) can span distances of hundreds of kilometres (Nieukirk et al. 2004). If subtle behavioural changes, or physiological effects are discovered to be important impacts, then biological studies conducted in association with seismic operations must consider expanding their scope significantly. The same change in scope may be necessary for temporally-related impacts: long-term behavioural changes, or chronic physiological effects may necessitate seismic-related studies be conducted earlier before and longer after the seismic programme is underway.

And even as such studies are carried out, a precautionary approach is warranted to modelling impacts as the modelling process is potentially very complex (Figure 15). Many potential inputs are required to model seismic impacts even for a single marine mammal species, and these data are often difficult to collect (such as determining "critical habitat" or annual distribution patterns). The amount of data necessary to satisfy input requirements for each step in the modelling process can be large (and therefore expensive and time-consuming). And to estimate potential variation in the system (e.g., how the scale of potential impacts changes depending on underlying structure such as marine mammal distribution) the entire process should be repeated multiple times with various combinations of input data (a bootstrapping approach). And finally, in Figure 14 "effect models" can assume a variety of scales, from individual animals, to stocks, to entire populations. What scale of model we are most interested in depends on the management strategy; for a SARA-listed species such as the northern right whale impacts on even a single individual could be deemed important.

The development of acceptable criteria for seismic exposure is the next step in the process of evaluating seismic exposure once the potential magnitudes of impact are determined through a modelling process such as we have just described. While a variety of criteria have and are being employed at various locations in the world, these have differed and continue to change. NMFS has assembled a panel of internationally-recognized experts in acoustics and marine mammal biology and tasked them to draft new criteria that will be based on energy exposure (to account for whether the sounds are impulsive or continuous, for example), and on the type of marine mammal exposed to the sounds.

Descriptions and Efficacy of Mitigation and Monitoring Strategies in Reducing or Eliminating the Potential Seismic Risks for Marine Mammals

In this section we provide brief descriptions of various monitoring and mitigation strategies employed in an effort to reduce or eliminate the potential risks of seismic sounds for marine mammals.[6] With each, we also present a summary description of what is known about the apparent efficacy of these strategies with the understanding that in some cases there is overlap in the functions of a particular strategy. For example, a process that monitors for the presence of marine mammals could also be considered to be a form of mitigation if this monitoring collects data used to later reduce seismic impacts, or if the monitoring is a component of a mitigation process such as shutting down an array when a marine mammal comes too close.

A. Brief Review of Mitigation and Monitoring Strategies

1. Ramp up or Soft Start of Seismic Sound Sources

In many countries where seismic is conducted, regulators require that airgun arrays be activated gradually rather than initiating operations at full power and sound output (see an example in the Australian guidelines in Appendix A). This procedure is known as a "ramp-up" or "soft-start", and is primarily intended to reduce any potential for hearing damage to mobile marine animals such as marine mammals that might be near the array. It is assumed that marine mammals that are close to the seismic array will move away, if they find the airgun sounds to be aversive, before they are exposed to the full power of the array.

Depending on the regulator ramp-ups can include requirements for the time from silence to full power (such as HESS 1999) requirement that array sound output no more than doubles the power (e.g., increases by 6 dB each minute), and that this ramp-up procedure be required either at the onset of operations, or after the array has been inactive for a set period (e.g., 2 minutes, Lawson 1999).

Although the airgun array ramp-up procedure is appealing on an intuitive level, there have been no thorough scientific studies of the effectiveness of this mitigation strategy. For example, in discussing this procedure Richardson (1997) indicated that there is little published evidence that marine mammals are displaced by seismic arrays during ramp-up before physiological effects might occur. Further, several authors (such as Gordon et al. 2004) have suggested that ramp-up might actually be hazardous if marine mammals remain in close proximity to the array as its output power increases such that the mammal's total energy exposure is greater than if they had fled a louder startup airgun shot. Based on the advice of experts (e.g., Richardson et al. 1995b, Caldwell 2002) Minerals Management Services in the United States has been trying to initiate a study of ramp-up procedures for some years. Until such a (difficult) study is completed there is no way of knowing if this procedure is an effecttive strategy to mitigate potential effects of seismic sounds on marine mammals. In fact, an animal may only react to a ramp-up by avoiding the area if it had previously been exposed to high enough seismic sound levels to cause discomfort (Gordon 1998)

2. Shutdown or Power-down of Seismic Sound Sources

In addition to ramp-ups, many countries also require that seismic operators reduce the output of their arrays when certain conditions occur (see examples in the Australian guidelines in Appendix A). For example, a seismic operator might be required to reduce (power-down) or terminate (shutdown) sound output from the airgun array immediately when cetaceans or pinnipeds are detected within or about to enter a prescribed "safety zone" (see §*Safety Radii for Seismic Sound Sources*). A power-down could involve decreasing the number of airguns to one (usually the smallest) airgun. The continued operation of one airgun is intended to alert marine mammals to the presence of the seismic vessel in the area, much as is the intention for the ramp-up. In contrast, all airgun activity is suspended during an array shutdown. Following a shutdown or power-down event airgun activity cannot resume until the marine mammal has

[6] For a recent review see "Assessment of Regulatory Practices Governing the Limits of Sound Energy Produced during Seismic Operations" by LGL Ltd. (2004).

cleared[7] the safety zone. When airgun operations resume following a shutdown or power-down whose duration has exceeded specified limits, the airgun array will be ramped up gradually.

The intent of the shutdown or power-down is to eliminate or limit the sound energy exposure for marine mammals within some pre-defined distance (often called a "safety zone" or "safety radius") of the airgun array. There are major uncertainties in defining the size of "safety zones", and whether these zonal criteria should apply in all cases where marine mammals are sighted near the operating array (e.g., the JNCC guidelines do not require an array shutdown if marine mammals approach an operating array on their own volition).

3. "Safety" Zones or Radii for Seismic Sound Sources

So-called "safety zones" or shutdown radii are intended to eliminate or limit the sound energy exposure for marine mammals within some pre-defined distance from an airgun array. The major uncertainties in defining the size of these zones are related to our relatively limited knowledge of marine mammal hearing capabilities, and just as importantly, the intensity and characteristics of sound exposures necessary to elicit hearing changes or significant behavioural responses. Questions have also been raised as to whether these zonal criteria should apply in all cases where marine mammals are sighted near the operating array (e.g., the JNCC guidelines do not require an array shutdown if marine mammals approach an operating array on their own volition).

a. Marine Mammal Hearing Capabilities

There is a large, although confusing and narrowly-focussed literature describing studies of marine mammal hearing. Recent literature reviews (Richardson et al. 1995b, Kastak and Schusterman 1998a, 1999, Ketten 2000) provide a good synthesis of the studies that have been conducted, so this document describes only key findings and problems.

According to a review by Ketten (2000) a variety of laboratory studies have shown that marine mammals have a hearing system similar to other mammals, although evolved to have a broader hearing range (for a detailed description of study results see the review). Hearing sensitivity measures (although many studies have been limited in scope) are available for only 11 species of toothed whales and seals. For other species, hearing ranges have been estimated with mathematical models based on ear anatomy or inferred from emitted sounds and playback experiments. There is considerable variation among marine mammals in both absolute hearing range and sensitivity, and for marine mammals as a group ranges from ultra to infra-sonic. Toothed whales are able to hear sounds ranging between 200 Hz and 100 kHz, although individual species may have functional ultrasonic hearing to nearly 200 kHz (e.g., porpoises).

It appears that the best lower frequency hearing is confined to larger species of cetaceans and pinnipeds. Baleen whales have never been tested directly for any hearing ability, but functional models indicate that their functional hearing range may extend as low as 20 Hz, with several species (such as blue whales and fin whales) expected to hear well into infrasonic frequencies(see reviews in Richardson *et al.* 1995b, Ketten 2000). Baleen whales also reacted to sonar at 3.1 kHz and other sources centred at 4 kHz (see Richardson et al. 1995 for a review). In addition, baleen whales produce sounds at frequencies up to 8 kHz. Ambient noise energy is higher at low frequencies than at mid frequencies.

Within the seals, only the elephant seal has been shown to have good to moderate hearing below 1 kHz; the relationship between frequency and hearing thresholds for pinniped species demonstrates a similar "U"-shaped pattern similar to toothed whales and other mammals, with best hearing begins at frequencies of 8 to 10 kHz and thresholds become higher with decreasing frequency. Measured and speculated hearing limits for the main marine mammal types are illustrated in Table 3.

Not all sound produced by seismic arrays will be audible to all species of marine mammals. Some sounds will be above or below their hearing sensitivity ranges. Some sounds will be within the hearing capabilities of some species, but the level will be so low relative to the hearing threshold that an mammal

[7] Under Australian regulations, the marine mammal is considered to have cleared the safety zone if it is visually observed to have left the safety zone, has not been seen within the zone for 15 min in the case of small odontocetes and pinnipeds, or has not been seen within the zone for 30 min in the case of baleen whales and large toothed whales.

would have to be within a few meters of the source to hear the sound, especially in noisy conditions such as in high sea states. One issue that has not been addressed in many seismic impact assessments is a review of the critical components of marine mammals' use of sound? For example, do they use different frequency ranges for communication versus prey detection.

In summary, despite many captive studies, there remain key information gaps: (1) we have no hearing measures for baleen whales and assume that they hear well at lower frequencies based on their low-frequency vocalisations, (2) there have been few studies on odontocete hearing except for a few captive animals, and (3) there are suggestions that ziphiids (beaked whales such as the northern bottlenose whale) might have a different hearing mechanism or reaction to impulsive sounds than other toothed whales.

b. Methodology to Develop Seismic Sound Exposure Criteria for Marine Mammals

Previous development of sound exposure criteria for marine mammals has employed extrapolations of hearing effects based on controlled exposure experiments on captive marine mammals, on extrapolations from controlled exposure experiments with terrestrial animals, or on theoretical extrapolations based on mammalian hearing models. Recently, NMFS assembled a panel of internationally-recognized experts in acoustics and marine mammal biology to draft new criteria on energy exposure (to account for whether the sounds are impulsive or continuous, for example), and on the type of marine mammal exposed to the sounds. These sound exposure criteria could be described within a matrix such as that in Table 4.

DFO could simplify this matrix by ignoring sounds in the columns indicated in red, and restrict criteria to seismic impulses (and omit the continuous sounds emitted by the travelling seismic source and other large commercial vessels). If oil and gas production (and shipping) are considered continuous, it is desirable to include them during the creation of exposure criteria. The NMFS panel of experts is currently deriving criteria for these categories on a precautionary basis; since DFO has to evaluate projects producing with these types of sounds, the Department would likely consider them at some point.

The criteria for hearing sensitivity changes would be based on estimating sound exposures above the species' hearing threshold at the frequency range in the signal with the greatest acoustic energy, with adjustments for the mammals ears' protective "damping" response, critical band, and TTS/PTS recovery when exposed to intermittent impulses.

Such an approach probably represents the best way to move forward, although the criteria would have to be overlaid with the receiver's location in a highly variable acoustic space, estimating the magnitude and spatial scale for impacts would be difficult. A simple approach is to present the worst case situation: what is the highest sound energy exposure that does not produce changes in hearing sensitivity or significant behavioural changes within an environment with the best propagation, heard at the marine mammals' most sensitive hearing frequencies? However, another approach could be based on acceptable risk and associated mitigation measures: a suitable risk assessment framework and subsequent strategies to manage risk could ensure that marine mammal health is not exposed to unacceptable risk. Although, for a highly-endangered species, this may mean that the risk of even a single injured individual is unacceptable.

The Department will have difficulty (as is the NMFS expert panel) in deriving and defending behavioural "disturbance" criteria as it should represent "biologically significant" changes (a term that DFO will need to define eventually) versus a brief startle or short-term or small-scale displacement. DFO is aware of the context dependence, individual variability, and measurement difficulties in studies that have assessed behavioural responses by marine mammals to seismic (and other impulsive) sounds. Again, a precautionary approach that bases the criteria on worst-case exposure models and responses is advised.

Finally, DFO must decide on an approach to deal with impacts at the population level. Should these be tied into a discussion of "critical areas" or times in a marine mammal's life cycle? For highly endangered mammals, such as the blue and right whales, deleterious impacts to even a single individual are significant for the population. For SARA-listed species, such as fin whales, that are more abundant or dispersed DFO might consider utilising the NMFS guidelines for population-level impact assessments (e.g., Wade and Angliss 1997).

c. Verification of "Safety" Radii

Once exposure criteria for a particular seismic operation are decided upon in advance, models are derived for the distances from the array within which marine mammals might be exposed to sounds exceeding the criteria. In some countries (e.g., the Alaskan Beaufort Sea, the Sea of Okhotsk in 2001), at the start of seismic operations the proponent conducted field measurements of the near- and far-field sound characteristics of the array and reported these to the regulatory agency. Any changes to the "safety" radii was then made based on the actual measurements. Verification may not be required if acoustic measurements of sound levels from the same airgun array operated in the same location are already available.

4. Other Mitigation Strategies for Seismic Sound Sources

a. Design of Seismic Arrays

In an effort to reduce the size of the safety radii, and hence the risks to marine mammals and the costs due to shutdowns, efforts are being directed towards airgun array design that: (1) minimises the proportion of the sound energy that propagates horizontally, (2) avoids unnecessarily strong energy sources, and (3) minimises the amount of sound energy that is broadcast at frequencies above those useful for geophysical purposes (as an example, refer to the JNCC guidelines).

Alternate technologies, such as marine vibroseis or electromagnetic sources may result in significantly reduced or no acoustic energy being broadcast during geophysical exploration. For example, a marine "vibroseis" units, generating swept frequency pulses from 5 to 100 Hz and processed using matched filters, could reduce the peak sound pressure by approximately 30 dB. Although the peak intensity is lower, vibroseis emits longer impulses so the total acoustic energy output is similar (although this may be a useful difference if NMFS marine mammal sound exposure criteria are differentiated based on peak versus total energy). At present these technologies are still being tested as they are not yet suitable substitutes for seismic sources.

b. Design of Survey Line Sequences

During planning for the 2003 seismic exploration project near the Sable Gully, Marathon agreed to modify the orientation of their seismic shot lines such that they reduced the amount of sound energy transmitted towards the Gully through "end fire". This measure might reduce the disturbance effect in a situation where a seismic survey is planned in waters adjacent to an important area for a whale stock that has been recognized as "critically endangered".

c. Seasonal and Geographical Restrictions; Buffer Zones

In many areas, operators attempt to conduct seismic surveys at times of year when sensitive marine mammals are absent, present in relatively small numbers, or present but not engaged in sensitive activities such as breeding or feeding (this strategy is described in the JNCC, Australian, and HESS guidelines. This will be a particularly important proscription for areas deemed to be critical habitat for such SARA species as the northern right whale in the Bay of Fundy, and the northern bottlenose whale in the Sable Gully.

If seismic does occur in these areas and times, it is recommended that a guard vessel(s) should scout ahead of the seismic vessel during seismic acquisition to aid in detecting marine mammals within or about to enter the prescribed safety distance (LGL Ltd. 2004).

In addition to excluding seismic operations from occurring directly within a sensitive area, requirements might be imposed such that a no-seismic buffer be established around these areas to further reduce sound exposures. Such a buffer is in place around the Sable Gully. Australian guidelines recommend that a 20 km buffer zone be identified around each cetacean "aggregation area" identified as a "Category C2" habitat (see Appendix A).

5. Marine Mammal Monitoring

a. Shipboard Marine Mammal Observers

The Canadian, NMFS, JNCC, HESS, Russian, and Australian guidelines all require that one or more personnel dedicated to marine mammal observers (MMOs) to be stationed aboard the seismic source vessel to document the occurrence of marine mammals near the seismic vessel, to help implement mitigation requirements, and to record the reactions of marine mammals to the seismic survey (LGL Ltd. 2004).

While the Canadian requirements are not as strict in the types of personnel that act as MMOs, other jurisdictions place some restrictions on who can perform this task. JNCC guidelines suggest that "the most appropriately qualified and experienced personnel … act as marine mammal observers on board the seismic survey vessel. If possible, such observers should be experienced cetacean biologists. As a minimum, it is recommended that observers should have attended an appropriate training course." We concur with this recommendation, and further suggest that a minimum standard be set through training and testing to accredit MMOs for this work. Having qualified MMOs aboard not only enhances the effectiveness of this mitigation strategy, but ensures that baseline or other observational data is of the highest quality.

Normally MMOs are required to begin watching for marine mammals some time prior to the onset of seismic shooting (usually at least 30 minutes). Most areas require at least one MMO be on duty during seismic shooting, with other MMOs aboard to rotate shifts as needed (MMO shifts should be limited to four hours or less the reduce fatigue). The Australian guidelines require trained and dedicated cetacean observers are required during seismic surveys in habitats that are considered more sensitive (Habitat Categories B2, C and D).[8]

Visual aides are important to the MMOs and must include reticule binoculars (for scanning and to estimate distance), access to a GPS for real-time position and vessel speed, and some sort of paper- or computer-based data recording system. Night-vision system have been tried, but offer very small field of view resulting in few sightings.

b. Aerial Surveys for Marine Mammals

Various regulatory agencies recommend aerial surveys before, during and after seismic surveys to document the numbers and distributions of marine mammals, any changes in behaviour and distribution of marine mammals in the area, and to estimate the number of animals "taken" through potential harassment within the entire seismic survey area. See LGL Ltd. (2004) for a review of requirements for aerial surveys in various regions.}

These surveys may provide less statistical power to detect such changes in marine mammal distribution or behaviour than acoustical systems as the animals spend little time at the surface and the aircraft are moving much faster than a survey vessel or the marine mammals.

c. Acoustical Monitoring for Marine Mammals

In some situations, passive sonar methods such as towed acoustic arrays can be useful in detecting marine mammals (Richardson 1999). Also, a high-frequency active sonar might be useful in deep water to detect marine mammals (U.S. Navy 2001). These passive systems may be particularly useful during conditions of poor sightability (night, fog, high sea state), or in areas where a marine mammals species is a long-duration diver (such as sperm whales or northern bottlenose whales) and hence unlikely to be detected visually. Several recent studies suggest that acoustic detection systems may not be as effective as presumed if marine mammals stop vocalising in response to seismic sounds, or if their calls or echolocation signals are highly directional or have short range (e.g., high frequency).

As for visual monitoring, acoustic monitoring can provide data for further scientific study (reactions, distances, occurrence - especially during non-seismic periods).

d. Operations at Night and in Poor Visibility

It is recognized that, even on clear nights, visual detection of marine mammals is very difficult and unlikely even when some combination of floodlights, image intensifiers, and thermal infrared detectors is used. The probability of detecting marine mammals visually deteriorates further in fog, heavy rain, or snowfall either by day or especially by night (LGL Ltd. 2004)).

[8] The Australian guidelines recognize six habitat categories, and require different levels of monitoring and mitigation for different categories (see Appendix A).

The nighttime/poor visibility issue received much attention during development of the HESS (1999) guidelines. The HESS Team noted that:

> *"Operations at night involve a trade-off regarding the ability to visually detect animals in the study area and the advantages of achieving continuous operation…. Night operation requires a case-by-case evaluation. Factors to consider include seasonality (hours of daylight, weather, migration patterns), priority of animals of concern, air quality, fishing impacts, and economics."*

B. Recommended Mitigation and Monitoring Strategies for Seismic Operations in Canada

Several countries or jurisdictions have adopted various guidelines and practices – usually variations on the aforementioned practices {for a comprehensive review see (2004)}. Recommended mitigation and monitoring strategies vary considerably among countries and even areas within a single country. For example, while there has been an increase in the number and scope of seismic activities in Russia (e.g., the Sea of Okhotsk) there is apparently no accepted set of standard mitigation measures related to marine mammals required for marine seismic surveys. The same is true for Canada where differences exist between regions in the seismic monitoring and mitigation requirements.

The Department should develop protocols for the collection of data during seismic surveys. Many mitigation measures such as ramp-up are used as presumably "precautionary" strategies even though we don't know whether they work. If we are to be able to measure the effectiveness of the various measures that are put in place during a seismic survey, it is essential to study their effects. Data collection should include systematic observational data (species, distance and direction, observational conditions, etc.) by certified observers during all phases of operation, i.e. with airguns on and off, and while ramping up, and powering down the array.

Based on a review of monitoring and mitigation methods, we recommend that the following monitoring and mitigation strategies be adopted in a consistent manner for seismic operations in all marine and freshwater waters in Canada. We concur with experts at the ONR workshop on the effects of anthropogenic noise in the marine environment (Gisiner [ed.]) that "… in most situations, no single monitoring method is sufficient. A combination of complementary methods is usually required." In addition, seismic operators must be made aware of mitigation and monitoring requirements well in advance of the anticipated start of their project – particularly if the proponent or DFO will be conducting baseline biological or hydrographic studies or surveys prior to the start of seismic shooting.

It is best to offer a range of strategies, not all of which may be desirable or effective in a particular situation. The ultimate goal is to reduce the received sound level at the location of a marine mammal, and there may be more than one solution within a buffer zone.

<u>1. Ramp-up</u>

While the efficacy of this technique has yet to be proven through directed scientific studies, we recommend that it continue to be a standard requirement during seismic exploration as a precautionary measure.

We recommend that seismic arrays be ramped up at the start of a survey, and whenever the airguns have been inoperative or at reduced output for more than five minutes.

We recommend that the Department support MMS' efforts to study this mitigation method, either through cooperative research or participation in their project.

<u>2. Shut-down</u>

The efficacy of this technique is obvious, so we recommend that it continue to be a standard requirement during seismic exploration. Requirement for this procedure is not universal in all jurisdictions (JNCC does not require shutdown if mammals "voluntarily" enter the shutdown radius[9]), but we recommend that the Department adopt protocols whereby ANY time a "designated" marine mammal species enters the chosen "safety" radius that the array be shut down, or powered down. Designated species would be

[9] In our opinion this does not make sense if the purpose of a shut down in to limit a marine mammal's exposure to sound energy; whether the mammal enters the shutdown radius of its own accord should be immaterial.

selected prior to any seismic operations, and such designation would likely be species, location and season-specific (e.g., any large baleen whale would likely be designated, whereas smaller toothed whales might not be chosen as triggers for this type of mitigation).

Further, we recommend that a two-tier safety radii system should be defined where there is an inner zone for injurious effects (e.g., TTS, PTS, non-acoustic trauma), and an outer zone for “biologically significant” behavioural effects. How these are implemented will depend upon the species involved. For example, a SARA-listed species such as the right whale that enters the outer “safety” radius will require some action (shut down, alter speed and heading *if possible*) when entering the outer zone, while other, less-threatened species may only require these actions when they approach the inner zone.

Until there is sufficient data and analyses to show that seismic propagation models are reliable under a variety of conditions, field validation through near- and far-field recordings will remain essential and we recommend that it be standard practice. Reliability of a propagation model’s predictions depends not only on whether a given area has been modelled and calibrated beforehand, but also on the accuracy of the data that has been used to run it, and the temporal variability in the oceanographic conditions. Model inaccuracy can be as much due to improper assumptions and specifications about seasonal sound speed profiles as to the improper choice of model.

3. Buffer Zones (Geographical or Temporal Exclusion Zones)

The use of buffer and/or exclusion zones is likely a good mitigation measure for known critical habitat such as key feeding or breeding areas. However, for marine mammals we know relatively little about what defines critical areas or times so this type of approach may be problematic – hence the important of skilled seismic monitoring and pre-operational surveys and habitat studies. We recommend baseline studies and post-operational studies in areas where seismic is planned to occur and which have a high likelihood of being important habitat for at least one SARA-listed species. In this way DFO and the proponent can confirm whether or not these are areas of importance for the marine mammals of interest, whether the mammals’ use of these areas changes after the seismic operation (such as BACI studies), and whether mitigation measures are useful. These baseline and post-operational studies must be carefully designed over a long period of time so as not to confuse patterns of natural variability in habitat usage with potential effects of seismic.

In areas where SARA-listed species are present during critical times (migration, feeding, breeding, calving) the Department might recommend that no seismic operations be authorised until it can be shown that such operations will not have a significant impact on these biological activities. Even if there is doubt as to whether such a critical time exists, a precautionary approach could dictate that no seismic operations should be authorised by the Department.

Alternately, it has been suggested that in situations where endangered or critically endangered marine mammal species are present, it would be more appropriate to implement mitigation measures to prevent an unacceptable risk of harming these species. However, if the proponents cannot ensure that they detect these endangered mammals during seismic operations, than the Department cannot ensure that an individual will not find itself in a situation where damage can occur. In this context we recommend that very careful mitigation measures must be implemented, and BACI-type studies implemented. The risk assessment should reflect the availability of suitable habitat, and the potential severity of population level impacts for these marine mammals of concern.

4. Marine Mammal Monitoring

Despite its limited effectiveness during periods of darkness or poor visibility, visual monitoring still provides the easiest means to collect essential background data and support mitigation efforts when implementing array control (e.g., ramp-up and shut-down). We recommend that multiple, trained and experienced, and qualified[10] MMOs be employed on every seismic source vessel. These observers must have full authority to implement required mitigation procedures such as array shutdowns.

[10] Qualification could come through a written and visual identification test designed to provide a minimum acceptable standard for an MMO.

Experience and fatigue of the MMO, height of the observation platform, and visual aides employed are factors that affect detectability of marine mammals. It is therefore necessary to collect data on these variables in order to determine if detection rates are biased during a survey, and if the visual-based mitigation measures are effective.

Acoustic monitoring using towed arrays or active (high frequency) sonars to detect, identify, and track marine mammals near seismic source vessels is promising and encouraged, but is not recommended as a requirement until more studies demonstrate its effectiveness. If no airgun operation is permitted during times of poor visibility (at night, in fog, or in conditions of high sea state) then this would be a strong incentive for the exploration companies to support research into this experimental approach.

Aerial surveys can provide essential background data on marine mammal distribution and abundance relative to seismic exploration operational areas. However, they are of limited usefulness as a mitigation measure unless groups of right whales sighted in the path of the source vessel – a "guard vessel" is therefore a better platform for this type of mitigation. We recommend that the Department require aerial survey programmes prior to large-scale seismic operations in areas where there is either little information on marine mammal abundance and distribution, or where it is suspected that there is critical habitat or activities for SARA-listed species.

5. Alternate Means to Characterise Petrochemical Deposits

Some exploration companies have begun to investigate alternate sound sources and array configurations to minimize acoustic energy output. In particular, studies of the efficacy of towed marine vibrators or marine electromagnetic emitters as alternatives to airguns for petrochemical exploration should be encouraged and supported by the Department (perhaps through ESRF or COOGER funding).

We also recommend that modification of existing arrays (reducing source volume or array configuration) and the orientation of shot lines be such that sound exposure towards important areas for marine mammals is minimised.

Overall Summary and Suggestions For Further Study

A comprehensive review of the literature serves to emphasize the relative paucity of studies of marine mammal hearing sensitivity (especially for baleen whales), physical structure and underwater sound propagation characteristics of many Canadian hydrophysical areas, and the effects of seismic sounds on marine mammal hearing sensitivity or behaviour, both on an individual and population level. How reliably (repeatedly) these effects occur, the range of magnitudes of these effects, the range of "recovery times" after effects are detected, and the factors which seem to influence probability, magnitude, and time course of these effects are all types of data that remain limited for almost all marine mammal species.

This review {and that of LGL Ltd. (2004)} demonstrates the variation in marine mammal reactions to seismic sounds, and that fixed exposure criteria may be impractical given these variable reactions and the variable nature of sound propagation. A scientific approach to deriving exposure criteria for impulsive and continuous underwater sounds has begun in the United States with a team of international experts. When released, these well-researched criteria should be reviewed by DFO, and if scientifically sound accepted as Canadian standards.

Study of a number of issues (scientific, policy or other) related to the potential impacts of seismic sound on marine mammals are needed most urgently. The issues in most need of attention through scientific research or further analysis of existing data include:

(1) What are the best sound propagation models for the areas most likely to host seismic exploration? (This has been addressed somewhat by the recent review of acoustic models by JASCO.) Near-and far-field sound measurements should be standard requirements for any seismic operations planned for an area that has not been surveyed previously.

(2) There is a need for better and more accurate information on naturally occurring and man-made noise in the ocean. This would be addressed if the aforementioned field recordings also occurred during periods without seismic operations.

(3) There is a need for significantly more information regarding the reactions of marine mammals (and their prey) to underwater sound from seismic arrays. Baseline studies prior to seismic operations, plus comparative visual recording during periods with and without seismic would contribute important new data.

(4) Is ramp-up an effective mitigation method?

(5) Is passive and/or active acoustic monitoring of marine mammals from the source vessel an effective mitigation strategy?

(6) Possibly the most important scientific unknown limiting our ability to predict the potentially detrimental effects of seismic surveys on marine mammal populations is knowledge of their spatio-temporal distribution, and physiological state and needs. Without knowledge about what species are present in which areas at what time of the year and for what purpose, there will always be risks of disturbance and injury to sensitive species.

The scale, duration, and cumulative impacts of seismic exploration must also be considered when deciding to authorise a seismic project in an area that may be important to a SARA-listed marine mammal species.

The validity of any assessment regarding potentially harmful impacts of seismic sound on marine mammals will depend crucially on the accuracy and applicability of the models and the data used in this process. In particular, there is a need for better and more accurate environmental models (physical and biological), field validation of the models, more information on naturally occurring and man-made noise in the ocean, and significantly more information regarding the reactions of marine mammals to underwater sound (LGL Ltd. 2004). DFO will have to continue with a precautionary approach as it is unlikely there will ever be direct hearing sensitivity measures for the large whales, and behavioural reactions of marine mammals to seismic sounds will always be variable.

This document has concentrated on the elements of the physical environment that will effect seismic sound propagation in a number of broadly-defined hydrophysical regions within Canadian waters. The objective was to underline the complexities involved in developing protocols and standards for seismic exploration among the diverse physical environments making up the Canadian marine environment. However, ultimately the Department wants to understand the effects of seismic exploration on individuals and populations of living organisms that exploit these hydrophysical regions so as to find ways to minimise the impacts of this sound source. It is important to realise that due to the complex patterns of sound propagation in these diverse regions, some marine mammals may not necessarily encounter the average sound exposure conditions predicted for a seismic survey. Therefore we must determine and be sensitive to the worst-case conditions that can be encountered to ensure that we do not underestimate the impact upon a particular segment of a marine mammal population.

Especially when we are dealing with SARA-listed species, detrimental effects suffered by one individual can translate into detrimental effects on the population; in critical situations (e.g., the northern right whale and blue whale), the reduced fitness or loss of a single individual becomes a concern for the health and productivity of the population. The precautionary approach was designed for these circumstances. The onus falls on DFO to provide the necessary precautionary regulations and mitigation measures to ensure that no additional pressure is exerted on populations already at risk. This may entail extraordinary measures when endangered species are involved in critical behaviours (e.g., calving, feeding and migration), which might include closed areas and seasons, or operational shut downs when detection probabilities fall below certain standards due to sub-optimal observation conditions. (How scientists could provide input into the decisions by managers as to the scope and form of proposed seismic operations is outlined in Appendix C.)

Several of the hydrophysical regions described above (mainly the southern regions) are already subject to strong anthropogenic perturbation, both demographic in the form of significant and severe reductions in abundance of certain species, and acoustic in the form of noise from large commercial ship traffic, recreational vessel activities, and shoreline construction. The ambient noise in several localities can be considered as high. Therefore, in zones of high ambient noise, disturbance of natural behaviour is already a concern. In addition, high ambient noise will shorten detection distances thus shortening the reaction range available for fish and marine mammals to avoid vessels or predators. Although it can be argued that species resident within a noisy environment undoubtedly habituate to the increased noise levels and therefore may react less to an additional stimulus, this does not mean that the risk of reduced fitness is less. These resident animals may be more tolerant because they have already experienced significant hearing loss, thus diminishing their survival fitness, given the high importance that sound plays in the lives of marine mammals.

As DFO continues to move towards resource management within an ecosystem framework, we are becoming increasingly sensitive to the fact that multiple stakeholders (e.g., the ecotourism industry, living-resource harvesters, municipalities, NGO's etc.) rely on the same marine environment for their livelihood. To these established stakeholders, the regulatory approval of seismic exploration that has a potentially disruptive impact on their traditional activities is viewed with apprehension. Within several of the hydro-physical regions described in this document, there already exists the potential for direct and indirect competition for limited resources among stakeholders (e.g., harvesting of pelagic fish species that are important food for marine mammals, which in turn support a large and growing ecotourism industry). It is therefore the responsibility of both DFO and the seismic project proponents to proceed prudently, particularly where potentially fragile marine mammal populations are involved, to ensure integrated resource management, based on sound science and the involvement of all stakeholders.

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Table 1: Summary of major physical and biological features of the Gulf of St. Lawrence (termed in this review as an "enclosed continental shelf" hydrophysical region).

Hydrophysical Feature	Description[11]
Average Water Depth	60 m
Maximum Water Depth	535 m
Slope Features	Primarily little slope, with occasional canyons features
Salinity Patterns	Fresh water surface intrusion from the St. Lawrence watershed, intermediate salinities in the CIL and oceanic salinities in the deep bottom waters
Water Column Stratification	Highly thermally stratified: 2 layers in winter and 3 layers in summer
Bottom Composition	Highly variable and includes rocky, muddy and mixed types
Ambient Noise Levels	Maximum = 148dB; Minimum = 82dB
Main Human Noise Sources	Shipping, fishing vessels, tour boats, construction
Main Natural Noise Sources	Wind, fin and blue whale calls
Sound Speed Profile	Seasonal pattern according to creation of a CIL
Conservation Features	Saguenay Marine Park, proposed marine protected area
History of Seismic Exploration	Extensive seismic coverage (~33,000 km) throughout since 1968

Table 2. Data illustrating differences in acoustic properties between two NW Atlantic Ocean shelves, even through they border each other. The sound source is 40 Hz with a source level of 204 dB re 1 µPa, received at 150 km range. All units in dB.

Study Area	Transmission Loss	Ambient Noise	Signal Excess
Sable Island Bank	68	86	50
Southern Grand Banks	125	75	4

Table 3. Measured and estimated hearing thresholds for various functional categories of marine mammals (derived from Kastak and Schusterman 1995, Nachtigall et al. 1995, Richardson et al. 1995b, Nachtigall et al. 1996, Kastak and Schusterman 1998a, Tremel et al. 1998, Nachtigall et al. 2000).

	Hearing Threshold (dB)			
Hearing Limit	**Harbour Porpoise Type I**	**Bottlenose Dolphin Type II**	**Baleen Whale [a] Type M**	**Harbour Seal**
Low Frequency Limit	140dB@0.1kHz [b]	140dB@0.1kHz	<0.02kHz	100dB@0.7kHz
Best Hearing	45-50dB@8-30kHz	45-50dB@12-65kHz	60dB@0.02-6kHz[b]	65-70dB@12-35kHz

[a] Values for baleen whales are extremely speculative, and unconfirmed with direct measurements.

[b] Estimated.

[11] These features and their descriptions are geographic- and temporal-scale generalisations, and without field assessment cannot be assumed to represent every part of the proposed hydrophysical area, or different time periods.

Table 4. Maximum anthropogenic sound exposure criteria for different types of marine mammal receiver, subdivided by four sound characteristic categories and three-four effects types ranging from significant disturbance to injury.

Marine Mammal Receiver Type	Single Explosive Impulse[12]	Single Impulse	Repeated Impulse	Continuous Sound
Phocid Seal	Injury Criteria	Injury Criteria	Injury Criteria	
	PTS Criteria	PTS Criteria	PTS Criteria	PTS Criteria
	TTS Criteria	TTS Criteria	TTS Criteria	TTS Criteria
	Sign. Disturbance Criteria	Sign. Disturbance Criteria	Sign. Disturbance Criteria	Sign. Disturbance Criteria
Otariid Seal	*ditto*	*ditto*	*ditto*	*ditto*
Mid-frequency Hearing Small Cetaceans	*ditto*	*ditto*	*ditto*	*ditto*
High-frequency Hearing Small Cetaceans	*ditto*	*ditto*	*ditto*	*ditto*
Large Toothed Whales	*ditto*	*ditto*	*ditto*	*ditto*
Baleen Whales	*ditto*	*ditto*	*ditto*	*ditto*

[12] This type of sound is characterized by an extremely short signal rise time.

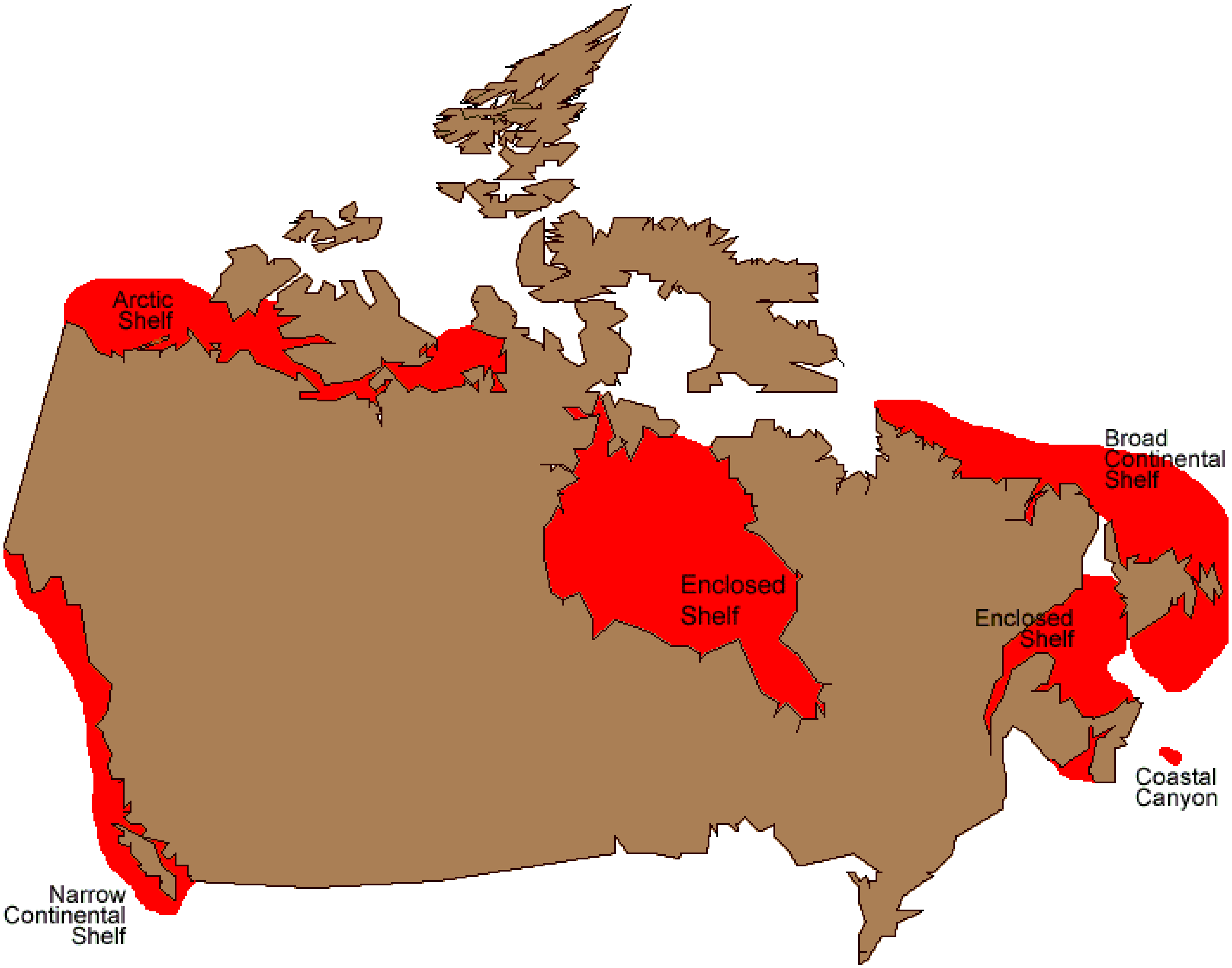

Figure 1. Canadian marine waters subdivided into five hydrophysical areas based on a number of broadly-defined physical features such as depth, bottom type, weather patterns, and surrounding land masses; there is likely overlap in these characteristics among the areas.

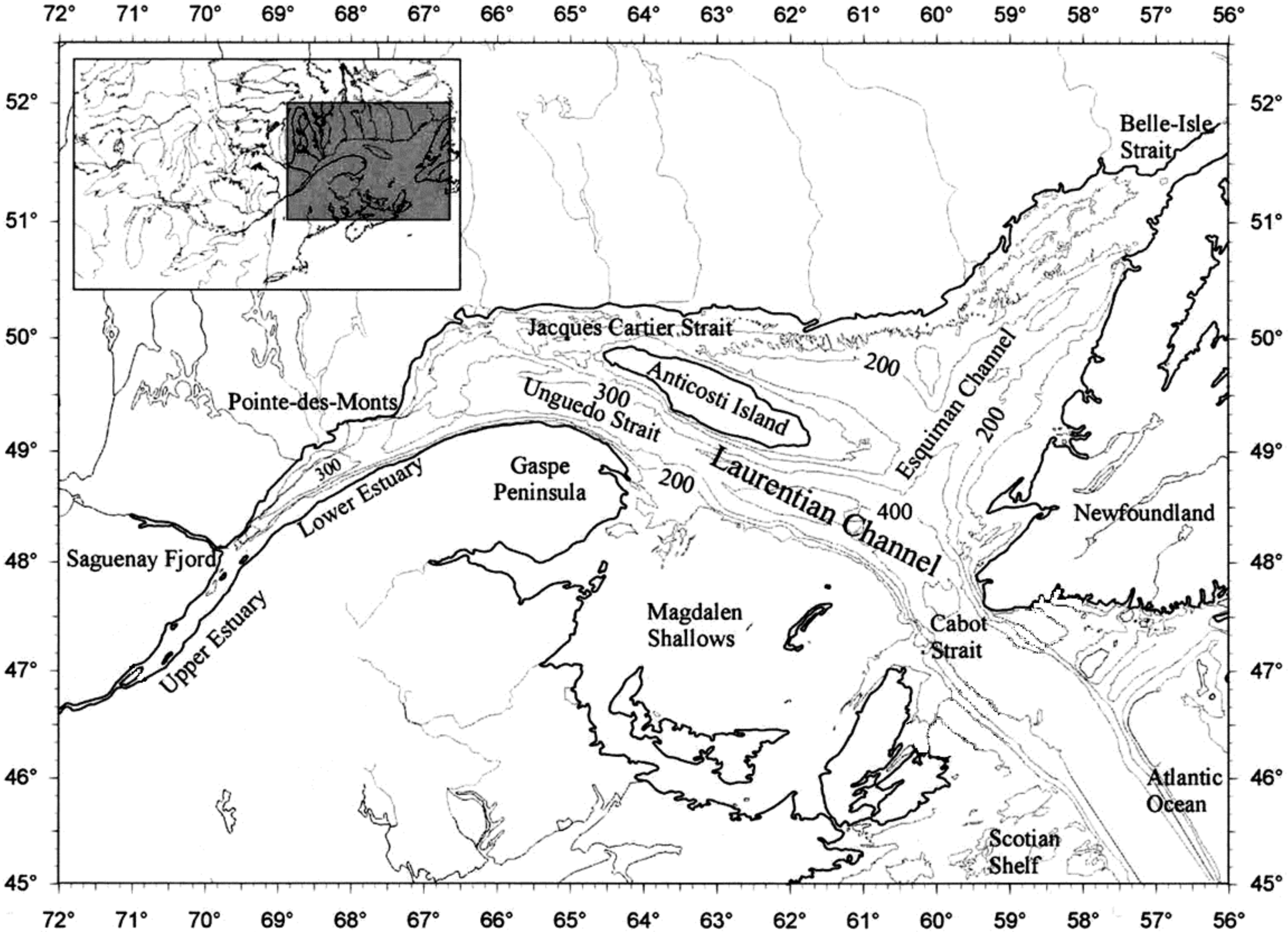

Figure 2. Gulf of St. Lawrence as an example of an “enclosed continental shelf” type of hydrophysical area (supplied by I. McQuinn, DFO).

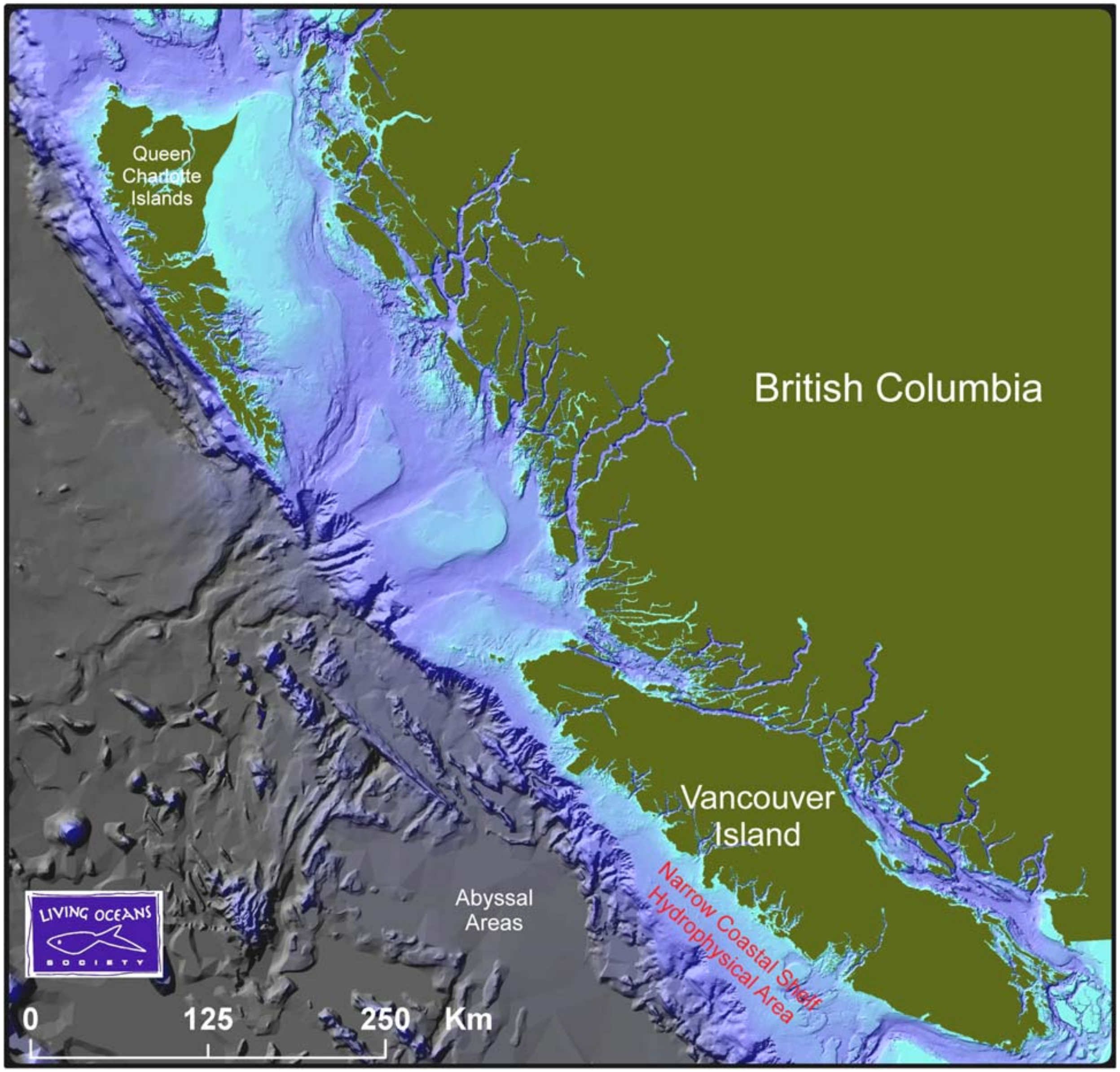

Figure 3. British Columbia coastal region as an example of a “narrow continental shelf” type of hydrophysical area (supplied by S. Vagle, DFO).

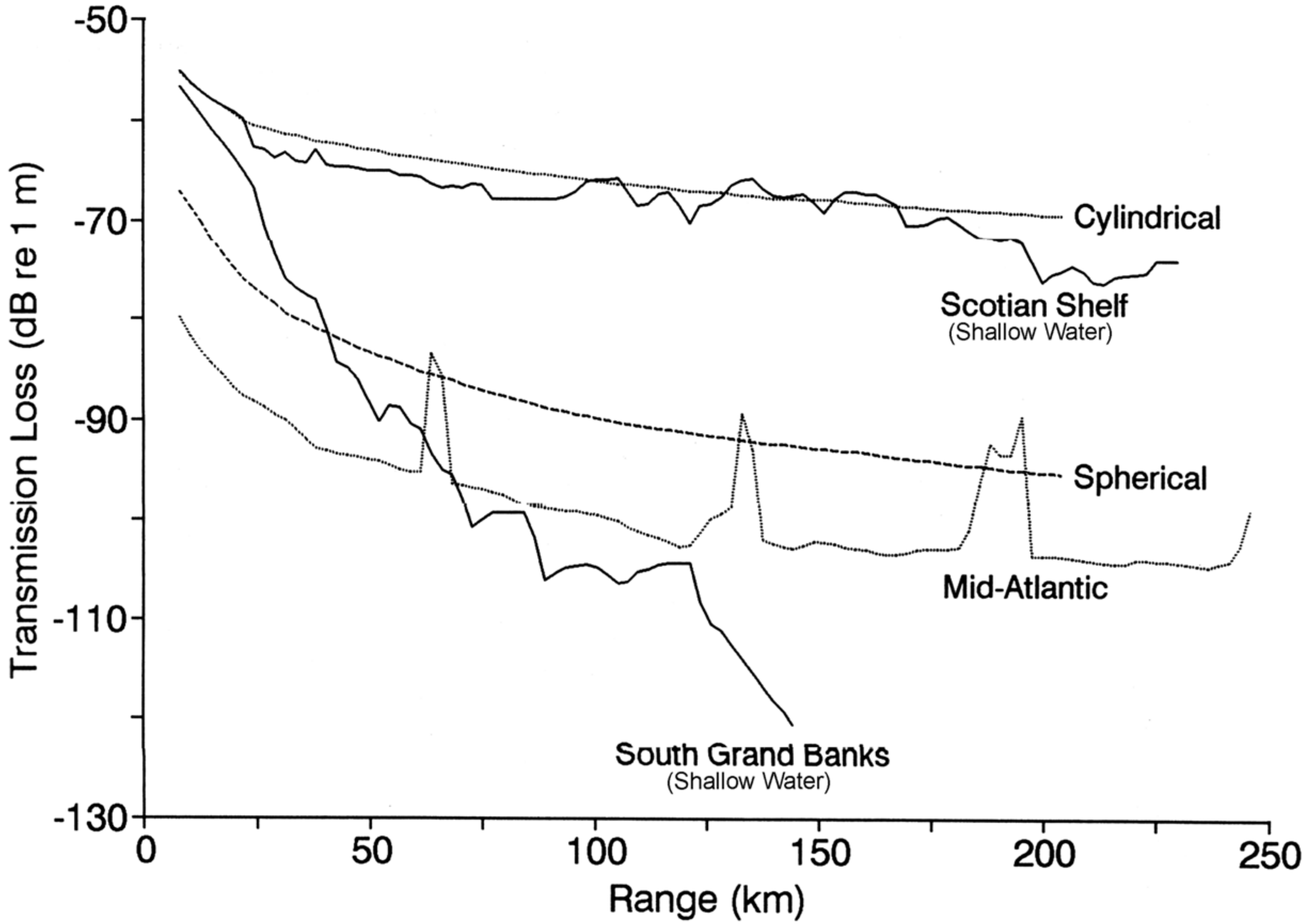

Figure 4. Propagation loss versus range for a 40 Hz sound travelling in shallow and deep waters of the Atlantic Ocean. Measurements from two shallow water areas (Scotian Shelf and South Grand Banks) illustrate the large differences in sound transmission loss that can occur as a result of different environmental conditions. Dotted lines are theoretical predictions for deep-water sites. Three "spike" features of reduced sound transmission loss on the mid-Atlantic curve are convergence zones. Modified from Stall (1985) and Richardson et al. (1995).

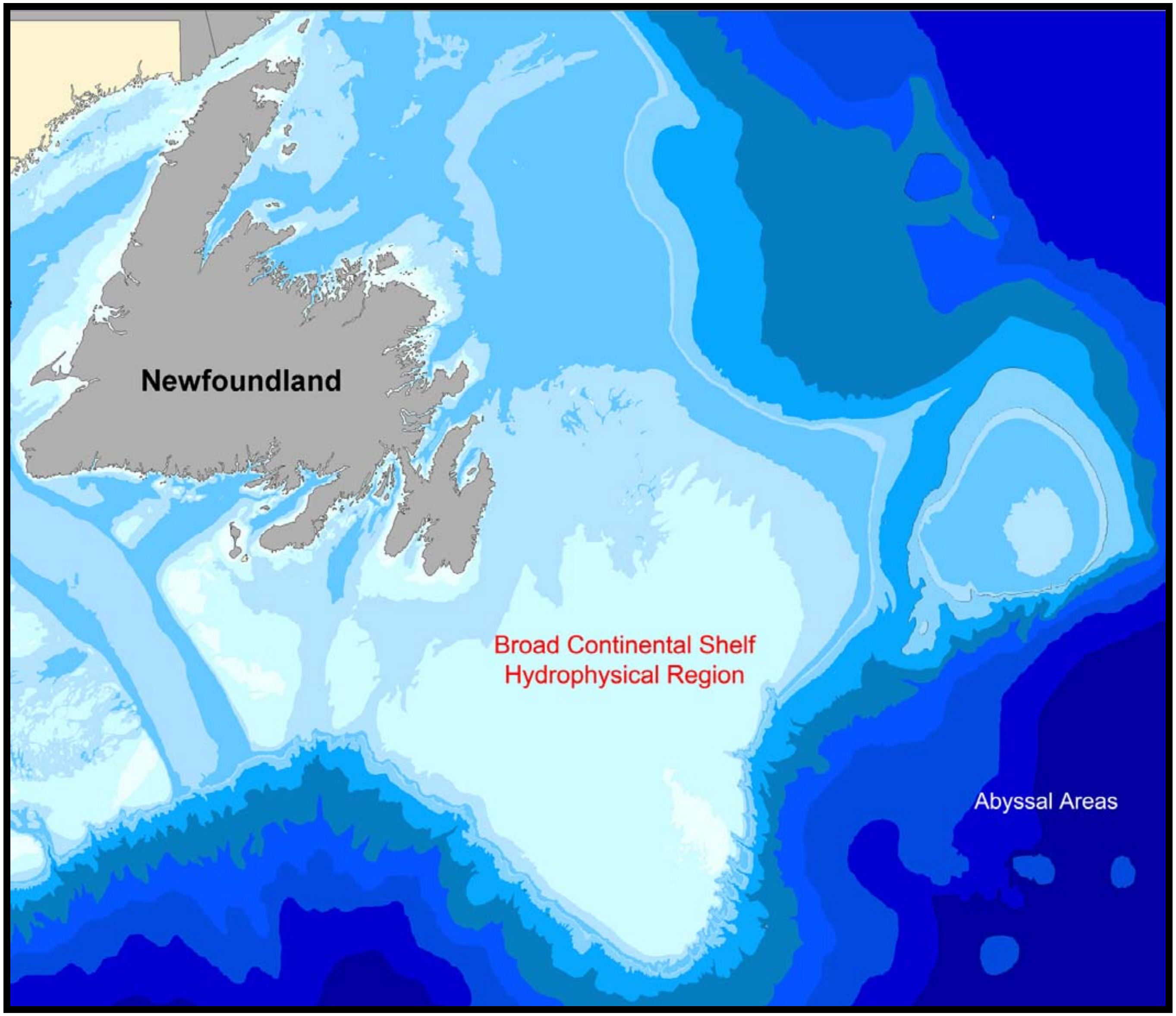

Figure 5. The Grand Banks of Newfoundland is an example of an “broad continental shelf” type of hydrophysical area.

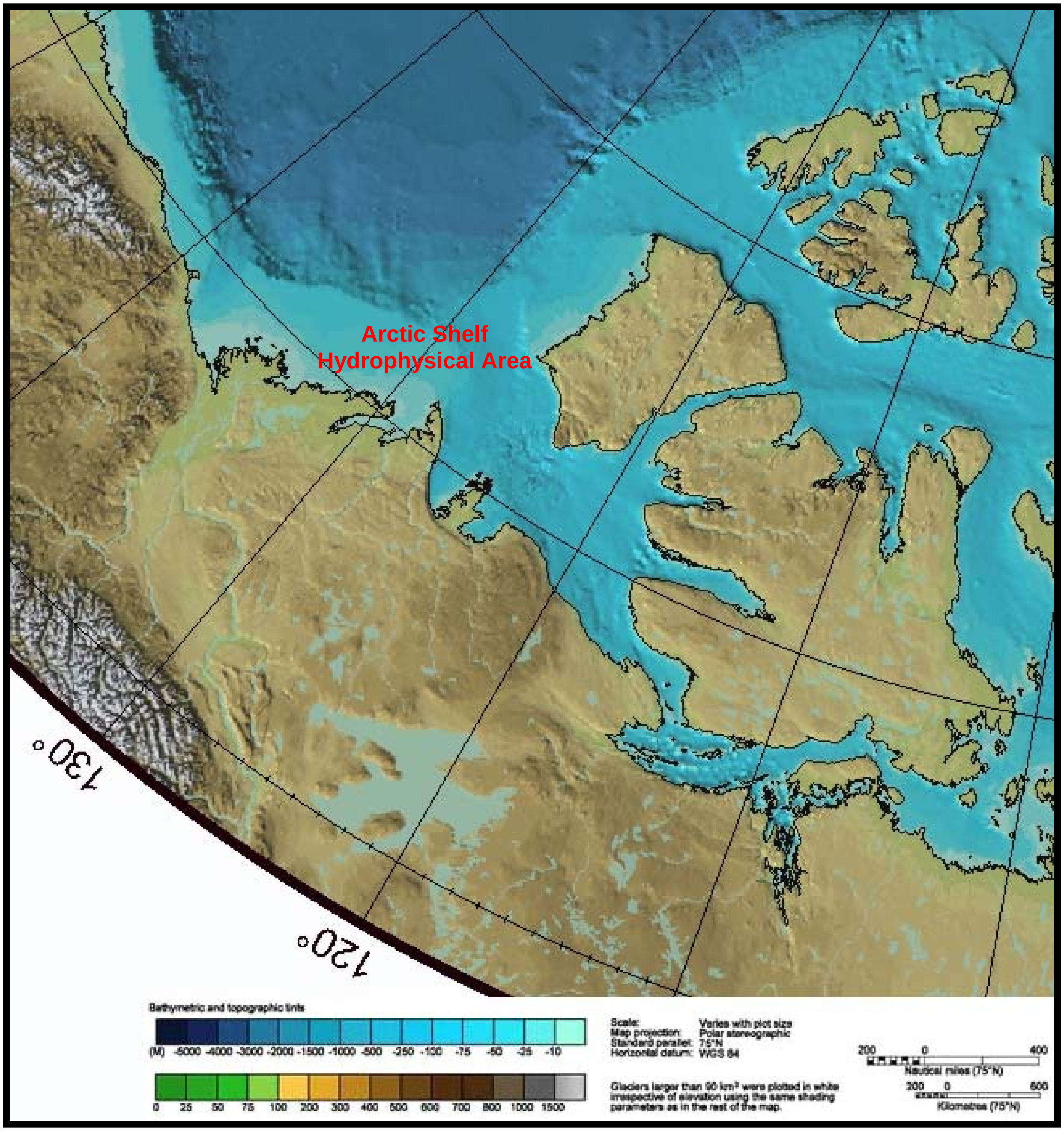

Figure 6. The western Canadian Beaufort Sea is an example of an “arctic shelf” type of hydrophysical area.

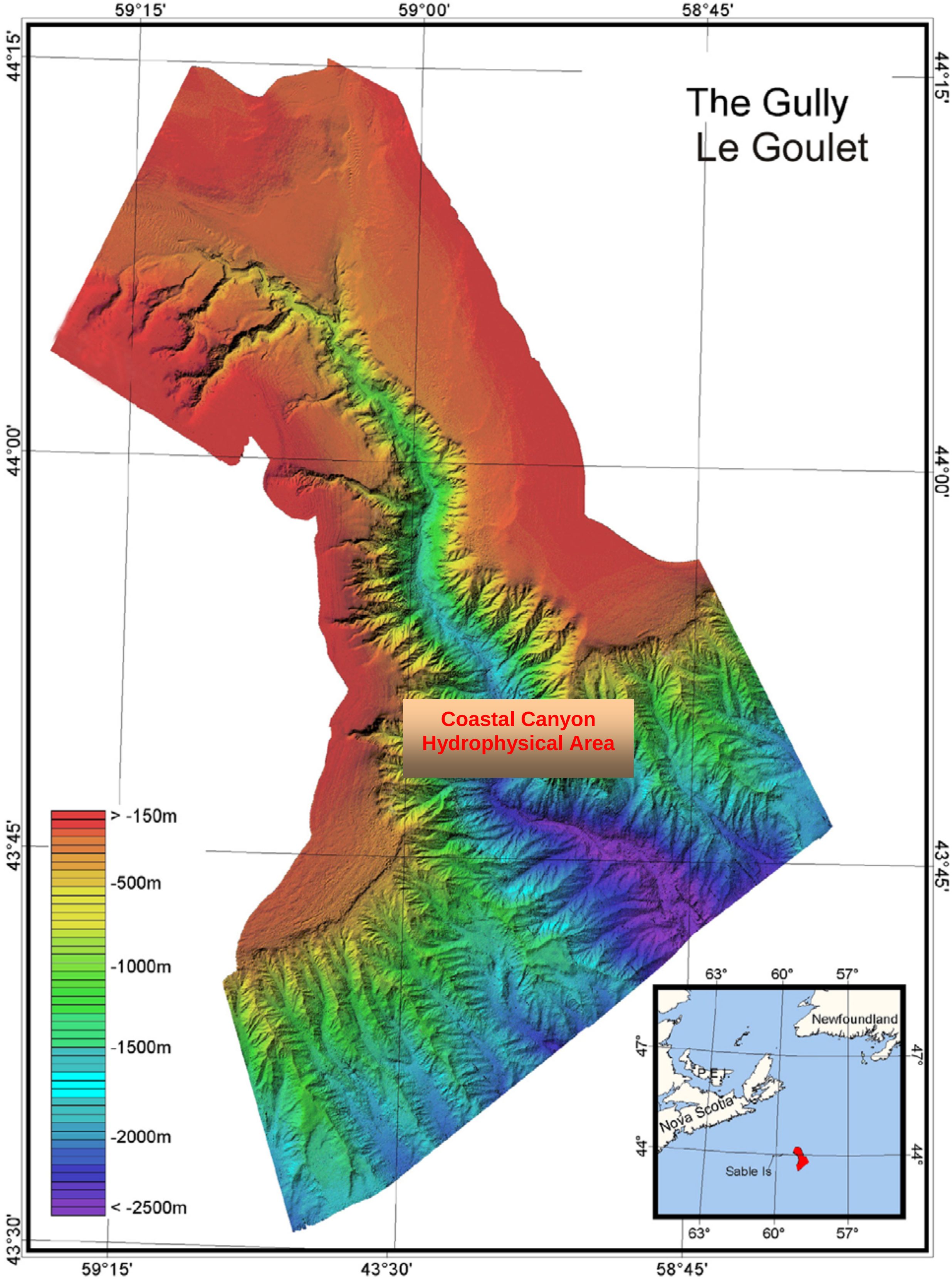

Figure 7. The Sable Gully as an example of an “coastal canyon” type of hydrophysical area.

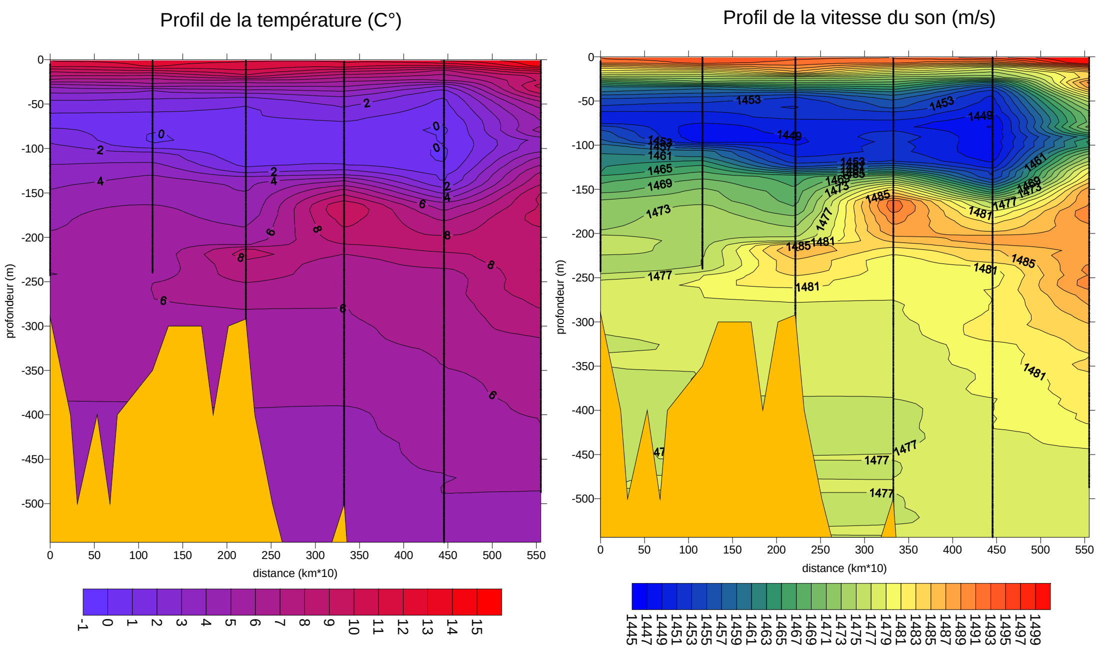

Figure 8. Line transect of temperature and sound speed profiles through the centre of the Sable Gully illustrating the sound channel produced by the CIL within this marine canyon (data from COOGER Gully Project).

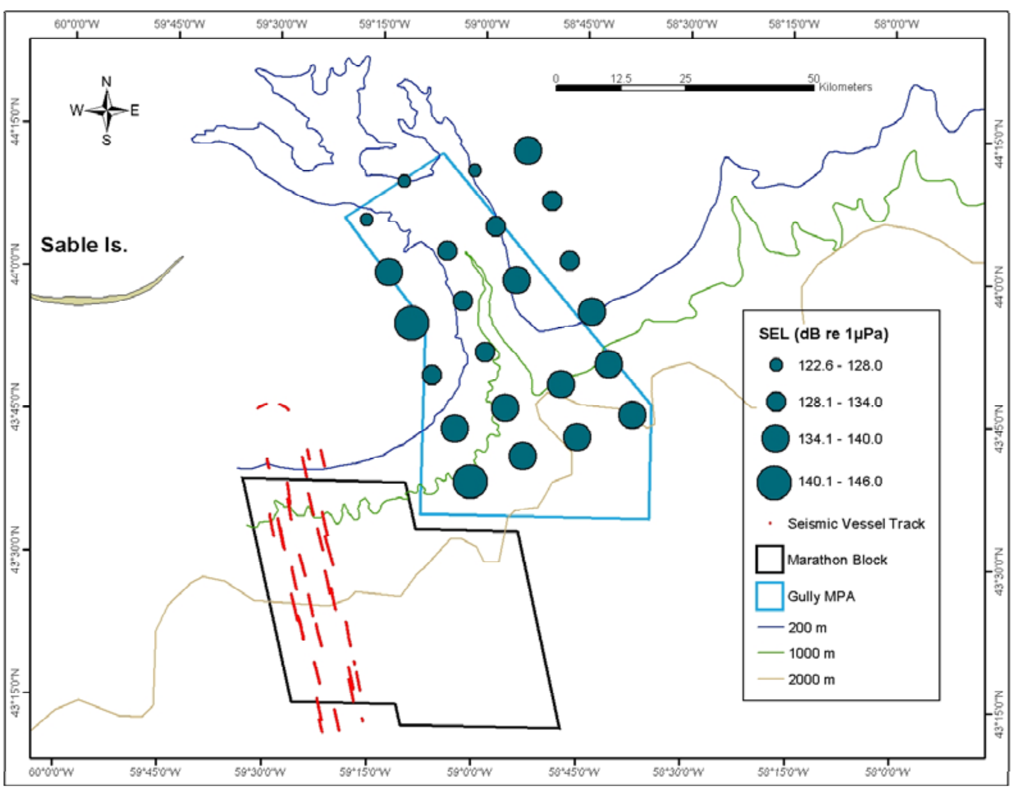

Figure 9. Measured average sound exposure levels (dB re 1 µPa) of seismic pulses (10-1000 Hz) emanating from within the Marathon Block in 2003. Data from COOGER Gully Project (McQuinn et al. 2004).

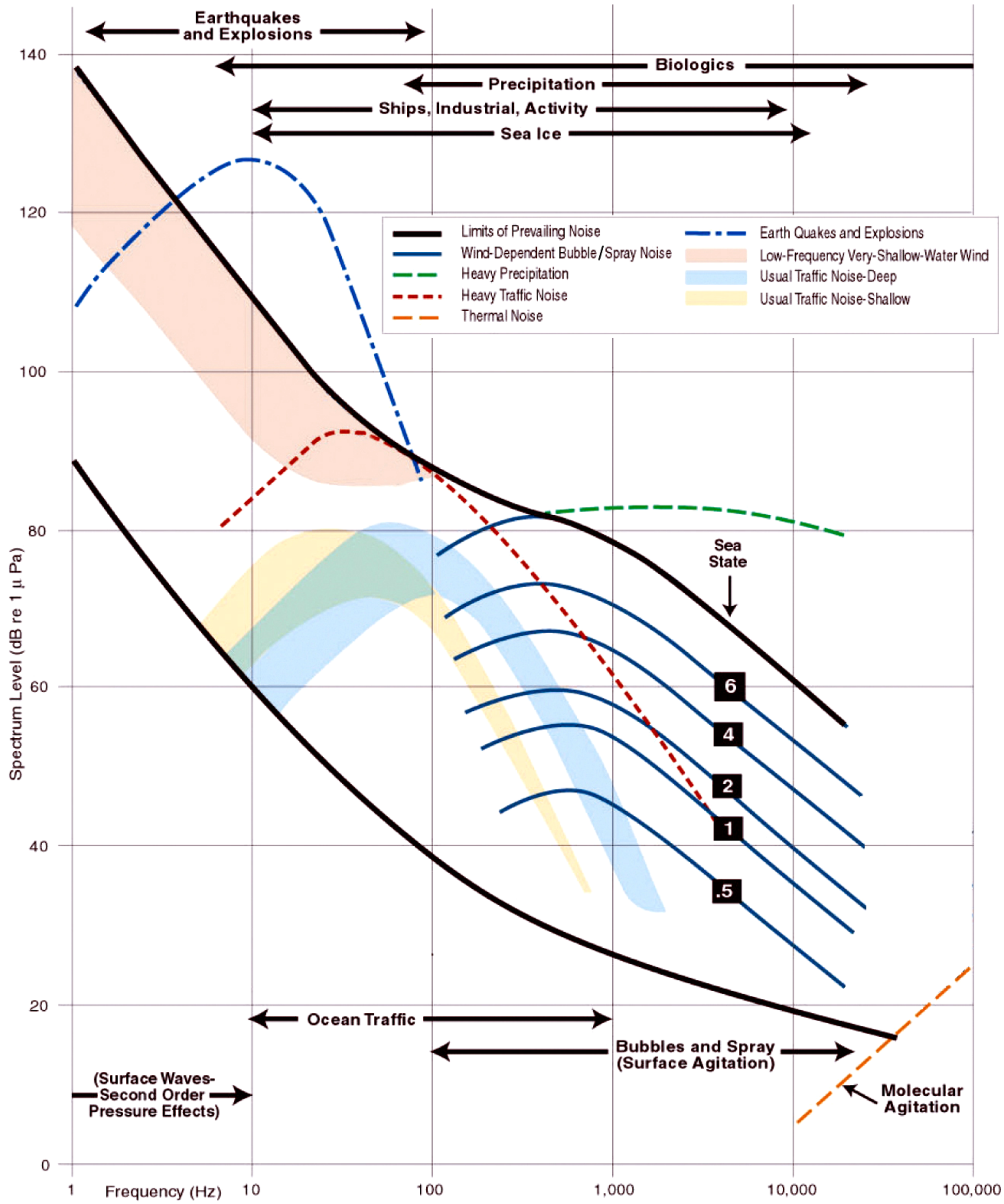

Figure 10. Schematic of the potential sources of sound that contribute to ambient noise in the ocean. Not only do sound sources vary in strength, but they can also be frequency-dependent (e.g., water thermal noise). Modified from NRC (2003) [adapted from Wenz (1962)].

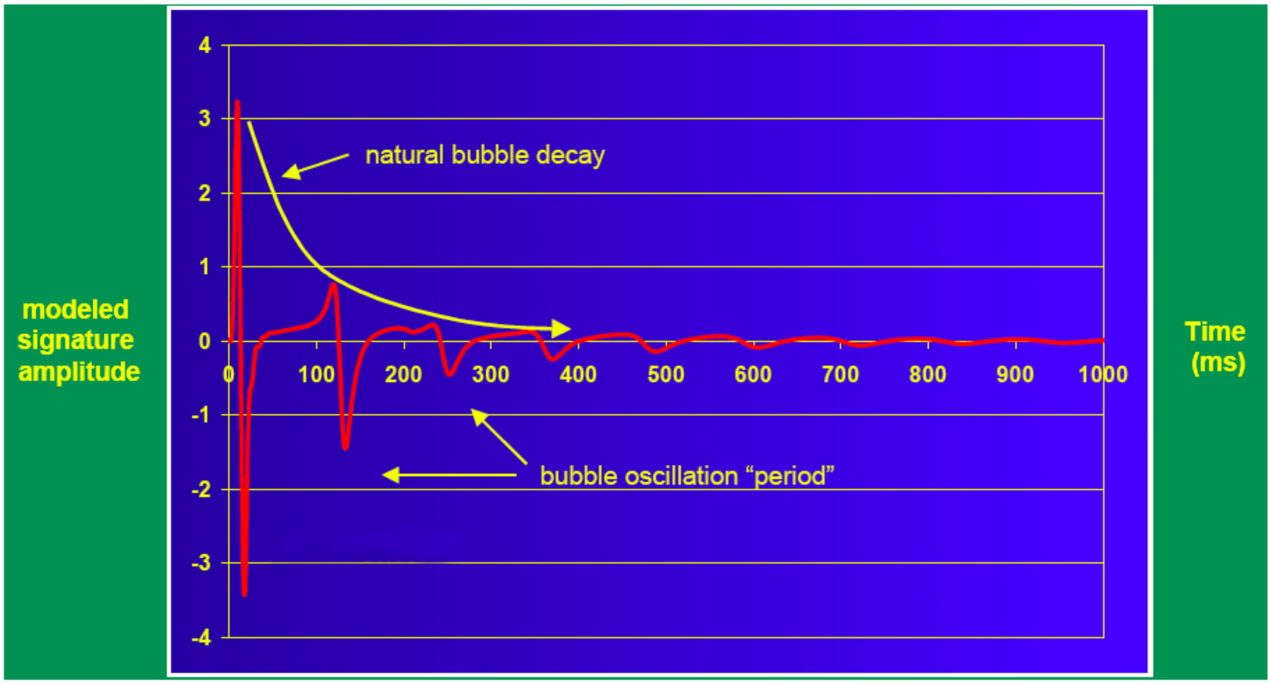

Figure 11. Schematic of the sound signature of an airgun illustrating form and duration o the primary pulse and oscillating signal created as the bubble decays. Adapted from Fontana (2002).

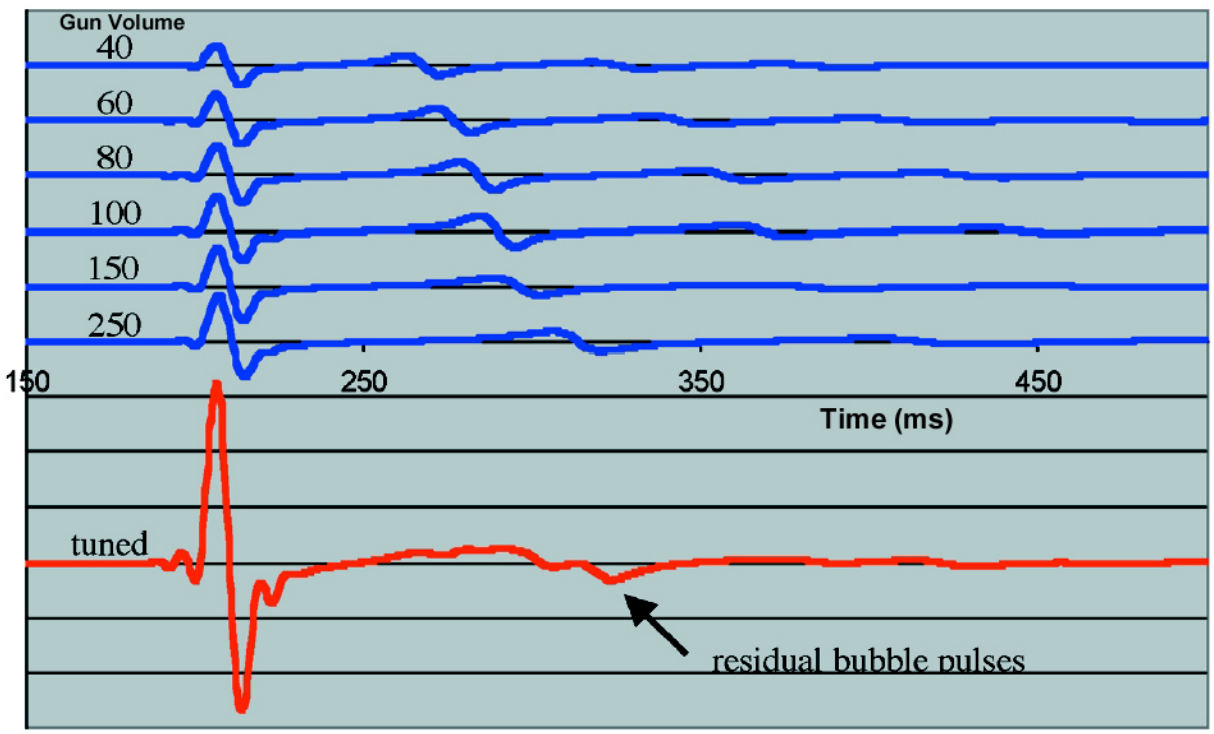

Figure 12. Schematic of the enhanced sound signal properties derived by using a tuned, multiple airgun array versus a single airgun. Sound signatures from individual guns are indicated in blue, while the coherent signal of these same airguns placed in an array and fired simultaneously is indicated in red. Adapted from Dragoset (2000).

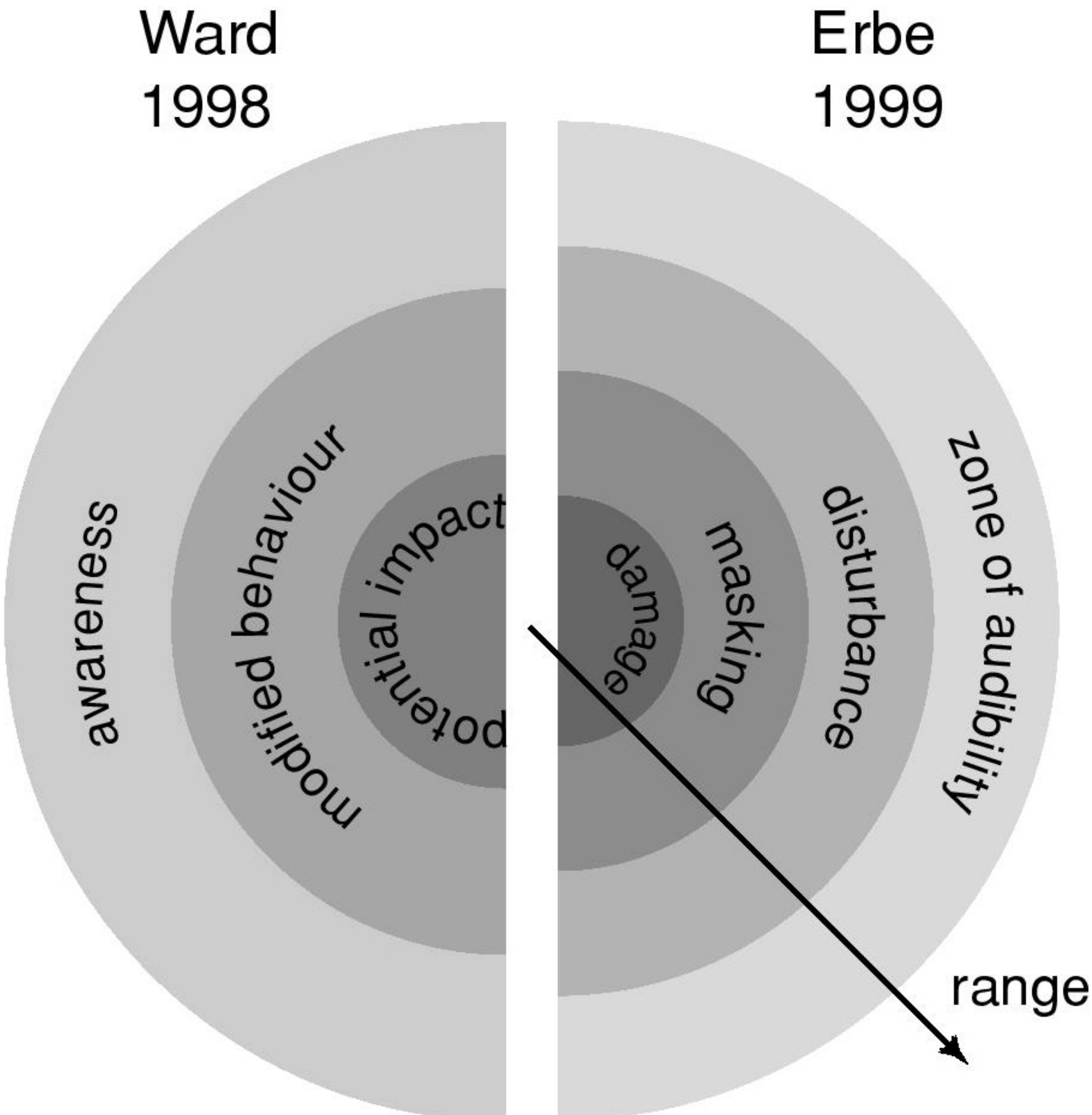

Figure 13. Two schematic representations of the range of effects marine mammals might experience at different distances between the sound source and the animal. The centre of represents the source, and distance from this source increases towards the outer margins of the circle (Ward et al. 1998, Erbe and Farmer 1999); the sizes of the zones within this figure are representative only and not drawn to scale.

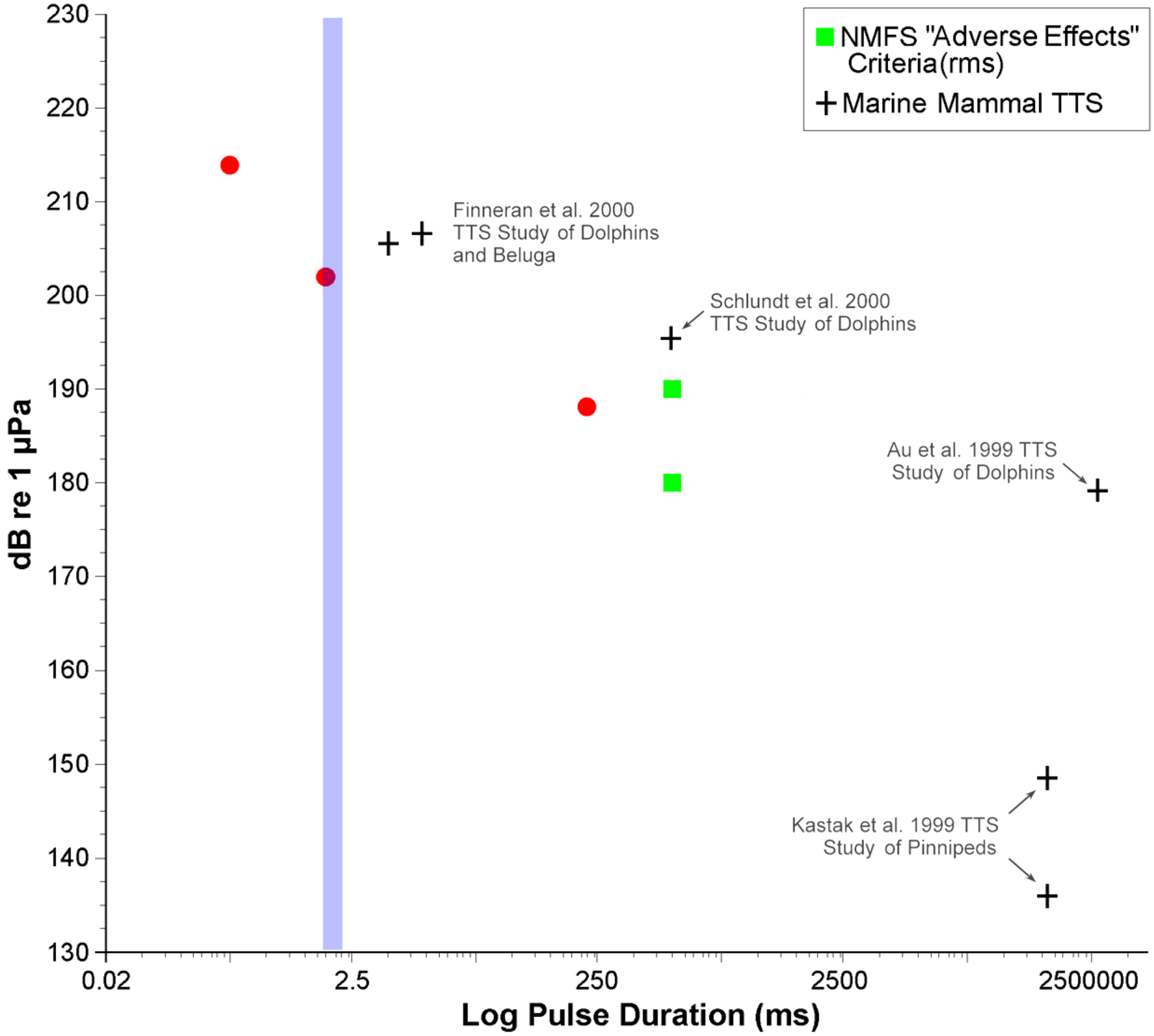

Figure 14. Levels of underwater sound that have resulted in TTS in marine mammals (black crosses) during captive studies using controlled sound exposures. The red dots represent the DRC safe single exposure sound exposure criteria for humans. The NMFS "adverse effects" criteria (green squares) are thought to be sound levels above which baleen whales or toothed whales and pinnipeds could experience TTS. The blue bar indicates the approximate pulse duration of a seismic array, in the near field; depending on airgun array design (e.g., air pressure, airgun sizes and arrangement), broadband source levels range from 235-259 dB re 1 µPa-m, zero-to-peak (Richardson et al. 1995b). Marine mammal data are from Au et al. (1999), Kastak et al. (1999a, 1999b), Finneran et al. (2000b), and Schlundt et al. (Schlundt et al. 2000).

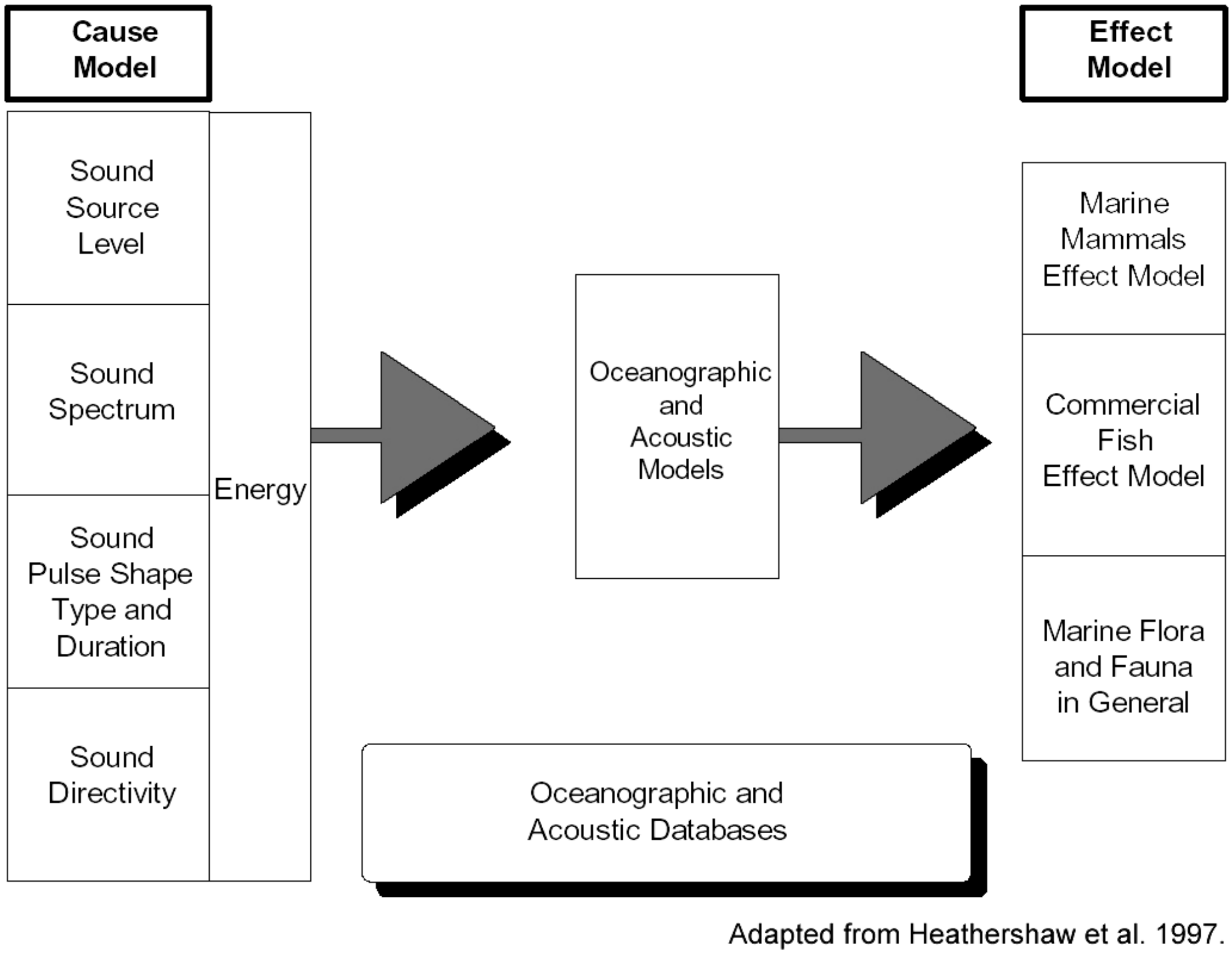

Figure 15. Schematic representation of the information input and processes required to estimate the types and magnitudes of effects an anthropogenic sound source might have on marine flora and fauna. The amount of data necessary to satisfy input requirements for each step in the modelling process can be large; to model potential variation in the system the entire process is repeated with various combinations of data (a bootstrapping approach).

Appendix A: Australian Seismic Operations – Guidelines For Minimising Acoustic Disturbance To Whales[13]

Introduction

Sound is a regular part of the marine environment, including reasonably high level sounds. Marine wildlife has evolved to live with and communicate using sound and some wildlife use sound to communicate over long distances. However intense sounds are a potential source of interference with marine wildlife going about their normal life strategies.

Environment Australia has identified as 'being of interest', due to the potential to interfere with cetaceans, those impulsive sound sources (short and sharp signals) that have a measurable sound of ≥150 dB re 1μPa "*mean squared pressure"* (see Appendix 1 for definition) as measured at 300 metres from the sound source (or ≥140 dB re 1μPa in category C or D areas). Sound sources that meet this requirement are particularly of interest if they are a) moving and b) the sound is continuous or continuously repeated over a period of days to weeks. Sounds over this level are known to cause significant behavioural changes in whales (swimming away from the source, swimming rapidly on the surface to avoid the source, repeated breaching etc), and it is for this reason that this sound level has been chosen. The distance at which the sound level is measured is based on the 'caution zone' outlined in the EPBC (*Environment Protection and Biodiversity Conservation Act 1999)* Regulations, that state that within 300 metres of a whale a no wake speed should be used and sound kept to a minimum.

Environment Australia consider that, unless measures are taken to avoid interference, sound sources meeting the above criteria are likely to interfere with a cetacean, and may be considered significant and/or require a permit under the EPBC Act.

Marine seismic surveys, which are essentially using a large sound source to identify seafloor geology, do not necessarily constitute a threat to whales if care is taken to avoid situations that could potentially have biologically significant effects on individuals or populations.

The Australian Petroleum Production and Exploration Association (APPEA) and Environment Australia have introduced the following guidelines, which are aimed at avoiding acoustic interference with whales during seismic surveys.

The guidelines have two basic precepts;

1. that measures should be taken to avoid a seismic vessel approaching a cetacean such that the cetacean will not experience sound levels above 150 dB re 1μPa (*mean squared pressure*) or above 140 dB re 1μPa (*mean squared pressure*) in category C or D areas;
2. that some locations and some periods of the year are more 'sensitive' than others in terms of the likely impact of interference, and greatly increased vigilance is required at these times to ensure that cetaceans are not approached.

Environment Australia would state that for a cetacean to be interfered with by sound would a breach of the Act unless a permit has been obtained.

The guidelines are designed to give guidance as to the likely distances required for normal seismic operations to not 'breach' the 150 dB re 1μPa level (*mean squared pressure*), to identify those areas and times agreed to be of increased sensitivity, and to identify the measures agreed to be appropriate if operations are to be undertaken in areas of different sensitivity.

It is however recognised that no two seismic operations are exactly the same and that companies may wish to adopt different approach distances if they are operating a particularly large or particularly small (for example geotechnical) acoustic source.

Application of the Guidelines

For the purpose of applying these guidelines, whale habitat in Australian waters has been separated into four categories: Category A, B, C and D. The definition of these different habitat categories is given in the

[13] For a thorough review of international monitoring and mitigation protocols, see LGL Ltd. (2004).

table below. The application of procedures described in these guidelines is phased to take into account the increasing need to minimise acoustic disturbance to whales from Category A to Category D habitats. This phased approach is outlined below.

Habitat Category	**Procedures**	
	Higher Energy Acoustic sources (air gun sources >100 in^3 capacity)	Low Energy Acoustic sources (geotechnical, bathymetric surveys with air gun sources <100 in^3)
Category A Offshore waters outside known migratory paths and periods	*Visual observations* *Delay procedures* *Soft start procedures* *Whale watch / stop work procedures*	*Reduced distances* *Visual observations* *Delay procedures* *Soft start procedures*
Category B1 Known Humpback whale migration pathways during migration periods but outside peak periods, and all inshore waters	*Visual observations* *Delay procedures* *Soft start procedures* *Whale watch / stop work procedures* *Night time operations procedures*	*Reduced distances* *Visual observations* *Delay procedures* *Soft start procedures*
Category B2 Known Humpback whale migration pathways during peak migration periods Mapped migratory 'paths' of Southern right whales and Blue whales during presumed migration periods	Operations in these areas are likely to result in interference even where mitigation measures are taken. A permit, if granted, is likely to include many of the following requirements: *Visual observations by trained and dedicated observers* *Delay procedures* *Soft start procedures* *Extended Whale watch / stop work procedures* *Night time operations procedures* *Aerial surveys – as appropriate, decided case-by-case* *Use of stand-off vessels to monitor interactions (assessed on a case-by-case basis)*	*Reduced distances* *Visual observations by trained and dedicated observers* *Delay procedures* *Soft start procedures* *Whale watch / stop work procedures* *Use of stand-off vessels to monitor interactions (assessed on a case-by-case basis)*

Habitat Category	Procedures	
Category C1 Recognised mapped aggregation areas or feeding areas within inshore or offshore areas **Category C2** Inshore waters that overlap known calving areas or periods, or resting areas for females with calves when calving females are present A 'buffer zone' of 20 km extends around each detailed aggregation area identified.	Operations in these areas are likely to be considered significant under the Act Conditions of approval, if approval is given, are likely to include: Category B1 procedures **plus**: *Extended whale watch/ stop work distances* *Aerial surveys* *Use of trained cetacean observers* *Use of stand-off vessels to monitor interactions (assessed on a case-by-case basis)*	Operations in these areas are likely to be considered significant under the Act Conditions of approval, if approval is given, are likely to include: *Visual observations* *Delay procedures* *Soft start procedures* *Whale watch / stop work procedures Use of trained cetacean observers* *Use of stand-off vessels to monitor interactions (assessed on a case-by-case basis)*
Category D Areas and times within Categories A, B or C identified as Critical Habitat under s207A of the EPBC Act. (At present, no areas have been identified under this category).	Operations in these areas are almost certain to be considered significant under the Act Conditions of approval, if approval is given, are likely to include: Category B1 procedures **plus**: *Extended whale watch/ stop work distances* *Aerial surveys* *Use of trained cetacean observers* *Use of stand-off vessels to monitor interactions*	Operations in these areas are almost certain to be considered significant under the Act Conditions of approval, if approval is given, are likely to include: Category C procedures **plus**: *Whale watch/ stop work procedures* *Aerial surveys* *Use of trained cetacean observers* *Use of stand-off vessels to monitor interactions*

The visual observation, delay and soft start procedures described in these guidelines shall be applied as standard operating procedure on all marine seismic and geo-technical surveys conducted in Australian waters. If a survey is operating over known migration paths and periods the whale watch / stop work and night time operations procedures described herein will be applied in addition to the visual observation, delay and soft start procedures. Additional requirements will apply during the peak migration period. Surveys in recognised aggregation areas or feeding areas or in inshore waters that overlap known calving areas or periods, or resting areas for females with calves when calving females are present or within 20 km of known calving areas/periods and resting locations for migrating females with calves will, where practicable, be avoided. Where it proves impractical to avoid seismic surveys in these Category C habitats, all of the procedures described in these guidelines are likely to be applied. In these cases, the application of additional procedures, including but not limited to extended whale watch/ stop work distances, aerial surveys, use of trained cetacean observers, use of stand-off vessels monitoring interactions and passive acoustic monitoring, will be considered on a needs basis.

The guidelines apply to all whales usually encountered in Australian waters. All cetaceans are protected under the *Environment Protection and Biodiversity Conservation Act 1999*. Some species are also listed as threatened or migratory and are of particular concern due to their conservation status. Such whales include, but are not limited to blue whales, southern right whales, humpback whales, fin whales and sei whales.

These guidelines incorporate procedures already developed and adopted by operators in Australia and overseas, including the Western Australian Department of Minerals and Energy procedures and the UK Joint Nature Conservation Committee guidelines.

Application of these guidelines will be part of the implementation strategy of Environment Plans for each seismic survey in Commonwealth waters, submitted by the operator and accepted by the Designated Authority under the *Petroleum (Submerged Lands) (Management of Environment) Regulations 1999*.

Operations

VISUAL OBSERVATIONS

- During daylight hours, a visual check (using binoculars from a suitable, high observation platform on the survey vessel) for the presence of whales will be made before the commencement of operations.
- Observations will begin at least 30 minutes prior to use of any high energy acoustic sources, with particular focus on a 3 km radius around the survey vessel.
- Indicators of whale activity may be in the form of blows and surface activity resulting in large splashes.
- Visual observations will be carried out every hour during seismic operations in daylight hours. These observations will be of 10 minute duration in areas of category A or B1.
- In areas of category B2 or higher, a case-by-case assessment will be made to ascertain if observations are extended. These may be up to 30 mins every hour by a trained and dedicated cetacean observer in B2 areas and may be required continuously in category C areas. The nominated observer is additional to standard bridge crew members and will have some experience with whale observations.
- Whale observations become increasingly difficult as sea state and wind speeds increase. An upper limit for practical whale observation is sea state 5 or less than 20 km wind speed. This coincides with the operational weather limits for most seismic vessels.

RANGE FINDING TECHNIQUES

A practical and reliable method to accurately determine the range of a marine mammal from a ships bridge is to measure the angle of the whale below the horizon. By then using standard formula which take into account the earths curvature and refraction, and using the known height of eye of the observer, a reasonable estimate of the whale range can be calculated. The Norie's Nautical Almanac has standard tables and formula for calculating range from angles below the horizon. There are two methods of measuring angles below the horizon:

- range finding binoculars which have a graticule of set angle increments fixed in one eyepiece, the number and fraction of graticule units from the whale to horizon gives the angle below the horizon;
- sextant angles below the horizon, these provide the most accurate measure, and although require some experience at using and reading a sextant, are relatively easy to measure, although care needs to be taken whether reading the angle off or on the arc

DELAY

- Discharge of the acoustic sources will not commence unless whales are a minimum distance of 3 km from the survey vessel.

- If whales are detected within this zone the start up of acoustic sources will be delayed until they have been observed to move away, allowing adequate time after the last sighting (at least 30 minutes) for the animals to move well out of range.

SOFT STARTS

- A sequential build-up of warning pulses will be carried out for line starts, in the event that the acoustic source has been shut down. The whole array will not be fired without a full soft start. Soft starts will be used even if no whales have been seen.
- The soft start procedure involves a gradual increase in the number of air-guns fired over a 20 minute period prior to commencement of a line, and serves to send out a series of warning pulses to deter whales and give them adequate time to leave the vicinity.
- Visual observation will be maintained continuously during soft starts to establish the presence or absence of whales within 3 km of the vessel.
- If whales are sighted during this soft start procedure within the 3km zone, the seismic source will be shut down. Re-commencement of soft start procedures will take place after 30 minutes has lapsed since the last whale sighting.

WHALE WATCH / STOP WORK

- It is important to monitor the behaviour of any whales that may be approaching the stop-work distance. Ascertain what the whale is doing and the direction it is travelling. If it is seen to be heading away from the seismic vessel, a shut down may not be necessary.
- In the event that an individual whale is seen to approach a seismic vessel whilst the acoustic source is operating, the shut down distance applied will be 3 km. Seismic source operations will not recommence until the group has been seen to move outside of a 3 km range, or has not been seen for 20 minutes.
- There will be continued discharge of the acoustic source during line turns or changes. Discharge of only a limited number of air-guns in the acoustic array would be sufficient in this case.

NIGHT TIME OPERATIONS

- During night time operations, the use of Infra-Red (IR) or night-vision binoculars for hourly observations will be considered. If utilised, night time visual observations will also be of 10 minute duration.

AERIAL SURVEYS

- Two types of surveys are envisaged and the requirement for either of both will be assessed on a case-by-case basis, considering associated logistics, costs and risks involved:

1. Aerial surveys to identify where cetaceans were in relation to seismic activity and identify when seismic vessels should be more vigilant. These surveys would be run between the areas to be surveyed by the seismic vessel and the likely approach direction of cetaceans, or in the area in advance of the survey vessel.
2. ‘Scientific’ surveys to identify which areas are important to cetaceans e.g., to identify breeding and resting areas and times of peak migration (similar to the study on humpbacks off WA). These surveys will have some linkages to seismic activities, especially in areas of potential increased sensitivity (C or D) where insufficient information exists to determine timing and appropriate management arrangements.

STAND-OFF VESSELS

- The major purposes of stand-off vessels are to:

1. Assist in identifying where cetaceans were in relation to seismic activity and identify when seismic vessels should be more vigilant; and

2. ‘Scientific’ surveys to identify which areas are important to cetaceans e.g., to identify breeding and resting areas and times of peak migration.

The requirement for a stand-off vessels for either of both of these reasons will be assessed on a case-by-case basis, considering associated logistics, costs and risks involved.

Recording & Reporting

- Any whale sightings will be recorded on the *Environment Australia Whale and Dolphin Sighting Report* form (attached). This form is also available in electronic format.
- At completion of the seismic survey, copies of all report forms will be submitted to:

Environment Australia, Marine Species Section

GPO Box 787 Canberra ACT 2601

These guidelines are in force from 1 January 2001 until 30 June 2003.

Appendix B: Summary of Potential Impacts of Seismic Sound Exposure on Marine Mammals

Source of Risk From Exposure to Seismic Sounds	Type of Receiver	Evidence of Effect (hypothetical, lab experiment, field observation)	Geographic Scale of Risk to Individual	Temporal Scale of Consequence to Individual	Probability of Effect at Individual Level	Severity of Effect at Individual Level [c]	Would Existing Mitigation Measures Reduce the Risk or Severity From Exposure to Seismic Sounds?
Direct mortality	Pinnipeds	No evidence (but poorly studied)	Short range [b]	Long-term	Low	High	Yes
	"Low-frequency hearer" Toothed Whales [a]	No evidence (but poorly studied)	Short range	Long-term	Low	High	Yes
	"High-frequency hearer" Toothed Whales [a]	No evidence (but poorly studied)	Short range	Long-term	Low	High	Yes
	Baleen Whales	No evidence (but poorly studied)	Short range	Long-term	Low	High	Yes
PTS	Pinnipeds	No evidence from lab studies	Short range	Long-term	Low	High (even given alternate sensory modalities)	Yes
	"Low-frequency hearer" Toothed Whales	No evidence from lab studies	Short range	Long-term	Low	High	Yes
	"High-frequency hearer" Toothed Whales	Not studied	Short range	Long-term	Low	High	Yes
	Baleen Whales	Not studied	Short range	Long-term	Low (given their putative hearing sensitivity at low frequencies)	High	Yes
TTS	Pinnipeds	Lab evidence (watergun source, atypical exposures)	Short range	Short-term	Low	Low unless repeated	Yes
	"Low-frequency hearer" Toothed Whales	Lab evidence (watergun source, atypical exposures)	Short range	Short-term	Low	Low unless repeated	Yes
	"High-frequency hearer" Toothed Whales	Lab evidence (watergun source, atypical exposures)	Short range	Short-term	Low	Low unless repeated	Yes
	Baleen Whales	Not studied	Short range	Short-term	Low	Low unless repeated	Yes

Source of Risk From Exposure to Seismic Sounds	Type of Receiver	Evidence of Effect (hypothetical, lab experiment, field observation)	Geographic Scale of Risk to Individual	Temporal Scale of Con-sequence to Individual	Probability of Effect at Individual Level	Severity of Effect at Individual Level [c]	Would Existing Mitigation Measures Reduce the Risk or Severity From Expo-sure to Seismic Sounds?
Damage to non-auditory body tissues	Pinnipeds	Not studied	Short range	Short to long term (trauma dependent)	Low	Low to high (trauma dependent)	Yes
	"Low-frequency hearer" Toothed Whales	Not studied	Short range	Short to long term (trauma dependent)	Low	Low to high (trauma dependent)	Yes
	"High-frequency hearer" Toothed Whales	No evidence (but poorly studied; possible exception is Ziphiid stranding)	Short range	Short to long term (trauma dependent)	Low	Low to high (trauma dependent)	Yes
	Baleen Whales	Not studied	Short range	Short to long term (trauma dependent)	Low	Low to high (trauma dependent)	Yes
Reduced Communication Efficiency?	Pinnipeds	Not studied	Short range	short to long term (behavior dependent)	Low (given their likely short range of vocal communication)	Low except during biologically critical periods	Yes
	"Low-frequency hearer" Toothed Whales	Not studied	Short range	short to long term (behavior dependent)	Low (given their likely short range of vocal communication)	Low except during biologically critical periods	Yes
	"High-frequency hearer" Toothed Whales	Not studied	Short range	short to long term (behavior dependent)	Low (given their likely short range of vocal communication)	Low except during biologically critical periods	Yes
	Baleen Whales	Evidence of call masking	Long range	short to long term (behavior dependent)	High (given their likely long range of vocal communication)	Low except during biologically critical periods (e.g., breeding)	Yes
Reduced echolocation efficiency?	Pinnipeds	NA	NA	NA	NA	NA	NA
	"Low-frequency hearer" Toothed Whales	Not studied	Short range	Short term	Low	Low if feeding / high if navigating	Yes

Source of Risk From Exposure to Seismic Sounds	Type of Receiver	Evidence of Effect (hypothetical, lab experiment, field observation)	Geographic Scale of Risk to Individual	Temporal Scale of Con-sequence to Individual	Probability of Effect at Individual Level	Severity of Effect at Individual Level [c]	Would Existing Mitigation Measures Reduce the Risk or Severity From Expo-sure to Seismic Sounds?
Reduced echolocation efficiency?	"High-frequency hearer" Toothed Whales	Not studied	Short range	Short term	Low	Low if feeding / high if navigating	Yes
	Baleen Whales	NA	NA	NA	NA	NA	NA
Passive acoustic prey or predator detection	Pinnipeds	Not studied	Short range	Short term	Low	Low if feeding / High for predator avoidance	Yes
	"Low-frequency hearer" Toothed Whales	Field evidence from non-seismic studies (noise from whale-watching boats reduced killer whale feeding - see working paper for a review)	Short range	Short term	Low	Low if feeding / High for predator avoidance	Yes
	"High-frequency hearer" Toothed Whales	Not studied	Short range	Short term	Low	Low if feeding / High for predator avoidance	Yes
	Baleen Whales	Not studied	Unknown range	Short to long term depending on geographic scale	Unknown	Unknown (could be important for non-visual feeding)	Yes
Avoiding human threats (e.g., ship strikes)	Pinnipeds	Not studied	Short range	Long-term	Low	High	Yes
	"Low-frequency hearer" Toothed Whales	Not studied	Short range	Long-term	Low	High	Yes
	"High-frequency hearer" Toothed Whales	Not studied	Short range	Long-term	Low	High	Yes
	Baleen Whales	Field evidence of increased risk of collision following exposure to noise (northern right whales)	Unknown range	Long-term	Unknown	High	Unknown

Source of Risk From Exposure to Seismic Sounds	Type of Receiver	Evidence of Effect (hypothetical, lab experiment, field observation)	Geographic Scale of Risk to Individual	Temporal Scale of Con-sequence to Individual	Probability of Effect at Individual Level	Severity of Effect at Individual Level [c]	Would Existing Mitigation Measures Reduce the Risk or Severity From Expo-sure to Seismic Sounds?
Parental care, protection, bonding	Pinnipeds	Not studied	Short range	Long-term	Low (given short range of communication)	High	Yes
	"Low-frequency hearer" Toothed Whales	Not studied	Short range	Long-term	Low (given short range of communication)	High	Yes
	"High-frequency hearer" Toothed Whales	Not studied	Short range	Long-term	Low (given non-overlap with most seismic frequencies)	High	Yes
	Baleen Whales	Not studied	Short range	Long-term	Low (given short range of maternal communication)	High	Yes
Behavioural Effects (displacement, diversion,dive and respiratory pat-terns, social behaviour, vocalisation)	Pinnipeds	Field studies of behavioural changes (localised displace-ment, dive patterns)	Short range	Unknown because of high context-related variability	Unknown because of high con-text-related variability	*	Yes
	"Low-frequency hearer" Toothed Whales	Field studies of behavioural changes (displacement, dive and respiratory pat-terns, social behaviour)	Unknown range	Unknown because of high context-related variability	Unknown because of high context-related variability	*	Yes
	"High-frequency hearer" Toothed Whales	Not studied	Unknown range	Unknown because of high context-related variability	Unknown (possible avoidance by ziphiids?)	*	Yes
	Baleen Whales	Field studies of behavioural changes (displacement, migratory deflection, dive and respiratory patterns, social behaviour)	Long range	Unknown because of high context-related variability	Unknown because of high con-text-related variability	*	Yes (in the case of temporal or areal exclusions)

Source of Risk From Exposure to Seismic Sounds	Type of Receiver	Evidence of Effect (hypothetical, lab experiment, field observation)	Geographic Scale of Risk to Individual	Temporal Scale of Con-sequence to Individual	Probability of Effect at Individual Level	Severity of Effect at Individual Level [c]	Would Existing Mitigation Measures Reduce the Risk or Severity From Expo-sure to Seismic Sounds?
Chronic effects (stress-related, e.g., reduced fecundity; immuno-suppression)	Pinnipeds	Not studied	Potentially long range	Potentially long term	Unknown (very difficult to detect)	Unknown (not manifested physically)	Unknown
	"Low-frequency hearer" Toothed Whales	Not studied	Potentially long range	Potentially long term	Unknown (very difficult to detect)	Unknown (not manifested physically)	Unknown
	"High-frequency hearer" Toothed Whales	Not studied	Potentially long range	Potentially long term	Unknown (very difficult to detect)	Unknown (not manifested physically)	Unknown
	Baleen Whales	Not studied	Potentially long range	Potentially long term	Unknown (very difficult to detect)	Unknown (not manifested physically)	Unknown
Indirect effects (e.g., reduction in prey availability)	Pinnipeds	Not studied	Potentially long range	Unknown; may extend beyond seismic period	Low	Unknown (very difficult to detect)	Unknown
	"Low-frequency hearer" Toothed Whales	Not studied	Potentially long range	Unknown; may extend beyond seismic period	Low	Unknown (very difficult to detect)	Unknown
	"High-frequency hearer" Toothed Whales	Not studied	Potentially long range	Unknown; may extend beyond seismic period	Low	Unknown (very difficult to detect)	Unknown
	Baleen Whales	Not studied	Potentially long range	Unknown; may extend beyond seismic period	Low	Unknown (very difficult to detect)	Unknown

[a] Low-frequency hearer toothed whales = beluga, sperm whales; high-frequency hearer toothed whales = harbour porpoise.

[b] We define "short" and "long" range relative to the array output: "short" is in the range of 10-100 meters, and "long" is in the range of 1-100 kilometres.

[c] These individual-animal effects can be extrapolated to population-level during this process; risk-management practices will be used for Sara-listed species.

Appendix C: Scientific Input Into Decisions For the Approval, Scope, and Procedures for Conducting Seismic Operations in Canadian Waters

Decisions as to if, when, where, and how seismic operations can proceed in Canadian waters should be based on the best available scientific information. Managers and stakeholders should adopt the precautionary principle in reviewing scientific advice, and scientists can facilitate this process by including descriptions of uncertainty in the data, and quantification of the risks associated with the different decisions managers could make.

As a first step, and based on field assessments and literature review, scientists can attempt to provide descriptions of ecologically and biologically significant areas (EBSA) or critical habitats in the marine area of interest. The characteristics defining EBSAs for marine mammals and other marine species have been reviewed at a scientific workshop held in November, 2004, the results of which and can be viewed through the Canadian Science Advisory Secretariate web site. These EBSAs may not be static in space or time, or may not be well defined. Scientists can inform managers about the variability in the likelihood of impacts related to operations at different times of the year or different areas, and of the uncertainty related to the location of these areas or period of sensitivity.

Based on laboratory studies, field assessments, and literature review, scientists can attempt to provide sound exposure thresholds and their associated probabilities of causing effects of different magnitudes for marine mammal species of interest (or the sensitive or critical habitats they inhabit), including areas of uncertainty in the data. These thresholds must be based on the precautionary principle – particularly for species where there is little information (e.g., baleen whales) or of particular concern (e.g., SARA-listed animals).

Using a collaborative multispecies approach,[14] scientists can develop scenarios where placement of boundaries or sound exposure limits would illustrate variable probabilities of causing impacts of different nature and severity to the sensitive or critical habitat or its associated species. Note that scientists' understanding of potential impacts is often limited to short-term and/or very apparent effects.

Finally, based on laboratory studies, field assessments, and literature review, scientists can attempt to provide the managers with a list of procedures that aim at reducing the risks of potential impacts on marine mammals and their habitats. The scientists could facilitate the decision-making process by providing an evaluation of the effectiveness of these different procedures in mitigating impacts.

In summary, scientists might assist managers in their decision process to allow or not seismic operations in a particular area by providing an assessment of existing science, including an evaluation of the uncertainty in the data and of the risks associated with different scenarios, or by suggesting directed science that could help managers address the following key issues:

- What are the space/time regions that can be defined as sensitive or critical habitat?
- Based on a precautionary approach, are there acceptable sound exposure thresholds or effects magnitudes for the species of interest in these regions?
- Can "safety" boundaries be defined around these habitats (based on the aforementioned thresholds) such that the potential risks of a seismic operation causing significant biological impact(s) are acceptably low or eliminated?
- Based on a precautionary approach, are there seasonal, spatial, or procedural limitations or other mitigation measures that, if applied to the proposed seismic operation, would reduce the risk of significant biological impact(s) to an acceptable level?
- If there are areas and periods of interest to seismic operators for which there is little or no scientific information regarding the species present, their life history patterns, and the magnitude and types of effects that might be expected from exposure to seismic operations, what types of directed study or monitoring should provide this information?

[14] Modelling and directed studies would provide crucial inputs to this process.