A Conceptual Framework for Tiered Risk Assessment to Evaluate the Effects Of Sound from E&P Operations on Marine Mammals

Final Report

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1. Introduction

Marine mammals are highly dependent on sound to carry out their life functions. They use sound to interpret the marine environment, navigate, hunt their prey, compete for mating opportunities, communicate with conspecifics, and avoid predators (Richardson et al. 1995). Animals that inhabit the marine environment have evolved to exploit a variety of habitats and different marine mammal groups are sensitive to differing sound frequencies. Marine animals, and specifically cetaceans and pinnipeds, are assumed to hear those frequencies that they themselves produce. They are also known or expected (depending on species) to be sensitive to broader frequency ranges, which could provide the ability to hear other sounds of biological significance (such as the sounds of predators or prey). The ocean is naturally noisy (Wenz 1962; Urick 1971; Ross 1976), with background or ambient noise resulting from a variety of natural (both physical and biological) and anthropogenic sources. However, as human activities in the oceans have increased, so has the amount of sound to which marine mammals are exposed. For example, in some areas of the world, shipping reportedly raises ambient sound levels by 10-40 dB (Potter and Delroy 1998; NRC 2005). When other human activities are considered, such as seismic exploration, sound levels more than 100 dB above ambient levels may occur intermittently (NRC 2005).

The effect of these increased sound levels on marine mammals is poorly understood. The fact that a sound is emitted into the oceans does not necessarily mean that a marine mammal will hear it or, if it does, that a biologically significant consequence will result (Richardson et al. 1995; NRC 2005). However several high profile strandings of beaked whales have occurred in recent years following use of mid-frequency sonar during naval exercises (Jepson et al. 2003; Fernández et al. 2004; Cox et al. 2006; D'Spain et al. 2006). It has also been suggested that marine seismic surveys may have resulted in one or more stranding events, although this is unproven (Hogarth 2002; Yoder 2002; Engel et al. 2004; IAGC 2004; IWC 2007). Our ability to assess the potential for biological impacts to marine mammals, including mortality, reduction in abundance or shifts in distribution is hampered by knowledge gaps about the hearing characteristics of most marine mammal species (NRC 2005; Southall et al. 2007). In addition, studies suggest that marine mammal responses to high sound levels are highly variable and dependent on factors such as the animal's activity, habituation and duration of the sound (Wartzok et al. 2004; Southall et al. 2007 and references contained therein).

Because it is difficult to detect and quantify biologically significant impacts, and these effects generally can only be assessed over a long time period (e.g. years), surrogate measures of impact such as auditory injury and behavioral disturbance that can be assessed in near real-time are typically used instead. Auditory injury involves permanent noise-induced threshold shifts (PTS) whereby an animal's hearing sensitivity is permanently lowered (i.e., hearing threshold increased) following exposure to a sound of sufficient intensity and duration at a given frequency. In contrast, in the case of temporary noise-induced threshold shifts (TTS), the auditory fatigue resulting from noise exposure is temporary and hearing eventually returns to normal; TTS does not constitute auditory injury (Southall et al. 2007). Acoustic disturbance can include a range of behavioral effects such as orientation behavior, changes in an animal's locomotion, speed, direction and dive profile, avoidance of the area near the sound source, and aggressive behavior (Southall et al. 2007). Determination of the actual received sound levels and durations that result in PTS, TTS and various levels of behavioral disturbance is an area of active research.

Southall et al. (2007) reviewed and compiled the current literature on cetacean and pinniped physiological and behavioral responses to anthropogenic sound, and used this as a basis to propose exposure level criteria for hearing injury. They also attempted to develop such criteria for behavioral disturbance, but concluded that (in most cases) the available data were too sparse and variable to allow identification of standardized criteria for behavioral disturbance at this time. Anthropogenic sound sources were categorized into three sound types: single pulse, multiple pulse and nonpulse, and five marine mammal functional hearing groups were defined: low, mid and high frequency cetaceans, and pinnipeds in air and water. (Sirenians, sea otters and polar bears were not considered). For each combination of sound type and functional hearing group, Southall et al. reviewed the literature and estimated the sound exposure conditions that would be expected to elicit the onset of PTS and TTS. As noted above, broadly-applicable exposure criteria could not be defined for behavioral disturbance. Southall et al. (2007) recognized the severe limitations of the available data and provided broad research recommendations to address data gaps associated with such issues as ambient noise levels, audiometric data for marine mammal species, auditory scene analysis, behavioral responses to sound exposure, simultaneous and residual physiological effects of noise exposure, and effects of sound on non-auditory systems. As more data become available in these and other research areas, the criteria defined by Southall et al. (2007) can be refined.

Although there is considerable debate about the significance of observable changes in marine mammal behavior (NRC 2005; Southall et al. 2007) when animals are exposed to anthropogenic sounds, these changes in behavior currently provide the best mechanism for assessing whether such sounds could potentially affect other life functions. To support this approach, the National Research Council (NRC 2005) proposed a methodology whereby observable behavioral effects from anthropogenic sound are used to infer population level effects. The NRC recommended that models be developed that link noise impacts with population parameters, and introduced a conceptual model, Population Consequences of Acoustic Disturbance (PCAD) (Figure 1.1), that provides a preliminary framework to link acoustic stimuli to population level effects on marine mammals. This model involves a series of transfer functions that tie sound to behavior changes, which in turn affect life functions that result in altered vital rates and, ultimately, population effects. The PCAD model also highlights the data gaps that presently dominate most facets of the framework.

1.1 Assessing the Potential Impacts of Anthropogenic Sounds

As the oil industry expands its offshore exploration and production (E&P) activities, it is increasingly finding itself operating in areas with resident or migratory marine mammal populations, some of which may be species at risk. In addition, industry is faced with heightened public awareness of marine issues and increased oversight by the regulatory authorities. Environmental impact assessments of proposed E&P activities that include an evaluation of potential sound levels and possible physical injury, behavioral disturbance and population level impacts to marine mammals are routinely required as part of the permitting process. Given the data gaps and level of uncertainty when attempting to evaluate these impacts, a useful approach is to conduct a risk assessment. This process systematically evaluates and organizes data, information, assumptions, and uncertainties to help understand and predict the relationships between stressors and ecological effects. The likelihood that an adverse effect to one or more biological receptors may occur as a result of exposure to one or more hazardous agents is evaluated, and a conclusion is reached about the effect's severity. The risk assessment process can be used to construct "what-if" scenarios, to evaluate new and existing technologies for effective prevention, control or mitigation of impacts, and to provide a scientific basis for risk-reduction strategies (EPA 1998; Defra 2002; Suter 2007). Although risk assessment is usually viewed as prospective—examining and predicting future adverse effects—it can also be retrospective, i.e., determining whether observed effects have been caused by past exposure to an identified stressor (EPA 1998).

In the present context, risk assessment is applied in evaluating potential hazards to marine mammals from sound produced by offshore E&P activities in order to flag areas and times of the year where there is high risk of a population level effect to a species. This requires knowledge about the sound source and its location (and movements if mobile) relative to any species to be protected. However there is typically a paucity of data on marine mammal distribution and movements in the region of an E&P activity, and patterns of habitat use within the overall distribution of the marine mammals usually are poorly understood. Filling these data gaps can require intensive survey effort over a period of years. Data are also needed to determine the likelihood and magnitude of sound exposure on these species, and the effects of that exposure. Accurate prediction of the spatial extent and levels of sound exposure from an E&P source is difficult, and requires detailed knowledge of the seabed substrate and topography, and water column characteristics that affect sound attenuation such as temperature and salinity profiles (Urick 1982; Jensen et al. 1994; Richardson et al. 1995; NRC 2005; Madsen et al. 2006). Even if extensive acoustic modeling is conducted, there is uncertainty in model predictions due to model assumptions and limitations, and variability in water column characteristics at the time of the actual activity. Consequently, any risk assessment that evaluates potential impacts of E&P sound to marine mammals must apply a methodology that can operate within the likely data gaps and uncertainties, yet is sufficiently robust to incorporate better quality data when these are available.

The existing data gaps and uncertainties place additional constraints on any methodology used to assess risk of injurious effects, TTS, or significant behavioral disturbance. Ecological risk assessments often focus on exposure to a stressor where a clear dose response can be determined (such as chemical exposure). A variety of methods can then be used to determine a quantitative estimate of risk, often with associated confidence intervals. However, ecological risk can also be assessed in a more general way even when it is difficult to establish a quantitative dose-response relationship due to data gaps, the inherent variability in a receptor's response, and limited understanding of the ecosystem, its components and their functional interdependencies. In these situations, semi-quantitative methods involving scoring systems or qualitative ranking schemes are often developed to determine a qualitative level of risk. For example, the Scientific Committee on Antarctic Research (SCAR) (2004) attempted to estimate risk to marine mammals by sound from acoustic equipment deployed in the Antarctic. They constructed matrices that contained cells for all possible combinations of six categories of behavioral response intensity and six "likelihood of impact" categories. Although this approach was useful in providing a better understanding of possible impacts to marine mammals from industry sound, it only provided a single evaluative ranking of consequence vs. likelihood for the most sensitive species present. It did not factor in other potentially relevant biological factors (such as the percentage of population at risk or the presence of important habitat) or issues of relevance for resource managers such as the status of the exposed species or potential cumulative factors.

Our study aimed to improve on existing risk assessment methodologies available to E&P managers and regulators by developing a robust methodology specifically designed to assess the risk of PTS, TTS and behavioral disturbance in cetaceans and pinnipeds from sound produced by offshore E&P activities. The methodology allows semi-quantitative and qualitative risk assessment depending on the effect of interest (PTS, TTS, behavioral disturbance), the receptor species selected by the risk manager, and the level of uncertainty inherent in the data sets available to the risk assessment. A primary goal of the study was to incorporate the sound thresholds for PTS and TTS that were recently developed by Southall et al. (2007). Data gaps and uncertainties prevented these sound thresholds from being expressed as dose-response relationships. Instead, each threshold is a specific sound level that is assumed to cause onset of the specified effect. Because Southall et al. (2007) were unable to determine exposure criteria for behavioral disturbance, the proposed methodology allows the use of expert opinion to assign qualitative likelihood for four levels of disturbance severity (in this context and throughout this document, expert opinion is defined as a acoustician or marine mammalogist with experience relevant in marine mammal acoustics). We also provided for adjustment of risk ranking based on population level heuristics (e.g., conservation status and presence of critical habitat), context specific factors known to affect a species' response to sound exposure, and cumulative effects. The method is to a degree qualitative because of the limitations and uncertainties of the sound thresholds coupled with the data gaps in species distribution and ecology, and magnitude of cumulative effects. However, the proposed methodology does allow the use of acoustic modeling to predict received sound levels and, when available, use of quantitative density estimates for the species of concern; this can reduce uncertainties in the risk estimation process. In addition, modeling approaches can be used to predict population level effects, with predictions used to adjust the risk ranking. We also developed computer software that implements the methodology to provide an interactive decision-making risk assessment tool. This software prompts resource managers to work through the necessary questions and to provide inputs at each stage where data are available. If data are not available, the tool allows the incorporation of expert opinion. The tool is modular so that components can be easily updated as more information becomes available.

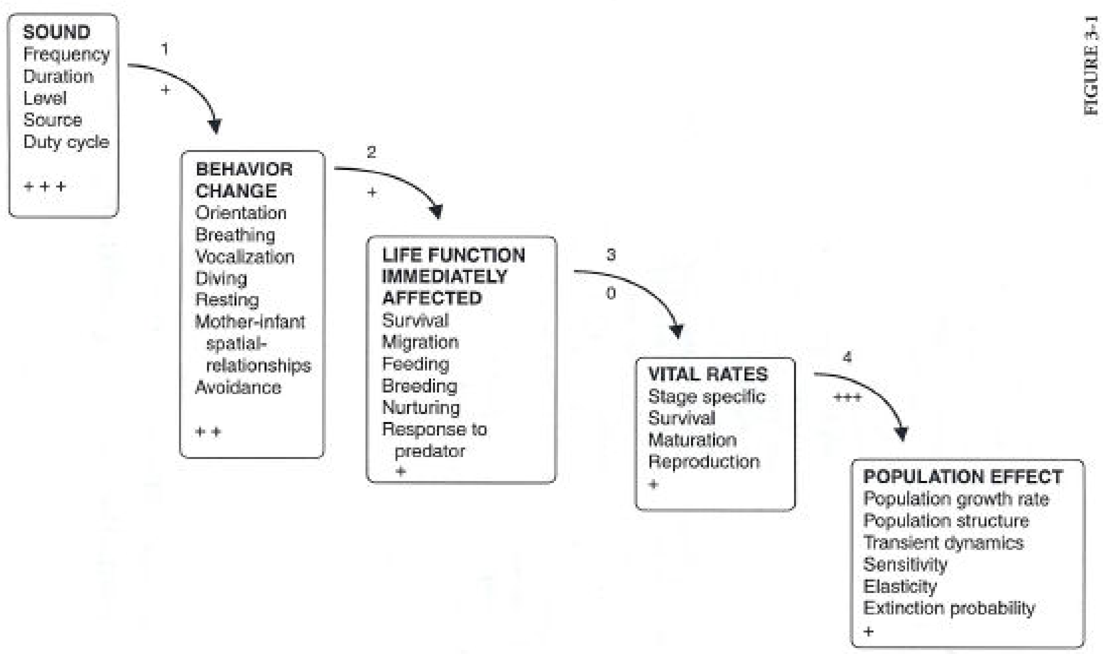


Figure 1.1. The conceptual Population Consequences of Acoustic Disturbance framework (from NRC 2005). Five groups of variables are of interest, and transfer functions specify the relationships between the variables listed, for example, how sounds of a given frequency affect the vocalization rate of a given species of marine mammal under specified conditions. Each box lists variables with observable features (sound, behavior change, life function affected, vital rates, and population effect). In most cases, the causal mechanisms of responses are not known. The "+" signs at the bottoms of the boxes indicate how well the variables can be measured. The indicators between boxes show how well the "black box" nature of the transfer functions is understood; these indicators scale from "+++" (well known and easily observed) to "0" (unknown).

1.2 Objectives and Key Questions

The objectives of this study were to

(1) examine and assess existing risk assessment tools to determine their application to sound exposure;
(2) modify existing risk assessment tools, if feasible, to meet specific sound-related criteria;
(3) examine and summarize existing databases for suitability in providing data for risk assessment purposes;
(4) summarize the key sound criteria for behavioral and physiological impacts on marine mammals;
(5) develop a series of risk scenarios to test and calibrate a risk scoring system;
(6) develop a comprehensive framework that can be used as a planning tool to assess risk to cetaceans and pinnipeds from a variety of sound sources associated with offshore E&P activities;
(7) develop a prototype model for acoustic risk assessment; and
(8) provide recommendations for future studies/assessments.

This study addressed the following key questions on the effective use of risk assessment in the context of E&P activities in marine environment:

1. What are the sound-related hazards associated with offshore E&P activities? Differentiate between primary stressors (i.e., airguns) and secondary stressors (i.e., support vessels, helicopters, and impacts on prey).
2. What is known about dose response in the receptor species of interest (marine mammals)? How is dose response affected by distance and frequency? What other factors may affect the dose response (topography, ambient noise levels, habituation, context, i.e. what activity the animal is engaged in and its life stage/life function)? Are there indirect factors that may affect the response? Does the behavior or location of the receptor species affect the dose response?
3. What real-time, field-collected information is available for the species of interest? How reliable are those data?
4. What modeling data exist for different sound sources? How accessible are those data and how applicable to other scenarios?
5. Assess the usefulness of demographic models, individual-based models (Acoustic Integration Model), categorical or qualitative models (Population Consequences of Acoustic Disturbance Model), and Bayesian belief networks, and how they may be used in the risk assessment process.
6. What methods of sound exposure assessment can be used? What behavioral parameters can be effectively used? Can life functions and vital rates be integrated into the assessment?
7. How comprehensive are data on the distribution of marine mammals and their use of key habitats?
8. What are the risks to individuals and populations from noise exposure? Can population level effects be determined with the data available? If not, what additional data are needed? Can cumulative effects be integrated into the risk assessment?

2. Risk Assessment Methodology

2.1 Introduction

A number of countries, including Canada, the United States, Australia, New Zealand and South Africa, have developed ecological risk assessment frameworks (e.g. ANZ 1995; CCME 1996; EPA 1998; NEPC 1999; Claassen et al. 2001; DEFRA 2002) that define a structured approach and ensure essential components are included (Suter 2007). Although these frameworks often differ in the degree of stakeholder involvement and the nature of the decision making process (Suter 2007), most frameworks consist of this core sequence of phases:

Problem formulation > Risk estimation > Risk characterization > Risk management

Problem formulation assists risk assessors in determining the level and type of risk assessment to be conducted (DEFRA 2002). The problem (i.e., the planned activity or existing situation of concern) is defined; the scope, objective(s), and justification for the risk assessment are specified; and a plan for analyzing and characterizing risk is developed (EPA 1998; DEFRA 2002). The nature and magnitude of risk to each species of concern is then estimated, followed by an interpretation of the significance of the risk estimate regarding its potential for adverse effects. The level of confidence in each risk estimate is also evaluated and described. Finally, the results of the risk assessment are reported and communicated to all interested parties and stakeholders, and management decisions are made. These phases are described in more detail below.

Uncertainty can affect all phases of a risk assessment, and assessors need to decide how much uncertainty is acceptable without precluding use of the results of an assessment (EPA 1998; Harwood 2000). An explicit description of the magnitude and direction of uncertainty during each risk assessment phase is a key component to understanding and describing the level of confidence in the conclusions (EPA 1998). How uncertainty contributes to the overall variability of the final risk estimate also clarifies the potential for misleading results, increases the credibility of a risk assessment and assists in making management decisions (EPA 1998; DEFRA 2002; Arhonditsis et al. 2007). Identification of uncertainty during problem formulation is particularly important because it has repercussions throughout the remainder of the assessment (EPA 1998). In addition, recommendations should be made as to how to fill data gaps.

Uncertainty can be due to many factors such as data gaps, extrapolation of data from other sources, use of models to predict a species' response to a stressor, and inherent variability in the environment or individuals that may influence a stressor's effect (EPA 1998; Harwood 2000; DEFRA 2002; Suter 2007). Although some uncertainties are difficult to quantify, it is desirable to address these uncertainties at least qualitatively (e.g. categorical levels) to maintain openness in the risk assessment process (Suter 2007). Uncertainty is due to lack of knowledge about a system, and consequently can be decreased by obtaining additional information (Suter 2007). However, variability that may contribute to uncertainty cannot be reduced because it is an inherent property of entities or events that differ in some trait (Suter 2007). Nonetheless, uncertainty about the characteristics and consequences of that variability can be reduced through data gathering and testing (Suter 2007), including identification of covariates and quantification of their influences.

There are two main classes of risk assessments, **screening** and **definitive** (Suter 2007). Screening assessments are based on minimal exposure and effects data, and are intended to quickly and easily divide risks into those that need further analysis and those that can be ignored because they are deemed to be of little or no concern. Screening assessments may be quantitative or qualitative, or if data are insufficient, based on expert opinion (Suter 2007), or some combination of each of these approaches. During a screening assessment, it is not necessary to estimate the nature, magnitude or probability of effects, but it is crucial to ensure that the risk from a particular stressor falls into the correct category. It is particularly important to prevent a stressor from being screened out as a risk simply due to uncertainties and data gaps (Suter 2007). An important component of a screening assessment is to evaluate if there is potential connectivity between the stressor, the exposure pathway, and the species of concern. If not, then the risk assessment need go no further because there is no exposure and consequently no risk (EPA 1998; DEFRA 2002). The description of the spatial and temporal distribution of the stressor is used to estimate the extent and pattern of contact or co-occurrence among the stressors and the species of interest (EPA 1998).

Definitive assessments may be used to follow up on stressor-species pairs that were not eliminated during the simpler screening process, or may be initiated without a screening assessment first being completed. Definitive assessments require detailed exposure and effects data, a comprehensive analysis of the exposure-response relationship, and more robust evaluation of the relevant uncertainties, data gaps, and assumptions and limitations. Consequently, definitive assessments provide detailed risk estimates for each species, which can also be used as input to a quantitative decision support tool (Suter 2007).

Risk assessments often must be conducted with a paucity of data. Consequently, assessors frequently use an iterative "tiered" approach that repeats the risk assessment process until a sufficiently complete and defensible result is achieved (Suter 2007). The first tier is often a screening assessment that is based on minimal data and typically applies some simple rule, model or other analysis to assess risk that errs on the protective side. If the first tier assessment indicates a potential for risk, then the assessment enters the next tier, which performs a more complex analysis with more stringent data and/or model requirements. This process is repeated, with increasingly complex tiers of risk assessment that move from screening assessments to definitive assessments, and have the objective of producing more realistic risk estimates with less uncertainty and better accuracy. Tiered approaches provide potential cost effectiveness and timeliness by attempting to complete a risk assessment with a smaller and less expensive data set, simpler modeling or other analytical methods, and less effort (Suter 2007).

2.2 Problem Formulation

Problem formulation consists of many steps. The spatial and temporal extent for potential harm is defined (Suter 2007), and other relevant pre-existing hazards that may affect the outcome of the risk assessment are identified (DEFRA 2002). Factors that control an activity of concern need to be clearly defined because modification of these factors is often a key consideration in the appraisal and selection of risk reduction options during the risk management phase (DEFRA 2002). These factors include the timing, intensity and duration of each activity, as well as social or policy level factors (DEFRA 2002).

Species that may be harmed by the activity are identified based on surveys, if available, to determine which species are present, their abundance and distribution, and life stages (Suter 2007). If survey data are unavailable, then habitat models or expert opinion may be used to identify species that may be affected. Potential hazards from the activity are determined by identifying each stressor that may harm a species of interest, a measurable attribute(s) of that species(s) that can be estimated or modeled in order to assess effects, and the pathway between each stressor and species pair (EPA 1998; Suter 2007). A species selected for risk assessment should satisfy the following criteria: be present in the defined study area, be susceptible to the stressor, and be relevant both ecologically and to management goals and policies (Suter 2007). Common measurable attributes of organisms include mortality, growth, fecundity and deformity. However, ecological risk assessments seldom use entities at the organism level. Instead, organism-level attributes are usually associated with a population so that risks to abundance, production, extirpation and other population level attributes are assessed (Suter 2007). This can result in complications when regulations specifically protect individual animals, as with the U.S. Marine Mammal Protection Act that prohibits the "taking" of marine mammals without specific authorization. In such cases, a risk assessment may have to consider individuals rather than populations.

The hypothesized relationship between each stressor and species of concern is typically portrayed as a written description and visual representation (e.g., flow diagram) termed a "conceptual model." The conceptual model may also include primary, secondary, and tertiary exposure pathways that may affect a species. There is often uncertainty in developing conceptual models due to a lack of knowledge, failure to identify hazards, failure to consider the boundaries of the risk assessment correctly, or failure to consider direct or indirect effects. These factors become increasingly important when dealing with multiple stressors in complex situations (DEFRA 2002). Uncertainty cannot be completely eliminated but should be acknowledged and described wherever it arises (DEFRA 2002).

2.3 Risk Estimation

This phase estimates the nature and magnitude of risk to each species that was identified in Problem Formulation (EPA 1998; Suter 2007). First, the intensity and spatiotemporal extent for each stressor is determined, and the results are then used to estimate the extent and pattern of contact or co-occurrence with each species (EPA 1998; Suter 2007). The temporal extent is usually represented by the expected duration of exposure, but can also described by the frequency of intermittent exposure, and the timing or seasonality of exposure (Suter 2007). Spatial extent is often delineated as an area or a linear distance from the source (Suter 2007). If there is no contact or co-occurrence between a stressor and a species, then there is no exposure and consequently no risk from that stressor (EPA 1998).

The intensity of exposure is often specified as a concentration in an ambient medium, with responses described as functions of those concentrations (Suter 2007). Consequently, it is typically necessary to understand the physical-chemical properties of the medium and have information on prevailing environmental conditions in order to estimate exposure at different locations (Suter 2007). The relationship between the exposure intensity and the effect on each species of concern is determined, and used to predict the magnitude of that stressor's effect.

The risk estimation for a species may be based on a single actual or hypothetical case such as the only one, the most representative or most protective (Suter 2007). Alternatively, multiple cases that include reasonable or typical cases, the expected range of cases, a set of plausible bad cases or reasonable worst cases may be combined to infer the level of risk according to a weighting scheme (e.g., equal weights, weights based on data quality and uncertainty) developed for that particular assessment (Suter 2007). The method(s) used to estimate the magnitude of an effect depends on whether a screening or definitive assessment is being conducted, the species being assessed, the data type and quality, and the preferences of the risk manager (Suter 2007). Common risk estimation methods include

- *Rule-based inference:* A simple rule is used to determine whether or not a risk is acceptable. Typically a single number is specified, e.g. a sound exposure, that is presumed to be a sufficiently protective level for a species. The rule can be a published standard, or a protective exposure level can be developed for a particular species during problem formulation (Suter 2007). It is crucial that rules represent protective levels so that harmful stressors are not inadvertently screened out of the assessment (Suter 2007).

- *Structured judgment:* Many risk characterizations are too complicated and have too much uncertainty to allow simple rule-based inference. An alternate approach uses simple heuristics to evaluate the evidence, and then applies a scoring system based on expert opinion to estimate the risk (Suter 2007). The scoring system can be based on any number of factors, which are then weighted and combined according to some pre-defined scheme (EPA 1998). A scoring system can be entirely qualitative (e.g., high, medium, and low categories) or semi-quantitative whereby a numerical score is determined based on some pre-defined criterion. The scoring system should, ideally, be calibrated by running a series of risk scenario tests, with scoring criteria adjusted as needed to provide scores that correspond to identified risk categories.

- *Comparison of single point estimates of exposure and effects:* If both exposure and effects can be quantified as single-point estimates, then overlap in these two numbers can be evaluated to estimate risk (EPA 1998). Alternately, single-point estimates of effects can be compared to confidence intervals for a mean exposure estimate (EPA 1998).

- *Use of a mathematical exposure-response function:* If the magnitude of the effect can be expressed as a mathematical function of the exposure, then predicted exposure levels can be used to parameterize that function and estimate risk. The simplest application of this approach estimates the effect by solving the exposure-response function for a single exposure estimate (Suter 2007). Alternately, an exposure-response distribution can be built by estimating effects for many different exposure levels. In addition to depicting the magnitude of the response, the shape of the distribution shows the pattern of change in effects with changing exposure levels, and which exposure levels have the most effect. This method is useful for comparing different risk management options that produce different exposure levels (Suter 2007).

- *Use of demographic models to assess extinction risk:* Parameters of a demographic model can be modified based on predicted effects, and then the model can be run to predict a population's sensitivity to a stressor (Borsuk et al. 2006; Billoir et al. 2007; Suter 2007).

- *Qualitative techniques such as risk rankings or a risk matrix:* Categorical ranks of severity such as mortality, a reduction in abundance, or a shift in distribution are defined for an effect, and then expert opinion is used to assign a likelihood of that category of effect given the predicted intensity of a stressor (EPA 1998; Suter 2007). A risk matrix is a common format used to capture risk rankings, with one dimension of the matrix representing categorical likelihoods of an effect and the other dimension representing categories of effects. For example, SCAR (2004) developed such matrices for acoustic equipment deployed in the Antarctic.

There is a need to clearly identify and summarize data gaps, possible errors in the available data, and the variability, uncertainties, assumptions and limitations of the data and analyses used to estimate the risk to each species of interest. The results of this exercise may then be used to modify the estimate of risk (EPA 1998; Suter 2007). It is important to consider extrapolations when evaluating uncertainty during risk estimation. Extrapolations may include applying results of a study of one species to another, one temporal or spatial scale to another, or a laboratory setting to the field. Extrapolation is also of concern when results are extended beyond the range of values actually available (EPA 1998). In addition, major data gaps should be identified, and where appropriate, data gathering that would substantially add content to the overall confidence in the assessment results should be specified.

Because models are simplifications of reality that approximate actual processes (Arhonditsis et al. 2007), it is essential to investigate the degree of uncertainty in predictions for any models used during risk estimation. Methods to evaluate uncertainty are described in more detail in Chapter 4.

2.4 Risk Characterization

This phase interprets the risk estimate for each species from a practical perspective, i.e., what is the significance of the risk estimate in regards to its potential for adverse effects that negatively alter valued structural or functional attributes of the species of concern (EPA 1998). Criteria to determine adversity include the nature and intensity of the effects, the spatial and temporal scale, the presence of critical habitat and the potential for recovery, and non-ecological factors such as economic, legal or social consequences (EPA 1998). It is important to differentiate between statistical significance and biological significance of an effect when estimating adversity (EPA 1998). For example, a small, but statistically significant increase in adult mortality rate may not affect a species' persistence, particularly if there is a compensatory increase in birth rate or recruitment of juveniles into the population (EPA 1998). Conversely, a biologically significant effect may be occurring that is not detected by a statistical test due to insufficient statistical power in a study (EPA 1998). Determination of the degree of adversity is often difficult, so it frequently is based on expert opinion (EPA 1998).

The level of confidence in each risk estimate is evaluated and described based on the uncertainties and data gaps identified in the other phases of the risk assessment. For transparency, risk assessors should provide a thorough summary and evaluation of risk estimation methods that were developed and used for the risk assessment (EPA 1998). An estimation method is evaluated by considering the adequacy and quality of data for any studies or models that were used, and the degree and type of uncertainty associated with the evidence of the relationship between a stressor and effect (EPA 1998). There is greater uncertainty and correspondingly less confidence in a risk estimate when qualitative rather than quantitative methods have been used. Uncertainties and limitations resulting from insufficient data also need to be evaluated and clearly communicated. Estimation methods directly related to the risk hypotheses, and those that establish a cause-and-effect relationship based on a definitive mechanism rather than just spatial and temporal associations of the stressor with the effect, are likely to be of greatest importance (EPA 1998). In addition, confidence in the conclusions of the risk assessment may be increased by using multiple methods to estimate risk. Results can then be compared for consistency (EPA 1998). It is important to investigate the reasons if different lines of evidence provide different conclusions about the risk (EPA 1998). The differences may be due to true inconsistencies, differences in the statistical power to detect a difference, or errors in model assumptions and predictions (EPA 1998). Comparison of the amount of uncertainty across the different risk estimation methods also allows the relative significance of these different estimates to be evaluated (EPA 1998).

2.5 Risk Management

This phase involves the reporting and communication of the risk assessment to all interested parties and stakeholders. The results, major assumptions and uncertainties should be clearly expressed, reasonable alternative interpretations should be identified, and scientific conclusions should be separated from policy judgments (EPA 1998; Suter 2007). In addition, it is important to communicate the limitations of the risk assessment that was conducted. For example, a risk assessment focused on noise impacts from a seismic survey vessel would provide no information about the risk of collision with that vessel. Risk managers use the risk assessment results along with other factors (e.g. economic or legal concerns) to make risk management decisions, and as a basis for communicating risks to interested parties and the general public. When there are data gaps and substantial uncertainties in a risk assessment, an adaptive management approach (Walters 1986) is often warranted. In that case, additional data gathered during the course of the project can be used to verify assumptions, support management decisions that were made during the assessment, and improve future risk assessments. After completion of the risk assessment, risk managers may consider whether follow up activities such as mitigation and/or monitoring are needed. If mitigation measures are deemed appropriate, it may be useful to repeat the risk estimation process with these measures incorporated to determine if the risk will be reduced to a more acceptable level.

3. Risk Assessment Methodology to Determine Effects on Cetaceans and Pinnipeds from Offshore E & P Sound

3.1 Introduction

A risk assessment methodology to determine potentially harmful effects from offshore E&P sound to cetaceans and pinnipeds must satisfy several requirements. Data needs are substantial insofar as both the sounds and the marine mammal are concerned. The sound source characteristics, i.e. including level, frequency range, and whether the sound is intermittent or continuous needs to be clearly understood to predict the magnitude of effects on a particular species. The spatial and temporal characteristics of sound propagated through the marine environment from the source(s) also need to be understood. For a quantitative assessment, this would require knowledge of local factors that affect sound propagation, such as bathymetry, seabed substrate, water temperature and salinity profiles (Clay and Medwin 1977; Hamilton 1980; Pickard and Emery 1990; Medwin 2005). Data on the seasonal distribution and abundance of each cetacean and pinniped species that may be present in the ensonified region are required to determine if that species might be exposed, and to quantify the numbers of animals involved. In addition, details of a species' ecology, such as life history and seasonal habitat use, are important to consider because the magnitude of a potential effect may be influenced by these factors.

As noted earlier, there are substantial data gaps and uncertainty regarding how cetaceans and pinnipeds respond to E&P sound. In addition, although sound exposure from E&P activities can potentially be modeled, this process necessitates a detailed level of information for marine conditions near the sound source, which is often unavailable. Consequently, there is likely to be considerable uncertainty in predictions of sound exposure and spatio-temporal extent. Finally, while general ecological knowledge regarding cetaceans and pinnipeds is available, detailed knowledge of the ecology, distribution and abundance patterns, critical habitat and specific habitat use does not exist for most species and situations.

Given the data gaps and uncertainties inherent in a risk assessment to determine effects of offshore E&P sound on cetaceans and pinnipeds, we have developed a methodology based on an iterative tiered approach (Figure 3.1). This methodology consists of an initial problem formulation phase followed by a risk estimation and risk characterization for each combination of sound source and species. Finally, there is a risk management phase that integrates the results across all sound and species pairs. A conclusion is then reached as to the potential level of overall risk from the planned E&P activity, and management recommendations, including possible mitigation measures, are made. The risk estimation and characterization phases are based on the use of four tiers that each consists of four steps: data gathering, evaluation of uncertainty, risk estimation and identification of management options. Successive tiers use a progressively more complex and to some degree more quantitative analysis to determine an estimate of risk, and require progressively more detailed data. The data gaps and uncertainties for each tier are assessed and clearly documented so that the assumptions, limitations and defensibility of any conclusion regarding risk to a species are clearly understood.

The first two tiers are screening assessments based on minimal data. The main objective of these tiers is to create a candidate list of species that may potentially be at risk. It is essential to take a protective approach in these screening phases and not assume that lack of data implies a lack of risk. The goal of Tier 1 is to identify species that may have spatial and temporal overlap with the sound exposure, and consequently are potentially at risk. If any species do have overlap, or data are insufficient to reach a conclusion, they are included in the candidate list, and the assessment moves to the next tier. The objective of Tier 2 is to determine if ensonification has the potential to affect the candidate species. This is accomplished by comparing the characteristics of the emitted sound to the hearing frequency range of each candidate species output from Tier 1. A species is screened out, i.e., removed from the candidate list, if the frequencies emitted by the sound source do not overlap with the functional hearing range for the marine mammal group to which the species belongs (Southall et al. 2007). There is some uncertainty as to whether a particularly strong sound source could impact a species even if the sound frequency is outside of the functional hearing range. This is expected to be an issue only with extremely high received sound levels close to a strong sound source. In that case, a protective approach is recommended; a marine mammal is retained as candidate if it is likely to occur near the source within that ensonified zone. If any candidate species remain after the first two tiers, the assessment moves forward to Tier 3.

Tier 3 involves a semi-quantitative definitive risk assessment for each candidate species based on a scoring system, as introduced in Chapter 2. This tier requires more detailed information on noise exposure, species ecology and distribution, and cumulative effects in order to apply the scoring criteria. Most scoring criteria consist of a yes/no/unknown response that is determined from these data, or is based on expert opinion when data are unavailable. Tier 3 also allows the risk of PTS, TTS and four levels of behavioral disturbance to be evaluated separately by using the sound thresholds defined by Southall et al. (2007) for each of the three sound types and five functional hearing groups. The four levels of behavioral disturbance were derived from the ten categories of behavioral disturbance recognized by Southall et al. (2007). Their response categories were grouped into three broader categories plus their "no observable response" (response score 0) category. "No observable response" was kept as a separate category to allow risk to be assessed for animals expected to be ensonified, but at a level believed to be too low to result in any apparent behavioral change. This category was included to permit a protective approach where animals are within the sound field generated by the activity and thus could be subject to stress or other physiological effects that do not manifest in behavioral changes. Present data concerning received sound levels associated with different levels of behavioral disturbance are too sparse and variable to allow firm exposure criteria to be determined. However, expert opinion can be used to predict the relationship between sound exposure and the most probable behavioral response category. It is also possible, based on observational data summarized in Southall et al. (2007), to estimate received sound levels that are most likely to have certain behavioral effects on each hearing group.

If the results of Tier 3 indicate potential for risk to a species, and data are available to support the use of acoustic modeling to predict the spatial extent of relevant sound exposure levels or received sound exposure levels, then a Tier 4 assessment can be conducted to provide a more detailed risk assessment for that species. Alternately, a Tier 4 assessment can also be conducted if detailed density data are available for a species of interest in the assessment area. Like Tier 3, Tier 4 also applies the scoring system to estimate risk, but uses a quantitative or semi-quantitative analysis to estimate the number of animals expected to be ensonified to levels sufficient for onset of PTS, TTS, or behavioral disturbance. This reduces uncertainty and consequently produces a more reliable risk estimate. Tier 4 also allows the use of models, if available for a species of interest, to predict population level effects for that species.

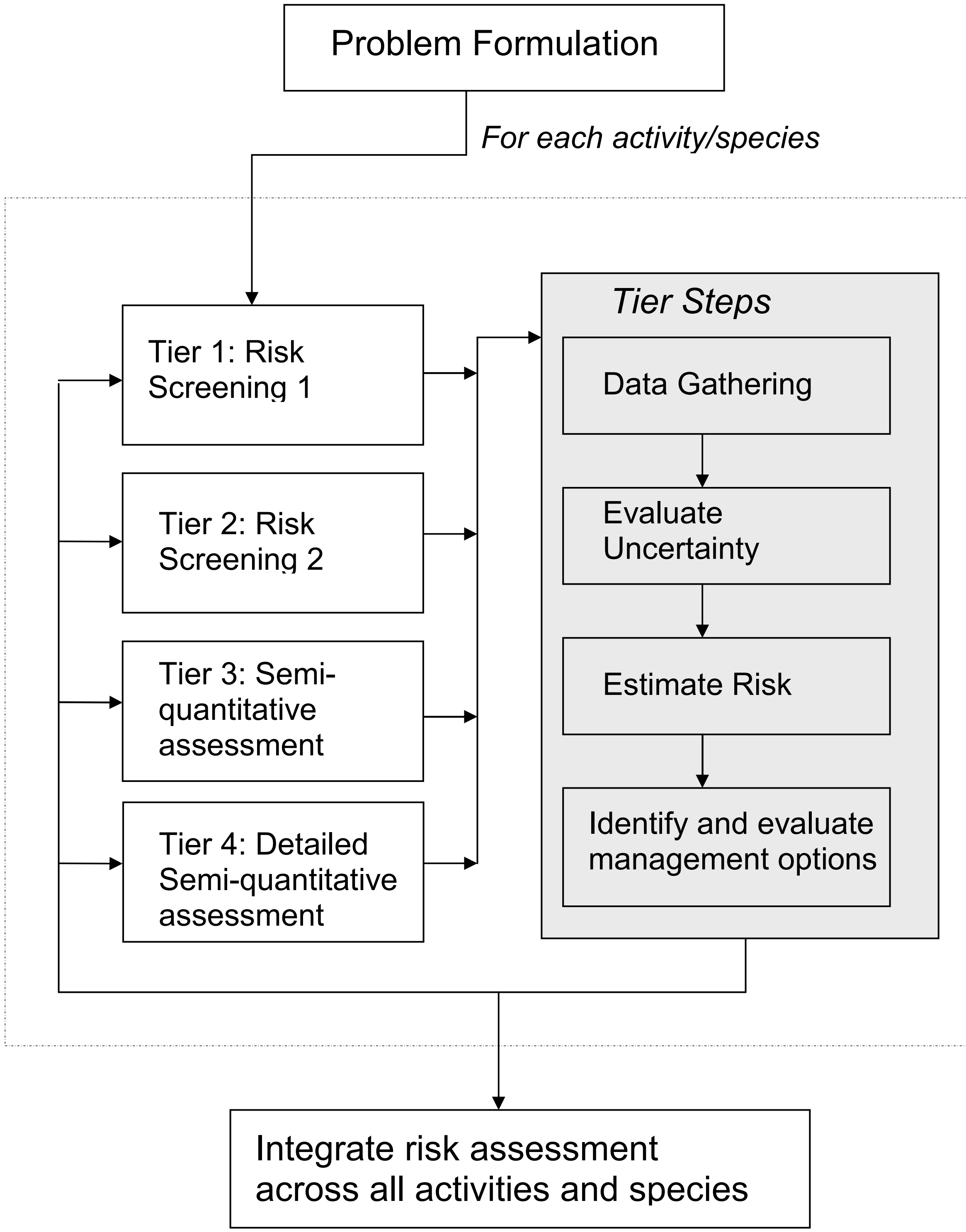


Figure 3.1. Methodology for tiered risk assessment of cetaceans and pinnipeds exposed to E&P sound.

3.2 Problem Formulation

The purpose of the assessment is outlined in the Problem Formulation phase. In the case of marine mammals and the sound generated by E&P activities, the problem can be stated as follows:

"What are the risks to marine mammals arising from sounds generated by E&P activities, and how can these risks be qualitatively or quantitatively assessed?"

Risk assessors must determine how, when and where sound exposure from the planned E&P activity may occur. Consequently, all available information on the E&P activities, location, timing, sound sources (e.g. airguns, sub-bottom profilers, multi-beam bathymetric sonar, mid-frequency sonar, vessels, aircraft, drilling, etc.) are collected (see §3.2.1 below). All sound sources from the industrial activity need to be identified including both primary (e.g. airguns, sub-bottom profilers, sonars, drilling, construction, major shipping) and secondary stressors (support vessels, aircraft; see §3.2.1 below). The cetacean and pinniped species that may be present in the vicinity of the sound source and potentially exposed to sound from the E&P activity must be identified (see §3.2.2 below). Note that detectable levels of the sound need to reach marine mammals of the relevant species for risk to that species to be possible. In addition, the sound threshold for the effect to be assessed (i.e. PTS, TTS or behavioral disturbance) needs to be determined for each sound source and species (see section 3.3, below).

3.2.1 E&P Sound Sources

Exploration and production activities produce underwater and/or in-air sound from a variety of sources. Some of these sounds may be intentionally produced (such as sound from airguns, bathymetric sonar, and sub-bottom profilers) but the majority are produced as by-products of the activities, such as pile-driving, pipe-laying, artificial island construction, installation of offshore platforms, drilling, maintenance, support and research vessels, tankers, and aircraft. Every stage of the exploration, production, and decommissioning process will generate sound and each activity needs to be assessed in terms of the type and level of the sound produced and the sound field that results.

Three sound types can be distinguished: single pulse, multiple pulse, and nonpulse (Southall et al. 2007).

Pulsed sounds are often characterized as being single pulse or multi-pulse. Single pulses are typically single-acoustic events such as the sound from an explosion, an airgun or airgun-array firing once, or a single pile strike. Multiple-pulses involve the serial firing of airguns, multiple pile strikes, or similar sequential sound events. Single and multiple pulses are broadband sounds with rapid rise times and generally short duration. In contrast, nonpulse or continuous sounds are typically those that, if not continuous, have relatively slow rise times; they may be either broadband or narrowband.. Sounds usually classified as nonpulse or continuous include drilling and vessel noise, and most construction activities (except for pile driving or other similar activities).

The difference between a pulsed sound and a nonpulse one is not always clear. While there are empirical distinctions that can be made (see Southall et al. 2007 for a discussion), some sounds have characteristics of both pulsed and nonpulsed sounds (such as acoustic deterrent and harassment devices, some depth sounders, and some sonar systems). In addition, some sources (such as airguns) may produce pulses that eventually, through propagation effects, become nonpulses when received at long distances. Marine mammal hearing is believed to be more vulnerable to pulsed sounds compared to nonpulse sounds because of the rapid rise-times and high peak pressures of pulsed sounds. Although the transformation of a sound from pulsed to nonpulsed with increasing distance would be expected to reduce any impacts on a receiving animal, the distinction between pulsed and non-pulse sounds is not clear-cut, and it is difficult to predict the distance at which that transition would occur. For practical and protective reasons, Southall et al. (2007) recommend that sound type be categorized based on its characteristics at the point of origin.

Table A.1 (Appendix A) summarizes a variety of source levels for selected sources of anthropogenic sound.

3.2.2 Evaluating the Presence of Marine Mammal Species

Once the risk assessor has determined the source level and frequency of the sound generated by the planned activities, it is necessary to determine what, if any, species of marine mammals are present in the area. During the initial assessment it is likely that little, if any, site specific acoustic modeling will have been conducted, so any assessment of the regional impacts of the planned activity should include a broad area around the activity focal point—for example based on the identified Large Marine Ecosystem in which the activity occurs (see below).

Tables A.2 to A.4 summarize information on marine mysticetes (baleen whales), odontocetes (toothed whales), and pinnipeds (seals, sea lions and walrus). Information on the distribution and abundances of these species is often limited and often highly generalized, with distributions largely being attributed to ocean-wide regions or within broad bounds of polar, temperate, or tropical waters.

While available data are incomplete for many (if not most) species, there are a number of sources that provide access to relevant information. The following sources are recommended for providing preliminary assessments of species presence, which can then be fine-tuned from the literature and/or from local expert knowledge, where possible taking account of more detailed information on oceanographic factors, water depths etc., that may influence marine mammal distribution.

3.2.2.1. Large Marine Ecosystems of the World

Large Marine Ecosystems are large ocean regions of 200,000 km^2 or greater that include coastal areas and extend to the seaward boundaries of continental shelves and outer margins of major current systems. The Large Marine Ecosystem (LME) online database is a collaborative association between the IUCN-The World Conservation Union, U.S. National Oceanographic and Atmospheric Administration—National Marine Fisheries Service, and the Intergovernmental Oceanographic Commission of UNESCO (Figure 3.2 and Table 3.1). Two interfaces are available that both provide clickable maps to access the 64 LMEs and descriptive information for each LME. The interface at http://www.lme.noaa.gov/ provides additional information on socioeconomic factors for each LME, while the interface at http://www.seaaroundus.org/lme/lme.aspx provides a marine mammal species list for each LME.

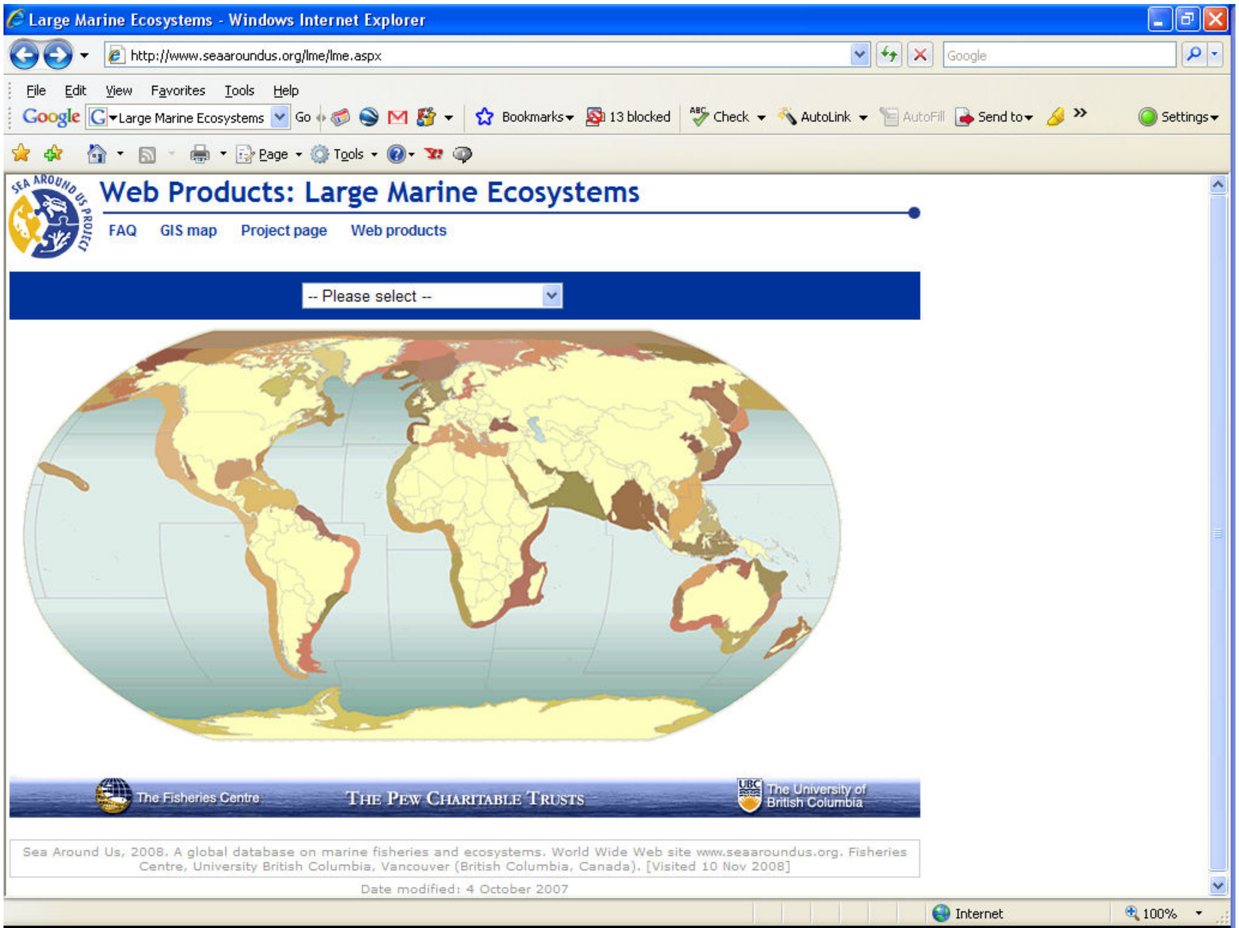


Figure 3.2. Map showing the locations of the 66 Large Marine Ecosystems. Available at http://www.seaaroundus.org/lme/lme.aspx

A drop-down menu provides access to each of the LMEs (Table 3.1). In addition, the database at http://www.lme.noaa.gov/index.php?option=com_content&view=article&id=177&Itemid=75 provides the coordinates for each of the LMEs as data downloads—as polygons, line or grid data.

Table 3.1. Number of marine mammal species known to be present in each Large Marine Ecosystem of the world (available at http://www.seaaroundus.org/lme/lme.aspx). N/A means that no marine mammal data are currently available for this LME.

Large Marine Ecosystem	Number of Marine Mammal Species Present
East Bering Sea	27
Gulf of Alaska	36
California Current	46
Gulf of California	39
Gulf of Mexico	31
Southeast U.S. Continental Shelf	31
Northeast U.S. Continental Shelf	42
Scotian Shelf	26
Newfoundland-Labrador Shelf	29
Insular Pacific-Hawaiian	36
Pacific Central-American Coastal	59

Large Marine Ecosystem	Number of Marine Mammal Species Present
Caribbean Sea	31
Humboldt Current	59
Patagonian Shelf	50
South Brazil Shelf	50
East Brazil Shelf	32
North Brazil Shelf	28
West Greenland Shelf	24
East Greenland Shelf/Sea	24
Iceland Shelf/Sea	24
Barents Sea	28
Norwegian Sea	29
North Sea	25
Baltic Sea	21
Celtic-Biscay Shelf	28
Iberian Coastal	33
Mediterranean Sea	15
Canary Current	39
Guinea Current	32
Benguela Current	49
Agulhas Current	47
Somali Coastal Current	28
Arabian Sea	31
Red Sea	17
Bay of Bengal	31
Gulf of Thailand	19
South China Sea	38
Sulu-Celebes Sea	29
Indonesian Sea	29
North Australian Shelf	27
Northeast Australian Shelf/Great Barrier Reef	32
East-Central Australian Shelf	48
Southeast Australian Shelf	49
Southwest Australian Shelf	43
West-Central Australian Shelf	44
Northwest Australian Shelf	33
New Zealand Shelf	47
East China Sea	46
Yellow Sea	31
Kuroshio Current	47
Sea of Japan	45
Oyashio Current	34
Sea of Okhotsk	32
West Bering Sea	26
Chukchi Sea	N/A
Beaufort Sea	N/A
East Siberian Sea	N/A
Laptev Sea	N/A
Kara Sea	N/A
Faroe Plateau	26
Antarctica	17
Black Sea	5
Hudson Bay	N/A
Arctic Ocean	N/A

Although data for some LMEs are incomplete (see Table 3.1), for most of the regions, basic marine mammal information is available online. For example, by clicking on the East Bering Sea region on the map shown in Figure 3.2, the following information is accessed (Figure 3.3)

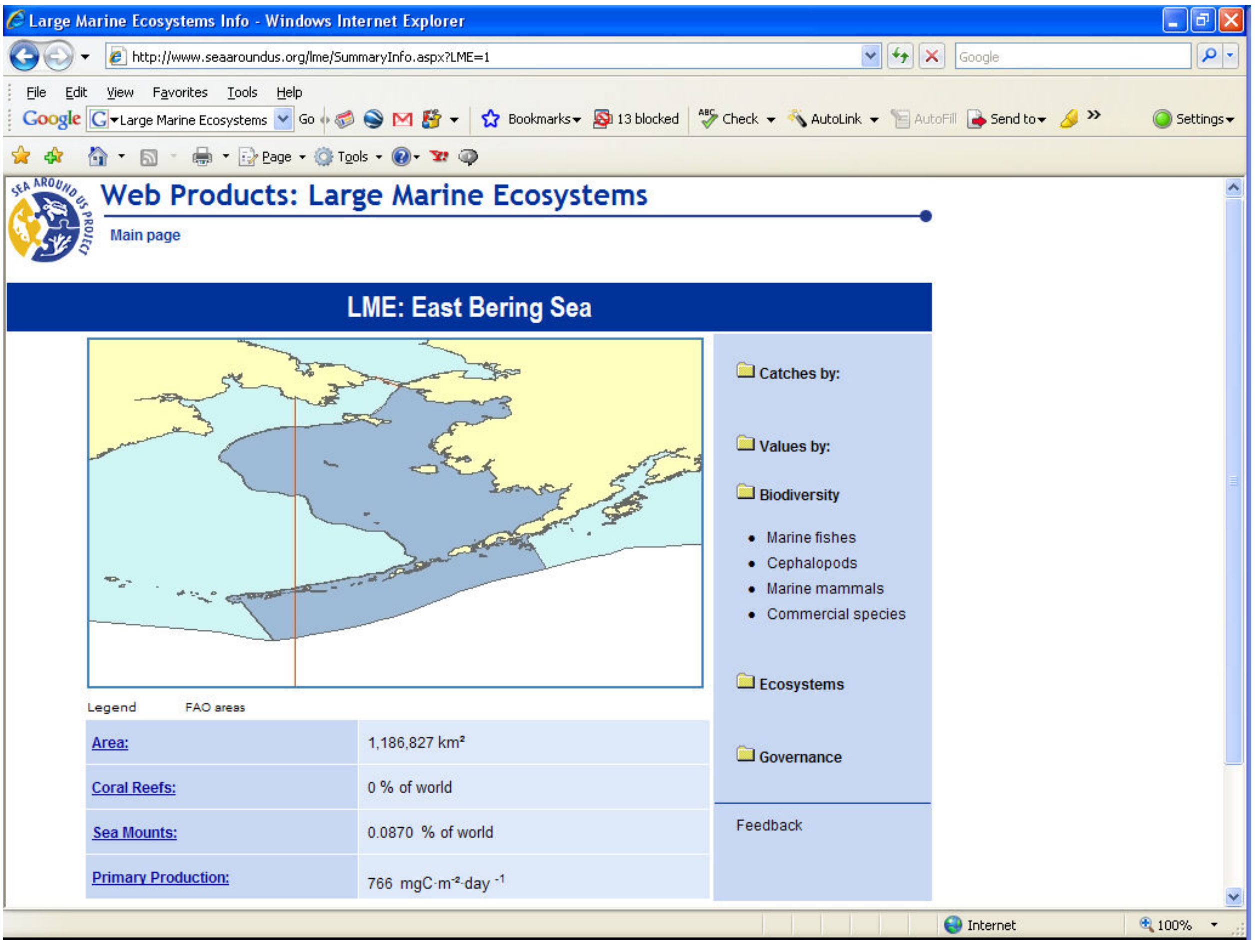
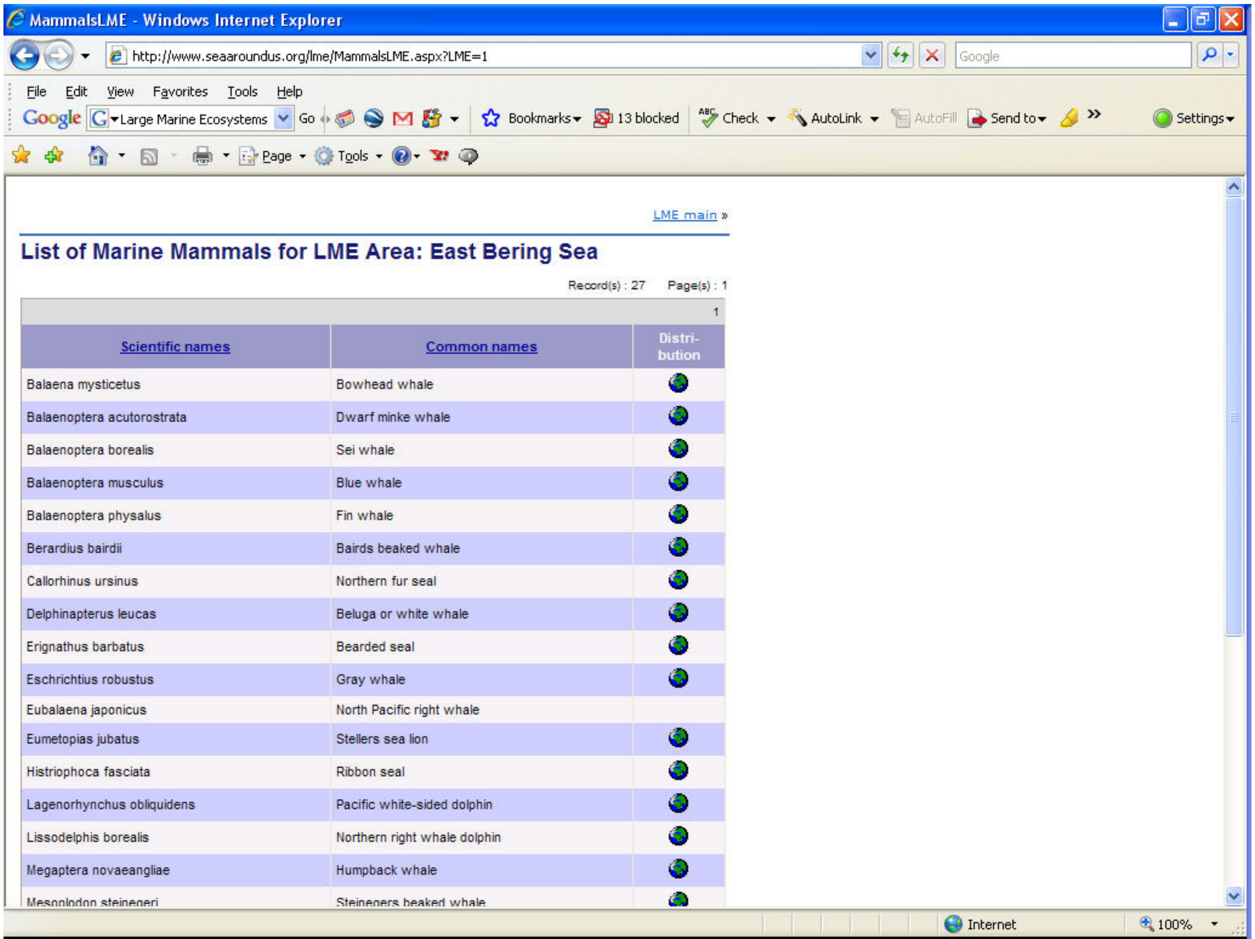


Figure 3.3. Data entry point for an example LME: the East Bering Sea.

Accessing the "Marine mammal" listing under the Biodiversity folder on the right of the screen opens up a screen that lists 27 species of marine mammals as occurring in the East Bering Sea LME (Figure 3.4). Global distribution maps are linked to (most) of the species identified.



LME main »

List of Marine Mammals for LME Area: East Bering Sea

Record(s) : 27 Page(s) : 1

Scientific names	Common names	Distri-bution
Balaena mysticetus	Bowhead whale	
Balaenoptera acutorostrata	Dwarf minke whale	
Balaenoptera borealis	Sei whale	
Balaenoptera musculus	Blue whale	
Balaenoptera physalus	Fin whale	
Berardius bairdii	Bairds beaked whale	
Callorhinus ursinus	Northern fur seal	
Delphinapterus leucas	Beluga or white whale	
Erignathus barbatus	Bearded seal	
Eschrichtius robustus	Gray whale	
Eubalaena japonicus	North Pacific right whale	
Eumetopias jubatus	Stellers sea lion	
Histriophoca fasciata	Ribbon seal	
Lagenorhynchus obliquidens	Pacific white-sided dolphin	
Lissodelphis borealis	Northern right whale dolphin	
Megaptera novaeangliae	Humpback whale	
Mesoplodon stejnegeri	Stejnegers beaked whale	

Figure 3.4. Initial portion of the list of marine mammals for an example LME area: East Bering Sea.

LMEs listed in Table 3.1 do not include all open ocean regions. To identify species present in those far offshore areas it is necessary to review the global distribution maps accessible through each LME page, or via other sources such as the IUCN and Convention on Migratory Species (see below).

The LME database provides a useful starting point, however, it should be noted that the data available are likely to vary in quantity and quality for each region and may not be updated on a regular basis to incorporate recently published data. It is therefore recommended that such sources be used with appropriate caution and data verified from multiple sources where possible.

3.2.2.2. IUCN-World Conservation Union

The IUCN-World Conservation Union (www.iucn.org) is a membership union with more than 1,000 government and NGO member organizations and includes ~11,000 volunteer scientists in more than 160 countries. The IUCN's mission is to "influence, encourage and assist societies throughout the world to conserve the integrity and diversity of nature and to ensure that any use of natural resources is equitable and ecologically sustainable." One of the IUCN's most visible roles has been to conduct conservation status assessments of species, subspecies, varieties, and selected subpopulations on a global scale. For four decades, the IUCN has produced the IUCN Red List of Threatened Species (www.redlist.org) that is now fully searchable online. The IUCN Red List is compiled independently of countries that have produced their own national accounting of threatened and endangered species. The Red List follows a hierarchical system (Figure 3.5); species that are evaluated as Critically Endangered, Endangered, and Vulnerable are considered to be Threatened.

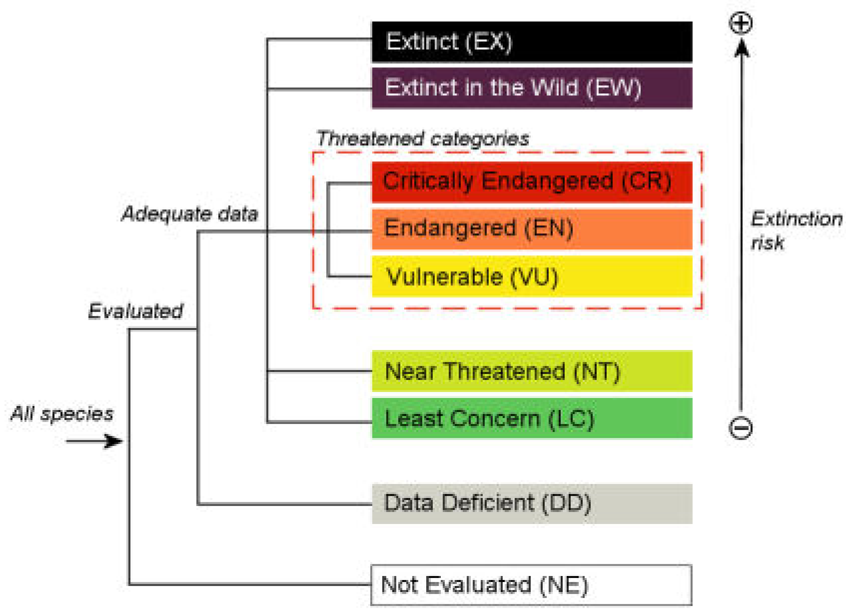


Figure 3.5. IUCN Red List categories (IUCN 2008).

In general broad terms the main IUCN categories are defined as follows (IUCN 2008):

- Extinct (EX). A taxon is Extinct when there is no reasonable doubt that the last individual has died. A taxon is presumed Extinct when exhaustive surveys in known and/or expected habitat, at appropriate times, throughout its historic range have failed to record an individual;
- Extinct in the Wild (EW). A taxon is Extinct in the Wild when it is known only to survive in cultivation, in captivity or as a naturalized population well outside the past range.
- Critically Endangered (CR). A taxon is Critically Endangered when the best available evidence indicates that it is facing an extremely high risk of extinction in the wild, e.g., an observed, estimated, inferred or suspected population size reduced of ≥90% over the last 10 years or three generations, whichever is longer.
- Endangered (EN). A taxon is Endangered when the best available evidence indicates that it is facing a very high risk of extinction in the wild, e.g., an observed, estimated, inferred or suspected population reduction of ≥70% over the last 10 years or three generations, whichever is longer.
- Vulnerable (VU). A taxon is Vulnerable when the best available evidence indicates that it is facing a high risk of extinction in the wild, e.g., an observed, estimated, inferred or

suspected population reduction of ≥50% over the last 10 years or three generations, whichever is longer.

- Near Threatened (NT). A taxon is Near Threatened when is have been evaluated against the above criteria and does not yet qualify, but is considered close to qualifying and is likely to qualify for a threatened category in the near future.
- Least Concern (LC). A taxon is Least Concern when it has been evaluated against the above criteria and does not yet qualify. Abundant taxa are included here.
- Data Deficient (DD). A taxon is Data Deficient when there is inadequate information to make a direct, or indirect, assessment of its risk of extinction.
- Not Evaluated (NE). These taxon have not been evaluated against the above criteria.

Additional assessment criteria for each of these categories can be found in IUCN (2008).

The IUCN provides detailed assessments for all listed species. Among cetaceans, the IUCN includes 115 species/subspecies/stocks on the 2008 Red List. Similarly, the Red List includes 35 species of pinnipeds.

Each species or stock assessment included on the Red List includes information on the assessment information used, the geographic range, population, habitat ecology, threats to the species, and conservation actions (Figure 3.6).

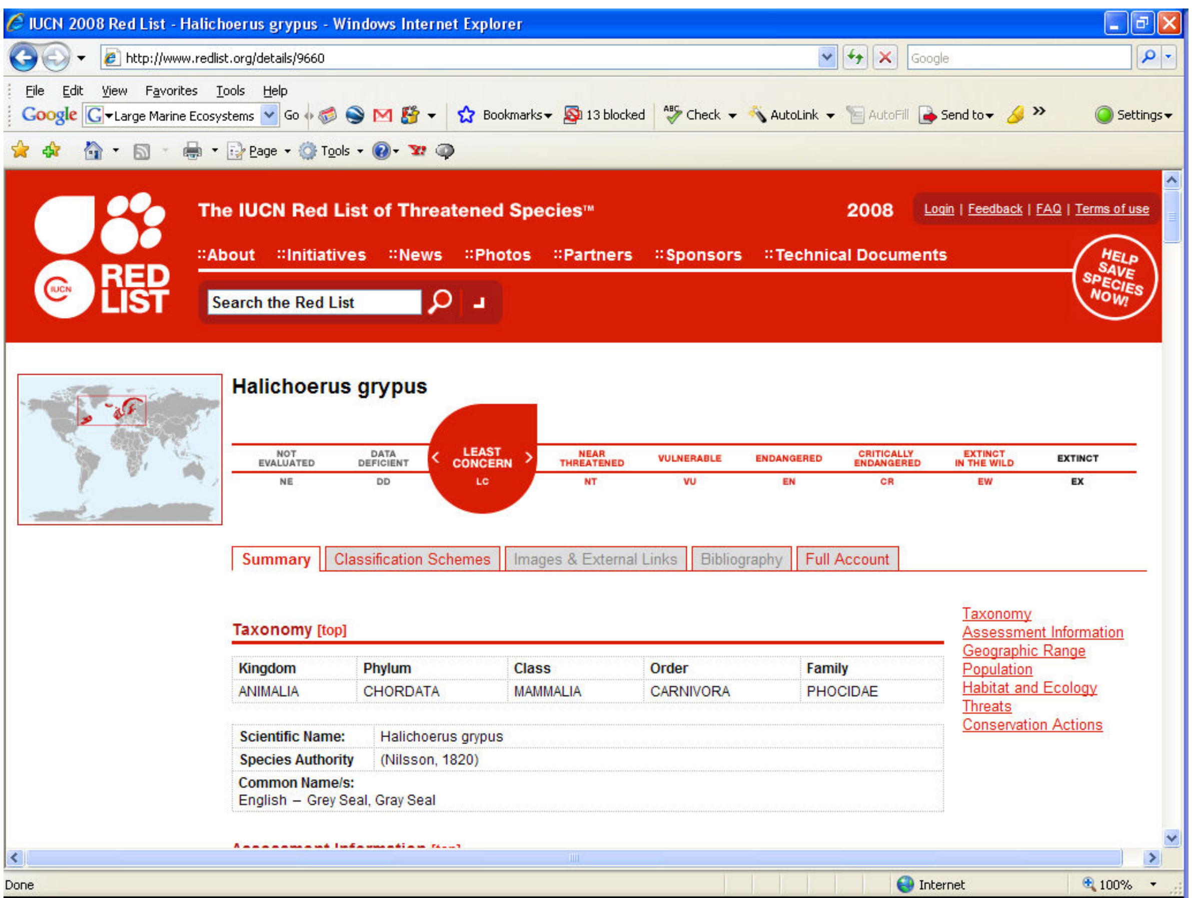


Figure 3.6. Initial portion of the IUCN Red List page for the gray seal, *Halichoerus grypus*.

For the purposes of a risk assessment, these species summaries are particularly useful for their range maps, summary data on population tends, and identification of threats to the population (such as vessel collisions, pollutant, by-catch, subsistence harvest etc.). Many of the maps available distinguish locations of breeding and non-breeding habitat (Figure 3.7).

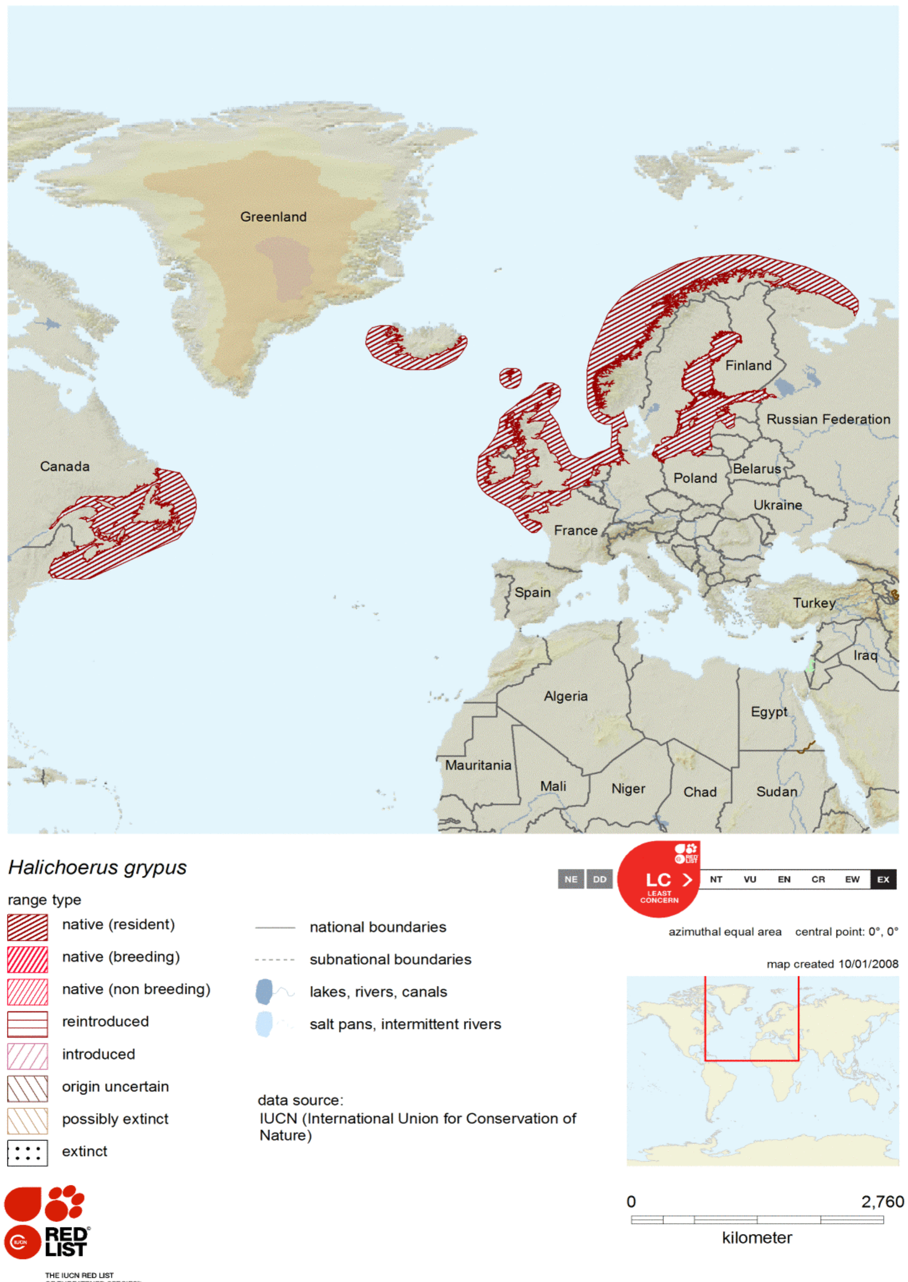


Figure 3.7. Range map for *Halichoerus grypus* (IUCN 2008).

3.2.2.3. Convention on Migratory Species (CMS), Review on Small Cetaceans

Complementary to the data available on the IUCN Red List is the *Review on Small Cetaceans: Distribution, Behavior, Migration and Threats* complied for the Convention on Migratory Species by B.M. Culik (2002).

This electronic report (available at http://www.cms.int/reports/small_cetaceans/index.htm) provides access to data on small cetaceans, which include all cetacean species except for the baleen whales and sperm whale.

As with the IUCN Red List, the CMS database provides information on distribution, population size (including densities in some cases), habitat, reproduction, feeding, migration, and threats.

3.2.2.4. Other Sources (Government, NGOs, Universities)

Regional marine mammal databases are often held by government agencies or intergovernmental bodies. These include institutions such as the U.S. National Marine Fisheries Service, U.S. Minerals Management Service, U.S. Fish and Wildlife Service, Joint Nature Conservation Committee (U.K.), European directory of Marine Environmental Data Sets, World Data Center for Marine Environmental Sciences, CSIRO Marine Research (Australia), Australian Fisheries Management Authority, Australia National Oceans Office, Ocean Biogeographic Information System (OBIS-SEAMAP), and NATO Undersea Research Centre. National resource agencies (such as U.S. NMFS, Environment Australia, and the Department of Fisheries and Oceans, Canada) frequently produce annual (or other regular) updates to their marine mammal stock assessments or species specific conservation and recovery plans.

There are also numerous databases held by non-governmental organizations and universities. While the use of inter-governmental data from such organizations as the IUCN and Convention on Migratory Species provides an inherent level of confidence in the data presented, other data sources should also be investigated, particularly if they offer more site-specific information.

Depending on the jurisdiction, national, provincial, and/or state universities may have marine biology departments with researchers working on marine mammals. The MARMAM email listserv can be a particularly useful tool for locating researchers in particular areas and focusing on the species of interest. Environmental groups may also fund or support studies and may provide a clearinghouse for data. Other E&P operators in the region may also have conducted surveys that could be relevant. One major open access database, OBIS-SEAMAP (http://www.iobis.org/), is hosted by Rutgers University, with major involvement (in the case of marine mammals) by Duke University. This database of marine life and the ocean environment currently holds 16 million records from 441 databases. It enables fairly detailed regional searches of marine mammal data, including mapping of marine mammal sightings that have been submitted for inclusion. However, not all of the available sighting data are included in this database.

3.2.2.5. Summary of Selected Information Sources

A summary of selected databases that will often provide assistance in locating useful information about marine mammals in a particular area of interest is provided in Table A.5.

3.3 Determining Exposure Criteria for PTS, TTS and Behavioral Disturbance

Noise exposure criteria specify sound levels above which adverse effects (e.g. PTS, TTS and behavioral disturbance) on marine mammals are expected to occur (Southall et al. 2007). These criteria can be used to estimate the spatial extent of the area around an industrial sound source that may be ensonified to levels meeting or exceeding the exposure criterion for a particular effect. This spatial extent can then be compared to known or predicted distribution and abundance patterns for a species, and the proportion of that species' stock that is potentially at risk for the associated effect can be estimated. The nature of sound exposure is such that, under most conditions, received sound level tends to decrease with distance from the source (Figure 3.8). As a result, the spatial extent for an effect varies inversely with the sound level above which that effect tends to occur. For example, the received level at which a sound will be barely audible is much lower than the received level above which it will cause hearing impairment. Consequently, the area within which the sound will be audible is much larger than the area within which it will cause hearing impairment.

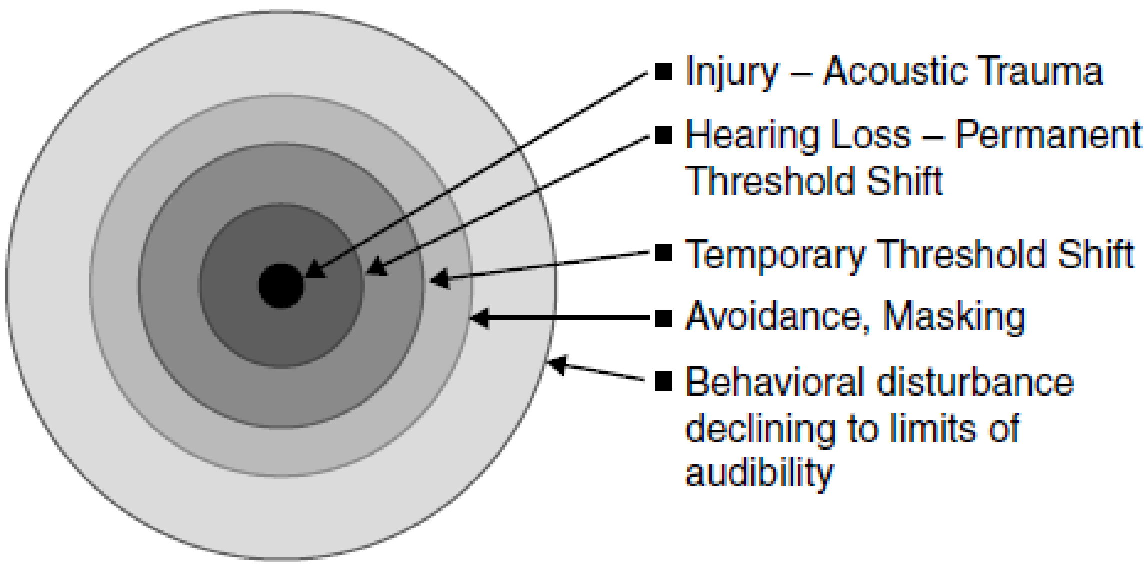


Figure 3.8. Sound exposure and distance. Source: NRC (2005), modified from Richardson and Malme (1993).

Determination of the received sound levels and durations that result in PTS, TTS and various levels of behavioral disturbance is an area of active research (e.g. Southall et al. 2007). The following sections provide background on marine mammal hearing sensitivity and summarize the sound thresholds specified by Southall et al. (2007). This information can be used to meet certain data requirements in the risk assessment process. In particular, the assessment requires information on the frequency range to which the marine mammal is sensitive, to determine whether there is any overlap with the frequencies emitted by the sound source being assessed. Also, the assessment requires all available data on the sound levels that elicit specific effects in the species of concern. Although information is generally available on the former (at least at the species-group level), it is mainly lacking for the latter. Also, available data are frequently inconsistent within and between species. However, despite these uncertainties and limitations, it is still possible to use these data to inform the risk assessment process.

3.4 Marine Mammal Hearing

The effects of noise on marine mammals are highly variable, and can be categorized as follows (based on Richardson et al. 1995):

1. The noise may be too weak to be heard at the location of the animal, i.e., lower than the prevailing ambient noise level, the hearing threshold of the animal at relevant frequencies, or both;
2. The noise may be audible but not strong enough to elicit any overt behavioral response, i.e., the mammals may tolerate it;
3. The noise may elicit behavioral reactions of variable conspicuousness and variable relevance to the well being of the animal; these can range from subtle effects on respiration or other behaviors (detectable only by statistical analysis) to active avoidance reactions;
4. Upon repeated exposure, animals may exhibit diminishing responsiveness (habituation), or disturbance effects may persist; the latter is most likely with sounds that are highly variable in characteristics, unpredictable in occurrence, and associated with situations that the animal perceives as a threat;
5. Any anthropogenic noise that is strong enough to be heard has the potential to reduce (mask) the ability of animals to hear natural sounds at similar frequencies, including calls from conspecifics, echolocation sounds of odontocetes, and environmental sounds such as surf noise or (at high latitudes) ice noise;
6. Very strong sounds have the potential to cause temporary or permanent reduction in hearing sensitivity, or other physical effects. Received sound levels must far exceed the animal's hearing threshold for any temporary threshold shift to occur. Received levels must be even higher for a risk of permanent hearing impairment.
7. Exposure of deep-diving cetacean species to sounds from mid-frequency naval sonars has occasionally been followed by stranding and death of the animals. The mechanism is unproven, but it is suspected that decompression illness resulting from sonar-induced disruption of the diving behavior of these animals may be involved.

3.4.1 Cetacean Hearing

The hearing abilities of some *odontocetes* have been studied in detail (Table A.6), as reviewed in Richardson et al. (1995), Szymanski et al (1999), Au et al. (2000), Klishin et al. (2000), Hemila et al. (2001), Kastelein et al. (2003) and Southall et al. (2007). The hearing sensitivity of several species has been determined as a function of frequency. The small to moderate-sized toothed whales have relatively poor hearing sensitivity at frequencies below 1 kHz, but extremely good sensitivity at, and above, several kHz. There are at present no specific data on the absolute hearing thresholds of the larger, deep-diving toothed whales, such as the sperm and beaked whales. However, Cook et al. (2006) found that a Gervais' beaked whale showed evoked potentials from 5 kHz up to 80 kHz (the entire frequency range that was tested), with the best sensitivity at 40–80 kHz.

Most odontocete species have been classified as belonging to the "mid-frequency" (MF) hearing group, and the MF odontocetes (collectively) have functional hearing from ~150 Hz to 160 kHz (Southall et al.

2007). However, individual species may not have quite so broad a functional frequency range. Very strong sounds at frequencies slightly outside the functional range may also be detectable. The remaining odontocetes—the porpoises, river dolphins, and species of the genera *Cephalorhynchus* and *Kogia*—are distinguished as the "high frequency" (HF) hearing group. They have functional hearing from ~200 Hz to 180 kHz (Southall et al. 2007).

The hearing abilities of *mysticetes* have not been studied directly, but they are almost certainly more sensitive to low-frequency sounds than are the small toothed whales (Table A.7). Behavioral and anatomical evidence indicates that baleen whales hear well at frequencies below 1 kHz (Richardson et al. 1995; Ketten 2000). Some baleen whales also react to sonar sounds at 3.1 kHz and other sources centered at 4 kHz (see Richardson et al. 1995 for review). Frankel (2005) noted that gray whales reacted to a 21–25 kHz whale-finding sonar. Some baleen whales react to pinger sounds up to 28 kHz, but not to pingers or sonars emitting sounds at 36 kHz or above (Watkins 1986). Baleen whales have been classified as belonging to the "low-frequency" (LF) hearing group, whose the functional hearing range is thought to be ~7 Hz–22 kHz (Southall et al. 2007). The absolute sound levels that they can detect below 1 kHz are probably limited by increasing levels of natural ambient noise as frequencies decrease below this level (Clark and Ellison 2004). The detection thresholds at those low frequencies are unknown, but speculated to be 60–80 dB re 1 μPa (Ketten 2004).

3.4.2 Pinniped Hearing

Underwater audiograms have been obtained using behavioral methods for three species of phocinid seals, two species of monachid seals, two species of otariids, and the walrus (reviewed in Richardson et al. 1995: 211ff, Kastak and Schusterman 1998, 1999; Kastelein et al. 2002). The functional hearing range for pinnipeds in water is considered to extend from 75 Hz to 75 kHz (Southall et al. 2007), although some individual species, especially the eared seals, do not have that broad an auditory range (Richardson et al. 1995). In comparison with odontocetes, pinnipeds tend to have lower best frequencies, lower high-frequency cutoffs, better auditory sensitivity at low frequencies, and poorer sensitivity at the best frequency (Table A.8).

At least some of the phocid seals have better sensitivity at low frequencies (≤1 kHz) than do odontocetes. Below 30–50 kHz, the hearing thresholds of most species tested are essentially flat down to ~1 kHz, and range between 60 and 85 dB re 1 μPa. Measurements for a harbor seal indicate that, below 1 kHz, its thresholds deteriorate gradually to ~97 dB re 1 μPa at 100 Hz (Kastak and Schusterman 1998).

For the otariid (eared) seals, the high frequency cutoff is lower than for phocinids, and sensitivity at low frequencies (e.g., 100 Hz) is poorer than for seals (harbor seal).

3.4.3 Marine Mammal Hearing Groups

Southall et al. (2007) identified five functional hearing groups of marine mammals based on an assessment of comparative anatomy, modeling, and audiogram data (Appendix Table B.1). The estimated auditory bandwidths of these functional hearing groups indicate that all groups have at least some sensitivity at low frequencies, and that there is considerable overlap among the groups.

3.4.4 Injury Criteria

For each of the functional hearing groups, Southall et al. (2007) estimated the acoustic exposures above which auditory injury (PTS) might be expected (Appendix Table B.2). Southall et al. concluded that, for each hearing group, auditory injury was possible if sound exposure exceeded either a specified peak pressure level or a cumulative received energy level (expressed as sound exposure level, SEL). The criterion values proposed by Southall et al. can be used to identify situations (to a first approximation defined in terms of distance and duration of exposure) in which auditory injury might be expected.

In the U.S., the National Marine Fisheries Service currently uses 190 dB re: 1 µPa as the injury criterion for pinnipeds exposed to pulsed sounds and 180 dB re: 1 µPa as the injury criterion for all cetaceans exposed to pulsed sounds.

3.4.5 TTS and Behavioural Criteria

While it is not possible, at this time, to establish clear exposure criteria for TTS onset or behavioral response in the same manner as for PTS, Southall et al. (2007) did summarize information on the occurrence and types of behavioral responses that have been observed at various received levels of multiple-pulse and nonpulse sounds. We further summarized these data for the four broad behavioral categories (TTS is considered equivalent to strong behavioral response) used in the risk assessment methodology described in this document (Table 3.2). Greater weight was given to larger sample sizes when determining sound levels typically associated with category of response. There is much overlap in the sound levels associated with different response categories, although for most mammal groups there is a trend toward greater behavioral reaction at greater received levels.

Although this information can provide a starting point for risk assessors in determining the possible impact of sound resulting from E&P activities if estimates of received sound levels are available, regulatory authorities may assume different values. In the U.S., the National Marine Fisheries Service currently uses 160 dB re: 1 µPa as the disturbance criterion for most cetaceans exposed to pulsed sounds. In some regions (such as Alaska), a lower disturbance criterion, 120 dB re: 1 µPa, has been implemented (for impulse sounds) when cow/calf bowhead whales are present. Also, in some areas, such as the Beaufort and Chukchi seas, it has been assumed that marine mammals exposed to continuous or near-continuous anthropogenic sounds with received level of 120 dB re: 1 µPa would probably be disturbed. Given the high variability of the behavioral responses to differing sound levels, it is considered advisable to use lower, i.e., protective, criteria in a risk assessment that can subsequently be modified as new data become available.

Table 3.2. Received sound levels associated with various categories of behavioral responses (based on data summarized by Southall et al. 2007.* The "Single pulse" column follows Southall et al. in assuming that, for a single pulse, the onset of appreciable disturbance would occur at the TTS threshold. For "multiple pulse" and "nonpulse" sounds, our "None", "Slight", "Moderate" and "Strong" categories incorporate Southall et al.'s categories 0, 1–3, 4–6, and 7–9, respectively. Except where indicated "peak" or SEL, all sound levels referred to in this table are RMS levels.

	Sound Type		
Marine Mammal Group	**Single Pulse**	**Behavioral Reaction to Multiple Pulses***	**Behavioral Reaction to Nonpulses***
LF cetaceans			
Sound pressure level	224 dB re: 1 µPa (peak)(flat)	None: 110-130 dB re: 1 µPa (peak)(flat)	None: 80-110 dB re: 1 µPa (peak)(flat)
		Slight: 110-130 dB re: 1 µPa	Slight: 100-110 dB re: 1 µPa
		Moderate: 120-130 dB re: 1 µPa	Moderate: 110-130 dB re: 1 µPa
		Strong: 150-160 dB re: 1 µPa	Strong: 130-150 dB re: 1 µPa
Sound exposure level	183 dB re: 1 µPa^2-s (SEL)	N/A	N/A
MF cetaceans			
Sound pressure level	224 dB re: 1 µPa (peak)(flat)	None: 110-140 dB re: 1 µPa (peak)(flat)	None: 100-190 dB re: 1 µPa (peak)(flat)
		Slight: no data	Slight: 80-130 dB re: 1 µPa
		Moderate: 120-180 dB re: 1 µPa	Moderate: 110-180 dB re: 1 µPa
		Strong: no data	Strong: 90-200 dB re: 1 µPa
Sound exposure level	183 dB re: 1 µPa^2-s (SEL)	N/A	N/A
HF cetaceans			
Sound pressure level	224 dB re: 1 µPa (peak)(flat)	None: 80-100 dB re: 1 µPa (peak)(flat)	None: 80-100 dB re: 1 µPa (peak)(flat)
		Slight: no data	Slight: no data
		Moderate: 80-170 dB re: 1 µPa	Moderate: 80-170 dB re: 1 µPa
		Strong: no data	Strong: no data
Sound exposure level	183 dB re: 1 µPa^2-s (SEL)	N/A	N/A
Pinnipeds (in water)			

	Sound Type		
Marine Mammal Group	**Single Pulse**	**Behavioral Reaction to Multiple Pulses***	**Behavioral Reaction to Nonpulses***
Sound pressure level	212 dB re: 1 μPa (peak)(flat)	None: 150-200 dB re: 1 μPa (peak)(flat)	None: 80-130 dB re: 1 μPa (peak)(flat)
		Slight: 130-140 dB re: 1 μPa	Slight: 120-140 dB re: 1 μPa
		Moderate: 160-200 dB re: 1 μPa	Moderate: 100-140 dB re: 1 μPa
		Strong: N/A	Strong: N/A
Sound exposure level	171 dB re: 1 μPa2-s (SEL)	N/A	N/A
Pinnipeds (in air)			
Sound pressure level	109 dB re: 20 μPa (peak) (flat)	None: 60-80 dB re: 1 μPa (peak)(flat)	None: 60-70 dB re: 1 μPa (peak)(flat)
		Slight: 60-70 dB re: 1 μPa	Slight: N/A
		Moderate: N/A	Moderate: 110-120 dB re: 1 μPa
		Strong: N/A	Strong: N/A
Sound exposure level	100 dB re: (20 μPa)2-s	N/A	N/A

*general range of received sound levels for marine mammals (individuals and/or groups) reported as showing strong, moderate, slight and no responses (based on data summarized by Southall et al. 2007). Frequently based on small sample sizes with great variation among individuals, studies, and species. Results involving larger sample sizes were given greater weight. Outliers were discounted. These figures provide general guidance for the categories of behavioral disturbance used in the risk assessment methodology described in this document.

3.5 Evaluating Factors Influencing Marine Mammal Stocks

Cetacean populations are potentially affected by numerous factors (Table 3.3), including those that can be classified as physical (such as water temperature and salinity), biological (such as predation, prey abundance, mate selection, genetic drift, and female fecundity), and anthropogenic (such as pollution, fisheries by-catch, hunting, prey competition, noise, disturbance, and vessel collisions). These effects may be direct or indirect, and their magnitude can vary with species, stock, season, or other factors. These factors should be reviewed during the risk assessment to determine which are applicable to the species or stock in question and the relative importance of each to the subject species. In many cases, data may be limited; however, the assessment must still recognize that these factors may be adding to the cumulative impacts on a species, which could (in turn) result in an elevated risk level. Information on threats can be found in the database resources, such as the IUCN Red List, discussed earlier.

Table 3.3. Natural and anthropogenic factors potentially affecting marine mammal populations. Anthropogenic factors associated with both non-E&P and E&P operations are listed under the more prevalent heading or, in some cases (vessels, oil spills, pollution), under both headings.

Natural/Environmental Factors	Non-E&P Industry Anthropogenic Factors	E&P Anthropogenic Factors
Predation	Commercial whaling	Airguns
Prey abundance	Subsistence whaling	Vibroseis
Genetic diversity	Illegal whaling	Pile driving
Sex ratio	Global warming and climate change	Dredging
Mass stranding	Prey depletion	Drilling
Disease	By-catch and entanglement	Platform installation
Climate cycles: El Niño, NAO	Vessel collisions	Vessel collisions
Competition	Vessel noise	Vessel noise
Changes in habitat	Sonar	Oil spills
Immigration/Emigration	Coastal development	Pollution
	Oil spills	Aircraft/helicopters
	Pollution	
	Underwater explosions	
	Acoustic harassment devices	

3.6 Risk Assessment Tiers

This section presents the four tiers of the risk assessment. The objective of each tier is summarized, and each step to be conducted within the tier is described.

3.6.1 Tier 1

This tier conducts the first screening risk assessment for a sound source and marine mammal based on temporal and spatial information. The objective of this tier is to determine if a marine mammal species may be exposed to sound produced by offshore E&P industrial activities. If both spatial and temporal overlap exists between the sound exposure and the marine mammal, then risk may occur and a more detailed risk assessment is required, i.e., the assessment moves to Tier 2. If data are insufficient to adequately assess the possibility of exposure to E&P sound, a protective approach is taken by assuming that exposure is possible and the assessment also moves to Tier 2. Alternately, if it is known that there is no spatial and temporal overlap, the risk estimate is set to zero for this marine mammal species, and the species is then "screened out," i.e., removed from the risk assessment. The effects of variability and uncertainty on exposure estimates and characteristics of the species' distribution are also assessed and described, and incorporated into the risk estimate.

3.6.1.1. Summary of Tier 1 Steps

- Identify if there is spatial and temporal overlap between the range of the marine mammal species and the proposed activity using an approximate protective estimate of the extent of the sound field;
- If there is overlap, can the project be changed so as to avoid that overlap?
- If the available management options cannot avoid overlap of the sound source and the identified marine mammal species, or if data are insufficient to make an assessment, proceed to Tier 2.

3.6.1.2. Data Gathering

This tier requires the least amount of data compared to the other three tiers. The expected timing and spatial extent of the sound exposure is required for comparison with the seasonal distribution of the species in the general area of the sound exposure. The spatial extent of the exposure is estimated based on expert opinion, and considers the received sound level at which even "slight" behavioral disturbance may result. The spatial extent of the species' known range is refined, if possible, for the time period that the sound exposure will occur.

3.6.1.3. Evaluate Uncertainty

Methods to evaluate uncertainty for this tier are described in Section 4.1.

3.6.1.4. Estimate Risk

The spatial extent of the exposure is estimated based on expert opinion, and considers the received sound level at which any category of behavioral disturbance may result. The general area of the sound exposure can be defined relative to the location of the sound source, with a larger area being assessed in the case of stronger sources (such as airguns or pile driving equipment). The spatial extent of the species' known range, as determined during problem formulation, is further refined (if possible) for the relevant seasons and compared to the anticipated spatial extent of the sound field around the source. The expected timing of the sound exposure is also compared to the expected time of year that the species is present in the general area of the sound exposure. The predicted spatial and temporal distributions of the sound and/or species can be buffered to allow for uncertainties in data, with buffer widths increased with increasing uncertainty. If spatial or temporal contact may occur, or data for the species are insufficient to make this determination, the assessment moves to Tier 2.

3.6.1.5. Identify and Evaluate Management Options

If the species may be exposed to the sound, it may be possible to mitigate risk by changing the timing of the E&P activity, reducing its spatial extent (e.g., reducing the area of a seismic survey) or employing other mitigation measures to reduce the received sound levels. Additional information on management options is discussed in Chapter 5.

3.6.2 Tier 2

This tier conducts the second level of screening to assess risk to a marine mammal species from a sound source, allowing for characteristics of the emitted sound and the species' hearing frequency range. As with Tier 1, the objective is to determine if a marine mammal may be exposed to detectable sound produced by offshore E&P industrial activities. The species' hearing frequency range is specified by its functional hearing group (Southall et al. 2007; see Appendix Table B.1). There is some uncertainty as to whether particularly strong sound source could impact a species even if the sound frequency is outside the "functional" hearing range of that species. This is expected to be an issue only with extremely high sound levels close to a strong sound source. In that case, a protective approach is recommended; if marine mammals are likely to occur near the source the assessment moves forward to Tier 3.

3.6.2.1. Summary of Tier 2 Steps

- Identify the sound frequency and level at the source;
- Identify the hearing frequency range of the target species;

- Determine whether the sound source is capable of producing PTS;
- Determine if there is any overlap between sound source frequency and target species hearing frequencies;
- If the available management options cannot avoid exposure of the species to the sounds, if PTS is possible, or if data are insufficient to make an assessment, proceed to Tier 3.

3.6.2.2. Data Gathering

This tier requires additional information about the emitted sound's characteristics and the species' hearing range. The frequency range and maximum anticipated received level of the sound need to be established. In addition, the Southall et al. (2007) functional hearing group and associated estimated auditory bandwidth needs to be determined for the species. This information is summarized in Southall et al. (2007) and is provided in Appendix Table B.1. If species-specific measurements of hearing thresholds vs. frequency have been obtained for the species in question, those can be used instead of relying on the generic information provided by Southall et al. (2007).

3.6.2.3. Evaluate Uncertainty

Methods to evaluate uncertainty for this tier are described in Section 4.2.

3.6.2.4. Estimate Risk

A species is screened out at this stage if the frequency range emitted by the sound source does not overlap with the species' hearing frequency range, as specified by direct auditory measurements or from its functional hearing group (Appendix Table 3.1; Southall et al. 2007). Otherwise, a more detailed risk assessment is required, i.e., the assessment moves to Tier 3. If data are insufficient to adequately assess the possibility of frequency range overlap, or to determine likely sound levels, then a protective approach is taken by assuming that detection is possible and the assessment also moves to Tier 3. A protective approach is also recommended if the sound is outside the functional frequency range but strong enough such that PTS might occur.

3.6.2.5. Identify and Evaluate Management Options

If the species might be exposed to and detect the sound, it may be possible to mitigate risk by changing the timing of the E&P activity, or reducing the spatial extent over which the activity occurs (e.g., by reducing the area of a seismic survey), or employing other mitigation measures to reduce sound exposure. Additional information on management options is discussed in Chapter 5.

3.6.3 Tier 3

Tier 3 is a level of risk estimation that is based on a semi-quantitative approach to characterize risk on a four point ordinal scale, i.e., low, medium, high, or very high. For each combination of sound source and species, a scoring system based on numerous criteria deemed to affect the magnitude and adversity of a species' response to sound exposure from E&P activities is applied. Criteria include aspects of the ecology and distribution of a species, characteristics of the sound exposure and the potential for impact, and habituation that may affect the severity of a population's response to the sound. Additional, criteria include the percent of the population expected to be ensonified, the population trend and conservation status, and cumulative effects that may influence the adversity of the predicted effect. Most scoring criteria consist of a yes/no/unknown response that is determined from existing data, or is based on expert opinion when data are unavailable. Uncertainty is accounted for by adjusting the final risk score upwards when data gaps are present and quality of existing data is poor.

Tier 3 also evaluates the risk of PTS, TTS and four levels of behavioral disturbance (no observable response, minor, moderate and strong) by allowing expert opinion to determine the proportion of the stock that is likely to be ensonified for each of these effects. These proportions are determined using the TTS thresholds and PTS criteria defined by Southall et al. (2007) for each of the three sound types (single pulse, multiple pulse and nonpulse) and five functional hearing groups as screening benchmarks. The four levels of behavioral disturbance, including one "no observable response" level, are discussed above (Table 3.2). The subcategory "No observable response" for free-ranging subjects (response score 0) was kept as a separate category to allow risk to be assessed for animals expected to be ensonified, but at a level believed to be too low to result in any apparent behavioral change. This "no observable response" category addresses the potential for stress or other related impacts that may not manifest in a visible response. The behavioral results summarized by Southall et al. (2007) suggest that 50 dB re: 20 µPa RMS for pinnipeds in air and 80 dB re: 1 µPa RMS for mammals underwater are levels at (and below) which no observable response would be expected. In many cases, there will be no observable response at received levels considerably higher than these.

Received sound levels associated with different levels of behavioral disturbance are too variable and too incompletely known to allow identification of specific sound levels associated with the onset of disturbance (Southall et al. 2007). Table 3.2 presents a general summary of disturbance data indicating the range (generally broad) of received sound levels associated with various categories of behavioral disturbance. Despite the severe limitations, this table provides a starting point for relating sound levels and disturbance categories in the different marine mammal groups. Expert opinion can be used to assign a qualitative risk ranking to predict the effect of exposure to various received sound levels. If dealing with a particular species, sound type and situation for which one or more disturbance response studies have been done, those results should be used to in preference to other less-directly-relevant data.

3.6.3.1. Summary of Tier 3 Steps

- Determine distances from the source at which PTS, TTS and various behavioural responses are likely to occur;
- Collate density information on relevant species and determine the proportion of each population or stock likely to be ensonified at each sound level above which adverse effects are expected to occur;
- Complete the assessment outlined in the scoring assessment for each stressor-species pair;
- Assign a final risk category to the total score;
- Proceed to Tier 4 if the final assessment indicates medium, high or very high risk, and if additional data are available.

3.6.3.2. Data Gathering

The data gathering phase for Tier 3 is extensive. Information on the sound source and species ecology and distribution must include the following elements:

- Sound type (single pulse, multiple pulse, nonpulse);
- The maximum sound level produced at the source (determined in Tier 2);
- The duration of the sound exposure and whether the exposure is sporadic or continuous;

- Sound thresholds for each species of interest based on Southall et al. (2007) and material presented in sections 3.3 and 3.4. Where Southall et al. identify the existence of directly relevant studies, those should be retrieved to assess the additional details that will be contained in the original reports. In addition, a literature review should be performed to determine if relevant studies have been published since Southall. If so, the rigor and scientific defensibility of these studies should be evaluated, and study results used to modify sound thresholds if deemed appropriate.
- A comparison of the predicted maximum sound level from each sound source with injury criteria for the functional groups of marine mammals present;
- The range of distances from the source at which PTS is possible, for each functional hearing group;
- The range of distances at which behavioral responses are likely for each functional hearing group, based on expert opinion and the rough guidance in Table 3.2, e.g., for LF cetaceans exposed to multiple-pulse sound, 110-130 dB re: 1 μPa for slight behavioral response, and >150 dB re: 1 μPa for strong response (See Table 3.2). These levels can be modified if additional field data are available. As data are likely to be highly variable, a protective approach would be to assume the highest observed category of response for each sound level.
- Information on species presence, ecology and distribution should be expanded upon. Earlier tiers provided data from the Large Marine Ecosystems database, IUCN Red List, and the Convention on Migratory Species. In Tier 3 a greater emphasis should be placed on site-specific regional databases available through national government agencies and academic institutions as well as through the published literature. In this tier, distribution data should be mapped to a scale that is appropriate to the project being evaluated.
- The proportion of each stock that is exposed based on available density information. The stock can be defined as the regional population, a defined stock management unit, or in the case of some species with known local structure, pods or small family groups (for example some dolphins and killer whales). Sound exposure will vary across individual marine mammals due to their varying distances from the sound source, movement patterns, etc. Diurnal behaviors that affect exposure should also be considered.
- The population trend for each species.
- Particular age and sex categories, animal activities, and habitats that are likely to be more susceptible to sound exposure need to be identified (Suter 2007). For example, is feeding habitat, breeding or calving habitat, migratory habitat, or some other area of aggregation (e.g., seamount or submarine canyon) present? Are the habitats geographically restricted, e.g., bays or lagoons, seamounts, island coastlines, localized upwelling zones, or submarine canyons?
- Other pressures that may affect the species of interest. Are there cumulative impacts from coastal development, subsistence harvesting, entanglements, or vessel collisions?

3.6.3.3. Evaluate Uncertainty

Methods to evaluate uncertainty for this tier are described in Section 4.3.

3.6.3.4. Estimate Risk

Risk is estimated through use of a scoring system that considers several factors (information on how the scores were developed is provided below). These factors include the estimated proportions of marine mammal stocks affected (using regional or national stock assessment reports and other data sources to provide stock data), species sensitivities, and species conservation status. Other factors to be considered include presence of key habitats and seasonal considerations.

The first step in this tier's risk estimation process assigns a base risk score to the marine mammal species; this is derived based on a categorical estimate of the proportion of the population predicted to be ensonified sufficiently to cause a specified category of effect (Table 3.4). Due to the difficulty in determining whether behavioral changes are occurring in the field, and the possibility that impacts may occur without any identifiable behavioral changes, the following scoring system is proposed as a protective approach. The actual scores used here may be modifiable based on site-specific information or if more information is available on the specific target species of interest.

Table 3.4. Risk score for proportion of stock potentially ensonified sufficiently to elicit a given effect. The effect can be PTS, TTS or one of four levels of behavioral disturbance.

Proportion of Stock Ensonified	PTS[1]	TTS	Strong Behavior Response[2]	Moderate Behavioral Response[3]	Slight Behavioral Response[4]	No Apparent Behavioral Change[5]
few (>0-<1%)	200	40	40	30	10	0
Some (25%)	325	65	65	50	15	5
Half (50%)	400	80	80	60	20	5
Most (75%)	450	90	90	65	20	5
All (100%)	475	95	95	75	25	10

[1] The score for PTS is five times that of TTS/Strong Behavioral Response as PTS is a permanent injury to an important auditory function while TTS and behavioral responses are transient effects.
[2] Strong behavioral response is assumed, under most circumstances, to be equivalent to TTS and is equivalent to response score 7-9 in Southall et al. (2007);
[3] Moderate behavioral response is assumed to be a level of response clearly observable in the field and is equivalent to response score 4-6 in Southall et al. (2007);
[4] Slight behavioral response is equivalent to response score 1-3 in Southall et al. (2007); and
[5] No apparent behavioral change assumes no visible change to behavior in the field or from later statistical analysis but animals still within audible sound field and is equivalent to response score 0 in Southall et al. (2007).

The remaining scoring criteria listed in Table 3.5 are then applied, and data quality is evaluated (Table 3.6), with the total risk score calculated and mapped to a four point risk level (low, medium, high, very high) as shown in Table 3.7. Although the cut off point between the risk levels is somewhat arbitrary, these levels do provide an indication of relative risk. Care should be taken with the interpretation of all risk levels. In addition, all assumptions should be supportable and documented, particularly if the assessment results in an evaluation of low risk. Stressor-species pairs estimated to have medium, high or very high risk then move on to Tier 4, the final tier of the risk assessment process, if data allow.

Table 3.5. Scoring Criteria.

Scoring Criteria	Description	Score
Biological Factors		
Species Status	IUCN status (from www.redlist.org) or national status—use whichever is more protective	Critically Endangered: +100 Endangered: +75 Vulnerable: +50 Near Threatened: +15 Data Deficient: +5 Least Concern: +0 Not Listed: 0 If none of the above, but of local/regional/special interest: +15
Global population involved	If status/range of population is such that the management unit or stock exposed is the entire global population	Yes: +50 No: 0
Mating habitat present within ensonified area	If the size of the ensonified area is known, overlay with map of known/presumed mating habitat. If the size of the ensonified area is not known, use protective approach based on sound source, i.e. within 25 km for construction activity or within 50 km for seismic survey	Yes: +20 Unknown: +20 No: 0
Calving/pupping habitat present within ensonified area and/or dependent offspring/juveniles present	As above, but applied to known/presumed calving/juvenile habitat.	Yes: +20 Unknown: +20 No: 0
Feeding habitat present within ensonified area	As above, but applied to known/presumed feeding habitat.	Yes: +20 Unknown: +20 No: 0
Migration corridors present within ensonified area	As above, abut applied to known/presumed migratory habitat.	Yes: +20 Unknown: +20 No: 0
Known aggregation areas present within ensonified area	As above, but applied to (e.g.) haul-out sites, prey concentrations.	Yes: +20 Unknown: +20 No: 0
Special restricted habitat conditions present	As above, but applied to (e.g.) narrow seaways, lagoons, coastal waters.	Yes: +20 Unknown: +20 No: 0
Known health concerns in population	e.g., skinny whales, documented high levels of contamination, disease, major die-offs recorded	Yes: +20 Unknown: +20 No: 0
Present population trend	From IUCN Red List (www.redlist.org) or other similar source	Downward: +20 Stable: -10 Upward: -20 Unknown: +20
Cumulative Factors		
Additional threat to population due to entanglements/fisheries	Identified as a threat in IUCN Red List (www.redlist.org), national species conservation plans or similar	Yes: +20 Unknown: +20 No: 0
Additional threat to population due to collisions	Identified as a threat in IUCN Red List (www.redlist.org), national species conservation plans or similar	Yes: +20 Unknown: +20 No: 0
Additional threat to population due to illegal harvest	Identified as a threat in IUCN Red List (www.redlist.org), national species conservation plans or similar	Yes: +20 Unknown: +20 No: 0

Scoring Criteria	Description	Score
Additional threat to population due to coastal development	Identified as a threat in IUCN Red List (www.redlist.org), national species conservation plans or similar	Yes: +20 Unknown: +20 No: 0
High societal value or subsistence hunting	From IUCN Red List (www.redlist.org) or national conservation plans	Yes: +20 Unknown: +20 No: 0
Secondary and/or tertiary effects possible	e.g., prey impacts	Yes: +20 Unknown: +20 No: 0
Industry Factors		
Habitation possible	Has habituation been recorded for this species in the past under similar circumstances?	Single or multipulse sound with risk of PTS/TTS: +20 Continuous sound with no risk of PTS/TTS: -20
Detrimental effect on population persistence likely due to ensonification	Will ensonification negatively affect vital rates and consequently, population persistence?	Yes: + 200 Unknown: +100 No: 0
Duration of sound exposure	From project plan.	Permanent (>generation for species of concern): +40 121-365 days: +30 91-120 days: +20 31-90 days: +15 15-30 days: +10 8-14 days: +5 1-7 days: +5
Quality of data sets	See Table 3.8 below	

The assessment of the quality of the available data set (Table 3.6) is based on both the data quality and the age of those data. Assessment of data quality will be largely qualitative, based on study design, sample sizes etc., whereas the age of the available time series is a quantitative factor.

Table 3.6. Assessing the quality of available data sets.

	Age of Available Data				
Data Quality	**No Data Available**	**Data >11 years old**	**Data 6-10 years old**	**Data 3-5 years old**	**Data 0-2 years old**
None	+30	-	-	-	-
Poor	-	+30	+25	+20	+15
Fair	-	+25	+20	+15	+10
Good	-	+20	+15	+10	+5
Excellent	-	+15	+10	+5	-5

Table 3.7. Mapping of the total risk score to a four point categorical level of risk. The maximum score possible is 1195.

Score	**Very High**	**High**	**Medium**	**Low**
≤0				√
1-20				√
21-40				√
41-60				√
61-80				√
81-100				√
101-120			√	
121- 140			√	
141- 160			√	
161- 180			√	
181-200			√	
201-220		√		
221-240		√		
241-260		√		
261-280		√		
281-300		√		
301-320	√			
321-340	√			
341-360	√			
361-380	√			
381-400	√			
401-420	√			
421-440	√			
>441	√			

The scoring system is based on five major subsets of factors (the number in parentheses indicates the maximum proportion of the total score that can come from this factor):

1. Proportion of the population involved vs. potential effect (40%);
2. Species conservation status (up to 12%);
3. Other biological factors such as key habitats and seasons (up to 14%);
4. Cumulative factors (up to 10%); and
5. Other industry factors (up to 24%).

We acknowledge that the weightings for each factor described in Table 3.4 and Table 3.5 are somewhat arbitrary. However, these weightings were structured to ensure that an appropriate relative emphasis is applied to each factor. Increasing values of most factors add to the total risk score, but some, such as the availability of high quality data, result in a reduced score.

The largest weighting is given to the likelihood of the emitted sound source resulting in PTS in any of the receiving animals (Table 3.4). PTS is weighted five times greater than TTS/Strong behavioral response because PTS represents a permanent injury to a vital auditory organ and could result in direct impacts to vital functions. The PTS score is set sufficiently high so that independently of all other scores, the total risk score will be at least at the top end of the medium risk scoring range. More typically, the final assessment will be high risk because other factors likely will contribute positive scores. The moderate behavioral response category is ~75% of the strong category; the slight behavioral category is ~30% of the moderate category; and, the no apparent behavioral change category is ~30% of the slight category. The scores are rounded up to the nearest 5 points. Although these percentages are arbitrary, they have been selected to provide a relative scaling that corresponds to the strength of the behavioral response. Note that this point matrix could be adapted for an individual species if more information becomes available on the behavioral reactions of that species to sound.

The next largest influence on the scoring system is species status (Table 3.5). Critically endangered was given the greatest weight with a score of +100 to ensure a ranking of at least medium (assuming at least one other item is scored positive). The Endangered status category is scored at 75% of critically endangered, and Vulnerable is scored at 50%. The IUCN (2008) ranks the Critically Endangered, Endangered, and Vulnerable categories as Threatened, while the lower categories (Near Threatened and Data Deficient) are not considered threatened and consequently are given substantially lower, but still positive, scores. If the industry activity results in the exposure of 100% of the global population or a defined local or regional stock or population, an additional +50 score is assigned. This latter addition is included to place additional weight in the event that a discrete localized stock is present, such as a pod of killer whales.

The other biological factors incorporated into the scoring system (Table 3.5) are each assigned a maximum score of +20. While these factors are unlikely to influence an overall rank on an individual basis, they may cumulatively affect the rank. For example, the total risk score is increased by +100 if mating and calving habitat, aggregation areas, restricted habitat, and a downward population trend are all present. This increased total score is likely sufficient to move the rank into a higher category.

Other factors, such as whether the population is subject to cumulative pressures (such as ship collisions or adverse fisheries interactions) will further elevate the risk level. Issues such as possible effects on prey are also included here and would need to be evaluated on a species-specific basis—for some species, cumulative pressures from non-industry sources may be considerable. Since these possible issues can be wide-ranging, they are not dealt with in detail in the present assessment (except as pertains to the overall status of the species). However, these issues may deserve more detailed examination if they are considered significant for a particular species of interest. Scores of +20 are assigned to each of these factors in order to be consistent with the score level given for the biological factors above. Again, while the individual scores are low, the intent is increase the final risk rank if a number of different threats are present.

The main attributes of the industry subset are the scale of the planned activity as it affects the proportion of the population, with a noisier activity presumably affecting a larger number of animals than a quiet activity, the duration of the activity, and the quality of the available data set as it relates to the subject species. The "detrimental effect on population persistence likely due to ensonification" item is given a score of +200, which automatically raises the final assessment into at least the high rank assuming at least one other positive score. This factor is included to allow for special circumstances, such as the impact on mid-frequency sonar on beaked whales. However, this factor would be unknown in most cases, and is given a score of +100 to be protective. A definitive no detrimental effect scores a zero.

The quality of the available data sets is ranked according to age, with more recent data assumed to be a greater asset than older data. A data set ranked as excellent (based on study design etc.) and <2 years old is the only item to decrease the overall score in this category.

This scoring system relies on the simple addition of ordinally-scaled scores. Clearly these scores are somewhat arbitrary and subjective. However, the scoring system ensures that multiple factors that may affect risk to each target species are evaluated and data quality is explicitly assessed. As noted earlier in 3.2.2.2., the IUCN provides extensive information on the threats facing listed species (IUCN 2008). The strength of the scoring system is in the cumulative assessment of each factor, with certain factors, such as the likelihood of PTS occurring or the species being listed as threatened having a disproportional impact on the overall score.

The scoring scheme described above was calibrated by testing a variety of hypothetical risk scenarios, varying each of the parameters to illustrate how the risk outcome changes (Tables 3.8-3.10). Additional hypothetical scenarios are provided in Appendix C.

Table 3.8. Risk Scenario: Not a listed species, few (>0—<1%) of the population exposed, no breeding, feeding, calving or migratory habitat, no dependent offspring present, industry activity of 1-7 days duration, habituation possible with no risk (continuous sound), no special restricted habitat present, population not under other threats, not considered high societal value, no subsistence hunting, known population trend upward, site specific data 0-2 years old, quality of data excellent.

Lowest score possible: -40

Scoring Criteria	**PTS**	**TTS**	**Strong Behavioral Response**	**Moderate Behavioral Response**	**Slight Behavioral Response**	**No Behavioral Response**
Non-listed species	0	0	0	0	0	0
No local/region/special interest	0	0	0	0	0	0
Few animals exposed to sound [see table header]	200	40	40	30	10	0
No mating habitat	0	0	0	0	0	0
No feeding habitat	0	0	0	0	0	0
No calving or pupping habitat	0	0	0	0	0	0
No migratory corridors present	0	0	0	0	0	0
No known aggregation areas	0	0	0	0	0	0
Habituation possible for continuous sound	-20	-20	-20	-20	-20	-20
No special restricted habitat present	0	0	0	0	0	0
Known population trend upward	-20	-20	-20	-20	-20	-20
No known health concerns in population	0	0	0	0	0	0
Detrimental effects on population persistence unlikely due to ensonification	0	0	0	0	0	0
Population not under threat from entanglements/fisheries	0	0	0	0	0	0
Population not under threat from collisions	0	0	0	0	0	0
Population not under threat from illegal harvest	0	0	0	0	0	0
Population not under threat from coastal development	0	0	0	0	0	0
Population not of high societal value or focus of subsistence hunting	0	0	0	0	0	0
No secondary or tertiary effects likely	0	0	0	0	0	0
Industry activity 1-7 days duration	5	5	5	5	5	5
Data 0-2 years old, excellent quality	-5	-5	-5	-5	-5	-5
TOTAL SCORE	**+160**	**0**	**0**	**-10**	**-30**	**-40**
	MEDIUM RISK	LOW RISK	LOW RISK	LOW RISK	LOW RISK	LOW RISK

Table 3.9. Risk Scenario: Worst case, Critically endangered population, all animals exposed to sound, global population affected, breeding, feeding, calving, and migratory habitat all present, known aggregation areas, industry activity permanent, habituation considered risky due to impulsive sound, detrimental effect from ensonification likely, restricted habitat present, population under threat from entanglements, collisions, harvest, and development, species of high societal value, known population trend downward, known health concerns, no site specific data, data quality poor, secondary effects likely.

Maximum score possible: 1195

Scoring Issue/Question	PTS Score	TTS Score	Strong Behavioral Response	Moderate Behavioral Response	Slight Behavioral Response	No Behavioral Response
Critically Endangered Species	100	100	100	100	100	100
Global population involved	50	50	50	50	50	50
All animals exposed to sound [see table header]	475	95	95	75	25	10
Mating habitat present	20	20	20	20	20	20
Feeding habitat present	20	20	20	20	20	20
Calving or pupping habitat present	20	20	20	20	20	20
Migratory corridors present	20	20	20	20	20	20
Known aggregation areas	20	20	20	20	20	20
Habituation possible for impulsive sound	20	20	20	20	20	20
Special restricted habitat present	20	20	20	20	20	20
Known population trend downward	20	20	20	20	20	20
Known health concerns in population	20	20	20	20	20	20
Detrimental effects on population persistence likely due to ensonification	200	200	200	200	200	200
Population under threat from entanglements/fisheries	20	20	20	20	20	20
Population under threat from collisions	20	20	20	20	20	20
Population under threat from illegal harvest	20	20	20	20	20	20
Population under threat from coastal development	20	20	20	20	20	20
Population of high societal value or focus of subsistence hunting	20	20	20	20	20	20
Secondary or tertiary effects likely	20	20	20	20	20	20
Industry activity permanent duration	40	40	40	40	40	40
Data unavailable or poor	30	30	30	30	30	30
TOTAL SCORE	1195	800	800	780	740	725
	VERY HIGH RISK	VERY HIGH RISK	VERY HIGH RISK	VERY HIGH RISK	VERY HIGH RISK	VERY HIGH RISK

Table 3.10. Risk Scenario: Endangered, some (25%) of population exposed, feeding habitat and calves present, industry activity 15-30 days duration, habituation possible risk due to impulsive sound, no special habitat present, population threatened by entanglements, collisions, population trend stable, known health concerns, not high societal value/subsistence, secondary effects unlikely, data set good 2-5 years old.

Scoring Issue/Question	PTS Score	TTS Score	Strong Behavioral Response	Moderate Behavioral Response	Slight Behavioral Response	No Behavioral Response
Endangered Species	50	50	50	50	50	50
Some animals exposed to sound [see header]	325	65	65	50	15	5
No mating habitat present	0	0	0	0	0	0
Feeding habitat present	20	20	20	20	20	20
Calving or pupping habitat present or dependent offspring	20	20	20	20	20	20
No migratory corridors present	0	0	0	0	0	0
No known aggregation areas	0	0	0	0	0	0
Habituation possible for impulsive sound	20	20	20	20	20	20
Special restricted habitat present	0	0	0	0	0	0
Known population trend stable	-10	-10	-10	-10	-10	-10
Known health concerns in population	20	20	20	20	20	20
Detrimental effects on population persistence unlikely due to ensonification	0	0	0	0	0	0
Population under threat from entanglements/fisheries	20	20	20	20	20	20
Population under threat from collisions	20	20	20	20	20	20
Population not under threat from illegal harvest	0	0	0	0	0	0
Population not under threat from coastal development	0	0	0	0	0	0
Population not of high societal value or focus of subsistence hunting	0	0	0	0	0	0
Secondary or tertiary effects unlikely	0	0	0	0	0	0
Industry activity 15-30 days duration	10	10	10	10	10	10
Data good quality 2-5 years old	10	10	10	10	10	10
TOTAL SCORE	505	245	245	230	195	185
	VERY HIGH RISK	HIGH RISK	HIGH RISK	HIGH RISK	MEDIUM RISK	MEDIUM RISK

While the previous tables kept the exposure level constant across columns, the following tables (Tables 3.11-3.12) vary the exposure level from column to column while maintaining all other factors as constants. The nature of sound exposure is such that, under most conditions, received sound level decreases with distance from the source (Figure 3.8). Therefore a more realistic scenario would presume that disturbance effects would lessen with increased distance. While increased distance results in less exposure to noise, it may result in the exposure of a larger proportion of the population to sound levels that are still capable of eliciting behavioral disturbance.

Table 3.11. Risk Scenario: Near Threatened species, feeding and migratory habitat present, dependent offspring present, industry activity duration 31-90 days, habituation considered risky due to impulsive noise, restricted habitat, population under threat from entanglements, collisions, stable population, data quality fair 0-2 years old, no secondary effects likely. Proportion of population exposed indicated in column headings.

Scoring Issue/Question	**Few (>0-<1%) PTS**	**Few (>0-<1%) TTS**	**Few (>0-<1%) Strong Behavioral Response**	**Some (25%) Moderate Behavioral Response**	**Some (25%) Slight Behavioral Response**	**Half (50%) No Behavioral Response**
Near Threatened Species	15	15	15	15	15	15
Proportion exposed to sound [see header]	200	40	40	50	15	5
No mating habitat present	0	0	0	0	0	0
Feeding habitat present	20	20	20	20	20	20
Calving or pupping habitat present or dependent offspring	20	20	20	20	20	20
Migratory corridors present	20	20	20	20	20	20
No known aggregation areas	0	0	0	0	0	0
Habituation possible for impulsive sound	20	20	20	20	20	20
Special restricted habitat present	20	20	20	20	20	20
Known population trend stable	-10	-10	-10	-10	-10	-10
No known health concerns in population	0	0	0	0	0	0
Detrimental effects on population persistence unlikely due to ensonification	0	0	0	0	0	0
Population under threat from entanglements/fisheries	20	20	20	20	20	20
Population under threat from collisions	20	20	20	20	20	20
Population not under threat from illegal harvest	0	0	0	0	0	0
Population not under threat from coastal development	0	0	0	0	0	0
Population not of high societal value or focus of subsistence hunting	0	0	0	0	0	0
Secondary or tertiary effects unlikely	0	0	0	0	0	0
Industry activity 31-90 days duration	15	15	15	15	15	15
Data fair quality 0-2 years old	10	10	10	10	10	10
TOTAL SCORE	370	210	210	220	185	175
	HIGH RISK	HIGH RISK	HIGH RISK	HIGH RISK	MEDIUM RISK	MEDIUM RISK

Table 3.12. **Risk Scenario:** Critically endangered population, global population affected, breeding, feeding, calving, and migratory habitat all present, known aggregation areas, industry activity permanent, habituation risky, detrimental effect from ensonification likely, restricted habitat, population under threat from entanglements, collisions, harvest, development, high societal value, known population trend downward, known health concerns, no site specific info, data quality poor, secondary effects likely. Proportion of population exposed indicated in column headings.

Scoring Issue/Question	**Few (>0-<1%) PTS Score**	**Some (25%)TTS Score**	**Some (25%)Strong Behavioral Response**	**Some (25%) Moderate Behavioral Response**	**Half (50%) Slight Behavioral Response**	**Most (75%) No Behavioral Response**
Critically Endangered Species	100	100	100	100	100	100
Global population involved	50	50	50	50	50	50
Proportion exposed to sound [see header]	200	65	65	50	20	5
Mating habitat present	20	20	20	20	20	20
Feeding habitat present	20	20	20	20	20	20
Calving or pupping habitat present	20	20	20	20	20	20
Migratory corridors present	20	20	20	20	20	20
Known aggregation areas	20	20	20	20	20	20
Habituation possible for impulsive sound	20	20	20	20	20	20
Special restricted habitat present	20	20	20	20	20	20
Known population trend downward	20	20	20	20	20	20
Known health concerns in population	20	20	20	20	20	20
Detrimental effects on population persistence likely due to ensonification	20	20	20	20	20	20
Population under threat from entanglements/fisheries	20	20	20	20	20	20
Population under threat from collisions	20	20	20	20	20	20
Population under threat from illegal harvest	20	20	20	20	20	20
Population under threat from coastal development	20	20	20	20	20	20
Population of high societal value or focus of subsistence hunting	20	20	20	20	20	20
Secondary or tertiary effects likely	20	20	20	20	20	20
Industry activity permanent duration	40	40	40	40	40	40
Data unavailable or poor	30	30	30	30	30	30
TOTAL SCORE	740	605	605	590	560	545
	VERY HIGH RISK	VERY HIGH RISK	VERY HIGH RISK	VERY HIGH RISK	VERY HIGH RISK	VERY HIGH RISK

3.6.3.5. Identify and Evaluate Management Options

Tier 3 does not directly include mitigation measures in the scoring criteria that are used to derive a risk conclusion. Instead, mitigation measures are subsumed into the methodology in that they reduce the proportion of the stock that is ensonified to various degrees. A recommended approach to use at the Tier 3 stage would be to first conduct the risk assessment assuming no mitigation (or no mitigation beyond standard industry practice/regulatory requirements). If the risk conclusion is considered too high, then mitigation measures described in Chapter 4 can be considered and incorporated into the planning of the activity. The mitigation measures will reduce the proportion of the stock ensonified sufficiently to elicit various specified effects, and risk can then be reassessed by rerunning Tier 3 with the modified estimates.

Once the assessment has been satisfactorily run for each of the stressor-species pairs, it may be necessary to combine the risk assessments across all pairs into a single risk assessment. In most practical applications, a mitigation and monitoring program will need to be designed to reduce this integrated level of risk. Expert opinion will be needed to determine where the focus of such a program should be. For example, the risk assessment may show that to reduce the risk to species 1, the risk must be increased for species 2. Priorities will need to be determined for each species and any mitigation or monitoring implemented will typically focus on the highest priority species. More information on mitigation, monitoring and management options can be found in Chapter 4.

EPA (1998) recommended that this phase of risk assessment include (1) an assessment of the evidence for causality, i.e., evaluate evidence that the stressor actually causes the effects of concern. EPA (1998) also recommends evaluating the limitations and uncertainty in the risk estimates that are produced for each species-sound source pair. Southall et al. (2007) thoroughly considered causality and uncertainty for PTS, TTS and behavioral disturbance by evaluating studies, summarizing results, applying expert opinion and using protective principles to propose noise exposure criteria and thresholds. In addition, Southall et al. (2007) recognized and documented the severe limitations of the available data. They provided broad research recommendations to address data gaps associated with such issues as ambient noise levels, audiometric data for marine mammal species, auditory scene analysis, behavioral responses to sound exposure, the simultaneous and residual physiological effects of noise exposure, and the effects of sound on non-auditory systems. Once additional relevant data become available, that information should be integrated into the current data set and modifications made to the criteria and thresholds, if warranted.

3.6.4 Tier 4

Tier 4 assesses risk based on the scoring system applied in Tier 3, but uses more detailed knowledge of the potential sound exposure and/or a species' distribution to quantitatively estimate the actual percentage of the stock that would be sufficiently ensonified to incur PTS or TTS based on the thresholds specified by Southall et al. (2007). The additional information and use of analytical results would allow a more quantitative risk assessment to be conducted, which reduces uncertainty and provides a stronger justification for the risk conclusion.

Risk assessors may want to estimate effects on a marine mammal population's abundance, productivity and persistence (Suter 2007). In Tier 4, expert opinion could be used with a variety of techniques to qualitatively or quantitatively predict changes in life functions, vital rates and population level effects. For example, qualitative risk matrices based on expert opinion could be constructed to bridge from sound exposure or behavioral disturbance to any of the remaining PCAD components (i.e. life functions, vital rates and population effects). Alternately, generic (and when available, species specific) demographic models may be used to quantitatively determine potential effects of the predicted ensonification on a marine mammal species' population trend for use in the scoring system or as a stand-alone risk assessment of effects on a marine mammal population's abundance, productivity and persistence. This use of demographic models would likely involve using "worse case" scenarios to modify model parameters based on expert opinion. These demographic models could then be run using Monte Carlo simulation (see section 4.5.6), to project population estimates through time and infer population level effects. However, model predictions need to be used with caution as the literature presently shows no effect of PTS (or other threshold effects) on fecundity or survival. In particular, linkages between sound exposure and marine mammal life functions, vital rates and population level effects have not been established and quantified (NRC 2005).

Bioenergetics or individual based models (IBMs) can also be used to link behavior disturbance to effects on life functions and vital rates. Predicted changes in rates could then be used in demographic models as described above to predict population level effects. Note that few such models exist at present, so implementing this approach would be a future enhancement of present risk assessments capabilities. Bayesian Belief Networks (BBNs) are another potentially useful modeling approach. BBNs graphically express complex relationships and problems in resource management, address uncertainties in a structured way, and probabilistically evaluate the effects of alternative management activities on response variables of interest (in this case, population level effects). BBNs could thus assist in management decision making (McCann et al. 2006). Bioenergetics, IBM and BBN modeling approaches are described in more detail below.

3.6.4.1. Summary of Tier 4 Steps

- Determine distances from the source at which PTS, TTS and various behavioural responses are likely to occur using acoustic modelling;
- Collate effort-corrected density information on relevant species;
- Determine if demographic or other models are available for use;
- Determine the percentage of the stock ensonified with the best data available by combining information from the acoustic modelling and density data;
- Complete the assessment outlined in the scoring assessment for each stressor-species pair;
- Map the semi-quantitative risk assessment result to the risk matrix and assign a final category to the result.

3.6.4.2. Data Gathering

Data gathering for Tier 4 focuses on improving sound exposure estimation, refining species distribution and abundance information, and identifying models that can be used to assess E&P impacts on population trends.

Sound Exposure:

Sound exposure from E&P activities can potentially be modeled, however accurate prediction of the sound field around an E&P source is difficult, and requires detailed knowledge of the seabed substrate and bathymetry, and of the temperature-salinity profile of the water column during the relevant seasons. For example, acoustic modeling of this complexity has been used to predict the sound fields around planned seismic surveys offshore Sakhalin Island, Russia (IUCN 2007) and Central America (Carr et al. 2006). In the Sakhalin Island case, site-specific empirical measurements of sound propagation loss provided a basis for checking and improving the model predictions (IUCN 2007). Modeling cumulative sound exposure associated with multiple pulses or continuous noise involves additional complications, especially where there is a need to allow for a moving source and/or moving animals. However, procedures for doing this have been developed (e.g., Frankel et al. 2002) and are presently being applied in predicting cumulative sound exposure from some marine operations, including some seismic operations (e.g., Frankel et al. 2006).

Species Distribution and Abundance:

If systematic survey data are available for a species of interest in the region of the E&P activity, then effort-corrected densities can be calculated that show patterns of relative abundance of that species. If correction factors for sightability and availability are incorporated, absolute abundance can be estimated. These densities can then be used to quantitatively estimate the proportion of that species' population present in a given sub-area around the sound source. The spatial resolution of these density estimates varies, and depends on the survey methods that were used. For example, densities can be estimated for geographic strata within a surveyed area if line transect methods have been used (Buckland et al. 2001). Methods also exist to estimate densities at a finer spatial scale, e.g., 1 sq. km., if suitable data sets are available. For example, Hedley and Buckland (2004) developed a method to predict relative densities based on opportunistic marine mammal sightings and covariates such as the geographic location and water depth associated with each sighting. Becker (2007) developed a method to predict absolute densities of cetaceans based on historical survey data, correction factors for missed animals, and oceanographic covariates. Methods have also been developed to estimate absolute densities for western gray whales at a 1 sq km spatial resolution in the Sakhalin NE shelf using data from systematic aerial, vessel and shore based surveys (J. Muir, LGL Limited, pers. comm.)

Models:

While demographic models have been developed specifically for some marine mammals (e.g. Cooke et al. 2007; Conroy et al. 2008), it may be necessary to use generic models with species and stock specific parameters instead. It may also be possible to use a model for a different species as a surrogate. It can be difficult, however, to parameterize generic or surrogate models even with well-studied species such as bottlenose dolphins. For example, Hall et al. (2006) used data on PCB concentration in newborn calves from three odontocete studies to parameterize an IBM model for bottlenose dolphins because only one value for bottlenose dolphins was available. Similarly, Schwacke et al. (2002) used the PCB dose response relationship from mink as a surrogate for bottlenose dolphins. Of particular importance here, there is very little information with which to model the effects of acoustic exposure on demography of marine mammals.

Other types of models, such as bioenergetics models, individual based models and Bayesian belief networks can also be assessed for relevance, with modifications, in characterizing population level effects from sound exposure.

Any candidate model needs to be carefully evaluated to assess its applicability to the species, life functions, environmental conditions, and temporal and spatial situation (Suter 2007). A model can often be improved by identifying and including allowance for confounding factors such as sex, age, animal activity, season, etc.). A model should be assessed for its level of documentation, clarity of methods and results, and adequacy of testing. Also, one should consider how widely the model is used, whether it has undergone peer review, and whether data needed for risk assessment are available to use with the proposed model (EPA 1998; Suter 2007).

3.6.4.3. Evaluate Uncertainty

Methods to evaluate uncertainty for this tier are described in Section 4.4.

3.6.4.4. Estimate Risk

Risk estimation using the Tier 3 scoring system

The scoring system described in section 3.6.3.4 can be used to estimate risk for each species of interest. However, the risk score for the proportion of stock affected will now be assessed semi-quantitatively or in a more quantitative way depending on the quality of the sound exposure data and the marine mammal distribution data.

If acoustic modeling has been done, then the spatial location of the sound isopeths ("contours") corresponding to relevant sound thresholds (e.g., for a specified level of behavioral disturbance) can be determined. This delineation of the area ensonified to a particular sound level can then used to estimate the proportion of stock potentially affected, with the risk score assigned based on Table 3.13. If only poor quality data on species distribution and/or density are available, the percentage of stock ensonified can be semi-quantitatively estimated by rounding to a selected percentage (e.g. nearest 10% or 20%).

If no acoustic modeling has been conducted, but estimated densities of the species are available for the area, then these densities may be used to refine estimates of the proportion of the stock affected based on less precise estimates (from Tier 3) of the maximum distances at which PTS, TTS and various levels of behavioral disturbance might occur. If density estimates are available at a fine spatial scale (e.g., 1 km^2 or 10 km^2), then the percentage of the stock ensonified can likely be estimated semi-quantitatively. If density estimates are available only for broader geographic strata, then it may only be possible to make a small improvement (relative to Tier 3) in the estimated proportion of the stock ensonified.

Quantitative determination of the percent stock ensonified can be performed if both modeled sound contours and estimated densities are available for a species. In this case, the relevant sound contours can be overlaid on these densities, e.g., in a geographic information system (GIS), and the percent of the stock occurring within each predicted sound contour can be calculated. This approach has been used to estimate potential impacts to individual species of cetaceans and pinnipeds during numerous planned marine seismic surveys. One example involved western gray whales occurring near the location of a proposed seismic survey offshore from Sakhalin Island, Russia (IUCN 2007). Another is described in LGL Ltd. (2008).

Table 3.13. Proposed risk scoring system for percentage of population ensonified versus potential physical or behavioral effect.

	% of Population Potentially Affected[1]														
Response	**≤1**	**5**	**10**	**15**	**20**	**25**	**30**	**40**	**50**	**60**	**70**	**75**	**80**	**90**	**100**
PTS[2]	200	225	250	275	300	325	350	375	400	425	450	450	475	475	475
TTS	40	45	50	55	60	65	70	75	80	85	90	90	95	95	95
Strong Behavioral Response[3]	40	45	50	55	60	65	70	75	80	85	90	90	95	95	95
Moderate Behavioral Response[4]	30	35	40	40	45	50	50	55	60	65	70	70	70	70	75
Slight Behavioral Resposne[5]	10	10	10	10	15	15	15	15	20	20	20	20	20	20	25
No Apparent Behavioral Response[6]	0	0	0	0	5	5	5	5	5	5	5	5	5	5	10

[1] Based on stocks/management units rather than global population (if status/range of population is such that the management unit or stock exposed is the global population add 50 points; if the size of the potentially ensonified area is unknown or the range of the population is unknown, be protective);
[2] The score for PTS is five times that of TTS/Strong Behavioral Response as PTS is a permanent injury to an important organ while TTS and behavioral responses are transient effects.
[3]Strong behavioral response is assumed, under most circumstances, to be equivalent to TTS and is equivalent to response score 7-9 in Southall et al. (2007);
[4] Moderate behavioral response is assumed to be a level of response clearly observable in the field and is equivalent to response score 4-6 in Southall et al. (2007);
[5] Slight behavioral response is equivalent to response score 1-3 in Southall et al. (2007); and
[6] No apparent behavioral change assumes no visible change to behavior in the field or from later statistical analysis but animals still within audible sound field and is equivalent to response score 0 in Southall et al. (2007).

If a demographic model has been identified for a species of interest, then this model can be run and its predictions of population trend used to determine the response for the scoring criteria "Detrimental effect on population persistence likely due to ensonification."

Estimation of Population Level Effects

The following sections provide more details concerning modeling approaches that may be useful in inferring population level effects of sound exposure from E&P activities.

Demographic Models and Population Viability Analysis

These include a broad range of models that predict changes in population size and structure over time based on demographic parameters such as the growth rate, or birth and mortality rates (Hastings 1997). Models range in complexity from single species models that only use growth rate to predict population change, to models that are structured according to age or development classes where cohorts move from one class to another based on class specific birth and mortality rates (Billoir et al. 2007). Biological processes such as density dependence and species interactions (e.g., predation, see Sabo 2008), and demographic and environmental stochasticity may also be included. Demographic models can be used to assess the relative influence of parameters on population growth and structure through sensitivity or elasticity analysis (described in section 4.5), or incorporated into population viability analysis (PVA).

PVA is a commonly used methodology to assess the risk of extinction and compare effects of different management actions on a population of interest (Brook et al. 2000; Sabo 2008). PVA uses a modeling framework that projects future population size based on a variety of methods such as deterministic or stochastic matrix demographic models, metapopulation models, and individual based models (Beissinger et al. 1998). While PVA has been criticized for a lack of biological realism and a limited ability to incorporate uncertainty (Sabo 2008), PVA conducted on 21 long-term ecological studies using 5 generic, single species tools (CAPPS, INMAT, RAMAS Metapop, RAMAS stage and VORTEX) accurately projected population sizes and predicted risk of population decline (Brook et al. 2000). A draw back of PVA is that robust biological data are needed to reliably estimate life history parameters needed for the models (Brook et al. 2000; Sabo 2008). These data are typically lacking (Coulson et al. 2001, Sabo 2008), and usually will need to be estimated by reference to other related species and/or expert opinion when using this approach to assess risk to population persistence from E&P sound exposure. Also, PVA models require that means and variances of vital rates remain fairly consistent through time to produce accurate predictions, unless these changes can be incorporated into the analysis (Coulson et al. 2001). Sabo (2008) suggests that violation of this assumption is a typical occurrence in nature because species interactions (e.g. predation, competition) that occur in ecological communities are seldom included in PVA models, and when they are, are often inadequately modeled without incorporating feedback between the interacting species. However, recent work by Holmes et al. (2007) indicates that simple state-space models can predict population change without modeling the actual mechanics of the population process, and consequently, species interactions need not be incorporated into a PVA.

3.6.4.5. Bioenergetic Models

These models incorporate the effect of a stressor (e.g. disturbance, toxic compounds) on energetic costs of life functions, and to predict the stressor's potential impacts on individual fitness and population size. For example, West et al. (2002) modeled the effects of disturbance on individual oystercatcher (*Haematopus ostralegus*) foraging behavior and food intake rates, which in turn affected survival rates and population size. The model included parameters for temperature related energy requirements, prey assimilation efficiency, prey energy density and night feeding efficiency. Billoir et al. (2007) modeled energetic effects of toxic compounds to assess changes in *Daphnia* population growth rate by determining how reduced growth with increased dose exposure affected birth rates.

3.6.4.6. Individual Based Models (IBM)

This approach models individual level responses, which are then extrapolated to population level effects. This is generally done by developing a model of the individual organism response, modeling the responses for hundreds or thousands of individual organisms, and either applying an analytical solution of the equations or a numerical simulation method such as Monte Carlo analysis to infer population level effects (Suter 2007). For example, Hall et al. (2006) simulated the accumulation of polychlorinated biphenyl (PCB) concentrations in individual female bottlenose dolphins with subsequent transfer of PCBs to calves via lactation, and from that predicted dose dependent effects on calf survivorship. The modified calf survival rate was then used with other previously estimated vital rates in a demographic model to predict population level impacts. Because stochastic effects are included in IBMs, confidence intervals can be determined by conducting multiple model runs to produce a distribution of population growth rates (Hall et al. 2006).

3.6.4.7. Bayesian Belief Networks (BBN)

Bayesian methods are particularly appropriate when studies cannot be replicated, and for environmental risk assessment when expert opinion is needed (Hilborn and Mangel 1997). In particular, Bayesian belief networks that represent and quantify relationships among variables through the use of conditional probabilities are useful tools to represent system variability, uncertainty of understanding and implications of these factors on possible management decisions (McCann et al. 2006; Castelletti and

Soncini-Sessa 2007). BBNs graphically express complex relationships and problems in resource management, address uncertainties in a structured way, and probabilistically evaluate the effects of alternative management activities on response variables of interest, thus assisting in management decision making (McCann et al. 2006). Bayesian belief networks can be used to integrate expert opinion with limited empirical data to model wildlife population distributions and identify the factors most likely to influence species' occurrence and abundance (Smith et al. 2007). For example, Marcot et al. (2001) developed a BBN to assess the effects of alternative land management decisions on the population viability of selected fish and wildlife species.

3.6.4.8. Identify and Evaluate Management Options

Management options should be identified and evaluated as described for Tier 3 (section 3.6.3.5).

4. Uncertainty

There is a need to clearly identify and summarize data gaps, possible errors in the available data, and the variability, uncertainties, assumptions and limitations of the data and analyses used to estimate the risk to each species of interest. The results of this exercise may then be used to modify the risk estimate (EPA 1998; Suter 2007), and be incorporated into the risk characterization phase and subsequent management decisions. It may not be possible to quantify uncertainty because of poor data quality and data gaps. This is likely the case in Tiers 1, 2 and 3. For these tiers, a categorical level of uncertainty should be determined instead. The incorporation of uncertainty factors (also known as safety factors) may also be a useful approach when data quality is poor in these tiers. This is a common technique to incorporate and allow for uncertainty in risk assessments, and helps to ensure that measures of effects are sufficiently protective for species of concern (EPA 1998; Suter 2007).

If data quality allow, such as in Tier 4, numerous methods are available to assess uncertainty in a quantitative manner. These include evaluation of model uncertainty, estimation of data distributions and confidence intervals, statistical modeling, Bayesian methods, Monte Carlo analysis, sensitivity analysis and elasticity analysis.

Guidelines for evaluating uncertainty specific to each tier, descriptions for uncertainty factors and quantitative methods to assess uncertainty are presented below.

4.1 Evaluate Uncertainty: Tier 1

The sound sources and seasonal timing of E&P activities are typically well specified during planning of the E&P activity. However, substantial uncertainty may exist concerning the spatial extent of a sound level that may cause minor disturbance to a species. If there is prior experience with conducting that E&P activity in the same geographic area, and if sound levels were monitored, this knowledge will likely be useful in predicting the spatial extent for the sound exposure. Otherwise, expert opinion (or more detailed acoustic analysis noted under subsequent Tiers) will be needed to predict the spatial extent. Alternatively, a large and protective region can be designated for the purpose of screening potential exposure contact with a species.

Existing information on the distribution and abundance of a species is often limited and highly generalized, with distributions largely being attributed to ocean or basin scales, or within broad bounds of polar, temperate, or tropical waters. However, the seasonal distribution is well known for some species, e.g. eastern gray whale, various beluga and humpback whale populations and North Atlantic right whale.

Such information may also be available for a relevant area and part of the year even if the overall seasonal distribution is incompletely known. For example, extensive surveys have been conducted in and near the known feeding grounds of the western gray whale during the months of June to November. While it is known that many species of baleen whales feed at high latitudes and calve and breed at low latitudes, such information is not readily available for many species of small cetaceans so that the seasonal presence of calving or feeding habitat may be a matter of conjecture.

The seasonal presence of certain animal activities such as feeding, breeding, calving, or migrating may influence how an animal responds to a sound. Marine mammals apparently are less subject to disturbance when engaged in some activities than in others (e.g., feeding vs. migrating in bowhead whales—Miller et al. 1999, 2005). Diel cycles of behavior may also influence the potential impact from a sound source, for example spinner dolphins rest in Hawaiian bays during the day and forage for fish elsewhere at night (Norris et al. 1994).

4.2 Evaluate Uncertainty: Tier 2

Knowledge of marine mammal hearing varies widely by group, but is largely recognized as being more limited compared to that of terrestrial mammals (Southall et al. 2007). For example, no direct measurements have ever been made of mysticete hearing and most information on odontocetes is based on auditory testing of small species that have been kept in captivity. Most such data are based on small sample sizes. When direct measurements are not available for the species of interest or a closely related species, considerable uncertainty must be assumed. Southall et al. (2007) provide a discussion of data gaps, uncertainties and limitations of their proposed sound thresholds and definitions of functional hearing groups (see also sections 3.3 and 3.4). Similarly, although data are available on sounds produced by a variety of industrial activities, generalization to different equipment or vessels will introduce uncertainty. The most reliable data will be those from the target species of interest and from the actual equipment to be used in the planned activity.

4.3 Evaluate Uncertainty: Tier 3

Uncertainty is a major confounding factor in this tier. Risk assessors must evaluate uncertainty, data gaps and data quality for industrial factors, information on species' ecology and distribution, and cumulative effects.

Industrial Factors: Substantial uncertainty may exist concerning the spatial extent of the area where sound level could exceed the PTS criteria or TTS thresholds. There is even greater uncertainty in determining the spatial extent of the area where different levels of behavioral disturbance might occur, given the uncertainty in both the sound field and in the exposure levels eliciting various categories of disturbance. If there is prior experience in conducting the same E&P activity in the same geographic area, and sound levels were monitored, this knowledge should be useful in predicting the areas of impact. Otherwise, expert opinion will be needed to predict the spatial extent for each effect. The duration of sound exposure will also be specified as part of the E&P activity planning.

Biological factors: Detailed information on species is unavailable for most areas. Assumptions can be made regarding the presence of different habitat types, for example winter calving and summer feeding habitat for great whales. However, site specific information will often be lacking, e.g., data on abundance and distribution, life functions, location of critical habitat, the presence of dependent juveniles, and the percentage of the regional stock present will be lacking. When information is insufficient, a protective approach would be needed, allowing for the best available data for that or similar species, and using local expert opinion to supplement any published literature.

Cumulative/other factors: The potential cumulative issues may be highlighted in the species assessments provided by such sources as the IUCN Red List, but they are usually not quantified or location specific, and may be out of date. (Assessments may not be updated annually). There is the possibility that some recent threats may not be considered if assessments are outdated. Where possible, local knowledge should be used and take precedence over more general assessments.

Data quality: The assessment should consider the quality of the available data. How robust are they? How long a time series is available? Have the data been published in peer-reviewed journals or otherwise subject to critical review and revision? Were survey designs appropriate to answer the questions posed? Were data collected during the season of interest? What are the data gaps and how might they be filled?

Sound Exposure Criteria: Southall et al. (2007) provide a comprehensive discussion of the data gaps and uncertainties associated with sound thresholds. The implications of this uncertainty for conclusions about risk to a species need to be carefully considered and documented. For example, there are no specific data on sound levels and durations that cause PTS in cetaceans or pinnipeds. Southall et al (2007) estimated PTS criteria from existing TTS onset data for marine mammals combined with data from terrestrial mammals concerning how much stronger the sound would need to be (above TTS onset) for PTS to occur. Available data on TTS in marine mammals were limited to a very few species and individuals of mid-frequency odontocetes and pinnipeds (no high-frequency odontocetes, deep-diving odontocetes, or baleen whales). PTS was assumed to be likely if a sound exposure was predicted to cause at least 40 dB of TTS, i.e., was predicted to elevate the hearing threshold by at least 40 dB. Data concerning sound exposures associated with TTS onset were limited, and this had implications in estimating PTS thresholds (Southall et al. 2007). TTS data were only available for two species of mid frequency cetaceans (bottlenose dolphin and beluga), and three species of pinnipeds (California sea lion, northern elephant seal, and harbor seals). Small sample sizes also contributed to uncertainty in establishing exposure levels associated with TTS and PTS onset. The extrapolation of results from belugas and bottlenose dolphins to all other cetaceans increases uncertainty in injury criteria for other groups. There is some preliminary evidence that at least one high frequency cetacean (harbor porpoise) may have lower TTS (and presumably PTS) thresholds than do belugas and bottlenose dolphins (Lucke et al. 2007). On the other hand, Southall et al. (2007) stated that the proposed injury criteria are likely protective for low frequency cetaceans because these animals are suspected to have less sensitive hearing compared to mid frequency cetaceans in their respective frequency ranges of best hearing sensitivity.

4.4 Evaluate Uncertainty: Tier 4

Uncertainties regarding sound exposure and species distribution should be assessed as described for Tier 3 (section 4.3). Even if extensive acoustic modeling has been conducted, there is uncertainty in the sound exposure predictions due to model assumptions and limitations, and variability in water column characteristics at the time of the actual activity, and variability in received levels as a function of the receiving animal's depth in the water column. The level of knowledge and certainty about physical oceanographic properties that affect sound propagation, for location and the time period of interest, needs to be assessed. Testing and calibrating the model in the area of interest during season(s) comparable to those of the proposed E&P activity can reduce uncertainty.

The occurrence of TTS and PTS in cetaceans and seals is believed to be related to the cumulative amount of acoustic energy received over a period of exposure. Marine mammals can be expected to move in somewhat unpredictable ways during the exposure period, and some types of sound sources will also be moving during the period of exposure. All of these factors complicate the process of predicting the effective sound exposure, and create additional uncertainty.

The assumptions, uncertainties, strengths and limitations of any model or other method used to estimate sound exposure, species densities or population level effects need to be critically evaluated and documented, including a description as to how these factors were handled. If a model was extrapolated to address a different species, then any uncertainties associated with that extrapolation need to be clearly documented. Since models are a simplification of reality, the robustness of model assumptions needs to be carefully evaluated (EPA 1998). The methods described below can be used to test model uncertainty, identify the variables with greatest influence, and assess the variability in model predictions. Risk assessors also need to document the variability and uncertainty in estimates of a model's parameters, and how this might affect interpretation of the model's predictions. If possible, model predictions should be tested in the ecological system of interest. Finally, risk assessors need to identify which uncertainties can be reduced through data collection (EPA 1998).

4.5 Uncertainty Factors and Quantitative Methods to Assess Uncertainty

4.5.1 Uncertainty Factors

Uncertainty factors are numbers that are applied to the parameters or the output of a risk estimation model to ensure that risks are not underestimated (Suter 2007; EPA 1998). They can also be used to compensate for uncertainty when extrapolating results from another study to a particular risk assessment (EPA 1998). Uncertainty factors are often based on a combination of scientific analysis, expert opinion and policy judgment, and are useful when decisions must be made about stressors in a short time with little information (EPA 1998; Suter 2007). The magnitude of an uncertainty factor typically is inversely related to the quantity and quality of the available data on effects (EPA 1998). Drawbacks to the use of uncertainty factors include "the informality" of their derivation and that they "propagate" uncertainty (Suter 2007) —that is, they increase uncertainty in the overall outcome of the risk assessment because there is uncertainty in the value of the uncertainty factor itself.

4.5.2 Evaluation of Model Uncertainty

This includes evaluation of model assumptions, simplifications and the model structure, i.e., (the parameters and forms of mathematical models), and if the model can be tested using empirical data, the goodness of fit of predictions with the empirical data (EPA 1998; Suter 2007). Predictions from different models can also be compared, with more confidence placed in consistent results. Variability, bias and uncertainty about the true values of model parameters should also be investigated (EPA 1998). It is important to distinguish between natural variability in an ecological variable and, on the other hand, uncertainty about the true value that results from knowledge gaps (EPA 1998; Brandon et al. 2007). Variability can be described using a statistical distribution (e.g. mean and variance), confidence intervals, and percentiles of a distribution (e.g., 25, 50 and 95th percentile) (EPA 1998). Uncertainty about a quantity's true value may include uncertainty about its magnitude, location or time or occurrence (EPA 1998). Sensitivity and elasticity analyses are valuable techniques to identify which parameters most affect model results (and hence need to be measured most accurately), and to assess the variability of a model's predictions (McCarthy et al. 1995; Brandon et al. 2007). Bayesian analysis is another useful method for quantifying uncertainty in model predictions; it involves determining the probability that a given result would be obtained given the observed data (Ellison 1996; Brandon et al. 2007). Uncertainty estimates of model predictions tend to be larger when using Bayesian analysis and thus more protective (Arhonditsis et al. 2007).

4.5.3 Data Distributions

Uncertainty can be described by fitting a mathematical function to a variable's frequency distribution, or alternatively, an empirical (e.g., smoothing) function can be fitted that shows the actual form and variability of the data (Suter 2007). This distribution function can then be used to estimate uncertainties in the mean value of the variable. Distributions can be used to represent the uncertainty or variability of a parameter in a mathematical model of exposure or effects; and they may also directly represent the uncertainty or variability of exposure or effects when metrics for these items are directly measured (Suter 2007).

4.5.4 Confidence Intervals

Confidence intervals and their bounds are useful statistics for expressing variability or uncertainty of a parameter (Suter 2007).

4.5.5 Bayesian Methods

Bayesian analysis is a constructive approach to address issues of sparse data, uncertainty about the inherent functioning of biological systems, and lack of understanding in how these systems might respond to human activities. Uncertainties in parameters and hypotheses are explicitly incorporated through a probabilistic framework (McCann et al. 2006). An important feature of Bayesian methods is the incorporation of prior knowledge (e.g. empirical data, expert opinion) about the system of interest, which is refined as new data are obtained (Harwood 2000; Alvarez-Flores and Heide-Jørgensen 2004; Amstrup et al. 2007; Uusitalo 2007).

4.5.6 Monte Carlo Analysis

Monte Carlo analysis is a useful technique to estimate uncertainty in mathematical models with multiple uncertain or variable parameters (Suter 2007). Values for each model parameter are determined by randomly sampling from each parameter's distribution, and then the model is solved using the sampled parameter values (Chow et al. 2005; Manly et al. 2006). These two steps are repeated many times, often in the order of thousands, to generate a distribution of results with confidence intervals.

4.5.7 Sensitivity Analysis

Sensitivity analysis is a method used to examine the behavior of a model by measuring the variation in outputs resulting from changes to model inputs (Suter 2007). Sensitivity analysis is typically conducted by varying a parameter by prescribed small amounts around its estimated value, and then assessing the magnitude of the resultant change in model predictions (McCarthy et al. 1995; Billoir et al. 2007). This technique identifies which parameters most influence a model's results and hence need to be measured most accurately, indicates the reliability of a model's predictions and provides management direction by highlighting a model's limiting factors (McCarthy et al. 1995; Suter 2007).

4.5.8 Elasticity Analysis

Elasticity is a form of sensitivity analysis commonly used for demographic matrix models that assesses the proportional contribution of each matrix element (i.e., age/stage specific vital rate) to a change in population growth rate (Beissinger et al. 1998; de Kroon et al. 2000; Billoir et al. 2007). The sensitivity ratio or elasticity is determined by the ratio of the change in output to the change in an input parameter (Heppell et al. 2000). The model is more sensitive to parameters with high elasticity (Suter 2007). This method allows the effects of different parameters to be compared directly, even though the parameters may have been measured on different scales (Heppell 1998).

5. Marine Mammal Mitigation Measures: Options for Managing Risk

5.1 Introduction

The proposed methodology for assessing risk to marine mammals does not directly include mitigation measures in the scoring criteria used to derive a risk conclusion. Instead, mitigation measures are subsumed into the methodology insofar as they reduce the proportion of the stock ensonified. This approach allows users to conduct comparative risk assessments with scenarios that include varying levels of mitigation. For example, a base level of risk to a species from the E&P activity can be established by estimating the proportion of the stock ensonified sufficiently for a given effect. Analysis or expert opinion can then be used to determine the reduction in the proportion of stock ensonified when one or more mitigation measures are applied, and the risk level can then be recalculated. Once the appropriate mitigation measures are adopted, the risk assessment can be run again for the selected species to finalize the risk assessment. For example, a revised assessment may recognize that day-time only activities, combined with Marine Mammal Observers who monitor a safety zone and initiate shutdowns when mammals are seen in that zone, effectively eliminates the likelihood of PTS, and significantly reduces the likelihood of TTS and strong behavioral disturbance. However, the assessment may further note that the safety radius extends beyond the visual range of the MMOs, so some animals may incur TTS or strong behavioral disturbance. By adjusting the input to each of the risk assessment tiers, risk assessors can assess which combination of mitigation measures is likely to result in an appropriate balance between benefit to the species of interest and minimal operational consequences for the planned project.

Many jurisdictions require that mitigation measures and monitoring programs be implemented when offshore E&P industrial activities are conducted. Mitigation and monitoring have three main goals:

- Reduce the impacts on marine mammals to an acceptable level;
- Collect real-time data needed to implement mitigation and to determine whether the adopted mitigation measures have the desired effect or if they need to be adapted; and
- Collect data for post-survey analysis to determine the overall impact of the activity.

Numerous mitigation measures and monitoring protocols have been adopted, or are being considered for, E&P industry activities around the world. Most of these protocols have been developed primarily for seismic surveys because the high level and impulsive nature of sound produced by airguns poses risk of hearing injury, strong disturbance, or both. Although there are no universally accepted mitigation requirements for seismic operations, a number of jurisdictions (e.g., U.K. Australia, U.S.A., Brazil, Canada, Ireland, New Zealand) have developed guidelines that include various combinations of mitigation measures and varying degrees of regulatory oversight (Table 5.1). Tsoflias and Gill (2008), along with several other recent reviews (McCauley and Huges 2006; Vos and Reeves 2006; Castellote 2007; Compton et al. 2008; Nichol and Ford 2008), summarize the statutory marine mammal mitigation measures current in force around the world. These measures include:

- Seasonal restrictions/Avoidance of sensitive areas;
- Acoustic modeling;
- Manned aerial surveys;
- Passive acoustic monitoring;
- Active acoustic monitoring;
- Alteration of airgun array size, configuration, and specification;
- Activity planning;
- Selection of safety distances/exclusion zones;
- Marine Mammal Observers'
- Pre-shoot observation;
- Ramp-up or soft start;
- Power-downs;
- Operational shut-downs; and
- Limitations on night-time and poor visibility operations.

Other techniques, currently unproven or new, that may be further developed and implemented in the future include

- Unmanned aerial surveys;
- Shipboard radar;
- Thermal imaging; and
- Satellite imaging.

Although most of these measures are most widely used in conjunction with seismic surveys, several of them have also been used in association with other E&P activities. For example, safety distances implemented via MMO or other monitoring programs can be established around construction activities (Blackwell et al. 2004). MMOs can also be placed on supply vessels to reduce collision risk to marine mammals. The following sections describe each of the above measures and outline the advantages and disadvantages of each.

5.2 Overview of Potential Mitigation Measures

5.2.1 Seasonal Restrictions/Avoidance of Sensitive Areas

One of the most effective methods to mitigate the impacts of an activity on marine mammals is to remove the activity from the vicinity of the animals temporally or spatially, i.e., conduct the activity during a season when no or few marine mammals are in the region. This mitigation measure is not always feasible because factors such as weather and ice conditions, technological limitations and safety may preclude conducting the activity at a different time of year. Also, different species may be present in different seasons, with no one season having no or few marine mammals.

5.2.2 Acoustic Modeling

Determining the propagation of sound from the source using acoustic models must include all sound source specifics in combination with known environmental conditions when actual field measurements are not available. Modeling permits the determination of safety radii for use during subsequent real-time monitoring and mitigation programs. These radii are sometimes required to be calibrated (verified) using field measurements prior to or soon after the start of activities. Several jurisdictions require field verification of safety zones prior to beginning a survey.

Real-time acoustic modeling can involve the deployment of acoustic buoys to record under water noise levels. These data are transmitted to receivers on shore (or vessels) and then analyzed and assessed in real time in order to apply that information to field operations. If real-time monitoring is not required, transmission of data is unnecessary. Instead, data can be stored within the instruments until retrieved at the end of the field season, or at intervals during the field season.

5.2.3 Manned Aerial Surveys

Manned aerial surveys over offshore areas traditionally involve the use of twin-engine aircraft. Surveys can be flown prior to the initiation of the activity, during the activity, and post-activity. Data collected before the survey commences can be used to determine which lines (in the case of seismic surveys) should be shot first by directing the seismic vessel to those areas with few or no marine mammals within a predetermined distance. However, the data are useful for only a limited time due to the mobility of the animals. In some other projects, seismic surveys have been allowed to begin (or resume) only if one or more aerial surveys is conducted and no more than some specified number of cetaceans is detected within a predetermined distance of the operating area (e.g., Funk et al. 2008). Aerial survey data can also be used during later data analysis to map any changes in marine mammal distribution before, during, and after the activity (e.g., Miller et al. 1999, 2005; Yazvenko et al. 2007).

Table 5.1. Statutory marine mammal mitigation measures currently used during seismic surveys in Australia, Brazil, Canada, Ireland, New Zealand, the United Kingdom and the United States (Tsoflias and Gill 2008).

	Australia (2)	**Brazil** (8)	**Canada** (4)	**Ireland** (6)	**New Zealand** (7)	**United Kingdom** (1)	**United States – GOM** (5)
Title and version cited	EPBC Act Policy Statement 2.1- Interaction between offshore seismic exploration and whales (March 2007)	Guide for monitoring marine biota during seismic data acquisition activities (April 2005)	Mitigation of Seismic Noise in the Marine Environment- Statement of Canadian Practice (2004)	Code of Practice for the Protection of Marine Mammals during Acoustic Seafloor Surveys in Irish Waters (August 2007)	Guidelines for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations (February 2006)	Guidelines for Minimising Acoustic Disturbance to Marine Mammals from Seismic	Implementation of Seismic Survey Mitigation Measures and Protected Species Observer Program (February 2007)
Type of surveys covered by guidelines	Seismic	Seismic	Any survey using an airgun or airgun arrays	• All seismic • Multibeam and side-scan sonar within 1500m of enclosed bays (*remainder of Table only discusses seismic)	Seismic	All seismic	Seismic
Species covered by guidelines	"Whales" including killer whales and pilot whales but excluding smaller dolphins and porpoises	Marine mammals and sea turtles	Marine mammals and sea turtles	All cetaceans	All marine mammal species	Seals, whales, dolphins, porpoises	All GOM marine mammals and sea turtles
Shut-down zone	500m	500m	500m	1 ,000m	Varies from 200m to 1.5 km	500m	500m
Observer qualifications and requirements	Observers should be "trained in whale observation, distance estimation and reporting"; a suitably trained crew member is permitted	• Observers must possess experience in marine mammal surveys or completion of a training course is required • Observers report directly to IBAMA • Each seismic vessel must have 3 observers	Requires "qualified marine mammal observer" however qualifications are not specified in guidelines	• Observers must attend JNCC marine mammal observer training course or • equivalent and have a minimum of 6 weeks marine mammal survey experience	Requires a designated "marine mammal coordinator"	• Observers must attend a marine mammal observer short course; crew members may attend short course • Two observers are required when daylight hours exceed ~ 12 hours	Observers must meet qualifications specified in guidelines; observers may be trained crew members
Pre-survey visual observation period	30 minutes	30 minutes	30 minutes	• 30 minutes for water depths < 200m • 60 minutes for water depths > 200m	30 minutes	30 minutes	30 minutes

	Australia (2)	**Brazil** (8)	**Canada** (4)	**Ireland** (6)	**New Zealand** (7)	**United Kingdom** (1)	**United States – GOM** (5)
Pre-survey visual observation requirements	• During daylight hours, observers must visually monitor the 3 km radius around the vessel in every direction for 30 minutes • Low-power zone and shut-down zone must be clear of whales before initiating soft-start procedure	• During daylight hours, 2 observers must visually monitor the 1000m radius around the vessel for 30 minutes • 1 000m warning zone must be clear of marine mammals and sea turtles before initiating soft-start procedure	• During daylight hours, observer must visually monitor the 500m safety zone for 30 minutes • 500m safety zone must be clear of whales (other than dolphins and porpoises) and sea turtles before initiating soft-start procedure	• Observer must visually monitor the 1000m safety zone for 30 minutes • 1 000m zone must be clear of marine mammals before initiating soft-start procedures	• During daylight hours, observer must visually monitor 1.5 km radius around source vessel for 30 minutes • Activation of any seismic source cannot begin if "species of concern" is sighted within 1.5 km radius or if any other marine mammal is sighted within 200m radius	• Before activation of any seismic source, observer must visually monitor the 500m safety zone around the source vessel for 30 minutes • 500m safety zone must be clear of marine mammals before initiating soft-start procedure	• Before activation of any seismic source, 2 observers must visually monitor the 500m safety zone and adjacent waters for 30 minutes • 500m exclusion zone must be clear of marine mammals and sea turtles before initiating ramp-up procedures
Soft-start or ramp-up procedure	• Initiate soft-start with lowest energy-output / volume airgun • Gradually add airguns over a 30 minute period • Visual observations are required continuously	• Initiate soft-start with lowest energy-output / volume airgun • Gradually add airguns over a 20-40 minute period	• Initiate soft-start with lowest energy-output / volume airgun • Gradually add airguns over a 20-40 minute period	• Initiate soft-start with smallest airgun • Gradually add airguns over a 20-40 minute period	• Initiate soft-start with single airgun • Gradually add airguns over a 20-45 minute period • Visual observations are required continuously	• Initiate soft-start with smallest airgun • Gradually add airguns over a 20-40 minute period	• Initiate ramp-up with smallest airgun in terms of energy output and volume • Gradually add airguns over a 20-40 minute period • Visual observations are required continuously
Visual observation procedure during operations	Visual observations are required during seismic survey operations	Visual observations are required during the entire survey duration	When safety zone is visible, visual observations are required	Not stated	During daylight hours, continuous visual observations of a 1.5 km radius surrounding the vessel are required	Visual observations only required during pre-survey period (before soft-start procedure)	During daylight hours, continuous visual observations required by 2 observers

	Australia (2)	**Brazil** (8)	**Canada** (4)	**Ireland** (6)	**New Zealand** (7)	**United Kingdom** (1)	**United States – GOM** (5)
Shut-down procedure	• Shut-down of seismic sources required if whale enters 500m safety zone at any time • Required power-down to single airgun if whale enters low-power zone at any time • After the whale has been observed leaving the low-power zone or 30 minutes has elapsed, the seismic source may be reactivated using soft-start procedures	• Shut-down of seismic sources required if marine mammal or sea turtle enters the 500m safety zone at any time • After the whale has been observed leaving the 1 000m warning zone or 30 minutes has elapsed, the seismic source may be reactivated using soft-start procedures	• Shut-down of seismic sources required if a whale or sea turtle listed as endangered, threatened, or species of concern enters 500m safety zone at any time • After the whale has been observed leaving 500m safety zone or 30 minutes has elapsed, the seismic source may be reactivated using soft-start procedures	• Shut-down of seismic sources required if a cetacean enters the 1000m safety zone at any time • The seismic source may be reactivated using soft-start procedure after the 1000m safety zone has been confirmed clear of cetaceans for 30 minutes (< 200m water depth) or 60 minutes (> 200m water depth)	• Shut-down of seismic sourced required if a cow-calf pair "species of concern" enters 1.5 km zone • Shut-down of seismic sources required if "species of concern" enters 1 km zone • Operations cannot recommence until animals have left respective zones (see above) or 30 minutes has elapsed	No requirement to shut-down seismic source if it is already operating at full power.	• Shut-down of seismic sources required if a whale enters 500m exclusion zone at any time • After a 30 minute visual survey has determined the absence of marine mammals and sea turtles, the seismic source may be reactivated using ramp-up procedures
Nighttime or low-visibility requirements	Operations may proceed at night or during low visibility provided there where no more than 3 whale-instigated power-down or shut-downs in the preceding 24 hours	Activation of seismic sources cannot begin during the night or low-visibility conditions	In areas where an endangered or threatened whale is "reasonably expected to be encountered," soft-start procedures cannot commence at night or during low-visibility *unless* PAM is utilized	Soft-start procedures must begin during daylight hours to allow for visual observation of the safety zone	Not stated	Encourages soft-starts to begin during daylight hours	Ramp-up procedures cannot be initiated at night or during times of low-visibility when the exclusion zone cannot be visually monitored
Passive Acoustic Monitoring	Not required, experimental use permitted	Not required, but encouraged	Not required, but encouraged when the safety zone is not visible	Not stated	Not required, but encouraged at night or when visibility is low	• Required in areas with sensitive species • Encouraged at night or when visibility is low	Not required, but encouraged

In the Beaufort Sea off Alaska, manned aerial surveys were required to monitor for bowhead whales in waters where airgun received sound levels could be >120 dB re: 1 µPa, RMS (MMS 2006; MMS and NOAA 2007). If four or more cow-calf pairs of bowhead whales were observed, no seismic surveying was to occur within the monitoring zone until no whales were observed for two consecutive surveys (aerial or vessel). In some cases, alternatives to aerial surveys (such as PAM deployment) may be implemented, subject to agency approval.

Manned aerial surveys can be severely limited by weather and sea conditions, short daylengths, mechanical failure of the survey equipment, and aircraft maintenance/safety issues. Suitable aircraft that can pass all required safety inspections may be of limited availability depending on the region. Aerial surveys are also limited in the degree that observers can detect all whales that are present in an area and in the ability to complete required transects in a timely manner. For remote areas, aircraft range and safety considerations may pre-empt all other factors.

5.2.4 Passive Acoustic Monitoring

Passive acoustic monitoring (PAM) involves deploying hydrophones (usually towed or bottom-mounted) to listen for underwater vocalizations by marine mammals. With appropriate experience and the use of specialized software, it is often possible to accurately identify and (to some degree) locate some vocalizing marine mammals that are not visually observed from a vessel. However, the use of PAM is limited by the difficulties in recognizing some marine mammal sounds both real-time by an operator and using detection algorithms, the identification of individual species, the level of ambient and anthropogenic noise in the environment that affects detection ranges and that can mask the lower frequencies used by baleen whales, and false alarm rates. It is also often difficult to determine the range and direction of vocalizing animals. PAM is further limited by the vocalizing behavior of the subject animals. Some species seldom vocalize, or produce faint or directional calls that are difficult to detect.

PAM systems have been used widely during seismic surveys in various jurisdications, with mixed results; in some areas it is a requirement or a recommendation for nighttime operations (see Table 5.1) or as an alternative to aerial monitoring (MMS and NOAA 2007). Where a significant portion of a survey will be carried out during periods of low visibility, PAM may offer the only reasonable opportunity to monitor the presence of marine mammals. As with any deployment of equipment at sea, there is a risk of equipment failure or loss that could significantly compromise data collection.

5.2.5 Active Acoustic Monitoring

Active acoustic monitoring involves the use of active sonar to detect marine mammals close to a vessel. Sound pulses emitted by the sonar system that are bounced back to the receiver are used to generate a 3-D image of the water column (NATO Undersea Research Center 2006). A trained operator can then visually identify large objects that are reflecting the sound and determine whether they are biological or physical in nature.

While active acoustic monitoring has the potential to detect mammals close to a vessel or facility, it does not allow for species identification, false positives can occur, and it involves the introduction of additional sounds into the marine environment.

5.2.6 Alteration of Airgun Array Size, Configuration, and Specifications

During marine seismic surveys, many jurisdictions require operators to use the lowest practicable volume of airguns (JNCC 2004). In addition, many authorities request that operators minimize unnecessary high frequency sound or horizontal sound propagation (JNCC 2004). For construction activities, project design may be able to minimize noise levels by modifying equipment design.

5.2.7 Activity Planning

The orientation of seismic lines may help mitigate noise impacts, depending on the underlying bathymetry. Under certain conditions, seismic lines perpendicular to the coast may minimize the propagation of sound to the near shore zone, while other conditions may favor a parallel-to-shore alignment. Furthermore, depending on the local distribution and concentration of marine mammals, certain lines of a planned shoot may have a much reduced likelihood of encountering marine mammals, and thus may be more suitable for night-time data acquisition, while those lines with a higher likelihood of encountering animals may need to be restricted to day-time data acquisition (Johnson et al. 2007). Options to modify a construction activity may be more limited, but modifications of a construction schedule may also facilitate reduced impacts.

5.2.8 Selection of Safety Distances/Exclusion Zones

Safety or exclusion zones are typically defined as the radius around a sound source within which real-time mitigation measures are implemented if a marine mammal is detected. In some jurisdictions, set safety zones are implemented regardless of the source level employed, while in others the safety zone varies depending on the source level (see Table 5.1). Safety radii may also vary depending on water depth or other factors considered to influence sound propagation or environmental sensitivities. In the U.S., the National Marine Fisheries Service specifies, for impulsive sounds, a potential injury threshold for cetaceans at 180 dB re 1 μPa (rms) and a potential disturbance threshold of 160 dB re 1 μPa (rms), while the potential injury threshold for pinnipeds is set at 190 dB re 1 μPa (rms); in the U.S., shut-downs or power-downs are required for injury but typically not for disturbance. These thresholds are currently being re-evaluated (see discussion in Chapter 3) to take into account specific frequencies used by certain species, so that species-specific safety zones may be established depending on the acoustic signature of the device being used (Southall et al. 2007). Safety zone distances for the required received sound level criteria are best calculated using acoustic models that account for the specific equipment used and site-specific environmental data for transmission loss and through calibration in the field.

5.2.9 Marine Mammal Observers

With the exception of seasonal restrictions and avoidance of sensitive areas, visual detection of marine mammals remains the most effective means of mitigating impacts from industry activities and nowadays Marine Mammal Observers (MMOs) are often deployed on seismic vessels (Table 5.1). The effectiveness of MMOs in detecting marine mammals and implementing the required mitigation measures varies widely depending on a variety of factors. These include the experience of the MMO(s), training received, the number of MMOs deployed on a vessel (and length of their shifts), number of MMOs on duty at any one time, appropriate stationing of the MMOs on the vessel, weather, and effective communication between the MMOs and the seismic operator to ensure timely responses to marine mammal observations.

Standard protocols typically call for MMOs to work no longer than 4-hour shifts to minimize observer fatigue. For summer surveys at high-latitudes, this typically requires the deployment of at least 3 observers on a seismic source vessel. If a PAM system were also deployed with a requirement for real-time human monitoring, an additional 2 PAM operators would be required.

Although it is standard practice to deploy MMOs onto the source vessel, a near shore operation may benefit from the use of additional shore-based MMOs whose observations are used to complement, in real-time, the observations made from the source vessel. While the source-vessel based MMOs will be focused on "clearing" the safety zone around the vessel, shore-based MMOs may focus on documenting behavioral changes and distributional shifts in subject animals. In addition to placing MMOs on the source vessel, MMOs can also be deployed on other vessels associated with the project, such as a support vessel or a dedicated small vessel stationed at some distance from the source vessel. These personnel can increase the detectability of marine mammals at distances beyond the effective range of MMOs on the source vessel, and can relay information on marine mammal distribution (Johnson et al. 2007; Funk et al. 2008).

MMOs can also be deployed to monitor marine mammals in the vicinity of other industry operations, such as construction activities, supply vessels, tankers, and platforms. For practical purposes, marine mammals are unlikely to be observed at or above sea state 5.

5.2.10 Pre-Activity Observation

Observations made by trained Marine Mammal Observers (MMOs) are typically made for 30 minutes prior to start-up of airguns. This is standard protocol in most jurisdictions (Tsoflias and Gill 2008), although Australian requirements stipulate a 90-minute watch prior ramp-up (see Table 5.1). Similar pre-activity observation periods may be implemented prior to the use of construction or other equipment.

5.2.11 Ramp-up or Soft Start

A ramp-up or soft start involves the gradual build-up of the sound level from airguns or another sound source over time. In a marine seismic survey, generally, the smallest airgun is fired first, with other guns added over at least 20 minutes. Often it is specified that sound output should be ramped up gradually over 30 minutes as each gun or group of guns is activated (Department of Environment and Water Resources 2007, Tsoflias and Gill 2008). The rationale behind a ramp-up/soft start is to alert nearby marine mammals and, if the sound is aversive, to allow the mammals to leave the vicinity before the sound output reaches its maximum. Ramp-ups are routinely used by seismic survey vessels and in some operations with sonars and explosives, and this method has become a requirement in many regions (see Table 5.1). A similar ramp-up may be possible with construction or other equipment.

5.2.12 Power-downs

Power-downs are often required when marine mammals (or, in some jurisdictions, particular species of marine mammals) enters the safety zone around a sound source, e.g., an airgun array, pile-drivers, or other construction activity. If a designated species does enter the safety zone and a complete shut-down is implemented, most jurisdictions require that the animal be observed to leave the safety zone and/or a 20-30 minute observation period has elapsed to ensure that the animal is no longer within the safety radius (Tsoflias and Gill 2008) prior to restart of the survey. Once an animal is known or considered to have cleared the safety zone, a ramp-up/soft start may be required to reinitiate operations, depending on the length of the shut-down period.

5.2.13 Operational Shut-downs

Seismic vessels do not typically operate continuously. Operational shutdowns may occur for maintenance and repairs. During line changes, it is usual for one airgun to remain firing (JNCC 2004, Department of Environment and Water Resources 2007) so that a ramp-up/soft start can be initiated when the next line begins even under dark or foggy conditions; however, the firing of a single gun may not always be permitted (in some jurisdictions it is actively encouraged). As described in the previous section, the requirements for commencement of ramp-up/soft start vary for different jurisdictions. During construction activities, equipment is rarely operating continuously, and operational shut-downs will occur frequently.

5.2.14 Night-time Operation/Poor Visibility

During periods of low visibility or hours of darkness, visual monitoring of marine mammals becomes largely ineffective. Night-vision devices have an effective range of approximately 100 m or at times somewhat more (Calambokidis and Chandler 2000), but may be unreliable. Most of these devices operate in the darkness by amplifying existing visible (or near-visible) external radiation (from moonlight, starlight, sky-glow, etc.). These systems operate well if there is sufficient (but not too much) external illumination; however, they cease to operate altogether in absolute darkness or in deep shadows. Observers using night-vision devices are also limited by the field of view of the devices, which further reduces the likelihood of spotting marine mammals as they surface in the dark. Thermal imaging devices are available as alternatives to image intensifiers, but thermal sensors are most costly and are also significantly limited by environmental conditions.

5.3 Determining Management Options

The implementation of a monitoring strategy to manage risk requires the integration of all relevant information for the target region. If multiple species are present and multiple industry activities are being conducted, the individual risk assessments for each species and sound source must be integrated for each activity and across the project as a whole. In some cases the recommended mitigation approach for one species could result in a greater level of impact to another. For example, avoiding a pinniped haul-out site may result in greater disturbance to whale feeding habitat. In these cases, expert opinion may be needed to determine which impact is greater and to prioritize the species that may be at risk. In most cases minimizing disturbance to a critically endangered species would take precedence over disturbance to a non-threatened species (subject to regulatory approval). In addition, a mitigation and monitoring study is typically designed around the most sensitive or high profile species of concern and thus by default other species at lesser risk will usually benefit from the measures adopted. However, the presence of multiple threatened species may require more detailed assessment and adoption of additional protective measures.

Mitigation measures under consideration should be practical for field application, provide a measurable benefit for the targeted species, and be appropriately cost effective. Risk assessments that result in a determination of no or low risk will still require, at a minimum, the use of statutory measures for the relevant jurisdiction, and low risk does not equate to no risk. Many jurisdictions require mitigation measures for seismic surveys and similar measures may be required for construction or other significant noise-generating activities. If a medium or high level of risk exists, the operator may need to consider an additional level of mitigation in consultation with the regulatory authorities. This additional level may target a particular high-profile species of concern, the rarest species present, or the one assessed as being most vulnerable to the specific noise being produced.

The complexity of ecosystems and the variability in marine mammal reactions to anthropogenic sounds mean that it is often difficult to predict consequences with any degree of confidence. By employing a suite of mitigation measures, managers can assess how each functions in the field under real-world conditions, and which has the greatest benefit in terms of risk reduction and real world application which can be modified as more information is obtained.

6. Risk Assessment Tool

A prototype Risk Assessment Tool was designed and implemented in order to assist users with performing an assessment to determine potential risk to cetaceans and pinnipeds from offshore E&P activities. The tool's main purpose is to interactively guide the user through the risk assessment methodology described in Chapter 3. The tool requests and validates input where needed, provides important information and links to useful resources along the way, and generates a summary of inputs and results. Note that the links to databases are not dynamic in this prototype version of the tool. Instead, the relevant information from these database links was hard coded in the tool. This means that the construction of species lists in the tool is based on data from Fall 2008, when the tool was implemented.

The Risk Assessment Tool is implemented in the Java programming language and uses Eclipse foundation libraries, including Rich Client Platform (RCP) and JFace/SWT. Java provides *platform independence,* which allows the application to run under most operating systems. The use of Eclipse RCP libraries simplifies development by supplying a substantial amount of pre-existing functionality and useful coding patterns. Eclipse RCP also features a plug-in architecture with standardized API specifications that supports future extensibility, and allows 3rd party developers to improve the tool. Eclipse JFace/SWT libraries provide a user interface familiar to most people who have used common office software.

6.1 Application Structure and User Interaction

The tool can be divided into two main components:

a main application window that

- displays the results of a risk assessment
- provides the menu and toolbar controls for the application
- shows the information about application status

and an interactive risk assessment guide (based on a wizard paradigm that should be familiar to most users) that

- guides the user through the risk assessment methodology (Chapter 3)
- allows the user to enter data required by that methodology, and
- validates user input

Standard usage sequence for the risk assessment tool is shown in Fig. 6.1 and consists of

1. Tool is started. Main window displays a welcome message.

2. The interactive guide is started and guides the user through the first three tiers (Tier 4 is not implemented in the current prototype) of the risk assessment methodology (Chapter 3). The guide is designed to be self-explanatory for users who are sufficiently familiar with commonly available office software. See the next section for a detailed example of Tiers 1 to 3.

3. After the interactive guide is completed, the risk assessment results are displayed in the main window.

4. If the user is satisfied with the results, the risk assessment report is generated and saved. Otherwise, the interactive guide can be rerun as many times as necessary to improve the results.

5. The tool can save and load projects to preserve user inputs and results.

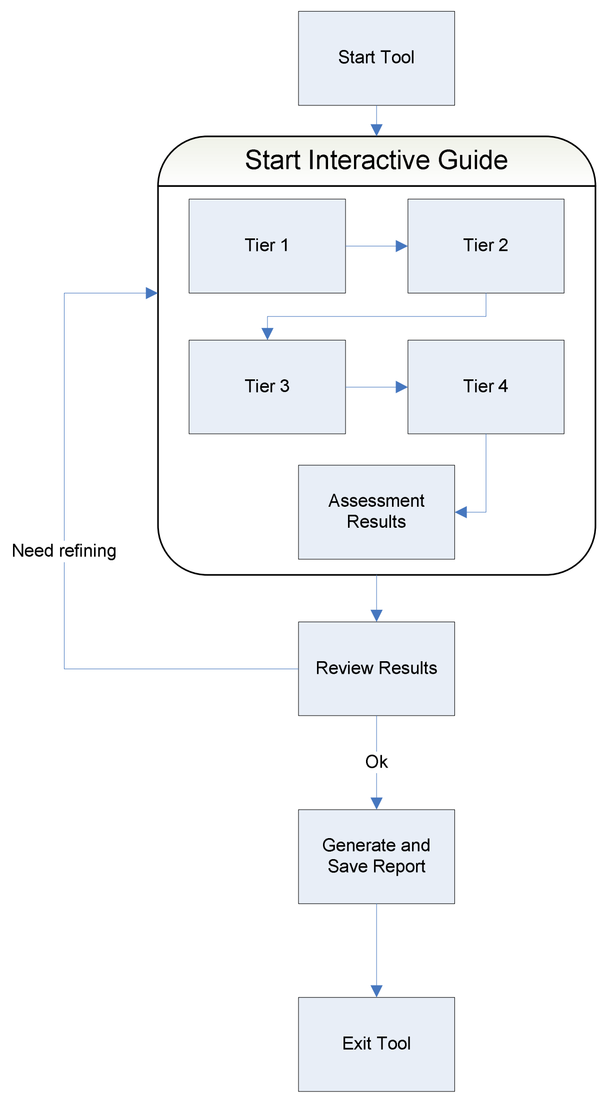
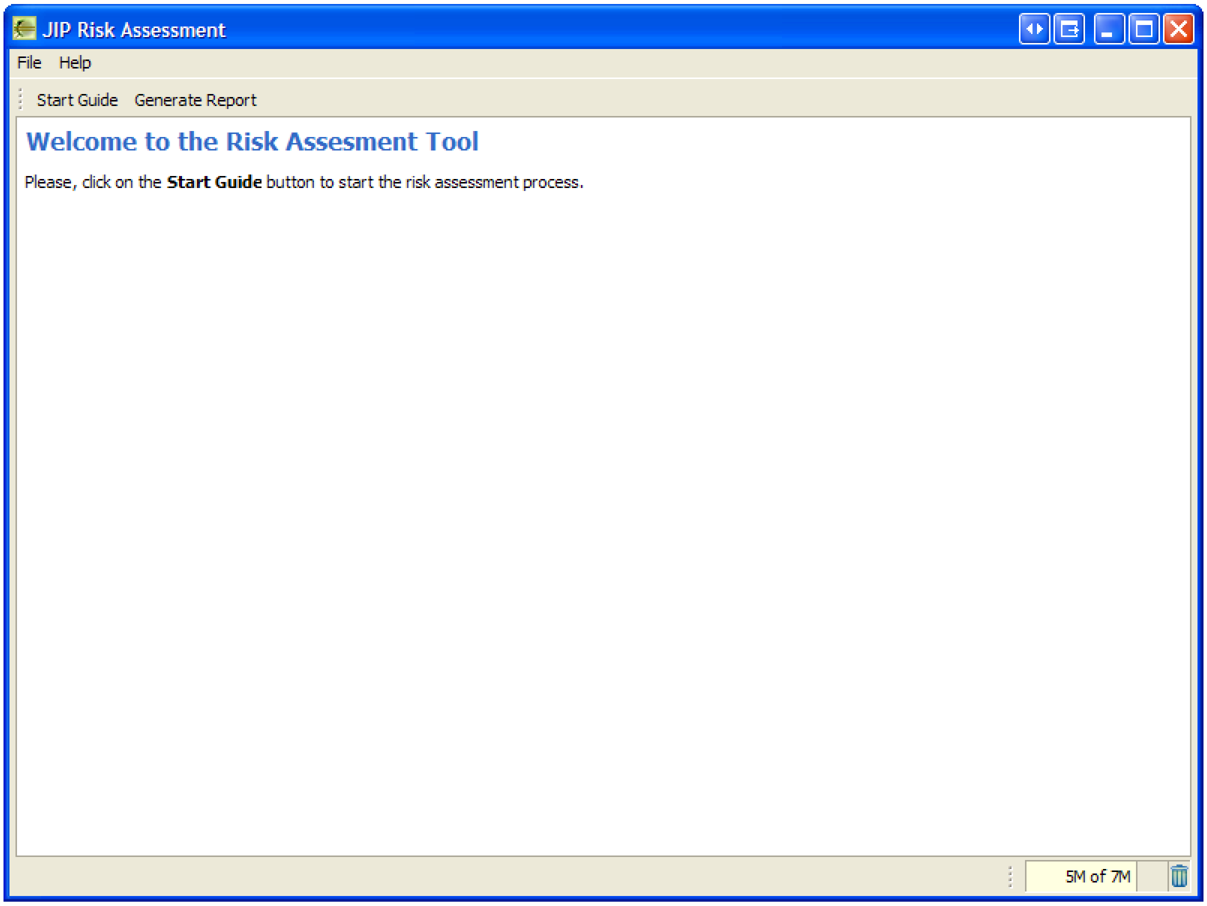


Figure 6.1. Standard usage sequence.

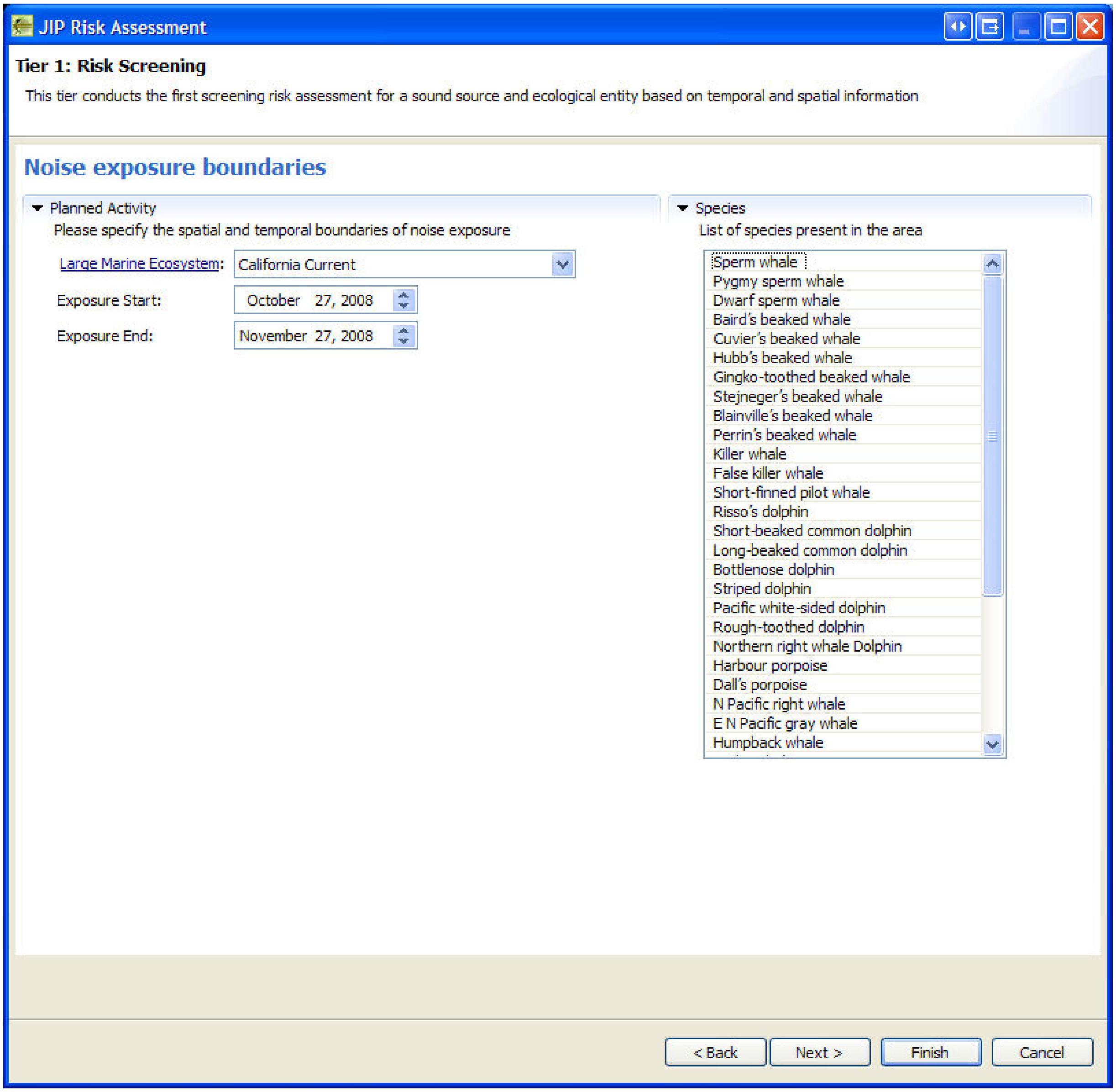
6.1.1 Sample Tool Walkthrough

1. Start the tool.

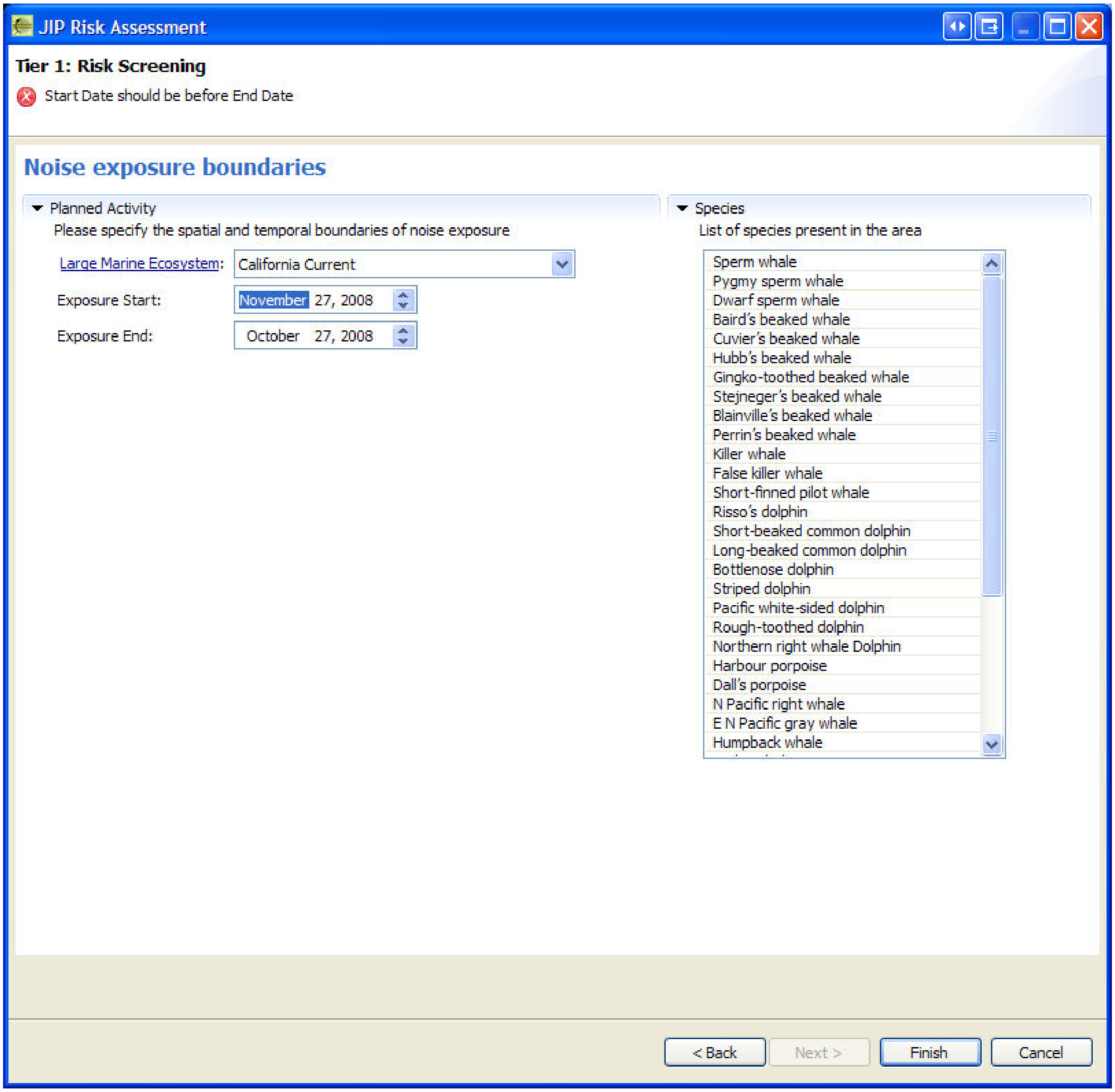


2. Click "Start Guide."
3. Go through the introduction screens (not shown here), clicking "Next" until you arrive at Tier 1.
4. Select the geographic area of planned activity from the pull-down menu. This geographic area will be one of the predefined large marine ecosystems (LME)[1]. Note that the list of known species in that LME is displayed for reference.

[1] http://www.edc.uri.edu/lme/clickable-map.htm

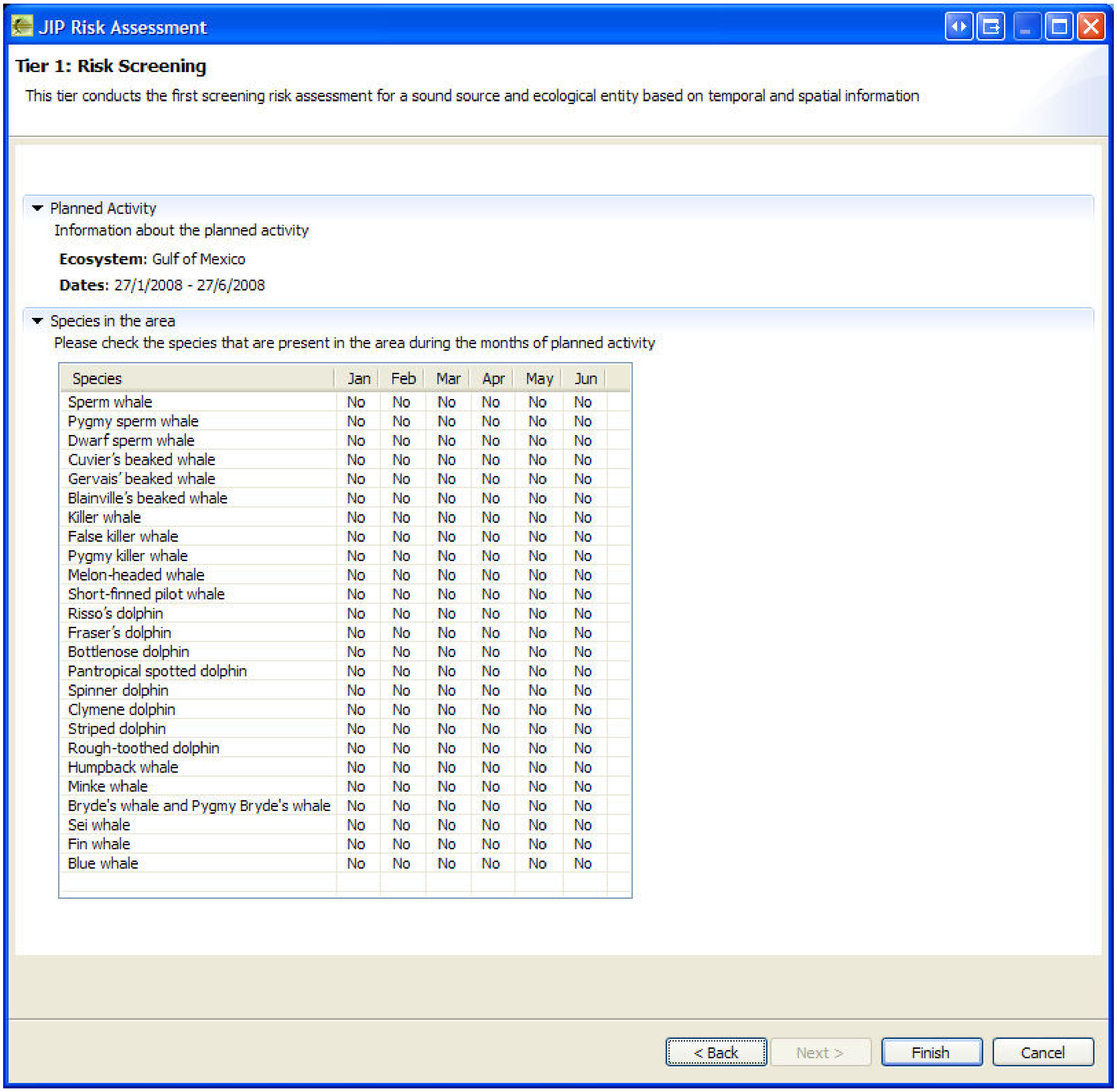


5. Enter the start and end dates of the planned activity. Note that if erroneous data is entered (e.g., the end date is earlier than the start date), an error message is displayed and the navigation buttons are disabled until the error is fixed.



6. Click "Next."

7. The table of species in the area is displayed in matrix format in relation to the months of the planned activity. For each of the species, check the months when it is present in this area. Note that a "?" can be entered to indicate if data are insufficient to determine if a species is present in the LME during that month.

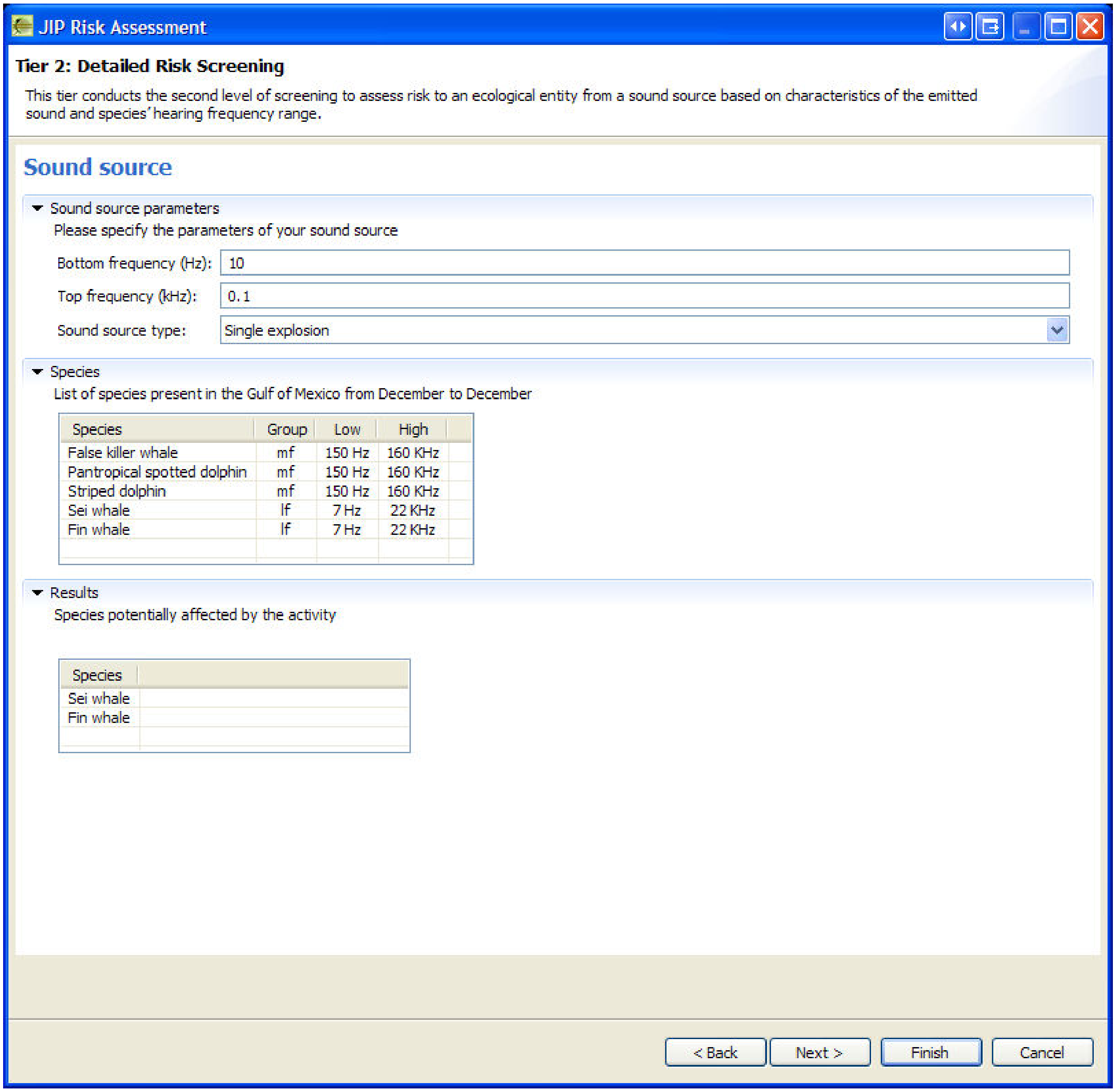


8. If none of the species are present during months when ensonification of the area will occur, then there is no risk. Click "Finish" to exit the guide.

9. If some of the species are present (or the species information is uncertain) then there is possible risk. Click "Next" to proceed to Tier 2.

10. Read Tier 2 Introduction. Click "Next."

11. Specify the parameters of your sound source. Note that the tool validates the user input and prevents entry of impossible values (e.g., top of the frequency range being lower than the bottom). The list of species present in the area along with the functional hearing ranges for the species groups to which they belong is shown in the Species section. List of species potentially affected by the activity is shown in the Results section.

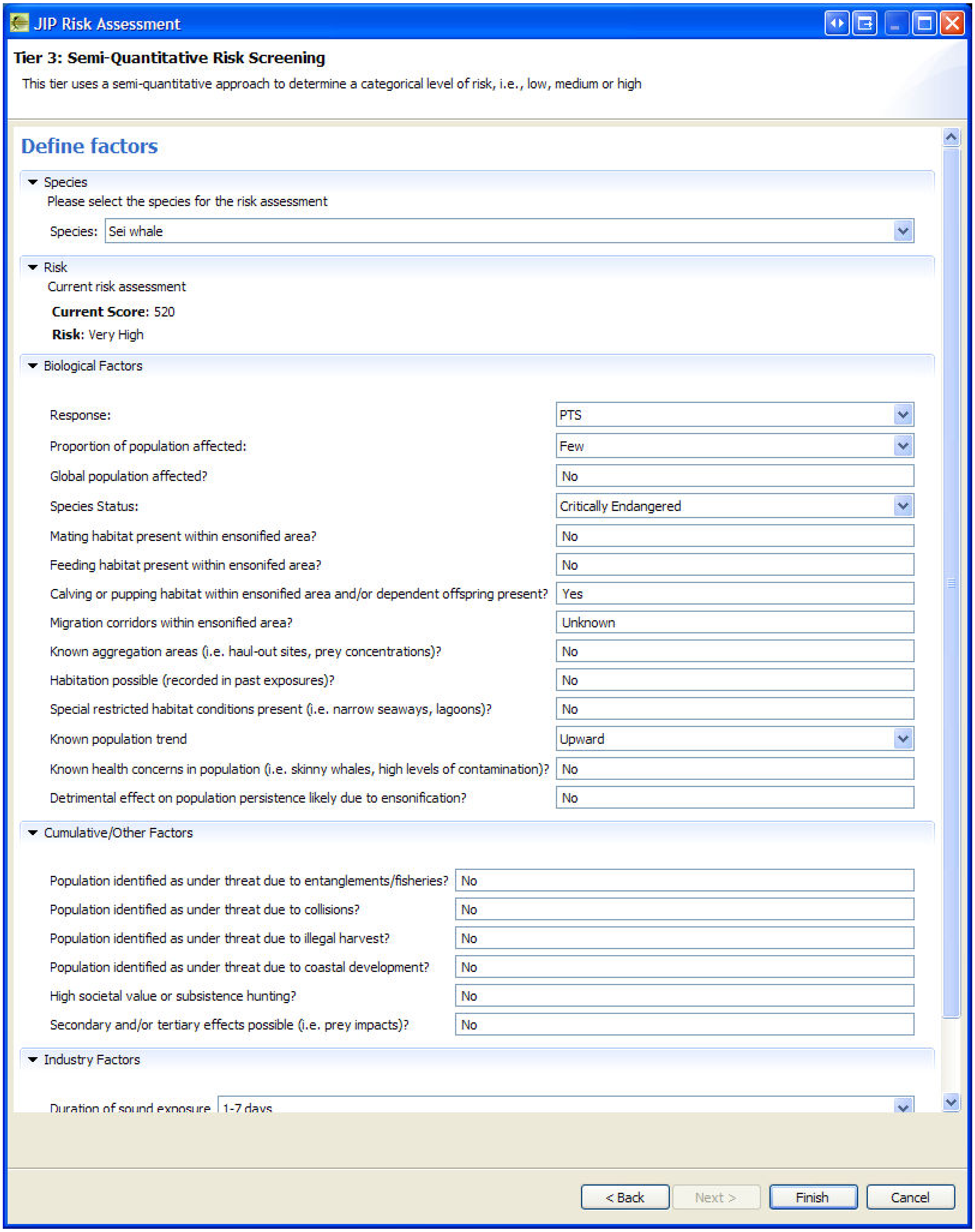


12. If none of the species have hearing ranges that overlap the frequencies emitted by the activity, then there is no risk. Click "Finish" to exit the guide.

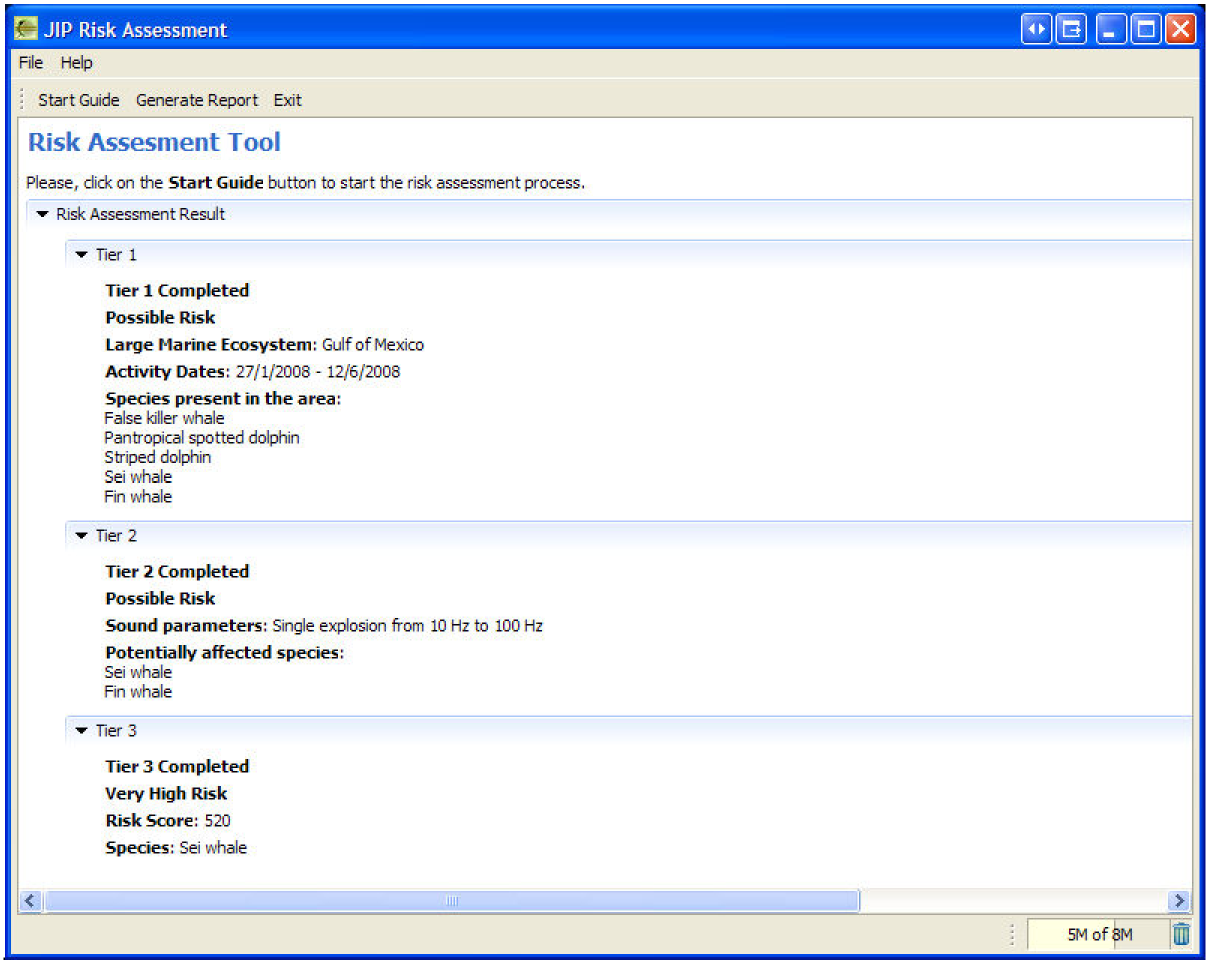
13. If some of the species are potentially affected then there is possible risk. Click "Next" to proceed to Tier 3.

14. Read Tier 3 Introduction. Click "Next."

15. At the Tier 3 stage, the current version of the tool can only work with one species at a time. Select the species in the Species section. The risk score and corresponding risk assessment are displayed in the Risk section and dynamically change according to the answers given in the other sections.



16. Click “Finish” to complete the risk assessment and return to the main window.



17. Review the results of the risk assessment.

18. A report in a Microsoft Word readable format can be generated by clicking on the “Generate Report” toolbar button.

6.2 Future Work

- The prototype tool is currently restricted to guiding user though the risk assessment of sound from a single source and one species at a time. The tool has to be run again to assess risk to another pair of sound source and species. The user interface can potentially be improved to allow risk assessments for multiple pairs of sound source and species to be conducted in a single run of the tool.
- The treatment of uncertainty in the current version of the tool is restricted to specific scores attached to the “Don’t know” answers to the questions asked by the tool. This can be expanded to a more complex scoring system to account for different levels of uncertainty.
- It would be advantageous to expand the tool to use Bayesian belief networks to deal with uncertainty and generate scores for Tier 3 questions. This can most likely be accomplished via the use of the Netica-J java library (provided by a widely used Norsys Netica program).

- The tool can be made more configurable, allowing the users to amend the internal databases and modify the scores and thresholds in Tier 3.
- Quantitative demographics models can be incorporated, if available, into the tool to better assist the user in answering population trend questions.
- APIs and extension points could be designed and implemented in various components of the tool (e.g., the demographics models component) to allow 3rd party developers to write plug-ins that can be easily integrated into the tool, thus considerably expanding its usefulness.

7. Discussion and Summary

Risk assessments provide a mechanism to evaluate and organize data, information, assumptions, and uncertainties to help understand and predict the relationship between stressors and ecological effects—in this case between noise resulting from E&P activities and marine mammal injury, behavioural disturbance and population level effects. A risk assessment process can be used to construct "what-if" scenarios; to evaluate new and existing technologies for effective prevention, control, or mitigation of impacts; and to provide a scientific basis for risk-reduction strategies.

There are many data gaps and uncertainties surrounding the potential for effects to marine mammals from E&P activities. These include data gaps and uncertainties concerning the definition and delineation of biologically-relevant effects; determination of sound thresholds for each effect; marine mammal distribution, abundance and ecology; accurate spatial delineation of exposure levels near an E&P sound source; and interactions of various factors in determining individual and population responses. These uncertainties and data limitations place substantial constraints on any methodology used to assess the risk of these potential effects. In addition, there is considerable subjectively in assigning relative weights to the different factors. At present, such risk assessments typically apply a qualitative risk matrix approach that uses expert opinion to assign risk ranks according to the severity of an effect in conjunction with the likelihood of its occurrence (e.g., SCAR 2004).

The main goal of this project was to improve on existing risk assessment methodologies available to E&P managers by developing a consistent and well-defined methodology specifically designed to assess the risk of PTS, TTS, and behavioural disturbance in cetacean and pinnipeds exposed to sound produced by offshore E&P activities. The methodology presented here allows semi-quantitative and qualitative risk assessment depending on the effect of interest. Although a fully quantitative approach would be preferable, the data gaps that exist are currently too substantial. Sound thresholds cannot (at present) be expressed as dose-response relationships such as those used in traditional quantitative risk assessment methods. Instead, the exposures eliciting PTS and TTS have been specified by Southall et al. (2007) based on specific sound levels expected to cause onset of the effect, with some considerable, but generally undocumented level of uncertainty. Southall et al. concluded that presently-available data do not allow definition of broadly-applicable exposure-based criteria for behavioral disturbance. Observational data show considerable variability, within and between species, in the behavioral reactions of marine mammals to E&P sounds.

We developed an iterative tiered risk assessment approach to address the data gaps and uncertainty inherent in assessing risk to marine mammals from E&P sound. The use of tiers allows the risk assessment to iteratively focus in on the most important species and interactions, with increasing levels of sophistication of analysis (and increasing data requirements) until a sufficiently complete and defensible result is achieved (Suter 2007). Through a four-tiered assessment, our approach examines sources of anthropogenic sound, the distribution of that sound in the environment, and the extent of co-occurrence with the marine mammal species potentially affected by that type of sound. Simple rules are used first, to screen out species that cannot be exposed to the sound due to no overlap in spatio-temporal extent between the sound exposure and the species known distribution patterns (Tier 1). Whether or not the sound source's frequency range overlaps with a species' hearing frequency range, as defined by Southall et al. (2007), is then used to screen out species that would not be affected (Tier 2).

If there is overlap both in terms of species distribution and hearing range, there is a potential for risk to a species from the E&P activity, and the assessment moves forward to Tier 3. Our goal in this tier was to provide a mechanism that evaluated risk from E&P activities in a broad context. In Tier 3, we estimate risk to a species based on the PTS and TTS thresholds developed by Southall et al. (2007), and we assign one of four levels of disturbance based on any available data plus expert opinion. Data on conservation status, the presence or absence of critical habitat and other biological/environmental factors of relevance are also incorporated in a semi-quantitative way into the risk estimate. Where information is lacking, we apply a mechanism for highlighting uncertainty or poor data quality. We also consider non-E&P anthropogenic factors to permit the inclusion of other potentially significant factors that may impact a species, such as vessel collisions, entanglements, coastal development, contamination, illegal harvest, and subsistence whaling. We include these factors to provide a contextual environment for the risk assessment—this is in recognition of the fact that E&P activities rarely exist in isolation of other human activities, and a species already at risk due to other factors may be less able to accommodate additional intrusions into its habitat.

We developed a scoring system for use in Tier 3 (and subsequently in Tier 4) to bring each of the biological, environmental, cumulative and industrial factors described above into a standardized risk assessment methodology. While necessarily arbitrary in many ways, we weighted the scoring system heavily toward the biological and conservation status of the subject animals, so that threatened species are more likely to enter into at least the medium risk category, and those species with vital habitats or behaviours occurring in the region of the activity are likely to score high. The scoring was also weighted heavily toward PTS and TTS/strong behavioural disturbance. We tested several scenarios to calibrate the scoring system, and to determine which elements had the greatest effect and thus where the sensitivity (and insensitivity) of this method lay. While necessarily subjective, the goal of the questions posed in Tier 3 is to prompt the risk assessor to consider all relevant factors and to recognize that the greater number of risk factors present, the greater the potential overall risk to the species being considered.

The scoring system is flexible and can be adapted according to unique program elements and target species. For example, separate scoring systems may be appropriate for each marine mammal functional hearing group, for impulsive or continuous sounds, and for resident versus migratory animals. It may also be appropriate at times, to assess risk without consideration of cumulative impacts if there is interest in focusing solely on the planned industry activity.

Tier 4 of the proposed risk assessment methodology uses the scoring system developed in Tier 3, but applies more detailed knowledge of the potential sound exposure and/or the ecology and distribution of a species to quantitatively estimate the actual percentage of the stock that is ensonified sufficiently to incur PTS or TTS. In addition, Bayesian belief networks, and demographic, bioenergetics and individual based models may be used to quantitatively determine potential effects on a species' population trend. The additional information and use of analytical results would allow a more quantitative risk assessment to be conducted, which would reduce uncertainty and provide stronger justification for the risk conclusion. However, under most circumstances it is unlikely that information to run Tier 4 is currently available.

We developed a computer software tool that implements Tiers 1 to 3 (tier 4 is not implemented in the current prototype) and serves as an interactive decision-making risk assessment interface. It prompts resource managers to work through a series of questions and determine whether they have the information to respond.

Key information essential to the implementation of the risk assessment methodology are

- Data on the E&P sound sources, including sound levels, frequencies and temporal properties;
- Data on the distribution and abundance of marine mammals in the project area;
- Data on the hearing sensitivity of the functional hearing groups of the marine mammals present;
- Data on the life cycle and habitat use of the marine mammals present;
- Data on sound propagation to determine the zone of influence around the planned project; and
- Data on relevant cumulative impacts affecting the species of interest.

Although site-specific data are often lacking, we identify resources available to risk assessors that provide broad-scale data that can be used to answer the necessary background questions in the risk assessment (for example data on Large Marine Ecosystems). When site-specific data are available, that information can take precedence over broader regional or global data.

Any risk assessment methodology must be practical to use in real-world situations. Complex sound modeling, while useful is not always available or possible, and risk assessors may have to use simple transmission loss equations to set radii for possible zones of influence around a sound source. In addition, there is ongoing discussion and research as to the actual sound levels likely to result in PTS or TTS, and the relationships between sound exposure and behavioral responses are likely be remain highly variable, precluding or complicating the definition of any simple dose-response relationship. For pulsed sounds, one practical approach may be to continue to use the U.S. NMFS injury/behaviour criteria, which assume that injury to pinnipeds and cetaceans might occur with exposure to pulse levels >190 and >180 dB re 1 μPa (respectively), and that behavioral disturbance may occur at received levels >160 dB re 1 μPa. The criteria and approach suggested by Southall et al. (2007) may be used to fine-tune an assessment of potential injury or TTS. Broadly-applicable behavioral criteria for particular regions, human activities, species, and animal activities, as already applied in some situations, may continue to be used, with progressive refinements to allow for the gradually accumulating body of relevant behavioral response data. The risk assessment methodology can be run using a variety of criteria and the outputs then compared.

7.1 Future Work

7.1.1 Tier 3 Scoring System

There was a considerable amount of discussion with the reviewers about the Tier 3 scoring system. The general concern was that the scoring system was somewhat arbitrary, and seemed to result in a medium to high risk category most of the time. The way that uncertainty had been incorporated into the scoring system (Table 3.5) was of particular concern because the highest score for a criterion was assumed if the answer was unknown. This approach substantially increases the final risk category because the level of certainty tends to be high with marine mammals. It was agreed that a better approach would be to remove uncertainty from each criterion in Table 3.5, and instead assign some level of overall uncertainty to the group of criteria in the table. The total risk score would then be assessed by the following steps:

i. score each criterion without uncertainty
ii. total up the criteria scores to derive the risk score
iii. modify the risk score for overall uncertainty

The assessment of uncertainty in Tier 3 should be categorical because this tier is a semi-quantitative risk assessment, and hence doesn't provide the level of information needed to derive a quantitative estimate of uncertainty. Determining a quantitative estimate of uncertainty is more feasible when a Tier 4 risk assessment is being conducted.

It would be better to provide a gradient of responses to scoring criteria in table 3.5 that are presently yes/no questions. The present system has an all or nothing approach that assigns the highest score to the criteria whenever an answer is not negative and consequently can over estimate risk.

There was a consensus among reviewers that the PTS scores in table 3.4 were too high and that Table 3.4 seems to have too much weighting in the final score based on scenarios that ENL has run. It was suggested that a solution might be to lower scores in Table 3.4, and increase scores for the criteria in Table 3.5.

Other recommendations include:

i. Have an interaction of "population trend" with the response to a relevant scoring criterion (e.g. criteria for critical habitat) when assigning the score for that criterion.
ii. An important objective for companies is to make decisions in face of uncertainty about things that may affect the ability to survive and reproduce. Companies mitigate at the life function level (feeding, habitat use), therefore it would be useful to link the scoring table with life function mitigation where possible. Each criterion should be assessed to determine if and how its score could be increased when the risk of an effect escalates up the PCAD chain to a life function and population level effect for that criteria.
iii. Provide sub-totals for each group of scoring criteria in table 3.5
iv. Mitigation strategies are handled in an indirect way, i.e., by re-running the tiers with information that is modified by a proposed mitigation. However the scoring system is relatively insensitive to mitigation. There was discussion about how to incorporate subtle effects. Tom Carlson will draft some thoughts for a strategy to incorporate mitigation with the interactive approach proposed in this study.
v. There is a need to continue assessing the sensitivity of the scoring system and this would best be achieved by running a series of tests using real-world data. The sensitivity tests conducted to date have been hypothetical, and it is envisaged that the use of real-world data would highlight areas in the tool that may be inappropriately weighted or that need expansion.

It was proposed that an expert workshop be held to address the above reviewer comments and suggestions regarding the Tier 3 scoring system criteria, and the handling of uncertainty.

7.1.2 Risk Assessment Tool

The current risk assessment tool permits running only a single sound source-species pair at one time. Future versions should permit the development of an interface that allows multiple sound sources (for example various construction sources, or a combination of seismic sources and other vessel sound sources) and to cover multiple species during a single model run. A possible approach would involve identifying all sound sources and all possible species during the Problem Formulation phase, simultaneous source-species pair analyses covering every possible combination, and a final report that integrates each risk characterization into an overall level of risk for the project.

A future version of the tool could also more fully integrated existing sighting and distribution data on marine mammals, including seasonal presence in each of the LME's, linking available databases, particularly those that are GIS based, directly to clickable maps. At present, available GIS-searchable data are limited, but existing data could be digitized to ease accessibility (for example maps and other data available through IUCN [2008]).

7.1.3 Risk Management Phase

As described above in future work for the tool, additional work is needed to develop methods that synergize risk to multiple species.

7.2 Summary

The key to an ultimately useful risk assessment methodology is ease of use in the face of data limitations, production of reasonable predictions that fit available data and (in the absence of data) are consistent with expert opinion, expandability as more data become available, and integration into existing decision-making strategies. It is essential that any risk assessment methodology is streamlined and user-friendly while recognizing uncertainty in the system. The methodology proposed here is designed to take risk assessors through the process of a risk assessment, highlighting the deficiencies that may exist, but still allowing a final assessment of risk. Once a level of risk has been assigned, risk managers can determine the appropriate level of mitigation and/or monitoring that can reduce that risk to a level that is acceptable to the regulating authority and the operator.

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APPENDICES

Appendix A.

Table A.1. Summary and comparison of source levels for selected sources of anthropogenic underwater noise (from Table 6.9 *in* Richardson et al. 1995).

	Source levels, dB re 1µPa-m							Highest level 1/3-octave band		Strong infrasonics?
		1/3-octave band center frequencies								
	Broadband (45-7070 Hz)	50	100	200	500	1000	2000	Freq.	Level	
Sound Source										
TRANSIENT										
Aircraft Flyover										
C-130 (4 turboprop)	175	149	150	151	150	145	146	63	170	No
Bell 212 helicopter	162	154	155	151	145	142	142	16	159	Yes
B-N Islander (2 prop.)	157	143	150	145	140	133	131	63	152	No
Twin Otter (2 turboprop)	156	134	140	141	141	136	133	160	151	No
Icebreaking, R. Lemeur	193	177	183	180	180	176	179	100	183	Yes
Seismic Survey										
Airgun array (32 guns)	216	210	209	199	184	191	178	50	210	Yes
Vibroseis on ice	210	203	198	194	188	177	168	125	204	Yes
Sonar, military	230+	0	0	0	0	0	0	2-5k	230+	No
Explosions, 60 m depth										
0.5 kg TNT	267 peak							21		Yes
2 kg TNT	271 peak							13		Yes
20 kg TNT	279 peak							6		Yes
Ocean Acoustics Studies										

	Source levels, dB re 1µPa-m							Highest level 1/3-octave band		Strong infrasonics?
		1/3-octave band center frequencies								
	Broadband (45-7070 Hz)	50	100	200	500	1000	2000	Freq.	Level	
Heard Island Test	220	217	0	0	0	0	0	50+63	217	No
ATOC	195	0	0	0	0	0	0	80	192	No
CONTINUOUS										
Vessels underway										
Tug and barge, 18 km/h	171	143	157	157	161	156	157	630	162	Yes
5-m zodiac	156	128	124	148	132	132	138	6300	152	No
Supply ship (Kigoriak)	181	162	174	170	166	164	159	100	174	Yes
Large tanker	186	174	177	176	172	169	166	100+125	177	Yes
Snowmobile (224-7070 Hz)	130	-	-	-	114	118	122	1600	124	No
Drillships										
Kulluk (45-1780 Hz)	185	174	172	176	176	168	-	400	177	No?
Canmar Explorer II	174	162	162	161	162	156	148	63	167	No?
Dredging										
Aquarius (45-890 Hz)	185	170	177	177	171	-	-	160	178	No?
Beaver Mackenzie (45-890 Hz)	172	154	167	159	158	-	-	100	167	No?

Table A.2. Summary of the Status, Population Trends, Global Population Size, General Ecology, and General Distribution & Movement of Mysticetes*

Species	*Status[1] ESA/ IUCN*	*Global Population Size/Trend[2]*	*Habitat*	*General Distribution/ Migratory Movements[3]*
N Atlantic right whale (*Eubalaena glacialis*)	E/ EN	~393/↑	Coastal, shallow shelf waters, occasionally offshore	Mostly temperate/subpolar N. Atlantic; winter US & Africa; summer SE Canada/NE US.
N Pacific right whale *(Eubalaena japonica)*	E/ EN	~400/↓	Coastal, shallow shelf waters, occasionally offshore	Mostly temperate/subpolar; summer Sea of Okhotsk to Gulf of AK; winter grounds/migratory patterns unknown
S right whale (*Eubalaena australis*)	E/ LC	~7000/↑	Coastal, shallow shelf waters, occasionally offshore	30-60°S; summer Antarctica, S Ocean; winter/spring Argentina, S Africa, S Australia
Bowhead whale (*Balaena mysticetus*)	E/ LC	~16,000↑	Associated with ice, juveniles in shallow waters in late summer.	Arctic/subarctic; summer arctic, winter subarctic; migrate spring/fall, calve spring
Pygmy right whale (*Caperea marginata*)	NL/ DD	NA	Coastal-pelagic, shallow- deep	Subantarctic/temperate waters 30-52° S; winters S Africa; unknown Breeding/calving/migration
E N Pacific gray whale (California stock = E gray whale) *(Eschrichtius robustus)*	NL/ LC	18,813/↑ —	Mostly shallow coastal lagoons	Winter Mexican lagoons; spring/fall migration coastal NE Pacific; summer Bering/Chukchi
Western gray whale *(Eschrichtius robustus)*	E/ CR	~130/↑?	Shallow-deep, often coastal	Summer Sea of Okhotsk; winter off southeast China (?)
Humpback whale (*Megaptera novaeangliae*)	E/ LC	~27.000-36.000/↑	Shallow-deep	Some remain in high latitudes year round
Minke whale (*Balaenoptera acutorostrata*) N. Atlantic subsp. N. Pacific subsp.	NL/ LC	~960,000/—	Shallow-deep, often coastal	All N hemisphere oceans; year-round Calif./Gulf of Calif.; breeding areas unknown.
Dwarf minke whale Subspecies (*B. a. subsp.*)	NL/ LC	NA	Shallow-deep	S hemisphere; winters Australia, New Caledonia, S Africa, Brazil; summers 65° S
Antarctic minke whale (*B. bonaerensis*)	NL/ DD	760,000/↑	Shallow-deep	Summer feeding Antarctic; winter breeding tropical/subtropical open ocean and off Brazil

Table A.2 Summary of the Status, Population Trends, Global Population Size, General Ecology, and General Distribution & Movement of Mysticetes*

Species	***Status[1] ESA/ IUCN***	***Global Population Size/Trend[2]***	***Habitat***	***General Distribution/ Migratory Movements[3]***
Bryde's whale (*Balaenoptera brydei*) and Eden's or pygmy Bryde's whale (*Balaenoptera edeni*)	NL/ DD	90,000/—	Shallow=deep	40° N-40° S; seasonally temperate W Pacific; year-round S Africa, Gulf of Calif.; breeding S Africa; feeding not known; pygmy Indian Ocean, Australasia, and W Pacific
Sei whale (*Balaenoptera borealis*)	E/ EN	>54,000/NA	Mostly offshore	Global, temperate waters; specific breeding grounds unknown
Fin whale *(Balaenoptera physalus)*	E/ EN	~100,000–150,000/↓?	Mostly pelagic, continental slope	Global, rare tropical/polar; common in Mediterranean Sea; some remain in higher latitudes year round; breeding areas, unknown but assumed mid-latitude pelagic waters
Blue whale (*Balaenoptera musculus*) Pygmy blue whale (*B. m. brevicauda*) Antarctic blue whale (*B. m. intermedia*) N. Hemisphere (*B. m. musculus*)	E/ EN DD CR VU (N. Atl.), LR/cd (N. Pac.)	~10,000–13,000/↓ Calif./Iceland populations ↑	Coastal/ pelagic shallow-deep	Global; winter continental shelf, incl. Bermuda; some summer low-latitude upwelling areas in Pacific; some may be year-round residents

[*] IUCN status is given for the species; populations/stocks may be classified individually.
[1] U.S. Endangered Species Act (ESA): E = endangered, T = threatened, NL = not listed / International Union for Conservation of Nature and Natural Resources (IUCN) 2008 Red List of Threatened Species: CR = Critically Endangered, EN = Endangered, VU = Vulnerable, LC = Least Concern, LR = Lower Risk, cd = conservation dependent, DD = Data Deficient. All species but the minke whale are also listed in by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in Appendix I, meaning threatened with extinction from international trade (UNEP-WCMC 2008).
[2] Population estimates from various sources: NA = reliable data not available; Trends: ↑ = increasing, ↓ = decreasing, — = stable, ? = unknown
[3] Summer feeding in high latitudes and winter breeding/calving in low latitudes unless otherwise stated.

Table A.3. Status, Population Trends, Population Size, Habitat, and Distribution and Movement of Marine Odontocetes

Species[1]	***Status*** [2] ***ESA/ IUCN***	***Global Population Size/Trend***[3]	***Habitat***	***General Distribution/ Migratory Movements***
Sperm whale (*Physeter macrocephalus*)	E/ VU	500,000 – 2 million/—	Deep water, especially along continental slope	Cosmopolitan, most abundant in warm tropical waters
Pygmy (*Kogia breviceps*) and dwarf sperm whales (*K. sima*)	NL/ DD	NA	Continental shelf edge, deep water	Cosmopolitan in warm waters
Baird's beaked whale (*Berardius bairdii*)	NL/ DD	NA	Pelagic	Pacific Ocean north of 35ºN, Bering Sea, Sea of Okhotsk
Arnoux's beaked whale (*Berardius arnuxii*)	NL/ DD	NA	Pelagic deep water	S oceans from 34ºS to ice edge
Shepherd's beaked whale (*Tasmacetus shepherdi*)	NL/ DD	NA	Pelagic deep water	Circumpolar in cold temperate waters of S hemisphere
Cuvier's beaked whale (*Ziphius cavirostris*)	NL/ LC	NA	Pelagic deep water	Worldwide, except polar waters
Longman's beaked whale (*Indopacetus pacificus*)	NL/ DD	NA	Pelagic	Tropical Pacific and Indian Ocean
Hector's beaked whale (*Mesoplodon hectori*)	NL/ DD	NA	Pelagic	All oceans in S hemisphere
True's beaked whale (*Mesoplodon mirus*)	NL/ DD	NA	Pelagic	N Atlantic Ocean, 30ºN–50ºN
Gervais' beaked whale (*Mesoplodon europaeus*)	NL / DD	NA	Pelagic	Tropical and warmer temperate Atlantic
Sowerby's beaked whale (*Mesoplodon bidens*)	NL/ DD	NA	Continental shelf edge and slopes;	N temperate to sub-polar north Atlantic
Gray's beaked whale (*Mesoplodon grayi*)	NL/ DD	NA	Pelagic	Circumpolar temperate S hemisphere
Pygmy beaked whale (*Mesoplodon peruvianus*)	NL/ DD	NA	Pelagic	Tropical oceans, 15ºS–25ºN
Andrew's beaked whale (*Mesoplodon bowdoini*)	NL/ DD	NA	Pelagic	Circumpolar temperate S hemisphere
Spade-toothed whale (*Mesoplodon traversii*)	NL-/ DD	NA	Pelagic	Only 3 stranding records from temperate S Pacific
Hubb's beaked whale (*Mesoplodon carlhubbsi*)	NL/ DD	NA	Pelagic	Cold temperate N Pacific
Gingko-toothed beaked whale (*Mesoplodon ginkgodens*)	NL-/ DD	NA	Pelagic	Temperate and cooler tropical waters Pacific and Indian oceans
Stejneger's beaked whale (*Mesoplodon stejnegeri*)	NL-/ DD	NA	Pelagic	Cold North Pacific, Sea of Japan, Bering Sea

Table A.3. Status, Population Trends, Population Size, Habitat, and Distribution and Movement of Marine Odontocetes

Species[1]	***Status*** [2] *ESA/ IUCN*	*Global Population Size/Trend*[3]	*Habitat*	*General Distribution/ Migratory Movements*
Strap-toothed whale (*Mesoplodon layardii*)	NL-/ DD	NA	Pelagic	Circumpolar temperate and subantarctic S hemisphere
Blainville's beaked whale (*Mesoplodon densirostris*)	NL-/ DD	NA	Pelagic	Tropical and warmer temperate worldwide
Perrin's beaked whale (*Mesoplodon perrini*)	NL- DD	NA	Pelagic	Strandings known from California
Northern bottlenose whale (*Hyperoodon ampullatus*)	NL-/ DD	NA	Pelagic , submarine canyons.	Subarctic north Atlantic to Nova Scotia;
Southern bottlenose whale (*Hyperoodon planifrons*)	NL-/ LC	NA	Pelagic	30ºS to ice edge; summer Antarctica, winter more temperate
Beluga (*Dephinapterus leucas*)	NL/ NT	100,000 – 150,000/ —; Some subpop. ↓	Coastal, estuaries	Arctic and subarctic; ice-covered seas winter, warmer estuaries early summer
Narwhal (*Monodon monoceros*)	NL-/ NT	NA	Edge of pack ice	Arctic, seasonal movements follow sea ice
Killer whale (*Orcinus orca*)	E[4]/ DD	1000s to tens of 1000s S Residents BC, WA ↓;	Open ocean to estuaries/ fjords.	Tropical to pack ice
False killer whale (*Pseudorca crassidens*)	NL -/ DD	Tens of thousands/NA	Pelagic	Tropical to temperate worldwide
Pygmy killer whale (*Feresa attenuata*)	NL-/ DD	Hundreds of thousands/NA	Deep water	Pantropical
Melon-headed whale (*Peponocephala electra*)	NL-/ LC	Tens of thousands/NA	Pelagic	Pantropical, 20ºN–20ºS;
Long-finned pilot whale (*Globicephala melas*)	NL/ DD	Millions/NA	Pelagic;	Mid-latitude N Atlantic and S hemisphere
Short-finned pilot whale (*Globicephala macrorhynchus*)	NL/ DD	Tens of thousands/NA	Pelagic	Circumglobal 40ºS–50ºN
Risso's dolphin (*Grampus griseus*)	NL-/ LC	Hundreds of thousands/NA	Ssteep slopes, seamounts, and escarpments	Tropical and mid-temperate worldwide,~55ºS–60ºN
Short-beaked common dolphin (*Delphinus delphis*)	NL-/ LC	Millions/NA	Shelf, pelagic, high relief	Tropical and temperate, worldwide
Long-beaked common dolphin (*Delphinus capensis*)	NL-/ LR-lc	>25 000/NA	Nearshore	Tropical and warm temperate of some oceans
Arabian common dolphin (*Delphinus tropicalis*)	-/-/-	NA	Coastal	Coastal Arabian Sea, South China Sea
Fraser's dolphin (*Lagenodelphis*	NL-/	Hundreds of thousands/NA	>1000 m deep	Tropical occasionally temperate

Table A.3. Status, Population Trends, Population Size, Habitat, and Distribution and Movement of Marine Odontocetes

Species[1]	***Status*** [2] ***ESA/ IUCN***	***Global Population Size/Trend***[3]	***Habitat***	***General Distribution/ Migratory Movements***
hosei)	LC			
Indo-Pacific humpback dolphin (*Sousa chinensis*)	NL/-/ NT	A few thousand/NA	Coastal and estuarine	Indian Ocean, southern China, Borneo, northern/ eastern Australia
Atlantic humpbacked dolphin (*Sousa teuszii*)	NL/VU	NA	Marine estuaries, river mouths	Western Sahara to Angola
Bottlenose dolphin (*Tursiops truncatus*)	Nl/ LC	Millions/NA	Continental shelf and upper slope <1000 m deep or pelagic	Temperate and tropical excluding Indian Ocean
Indo-Pacific bottlenose dolphin (*Tursiops aduncus*)	NL/ DD	NA	Coastal and shelf	Rim of Indian Ocean from western Pacific to Red Sea and Persian Gulf
Pantropical spotted dolphin (*Stenella attenuata*)	NL/ LC	Millions/NA	Deep waters	Tropical worldwide
Atlantic spotted dolphin (*Stenella frontalis*)	NL/ DD	Millions/NA	Continental shelf <250 m deep	Tropical and warm temperate western north Atlantic
Spinner dolphin (*Stenella longirostris*)	NL / DD	~2 million/NA	Pelagic; near oceanic islands	Pantropical 30º–40ºN and 20º–30ºS
Clymene dolphin (*Stenella clymene*)	NL/ DD	Thousands/NA	Depths 700 to >3000 m	Tropical warm Atlantic
Striped dolphin (*Stenella coeruleoalba*)	NL/ LC	Hundreds of thousands/NA	Pelagic edge of continental shelf	Tropical and temperate
White-beaked dolphin (*Lagenorhychus albirostris*)	NL/ LC	Tens of thousands/NA	Continental shelf	Subarctic north Atlantic, to edge of pack ice
Atlantic white-sided dolphin (*Lagenorhynchus acutus*)	NL/ LC	Tens to hundreds of thousands/NA	Continental shelf, slope, and canyons	Temperate and subarctic north Atlantic
Pacific white-sided dolphin (*Lagenorhynchus obliquidens*)	NL/ LC	~ 1 million/NA	Continental margins, occasionally inshore	Temperate North Pacific
Dusky dolphin (*Lagenorhynchus obscurus*)	NL/ DD	NA	Coastal and continental shelf <200 m deep	Discontinuous in southern Pacific;
Peale's dolphin (*Lagenorhynchus australis*)	NL /DD	NA	Shallow coastal	Argentinean and Chilean south of 40ºS
Hourglass dolphin (*Lagenorhynchus cruciger*)	NL/ LC	Hundreds of thousands/NA	Pelagic	Southern hemisphere south of 45ºS
Commerson's dolphin (*Cephalorhynchus commersonii*)	NL/DD	NA	Inshore, open coasts, fjords, bays, harbours, river mouths	Coastal Argentina, Tierra del Fuego, Falkland Islands, Kerguelen South Georgia and South Shetland islands
Heaviside's dolphin (*Cephalorhynchus heavisidii*)	NL/DD	NA	Coastal, within 8-10 km of shore, <100 m	Coastal southwestern Africa
Black or Chilean dolphin	NL/NT	NA but low	Open coasts, bays, river	Coastal Chile and Tierra del Fuego

Table A.3. Status, Population Trends, Population Size, Habitat, and Distribution and Movement of Marine Odontocetes

Species[1]	***Status*** [2] ***ESA/ IUCN***	***Global Population Size/Trend***[3]	***Habitat***	***General Distribution/ Migratory Movements***
(*Cephalorhynchus eutropia*)			mouths, estuaries	
Hector's dolphin (*Cephalorhynchus hectori*)	NL/EN	7.400	Shallow	Coastal New Zealand
Rough-toothed dolphin (*Steno bredanensis*)	NL/ LC	NA	Pelagic	Worldwide tropical, subtropical, and warm temperate
Northern right whale Dolphin (*Lissodelphis borealis*)	NL/ LC	Hundreds of thousands/NA	Shelf and slope >2000m	Cooler temperate and subarctic northern Pacific, 30º–50ºN
Southern right whale Dolphin (*Lissodelphis peronii*)	NL/ DD	NA	Mostly pelagic, occasionally coastal	Between subtropical and Antarctic convergences S hemisphere
Tucuxi (*Sotalia fluviatilis*)	NL/ DD	NA	Coastal, estuarine and riverine waters	Amazon–Orinoco River system, coastal from Columbia to southern Brazil
Irawaddy dolphin (*Orcaella brevirostris*)	NL/ VU	>1000/↓	Mangrove wetlands, estuarine, shallow coastal	Discontinuous in Eastern Indian Ocean, coasts of southeast Asia, India, Indonesia
Finless porpoise (*Neophocaena phocaenoides*)	NL/ VU worldwide, E in China	Thousands/↓	Coastal and estuarine waters	Tropical Asia, central Japan to Java and Persian Gulf
Harbor porpoise (*Phocoena phocoena*)	NL/ LC	Thousands/Many Subpopulations ↓	Shallow coastal and shelf	Arctic to temperate northern Atlantic and Pacific, Black Sea
Vaquita (*Phocoena sinus*)	E/CR	(177-1073(1997 est.) ↓	Shallow, lagoons, waters <30 m	Northern Gulf of California
Spectacled porpoise (*Phocoena dioptrica*)	NL/ DD	NA but rare throughout range.	Pelagic	Circumpolar colder temperate to Antarctic
Burmeister's porpoise (*Phocoena spinnipinnis*)	NL/ DD	NA	Coastal <100 m deep but up to 1000 m.	Cape Horn to N Peru
Dall's porpoise (*Phocoenoides dalli*)	NL/ LC	Hundreds of thousands to millions/NA	Inshore to pelagic	N Pacific and adjacent seas, 20º–65ºN

[1] Excludes all four species of river (freshwater) dolphins (Ganges and Indus river dolphins [*Platanista gangetica*], Amazon river dolphin [*Inia geoffrensis*], Yangtze river dolphin [*Lipotes vexillifer*], and Franciscana or La Plata dolphin [*L. vexillifer*]).
[2] U.S. Endangered Species Act (ESA): E = endangered, T = threatened, NL = not listed / International Union for Conservation of Nature and Natural Resources (IUCN) 2008 Red List of Threatened Species: CR = Critically Endangered, EN = Endangered, VU = Vulnerable, LC = Least Concern, LR = Lower Risk, cd = conservation dependent, DD = Data Deficient. All species but the minke whale are also listed in by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in Appendix I, meaning threatened with extinction from international trade (UNEP-WCMC 2008).
[3] Population estimates from various sources: NA = reliable data not available; Trends: ↑ = increasing, ↓ = decreasing, — = stable, ? = unknown
[4] Southern Resident Population

Table A.4. Status, Population Trends, Population Size, Habitat, and Distribution of Pinnipeds

Species	***Status*** ***ESA/ IUCN***	***Global Population Size/Trend***	***Habitat***	***General Distribution and Migration***
Walrus				
Pacific walrus (*Odobenus rosmarus divergens*)	NL/ DD	~200,000?/↓?	Shallow, coastal, pack ice	Polar Pacific and Arctic, from E Siberian Sea to W Beaufort Sea; move S with ice in fall and N with ice in spring
Atlantic walrus (*O. r. rosmarus*)	NL/ DD	NA up to 22,500?/NA	Shallow, coastal, pack ice	Polar N Atlantic and Arctic; move S with advancing ice in fall and N with ice in spring
Phocids (True or Earless Seals)				
Bearded seal (*Erignathus barbatus*)	NL/ LC	NA >500,000/NA	Drifting sea ice in shallow water	Circumpolar in N Hemisphere S of ~80°; some that winter in Bering Sea migrate N to Chukchi Sea in summer
Harbor (common) seal (*Phoca vitulina*)	NL/ LC	>500,000/ SE Alaska & NW Atlantic ↑; Gulf of Alaska & Bering Sea ↓	Coastal	Coastal N Pacific and N Atlantic; seasonal migrants south to New England, New York, New Jersey
Spotted seal (*Phoca largha*)	NL/ DD	~400,000?/ —?	Associated with sea ice	Polar Pacific Ocean, from Seas of Okhotsk and Japan to Bering and W Beaufort
Ringed seal (*Phoca hispida*)	NL/ LC	~4-7 million/—?	Associated with sea ice crustaceans.	Circumpolar through Arctic Ocean, Hudson Bay, Baltic and Bering Seas
Ribbon seal (*Phoca fasciata*)	NL/ DD	~240,000/NA	Offshore pack ice in winter and spring, pelagic rest of year	Polar Bering Sea, S Chukchi Sea, and Sea of Okhotsk
Gray seal (*Halichoerus grypus*)	NL/ LC	~300,000/↑	Coastal	Northern N Atlantic
Harp seal (*Phoca groenlandica*)	NL/ LC	6 million/—?	Pack ice	Arctic & N Atlantic; migrate N to feed during summer, S with advancing ice
Hooded seal (*Cystophora cristata*)	NL/ VU	~650,000/NA	Associated with sea ice, shelf areas, maybe deep oceanic waters in autumn and winter	Central and W N Atlantic; breeding in Gulf of St. Lawrence, E Newfoundland, Davis Strait, Jan Mayen Island
Southern elephant seal (*Mirounga leonina*)	NL/ LC	~600,000/ South Georgia & Kerguelen Isl —; Argentina ↑; other islands ↓	Oceanic islands, coastal to pelagic during foraging	Breed on oceanic islands in subantarctic and S Argentina; during non-breeding season, some migrate S to near Antarctica

Table A.4. Status, Population Trends, Population Size, Habitat, and Distribution of Pinnipeds

Species	***Status ESA/ IUCN***	***Global Population Size/Trend***	***Habitat***	***General Distribution and Migration***
Northern elephant seal (*Mirounga angustirostris*)	NL/ LC	~115,000/ California ↑; Mexico — or ↓	Coastal to pelagic during foraging and migrating	NE Pacific; large breeding colonies at Channel Islands off S Calif., smaller colonies off central Calif., and W Baja Calif.; breed in winter, migrate N to the central and NE Pacific (as far N as Alaska)
Leopard seal (*Hydrurga leptonyx*)	NL/ LC	~200,000/NA	Pack and landfast ice, pelagic during foraging	S Ocean around Antarctica; migrate N during winter
Weddell seal (*Leptonychotes weddellii*)	NL/LC	~800,000	Near-shore fast ice	Antarctica, South Georgia, South Sandwich Islands, South Shetland Islands, South Orkney Islands
Crabeater seal (*Lobodon carcinophagus*)	NL/LC	~15 million	Pack ice	Southern Ocean, pack ice; near subantarctic islands
Ross seal (*Ommatophoca rossii*)	NL/LC	~220,000	Pack ice	Circumpolar Southern Ocean
Mediterranean monk seal (*Monachus monachus*)	E/CR	400	Coastal	Mediterranean Sea, northwest African coast
Hawaiian monk seal (*Monachus schauinslandi*)	E/CR	1300-1400	Coastal	Northwestern Hawaiian Islands
Otariids (Eared Seals)				
Antarctic fur seal (*Arctocephalus gazella*)	NL/ LC	1.5-4 million/↑	Oceanic islands, coastal to pelagic during foraging	Breeding colonies on oceanic islands in subantarctic and near Antarctica (95% of pop. breeds on South Georgia); during non-breeding season, some migrate S to near Antarctica
Juan Fernandez fur seal (*Arctocephalus philippii*)	NL/NT	12,000	Coastal; long feeding trips	Juan Fernández and San Félix / San Ambrosio island groups off Chile
South African and Australian fur seal (*Arctocephalus pusillus*)	NL/LC	1.5-2 million (South Africa) 30,000-50,000 (Australia)	Coastal, rocky inshore islands	Namibian and South African coastlines; Kangaroo Island, SA to Tasmania and Port Macquarie, NSW
Subantarctic fur seal (*Arctocephalus tropicalis*)	NL/ LC	>310,000/↑	Oceanic islands, pelagic to forage	Subantarctic breeding colonies in S Atlantic, Indian, and Pacific; most breed on temperate islands in S Atlantic and Amsterdam in Indian Ocean
Guadalupe fur seal (*Arctocephalus townsendi*)	T/ NT	~7408/↑	Coastal, shelf, pelagic to forage	NE Pacific off Calif. and Baja Calif.; breed almost exclusively on Guadalupe Island, Mexico

Table A.4. Status, Population Trends, Population Size, Habitat, and Distribution of Pinnipeds

Species	*Status ESA/ IUCN*	*Global Population Size/Trend*	*Habitat*	*General Distribution and Migration*
South American fur seal (*Arctocephalus australis*)	NL/LC	300,000-450,000	Coastal	South America from central Peru and S Brazil to Tierra del Fuego and Falkland Islands
New Zealand fur seal (*Arctocephalus forsteri*)	NL/LC	>50,000	Coastal, rocky coasts, islands	Western Australia, South Australia, Tasmania and New Zealand, subantarctic islands E and S of New Zealand
Galapagos fur seal (*Arctocephalus galapagoensis*)	NL/VU	40,000	Rocky coasts	Galapagos Islands
Northern fur seal (*Callorhinus ursinus*) E Pacific stock	NL/ EN	1.2-4 million (888,120 E Pacific stock)/↓	Pelagic	Temperate N Pacific, Bering Sea, and Sea of Okhotsk; primary breeding colonies at the Pribilof and Commander Islands; in fall, males remain in Bering Sea, females migrate to central N Pacific and Calif. coast
San Miguel Island (SMI) stock	NL/ VU	~7784/↑?	Pelagic	Temperate N Pacific; one breeding colony on San Miguel Island, Calif.; may occur there year-round
California sea lion (*Zalophus californianus*)	NL/ LC	~240,000/↑	Coastal, shelf	Temperate N Pacific; breed at Channel Islands, Calif. and Baja Calif. including Guadalupe Island
Steller sea lion (*Eumetopias jubatus*) Western U.S. stock	E/ EN	100,000 (44,780 W U.S. stock)/↓	Coastal, shelf	Temperate N Pacific Ocean and S Bering Sea; W stock includes animals west of 144ºW, along Aleutian Islands
Eastern U.S. stock	T/ EN	100,000 (47,885 E U.S. stock)/ ↑ (— or ↓ in Calif.)	Coastal, shelf	Temperate NE Pacific; E stock includes animals east of 144ºW
Australian sea lion (*Neophoca cinerea*)	NL/ EN	10,000-12,000/— or ↓	Offshore islands and coastal	Temperate, S Australia; largest colonies on offshore island in eastern S Australia
South American sea lion (*Otaria flavescens*)	NL/LC	265,000	Coastal, wide-ranging	South America from northern Peru and SE Brazil to Tierra del Fuego and Falkland Islands
New Zealand sea lion (*Phocarctos hookeri*)	NL/VU	12,000-14,000	Coastal	South Island New Zealand, islands south of New Zealand

[1] U.S. Endangered Species Act (ESA): E = endangered, T = threatened, NL = not listed / International Union for Conservation of Nature and Natural Resources (IUCN) 2008 Red List of Threatened Species: CR = Critically Endangered, E = Endangered, DD = Data Deficient. All species but the minke whale are also listed in by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in Appendix I, meaning threatened with extinction from international trade (UNEP-WCMC 2008).

[2] Population estimates from various sources: NA = reliable data not available; Trends: ↑ = increasing, ↓ = decreasing, — = stable, ? = unknown

Table A.5. Marine mammal information sources

Name	***Agency/ Organization***	***Country***	***Location***	***Coverage***
	Minerals Management Service	U.S.	Home Page: www.mms.gov/ http://gcmd.nasa.gov/records/GCMD_seamap271.html	Covering Alaska, Atlantic, Gulf of Mexico and Pacific regions Marine mammal and seabird computer database analysis system. Washington, Oregon, California 1975-1997
	Fish and Wildlife Service	U.S.	Home Page: www.fws.gov/	Jurisdiction over walrus
	Joint Nature Conservation Committee	U.K.	http://www.jncc.gov.uk/page-3	Information on special protection areas, sensitive habitats etc.
	CSIRO Marine Research	Australia	http://www.cmar.csiro.au/	Marine conservation and biodiversity management
	Australian Fisheries Management Authority	Australia	http://www.afma.gov.au/default.htm	Fisheries management
	Australia National Oceans Office	Australia	http://www.environment.gov.au/coasts/	Marine bioregional planning, marine protected areas, marine species conservation
	International Whaling Commission		www.iwcoffice.org	Global stock assessments of baleen whales and sperm whales, stock management
	University of Sydney	Australia	http://opac.library.usyd.edu.au/search/d?SEARCH=marine+mammals	Library catalogue of marine mammal publications
	Fisheries and Oceans Canada	Canada	http://www.dfo-mpo.gc.ca/index-eng.htm	Fisheries management, Species at Risk,
CETACEA Database	Woods Hole Oceanographic Institute	U.S.	https://darchive.mblwhoilibrary.org/bitstream/1912/1009/1/WHOI-90-19.pdf	A comprehensive index of literature references used to file, store, search, retrieve, and format the data on marine animals.
Convention on Migratory Species	United Nations			

Name	***Agency/ Organization***	***Country***	***Location***	***Coverage***
Effects of Sound on the Marine Environment	University of Santa Cruz	U.S.	http://repositories.cdlib.org/cgi/viewcontent.cgi?article=4898&context=postprints	A total of 448 references from reports, books, and peer-reviewed journal articles were obtained. The metadata describing each animal studied, location of the study, and equipment used were entered into the data base as well as empirical data describing the diving behavior and movement patterns of each animal. In total, the database contained 1815 entries from 51 different marine mammal species or subspecies.
Global Change Master Directory			http://gcmd.gsfc.nasa.gov/KeywordSearch/Keywords.do?Portal=GCMD&KeywordPath=Parameters%7CBIOSPHERE%7CAQUATIC+ECOSYSTEMS%7CMARINE+HABITAT&MetadataType=0&lbnode=mdlb1 http://gcmd.gsfc.nasa.gov/KeywordSearch/Freetext.do?Freetext=marine+mammals+&KeywordPath=Parameters%257CBIOSPHERE%257CAQUATIC%2BECOSYSTEMS%257CMARINE%2BHABITAT&Portal=GCMD&MetadataType=0	Marine habitat. Marine mammals.
IUCN	IUCN-The World Conservation Union	Switzerland	www.iucn.org www.redlist.org	International conservation, IUCN Red List of Threatened Species
KGSMapper	Kansas Geoological Survey	U.S.	http://drysdale.kgs.ku.edu/website/Specimen_Mapper/mxmapit.cfm	A tool to infer where appropriate habitat for a species exists based on records of that species' occurrence. Thus it can be used to predict where the species might occur in addition to where it is known – to map its range. It can also be used to identify habitats suitable for the species outside its natural range. International coverage.
Large Marine Ecosystems	IUCN, NOAA-NMFS, and the IOC of UNESCO	USA	http://www.edc.uri.edu/lme/intro.htm	Data on 66 Large Marine Ecosystems including biodiversity/marine mammal data

Name	***Agency/ Organization***	***Country***	***Location***	***Coverage***
Marine Environmental Data Sets		E.U.	http://www.sea-search.net/edmed/welcome.html	European Directory of Marine Environmental Datasets describes more than 3300 data sets, from a wide range of disciplines, held at over 630 Data Holding Centres from 30 countries across Europe.
Marine Mammal Sightings	Norwegian Polar Institute	Norway	http://mms.data.npolar.no/	Marine mammal sightings near Svalbard, Norway
Marine Mammal Sightings Database	Channel Islands National Marine Sanctuary	U.S.	http://www.cisanctuary.org/mammals/	Sightings of pinnipeds and cetaceans, Channel Islands, California, 1999-2008
Marine Wildlife Database	Orca	U.K.	http://www.orcaweb.org.uk/marinewildlifedatabase.htm	3,000 sightings records for the Bay of Biscay and English Channel. 1995-present.
MARMAM	University of Victoria	Canada	http://whitelab.biology.dal.ca/marmam.htm	Marine mammal research and conservation listserv.
National Marine Mammal Laboratory	National Marine Fisheries Service	U.S.	Home Page: www.nmfs.noaa.gov/ Stock Assessments: http://www.nmfs.noaa.gov/pr/sars/region.htm Fur seals: http://www.afsc.noaa.gov/nmml/alaska/nfs/fursealbib.php Steller sea lions: http://www.afsc.noaa.gov/nmml/alaska/sslhome/databases/ SE Alaska humpback whales: http://www.afsc.noaa.gov/ABL/Humpback/default.htm	Fur seal, Steller seal lion, humpback whale databases Marine Mammal Stock Assessments (comprehensive species coverage) 1995-2007 (Atlantic, Pacific, Alaska)
OBIS-Canada		Canada	http://marinebiodiversity.ca/OBISCanada/Data_Collections	Discovery metadata, shapefiles and active ACON. Extensive sighting databases searchable by region.
Ocean Biogeographic Information System (OBIS-SEAMAP)			http://www.iobis.org/	14 million records of 78,000 species from 437 databases. Very comprehensive databases searchable by location, GIS data points. Search by species or region.
World Data Center for Marine Environmental Sciences			http://www.wdc-mare.org/	The World Data Center for Marine Environmental Sciences (WDC-MARE) is aimed at collecting, scrutinizing, and disseminating data related to Global Change and earth system research in the fields of environmental oceanography, marine geosciences, and marine biology. It focuses on georeferenced data using the PANGAEA information system as its long-term archive and publication unit.

Table A.6. Summary of Underwater Hearing and Sound Production Characteristics of Selected Odontocetes

	Sound Production[a]			***Hearing***	
Species or Group	***Frequency Range (kHz)***	***Dominant Frequencies (kHz)***	***Source Level (dB re 1 µPa-m)***	***Frequency Range (kHz)***	***Threshold at Best Sensitivity (dB re 1 µPa)***
Sperm whale	<0.1–30	2–4, 10–16	202 & 236	2.5–60	-
Pygmy and dwarf sperm whales	60–200	120–130	-	90–150	-
Cuvier's beaked whale	13–17	-	-	-	-
Baird's beaked whale	12–134	23–24.6, 35–45	-	-	-
Arnoux's beaked whale	1–8.7	-	-	-	-
Bottlenose whales (*Hyperoodon* spp.)	0.5–26+	3–16	-	-	-
Beaked whales (*Mesoplodon* spp.)	0.3–80	0.3 – 2	200 – 220	5–80	at 40–80 kHz
Beluga	0.1–150	0.1–16, 40–60, 100–120	206 – 225	0.04–150	42 at 11–100 kHz[c]
Narwhal	0.3–18	0.3 – 10	-	-	-
Dolphins (*Cephalorhynchus* spp.)	0.32–150	0.8–2, 4–4.5, 116–134	160 – 163	-	-
Rough-toothed dolphin	0.1–200	2–14, 4–7, 25	-	-	-
Humpbacked dolphins (*Sousa* spp.)	1.2–16+	-	-	-	-
Tucuxi	3.6 – 23.9	7.1–18.5	-	<4–135[a]	50 at 85 kHz[a]
Bottlenose dolphins (*Tursiops* spp.)	0.05–150	0.3–14.5, 25–30, 95–130	125–173 228	0.15–135	42–52 at 15 kHz[c]
Dolphins (*Stenella* spp.)	0.06–160	5–60, 40-50, 130 – 140	210, 223	0.5–160	42 at 64 kHz[b, c]
Common dolphins (*Delphinus* spp.)	0.2–150	0.5 – 18 30 – 60	143–180	<5–150	53 at 65 kHz[d]
Fraser's dolphin	4.3–40	-	-	-	-
Dolphins (*Lagenorhynchus* spp.)	0.06–325	0.3–5, 4–15, 6.9–19.2, 60–80	80–219	0.5–135 0.1-140[e]	64 kHz[e]
Right whale dolphins (*Lissodelphis* spp.)	1–<40	1.8–3	170	-	-
Risso's dolphin	0.1–65	2–5, 65	216	1.5–100	63.6–74.3 at 4–80 kHz[c]
Melon-headed whale	8–40	8–12, 20–40	155–165	-	-
False killer whale	4–130	4.7–6.1, 25–30, 100–130	228	< 1–115	39-49 at 17 kHz 70 at 5 kHz[c]
Killer whale	0.08–85	1-20	105–160	< 0.5–120	35 at 15–42 kHz[c]
Pilot whales (*Globicephala* spp.)	0.28–100	2–14, 30–60	180	-	-
Porpoises (*Phocoena* spp.)	0.04–150	0.04-0.6, 1.4–2.5, 110 – 150	177	0.1–140	55 at ~ 30 kHz[c]
Dall's porpoise	0.04–160	0.04–12 120–130	175	-	-

Notes: [a] Sauerland and Dehnhardt 1998; hearing threshold directly measured.
[b] Kastelein et al. 2003; hearing threshold directly measured for striped dolphin.
[c] Richardson et al. 1995a; hearing thresholds directly measured for beluga, killer whale, harbor porpoise, bottlenose dolphin, false killer whale, Risso's dolphin, and *Stenella* dolphins.
[d] U.S. Navy 2005; hearing threshold directly measured.
[e] Tremel et al. 1998; hearing threshold measured based on behavioral/psychophysical response studies of Pacific white-sided dolphin.

Sources: Richardson et al. 1995a; Sauerland and Dehnhardt 1998; Au et al. 2000; Kastelein et al. 2003; Johnson et al. 2004; Miller et al. 2005a; U.S. Navy 2005b; Zimmer et al. 2005; Cook et al. 2006; Southall et al. 2007.

Table A.7. Summary of Underwater Hearing and Sound Production Characteristics of Mysticetes

	Sound Production		
Species	*Frequency Range (Hz)*	*Dominant Frequencies (Hz)*	*Source Level (dB re 1 µPa-m)*
N Atlantic right whale	70–600	Low-frequency calls: 70	137–192
N Pacific right whale	<400	90–150	-
S right whale	30–2,200	Tones: 160–500 Pulses: 50–500 & 1,500	172–187
Bowhead whale	20–3,500	Tonal moans: 100–400 Song: <4000	128–189
Pygmy right whale	60–300	Pulses: 90–135 with downsweep to 60	153–179
E gray whale	20–20,000	Knocks/pulses: 327–825 Tonal moans: 100–200 & 700–1,200 Calf clicks: 3400–4000	167–188
Humpback whale	10[(b)]–>22,000	Male Song: 120–4,000 Social sounds: <3,000 Feeding calls: 500 Calf sounds: 10–300[(c)]	Male song: 144–174 (mean 165) Social sounds: 190
Minke whale	60–20,000	Downsweeps: 50–250 Thumptrains: 100–200 Pulses: 50–9400 Moans: 60–140 Rachet: 850 Pings/clicks: <12,000	151–175
Bryde's whale	70–950	Moans: 124–250 Pulsed moans: 100–900 & <60 Calf pulses: 700–900	152–174
Sei whale	approx 100-150[(c)] – 3,500[(d)]	Low-frequency tonal moan & frequency swept calls: approx 100–1,000[(e)] MF pulsive bursts: 1500–3500[(f)]	147–156[(e, g)]
Fin whale	10–750	Pulses: 18–35 FM calls: 20–70 Moans: 20	155–190
Blue whale	10–390	Songs: 30–100 FM calls/moans: 15–25	180–190

Sources: Richardson et al. 1995a; Au et al. 2000; U.S. Navy 2005b; also see footnotes below.

Notes: [(a)] For some species, the frequency range of hearing has been suggested (e.g., footnotes [b, d]) based on indirect evidence, but there are no specific data for any mysticete and the stated ranges are of unknown accuracy. Some mysticetes may have at least limited hearing capabilities at frequencies as low as 7 Hz or up to at least 22-24 kHz (Miller et al. 2005a; Au et al. 2006; Southall et al. 2007), given their auditory anatomy, the frequencies of their calls, and their responsiveness (or lack thereof) to sounds at particular frequencies.

[(b)] Zoidis et al. 2005, 2008; Au et al. 2006.

[(c)] Miller et al. 2005a.

[(d)] Thompson et al. 1979; Knowlton et al. 1991.

[(e)] (rms) re 1 µPa-m.

Table A.8. Summary of Underwater Hearing and Sound Production Characteristics of Pinnipeds

	*Sound Production**			*Hearing***	
Species	*Frequency Range (kHz)*	*Dominant Frequencies (kHz)*	*Source Level (dB re 1 µPa-m)*	*Overall Frequency Range of Hearing (kHz)*	*Threshold at Frequency of Best Sensitivity (dB re 1 µPa)*
Walrus	Rasps: 0.2-0.6 Grunts: ≤1 Other: 0.1-10	Bell tone: 0.4-1.2 Rasps: 0.4-0.6 Grunts: ≤1 Other: <2	-	~0.13-15	67 (at 12 kHz)
Bearded seal	0.02-6	1-2	178	-	-
Harbor seal	Clicks: 8-150 Other: <0.1-4	Clicks: 12-40 Roar: 0.4-0.8 Growl: <0.1-0.25 Creak: 0.7-2	-	~1-180	60-85
Spotted seal	0.5-3.5	-	-	-	-
Ringed seal	0.4-16	<5	95-130	~1-100	60-81
Ribbon seal	0.1-7.1	-	160	-	-
Gray seal	Clicks, hiss: 0-40 Calls: 0.1-5 Knocks: to 16	Calls: 0.1-3 Knocks: to 10	-	20-25	-
Harp seal	Clicks: 30-120 Other: <0.1 to >16	Other: 0.1-3	Clicks: 131-164 Other: 130-140	~0.75-100	60-80
Hooded seal	Clicks: 30-120 Buzz: to 6	Clicks: 93 Grunt: 0.2-0.4 Snort: 0.1-1 Buzz: 1.2	-	3-60	-
S elephant seal	Drumming: 0.1-0.8 Continuous: 0.1-2.5	Drumming: 0.35 Continuous: 0.41	135	-	-
N elephant seal	0.2-6	0.7-2.5	-	<1-55	58 (at 6.4 kHz)
Leopard seal	Ultrasonic: to 164 Other: <0.04-7	Ultrasonic: 50-60	Low	-	-
Antarctic fur seal	-	-	-	-	-
Subantarctic fur seal	0.35 to 6.5	-	-	-	-
Guadalupe fur seal	-	-	-	-	-
N fur seal	-	-	-	0.5-40	60 (at 4-28 kHz)
California sea lion	Barks < 8 Whinny: <1-3 Buzz: <1-4	Barks <3.5 Buzz <1 Clicks: 0.5-4	-	0.75-64	80 (at 2-16 kHz)
Steller sea lion	F: 0.03-3	F: 0.15-1 M: N/A	-	M: <0.5 to >32 F: <4 to >32	M: 77 (at 1 kHz) F: 73 (at 25 kHz)
Australian sea lion	-	-	-	-	-

Notes: - = Not available/unknown. M = male. F = female.

Sources: *Richardson et al. 1995a; Wartzok and Ketten 1999; Sanvito and Galimberti 2000a, b; Campbell et al. 2002; Charrier et al. 2002, 2003; U.S. Navy 2005b.

**Richardson et al. 1995a; Kastak and Schusterman 1999; Kastelein et al. 2002, 2005; U.S. Navy 2005b.

Appendix B.

Table B.1. Marine mammal hearing groups, functional auditory bandwidths, genera represented in each group, and group-specific (M) frequency-weightings (Table 2 from Southall et al. 2007).

Hearing Group	Estimated Functional Auditory Bandwidth	Genera Represented (Number species/subspecies)
Low-frequency cetaceans	7 Hz to 22 kHz	*Balaena, Caperea, Eschrichtius, Megaptera, Balaenoptera* (13 species/subspecies)
Mid-frequency cetaceans	150 Hz to 160 kHz	*Steno, Sousa, Sotalia, Tursiops, Stenella, Delphinus, Lagenodelphis, Lagenorhynchus, Lissodelphis, Grampus, Peponocephala, Feresa, Pseudorca, Orcinus, Globicephala, Orcaella, Physeter, Delphinapterus, Monodon, Ziphius, Berardius, Tasmacetus, Hyperoodon, Mesoplodon* (57 species/subspecies)
High-frequency cetaceans	200 Hz to 180 kHz	*Phocoena, Neophocaena, Phocoenoides, Platanista, Inia, Kogia, Lipotes, Pontoporia, Cephalorhynchus* (20 species/subspecies)
Pinnipeds in water	75 Hz to 75 kHz	*Arctocephalus, Callorhinus, Zalophus, Eumetopias, Neophoca, Phocarctos, Otaria, Erignathus, Phoca, Pusa, Halichoerus, Histriophoca, Pagophilus, Cystophora, Monachus, Mirounga, Leptonychotes, Ommatophoca, Lobodon, Hydrurga, Odobenus* (41 species/subspecies)
Pinnipeds in air	75 Hz to 30 kHz	Same species as pinnipeds in water above (41 species/subspecies)

Table B.2. Proposed injury (PTS) criteria (adapted from Southall et al. 2007).

	Sound Type		
Marine mammal group Sound criterion (weight)[a]	**Single pulses**	**Multiple pulses**	**Nonpulses**
LF cetaceans			
Sound pressure level (flat)	230 dB re: 1 µPa (peak)	230 dB re: 1 µPa (peak)	230 dB re: 1 µPa (peak)
Sound exposure level (M_{lf})	198 dB re: 1 μPa^2-s	198 dB re: 1 μPa^2-s	215 dB re: 1 μPa^2-s
MF cetaceans			
Sound pressure level (flat)	230 dB re: 1 µPa (peak)	230 dB re: 1 µPa (peak)	230 dB re: 1 µPa (peak)
Sound exposure level (M_{mf})	198 dB re: 1 μPa^2-s	198 dB re: 1 μPa^2-s	215 dB re: 1 μPa^2-s
HF cetaceans			
Sound pressure level (flat)	230 dB re: 1 µPa (peak)	230 dB re: 1 µPa (peak)	230 dB re: 1 µPa (peak)
Sound exposure level (M_{hf})	198 dB re: 1 μPa^2-s	198 dB re: 1 μPa^2-s	215 dB re: 1 μPa^2-s
Pinnipeds (in water)			
Sound pressure level (flat)	218 dB re: 1 µPa (peak)	218 dB re: 1 µPa (peak)	218 dB re: 1 µPa (peak)
Sound exposure level (M_{pw})	186 dB re: 1 μPa^2-s	186 dB re: 1 μPa^2-s	203 dB re: 1 μPa^2-s
Pinnipeds (in air)			
Sound pressure level (flat)	149 dB re: 20 µPa (peak)	149 dB re: 20 µPa (peak)	149 dB re: 20 µPa (peak)
Sound exposure level (M_{pa})	144 dB re: $(20\ \mu Pa)^2$-s	144 dB re: $(20\ \mu Pa)^2$-s	144.5 dB re: $(20\ \mu Pa)^2$-s

[a] Peak pressure levels are to be measured without frequency weighting (i.e., flat weighted). Sound exposure levels are to employ the five frequency-weighting functions (M-weights) identified by Southall et al. (2007), which give less emphasis to sound components at frequencies near and outside the boundaries of the functional hearing range.

Appendix C. Hypothetical Risk Scenarios

Table C.1. Risk Scenario: Near Threatened, 20% of population affected, feeding and migratory habitat present, dependent offspring present, duration of industry activity 31-90 days, habituation considered risky due to impulsive noise, restricted habitat present, population under threat from entanglements, collisions, stable population, data quality fair 0-2 years old, no secondary effects likely.

Scoring Issue/Question	**PTS**	**TTS**	**Strong Behavioral Response**	**Moderate Behavioral Response**	**Slight Behavioral Response**	**No Behavioral Response**
Near Threatened Species	15	15	15	15	15	15
20% exposed to sound capable of [see table header]	300	60	60	45	15	5
No mating habitat present	0	0	0	0	0	0
Feeding habitat present	20	20	20	20	20	20
Calving or pupping habitat present or dependent offspring	20	20	20	20	20	20
Migratory corridors present	20	20	20	20	20	20
No known aggregation areas	0	0	0	0	0	0
Habituation possible for impulsive sound	20	20	20	20	20	20
Special restricted habitat present	20	20	20	20	20	20
Known population trend stable	-10	-10	-10	-10	-10	-10
No known health concerns in population	0	0	0	0	0	0
Detrimental effects on population persistence unlikely due to ensonification	0	0	0	0	0	0
Population under threat from entanglements/fisheries	20	20	20	20	20	20
Population under threat from collisions	20	20	20	20	20	20
Population not under threat from illegal harvest	0	0	0	0	0	0
Population not under threat from coastal development	0	0	0	0	0	0
Population not of high societal value or focus of subsistence hunting	0	0	0	0	0	0
Secondary or tertiary effects unlikely	0	0	0	0	0	0
Industry activity 31-90 days duration	15	15	15	15	15	15
Data fair quality 0-2 years old	10	10	10	10	10	10
TOTAL SCORE	470	230	230	215	185	175
	VERY HIGH RISK	HIGH RISK	HIGH RISK	HIGH RISK	MEDIUM RISK	MEDIUM RISK

Table C.2. Risk Scenario: Not listed, some (25%) of population exposed, no breeding or migratory habitat, feeding and calving habitat present, dependent offspring present, no known aggregation areas, 31-90 days industry activity duration, habituation possible risk (impulsive sound), no special restricted habitat, population not under other threats, not high societal value, no subsistence hunting, population trend stable, no known health threats, detrimental effects on population persistence from sound unlikely, good quality data 2-5 years old.

Scoring Issue/Question	**PTS**	**TTS**	**Strong Behavioral Response**	**Moderate Behavioral Response**	**Slight Behavioral Response**	**No Behavioral Response**
Not Listed Species	0	0	0	0	0	0
Some exposed to sound capable of [see header]	325	65	65	50	15	5
No mating habitat present	0	0	0	0	0	0
Feeding habitat present	20	20	20	20	20	20
Calving or pupping habitat present or dependent offspring	20	20	20	20	20	20
No migratory corridors present	0	0	0	0	0	0
No known aggregation areas	0	0	0	0	0	0
Habituation possible for impulsive sound	20	20	20	20	20	20
No special restricted habitat present	0	0	0	0	0	0
Known population trend stable	-10	-10	-10	-10	-10	-10
No known health concerns in population	0	0	0	0	0	0
Detrimental effects on population persistence unlikely due to ensonification	0	0	0	0	0	0
Population not under threat from entanglements/fisheries	0	0	0	0	0	0
Population not under threat from collisions	0	0	0	0	0	0
Population not under threat from illegal harvest	0	0	0	0	0	0
Population not under threat from coastal development	0	0	0	0	0	0
Population not of high societal value or focus of subsistence hunting	0	0	0	0	0	0
Secondary or tertiary effects unlikely	0	0	0	0	0	0
Industry activity 31-90 days duration	15	15	15	15	15	15
Data good quality 2-5 years old	10	10	10	10	10	10
TOTAL SCORE	400	140	140	125	90	80
	VERY HIGH RISK	MEDIUM RISK	MEDIUM RISK	MEDIUM RISK	LOW RISK	LOW RISK

Table C.3. Risk Scenario: Not listed, half of population exposed, feeding habitat, dependent offspring present, 1-7 days duration, habituation possible risk, no special restricted habitat, population not under other threats, not high societal value, no subsistence hunting, population trend upward, site specific data 0-2 years old, quality of data excellent.

Scoring Issue/Question	**PTS**	**TTS**	**Strong Behavioral Response**	**Moderate Behavioral Response**	**Slight Behavioral Response**	**No Behavioral Response**
Not Listed Species	0	0	0	0	0	0
Half exposed to sound capable of [see header]	400	80	80	60	20	5
No mating habitat present	0	0	0	0	0	0
Feeding habitat present	20	20	20	20	20	20
Calving or pupping habitat present or dependent offspring	20	20	20	20	20	20
No migratory corridors present	0	0	0	0	0	0
No known aggregation areas	0	0	0	0	0	0
Habituation possible for impulsive sound	20	20	20	20	20	20
Special restricted habitat present	0	0	0	0	0	0
Known population trend stable	-10	-10	-10	-10	-10	-10
No known health concerns in population	0	0	0	0	0	0
Detrimental effects on population persistence unlikely due to ensonification	0	0	0	0	0	0
Population under threat from entanglements/fisheries	0	0	0	0	0	0
Population under threat from collisions	0	0	0	0	0	0
Population not under threat from illegal harvest	0	0	0	0	0	0
Population not under threat from coastal development	0	0	0	0	0	0
Population not of high societal value or focus of subsistence hunting	0	0	0	0	0	0
Secondary or tertiary effects unlikely	0	0	0	0	0	0
Industry activity 1-7 days duration	5	5	5	5	5	5
Data good quality 0-2 years old	-5	-5	-5	-5	-5	-5
TOTAL SCORE	450	130	130	110	70	55
	VERY HIGH RISK	MEDIUM RISK	MEDIUM RISK	MEDIUM RISK	LOW RISK	LOW RISK

Table C.4. Risk Scenario: Species vulnerable, half of population exposed, feeding habitat, calves present, no mating habitat or migratory corridors, no known aggregation areas, no special restricted habitat, habituation possible risk, 15-30 days, detrimental effects on population persistence due to sound unlikely, population threatened by entanglements, collisions, population trend stable, known health concerns, population not of high societal value/subsistence, secondary or tertiary effects unlikely, data set good 2-5 years old.

Scoring Issue/Question	**PTS**	**TTS**	**Strong Behavioral Response**	**Moderate Behavioral Response**	**Slight Behavioral Response**	**No Behavioral Response**
Vulnerable Species	25	25	25	25	25	25
Half exposed to sound capable of [see header]	400	80	80	60	20	5
No mating habitat present	0	0	0	0	0	0
Feeding habitat present	20	20	20	20	20	20
Calving or pupping habitat present or dependent offspring	20	20	20	20	20	20
No migratory corridors present	0	0	0	0	0	0
No known aggregation areas	0	0	0	0	0	0
Habituation possible for impulsive sound	20	20	20	20	20	20
No special restricted habitat present	0	0	0	0	0	0
Known population trend stable	-10	-10	-10	-10	-10	-10
Known health concerns in population	20	20	20	20	20	20
Detrimental effects on population persistence unlikely due to ensonification	0	0	0	0	0	0
Population under threat from entanglements/fisheries	20	20	20	20	20	20
Population under threat from collisions	20	20	20	20	20	20
Population not under threat from illegal harvest	0	0	0	0	0	0
Population not under threat from coastal development	0	0	0	0	0	0
Population not of high societal value or focus of subsistence hunting	0	0	0	0	0	0
Secondary or tertiary effects unlikely	0	0	0	0	0	0
Industry activity 15-30 days duration	10	15	15	15	15	15
Data good quality 2-5 years old	10	10	10	10	10	10
TOTAL SCORE	555	235	235	215	175	160
	VERY HIGH RISK	HIGH RISK	HIGH RISK	HIGH RISK	MEDIUM RISK	MEDIUM RISK