Mitigation and Monitoring

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Abstract

Mitigating and monitoring the effects of manmade sound on beaked whales is one of the most challenging issues in underwater noise. The sound sources that have been associated with beaked whale strandings, military mid-frequency sonars (2-10 kHz) and airguns, are used widely throughout the world. Both sounds sources fulfill a critical need (defense and geophysical exploration, respectively), and alternative technologies are not readily available. Beaked whales are widely distributed and can be found in virtually all deep-water marine habitats that are free of ice. Some areas of high beaked whale abundance have been identified, but distribution and density is poorly known for most species and for most habitats. Beaked whales are difficult to detect visually or with passive acoustic sensors. Active acoustic detection by sonar remains untested for beaked whales. Commonly used mitigation measures (e.g. "ramp-up" and "detection-modification-avoidance") have not been assessed for effectiveness. Surveys to detect population-level impacts are likely to require many years of regular monitoring, and pre-exposure surveys are lacking in some critical areas where strandings have occurred. Risk assessment models can be used to determine the likely sound levels to which beaked whales will be exposed under a variety of scenarios; however, the lack of information on the causal mechanism for sound-related beaked whale strandings is an impediment to developing better mitigation methods. Controlled exposure experiments (CEE) may hold the greatest hope for understanding the complicated responses of beaked whales when exposed to sound and for designing mitigation methods to avoid future sound-related impacts on beaked whales.

Introduction

Recent observations of beaked whale strandings coincident with loud anthropogenic sounds (Anon. 2001; Peterson 2003) have focused attention on the potential impact of such sounds on beaked whale individuals and populations. In this report, we provide a brief overview of the technologies and methods available for monitoring and mitigating the effects of manmade noise on beaked whales. Our presentation is divided into four topics: 1) methods to detect beaked whales, 2) methods to mitigate the potential impact of anthropogenic sound on beaked whales, 3) methods to monitor noise impact on beaked whale individuals and populations, and 4) methods of risk assessment. We concentrate on the two sound sources that have been correlated with recent beaked whale strandings: military mid-frequency sonars and airgun arrays for geological exploration, but we acknowledge that other sound sources (shipping noise, underwater explosions, etc.) may adversely affect beaked whales.

1. Beaked Whale Detection Methods

Some acoustic mitigation strategies are based on the early detection and either the avoidance of marine mammals or the modification of sound sources. In this section, we review detection methods that are in common use and some new technologies that may aid in detecting beaked whales in the future.

Visual Detection

Visual surveys for beaked whales are typically conducted from ships or aircraft. Beaked whales are among the most difficult cetaceans to detect and to identify, which pose problems for both types of surveys (Barlow *et al*. 2004). Beaked whales dive for long periods and are at or near the surface for very short periods. For Cuvier's beaked whales, the median dive time is 29 min and the median surface time is 2 min; for mesoplodont beaked whales the corresponding times are 20 min and 2.5 min (Barlow 1999). The probability of detecting most beaked whales is very low in the best survey conditions and drops rapidly in sub-optimal survey conditions. In this section we review the methods used to detect beaked whales on the ship and aerial line-transect surveys that have been used to estimate their abundance (Barlow *et al*. 2004).

On typical ship line-transect surveys, two observers search using 25x150 binoculars and one or more observers search using naked eyes or 7x50 binoculars as the ship travels along planned track-lines at approximately 10 kts (18.5 km/hr). Observers search from the highest stable deck, often the flying bridge deck or top of the pilothouse, but sometimes the bridge wings are used on larger ships. From ships, beaked whales are detected only when they surface to breathe. The effective search width is typically 1-2 km for observers using 25X binoculars in excellent or good sighting conditions (Barlow *et al*. 2004, their Table 2). Accounting for both submerged animals and animals that are missed by the observers, only 23% of Cuvier's beaked whales and 45% of mesoplodont beaked whales are estimated to be seen on ship surveys <u>if they are directly on the survey track-line</u> in survey conditions of Beaufort 0-2 (Barlow 1999). The encounter rate of beaked whales decreases by more than an order of magnitude as survey conditions deteriorate from Beaufort 1 to Beaufort 5 (Barlow *et al*. 2004, their Table 1). Most estimates of beaked whale density from ship surveys are based only on search effort in excellent (Beaufort 0 to 2) or good (Beaufort 0 to 4) survey conditions (Barlow *et al*. 2004, their Table 2). Experienced observers have beaked-whale sighting rates that are approximately twice as high as less experienced observers (Barlow *et al*. 2004).

On aerial line-transect surveys, teams of 2-3 observers typically search by naked eyes from a survey altitude of 600-1000 ft (183-305 m) and at a speed of approximately 100 kts (185 km/hr). Bubble side windows are typically used to allow direct downward visibility, and ideally a belly window is also used to improve downward visibility. Aerial observers can see beaked whales only when the whales are near the surface (typically within 2-4 m). On aerial surveys, the ability to see submerged animals is adversely affected by sea state and cloud cover (Forney *et al*. 1991). Most estimates of beaked whale density from aerial surveys are based only on search effort in good survey conditions, generally Beaufort 0 to 4 (Barlow *et al*. 2004, their Table 2). Accounting only for animals that are missed because they are diving, only about 7% of Cuvier's beaked whales and 11% of mesoplodont beaked whales would be seen on aerial surveys <u>if they are directly on the survey track-line</u> (Barlow *et al*. 2004). The fraction seen decreases rapidly with distance from the track-line; the effective search width is typically only 250-500 m (on each side of the aircraft) for aerial observers searching by unaided eye in excellent or good sighting conditions (Barlow *et al*. 2004, their Table 2).

<u>Passive Acoustic Detection</u>

Passive acoustic detection refers to the detection of animals by listening for the sounds that they make. The past decade has brought explosive growth in the application of passive acoustic sensing of marine mammals (see review by Mellinger and Barlow 2003), along with automated signal processing tools for the examination of large data sets (Mellinger 2001; Mellinger *et al*. 2004). Cetacean sounds can be detected with towed hydrophone arrays, stationary hydrophones from ships or shore, autonomously recording bottom hydrophones, or drifting radio-linked sonobuoys deployed and monitored from ships or aircraft. Each monitoring system has distinct advantages and disadvantages, and the optimal choice depends on the frequency structure of the sounds of interest, the depth at which animals vocalize, and the logistics of mitigation (a stationary hydrophone might be inappropriate for a moving sound source, and a seabottom recorder is not appropriate for real-time monitoring). Localization of cetaceans typically requires more than one hydrophone. A DIFAR (Directional Fixing And Ranging) sonobuoy can give a compass bearing to a low-frequency sound source (<2.5 kHz), and two such buoys can be used to localize that source (Greene *et al*. 2003). Long towed arrays (1-5 km) with 16 or more elements can determine the bearing and distance to a sound source, but typically cannot resolve whether the source is left or right of the array. Short towed arrays with two or more elements can also give a bearing angle (again with the left/right ambiguity), and a sound source can be localized by the convergence of a series of bearing angles measured from different locations as the array is towed behind a ship (Leaper *et al*. 1992).

Most cetacean species make at least some sounds, and one advantage of acoustics is that these sounds can often be detected when the animals are submerged or out of range for visual observers. One disadvantage is that sound production is voluntary, and many cetaceans may be silent for long periods of time. At present there are no reports of the relative incidence of vocal activity for beaked whales. Species identification from vocalizations is easier for some cetacean species than others. Baleen whales, in particular, appear to make very stereotyped calls that can be used to distinguish species and, in some cases, populations (McDonald and Fox 1999; Mellinger and Barlow 2003). Dolphin whistles are more variable, and species identification from whistles is probabilistic, with 30-50% error rates in species classification (see review by Oswald *et al*. 2003). Echolocation clicks can be used to identify sperm whales with certainty, and frequency can be used to distinguish clicks made by porpoises and *Cephalorhynchus* spp.

from other odontocetes (Au 1993; Cranford and Amundin 2004; Nakamura and Akamatsu 2004).

Although all beaked whales may have the ability to make clicks and some or all may also make whistles (Dawson *et al*. 1998; MacLeod and D'Amico 2004), there have been many unsuccessful attempts to record sounds from Cuvier's and mesoplodont beaked whales (Dawson *et al*. 1998; Barlow and Rankin, unpubl. data). The frequent failure to detect sounds in the presence of beaked whales can be due to many factors: 1) they may primarily make sounds at great depth and these may attenuate before reaching the surface, 2) sounds may be highly directional, 3) sounds may be of very low amplitude, and/or 4) animals may reduce their sound production in the presence of ships or boats. However, past experience with other species has shown that the likelihood acoustic detection improves tremendously if the observer knows what to listen for, so we anticipate improvements in passive acoustic monitoring as we learn more about beaked whale vocalizations.

Basic research on beaked whale acoustics would be greatly aided by acoustic recording tags attached directly to the animals. Recently, researchers at Woods Hole Oceanographic Institution (Tyack, unpubl. data) succeeded in recording beaked whales using acoustic data-logger tags. These results should help focus efforts to apply passive acoustic sensing methods to beaked whales.

Active Acoustic Detection - Sonar

Active sonar has been used for some time to monitor the underwater movements of marine mammals for research purposes (Papastavrou *et al* 1989; Watkins *et al* 1993). More recently, active sonars have been designed specifically to detect and track marine mammals underwater (Miller 2004; Stein 2004). Active sonar has a tremendous advantage in that it does not rely on the animal making sound or making itself visually available at the surface. In practice, effective mitigation will require a high probability of detecting beaked whales. However, high detection rates are sometimes accompanied by unacceptably high levels of false detections (mistaking entrained air bubbles, fish, other whales, or other phenomena for the object of interest). This trade-off between correct detections, missed detections, false alarms and correct rejections of non-targets is referred to as the Receiver Operating Curve (ROC). At present there are only very limited ROC data for sonars used to detect marine mammals. Target (or species) identification is also a potential problem for active sonar. The acoustic reflection produced by sonar is typically vague and only indicates the location and approximate size of a target (more accurately, target strength, or the acoustic reflectance of the target). Although signal processing can improve data interpretation, the return signal varies with the animal's orientation, volume of respiratory air spaces (which change with depth), and other factors. False positive signals (things that "could" be beaked whales) may be too common to allow active acoustics to be a practical mitigation tool. Currently, no active system used to detect marine mammals had been sufficiently tested to provide quantitative performance data.

Performance is not the only metric for assessing the utility of active sonar. Because active sonar places an additional source of acoustic energy in the environment, it must also be assessed for possible adverse effects. The 30 kHz operating frequency of the LFA mitigation sonar (Department of Navy 2001) falls within the hearing range of many species of small cetaceans, pinnipeds, and some fishes. If animals can hear the source, they may react to that source. Also, a source within their hearing range has the potential for causing auditory damage if received levels are too high. Active sonar use for whale detection has been the target of strong opposition by some environmental groups, including threatened or actual litigation. Discussions of the costs and risks of applying these methods should therefore include the potential of litigation or other expressions of opposition or concern.

New Detection Technologies

A variety of new technologies (radar, infrared and hyper-spectral imagery, satellite imagery, and LIDAR) may hold promise for the detection of beaked whales. Light Detection and Ranging (LIDAR) is a raster scanned laser light source and receiver used to image subsurface objects to depths of 30 meters or more. LIDAR can reveal objects that would not be visible by ambient sunlight or non-coherent light sources. Given the difficulty in detecting beaked whales using visual and passive acoustic methods, an evaluation of these alternatives offers the potential to improve current probabilities of detection. However, because all of these methods involve detecting whales at or near the surface, the long, deep dives and short surface times of beaked whales will pose similar problems to those associated with visual survey. Some of these methods have already been tested and have shown promise for detecting other cetacean species. None have been evaluated for detecting beaked whales.

2. Mitigation Methods

Removal or Modification of the Sound Source

The simplest mitigation method would be to discontinue use of military sonar and airguns or to modify them so that they would no longer pose a potential risk to the beaked whales. Mid-frequency sonars are widely used by the navies of the world as an essential and critical part of their anti-submarine defense. It is therefore unlikely that any navy would willingly abandon use of such sonars altogether. Airguns are widely used by the marine geophysical exploration industry to locate potential offshore mineral deposits such as oil and natural gas. Airguns are also used in a variety of research applications, including the detection and mapping of offshore fault zones. Again, it is unrealistic to think that industrial and research use of airguns will stop in the near future.

While complete cessation of sonar operations might pose unacceptable risks to naval personnel and vessels, restricted or modified use may be acceptable in some circumstances. Most sonar use is in training and equipment testing rather than in combat. One option might be the regional or seasonal closures of high-density habitats for all training and test exercises (see Avoiding Beaked Whale Habitat, below). Another option might be to increase the use of simulations for sonar training in place of ship-based training. However, realistic training is considered critical to maintaining a combat-ready fleet, so it is unlikely that all training will ever be shifted to simulators.

Another acceptable modifications might be changes in the frequency or amplitude characteristics of the sonar signal. If adverse effects seen in beaked whales are caused by narrow range of frequencies or by a particular waveform, other signal types might work just as well. Improvements to the signal processing of the received signal might enable sonars to achieve current performance standards with reduced source levels. However, advances in signal processing would not necessarily lead to reduced source levels because there would still be a tactical advantage in using both improved signal processing and the maximum achievable source levels.

Low Frequency Active (LFA) sonar (operating below 2 kHz) is being developed by several nations to address the need for increased sonar detection ranges against modern quiet diesel submarines equipped with faster, longer-range torpedoes. There have been no reported beaked whale strandings associated with LFA sonars by themselves; however, the stranding in Greece in 1996 occurred in conjunction with testing of a bistatic sonar possessing both low frequency and typical mid-frequency sound sources (D'Amico 1998). While LFA sonars have been the subject of considerable attention due to the greater area ensonified by LFA relative to mid-frequency sonars, the potential of LFA sonars to cause strandings or other adverse effects on beaked whales is still uncertain. If the impact on beaked whales is frequency-specific, LFA sonars might have fewer adverse effects than mid-range tactical sonar.

The apparent association between airgun use and beaked whale strandings (Peterson 2003) is not as well established as the relationship between tactical mid-frequency sonars and beaked whales (Anon. 2001). Alternative sources of acoustic or vibrational energy for imaging geological structures have been substituted for airguns in some cases, but are not widely used. A technical review is needed to evaluate the relative merit of available alternative marine geophysical sensing methodologies. Again, improved signal processing methods may allow for use of lower source levels for airguns without loss of performance.

Avoiding Beaked Whale Habitat

Another mitigation option is simply to avoid beaked whale habitat. Unfortunately, beaked whales can be found in virtually all deep-water habitats that are not ice-covered (MacLeod *et al*. 2004). Previous studies of sightings and strandings (Waring *et al*. 2001; D'Amico *et al* 2003; MacLeod *et al*. 2003) led to the identification of continental slopes, canyons and seamounts as areas of particularly high beaked whale abundance. MacLeod *et al*. (2003) presented lists of beaked whale "hot spots" - areas with high densities of beaked whales. Barlow *et al*. (2004) show that the habitat preferences observed in the NE Atlantic and Mediterranean Sea do not appear to hold in the eastern tropical Pacific, where beaked whales are found in more pelagic waters, far from continental slopes. While there is little doubt that "hot spots" of high beaked whale density do occur, the "hot spots" that have been identified to date are based on very preliminary analyses and limited data, and caution is recommended in extrapolating habitat preferences to un-surveyed areas (Barlow *et al*. 2004). Consideration should be given to the potential sound impacts on other animals if sound production is shifted away from beaked whale habitat; for example, the densities of dolphins and baleen whales are often much higher in shelf waters where beaked whale densities are low.

Ramp-up Procedures

Perhaps the most widely used mitigation method is “ramp-up”, the phased increase of sound levels over a period of several minutes or hours, to enable animals to detect the sounds at low levels and, hopefully, move away before harmful effects are produced. This is practical, though not without cost, in some cases (for example, air gun arrays, see Appendix), but in other cases (such as actual tactical use of sonar in anti-submarine warfare), announcing one’s presence with a low but tactically ineffective sound level is not an option. "Ramp-up" mitigation is based on the assumption that animals will detect the location of this lower-level sound and will react as desired. However, this mitigation method has not yet been tested for effectiveness. The potential remains that ramp-up may not have the desired effect, and may even create greater risk by causing animals to approach. Another premise of "ramp-up" mitigation is that when a sound source is fully powered up, animals that are exposed by movement of the sound source will experience a gradual ramp-up as the sound source approaches. Although the theory seems sensible, most of the sound-related beaked whale strandings have occurred with moving sound sources that had been active for some time.

Detection of Beaked Whales and Modification of Sound-Producing Activities

Many mitigation plans include a plan to detect animals (visually or acoustically) and to modify activities (such as to avoid the area, decrease amplitude, or turn off the sound source) if the animals are within a critical distance. This method is dependent on the ability to detect animals before they are exposed to potentially dangerous levels of sound.

Mitigation plans for seismic surveys or experimental sound sources usually require searching by ship-based marine mammal observers during daylight hours and (in some cases) at night using night vision scopes (see Appendix). Typically, mitigation observers search by unaided eyes and 7X binoculars during daylight hours. Mitigation plans often provide no guidelines for "acceptable" survey conditions, and, in some cases, searching may continue in Beaufort sea states of 7 or 8 (Appendix). In some mitigation plans, such as for the ship-shock trials of the destroyer USS *John Paul Jones* in the Pacific, aerial observations made in front of a moving vessel may augment visual surveys from a ship (Dept. of Navy 1994). Given the difficulty in detecting and identifying beaked whales using experienced observers in optimal conditions (see Visual Detection, above), mitigation observers from either ships or aircraft will detect only a small fraction of the animals that are within their range of vision.

Passive acoustic detection has been used in some mitigation plans. Sonobuoys dropped from aircraft were used to detect whales during the *John Paul Jones* ship-shock trials in the Pacific and resulted in several detections of baleen whales. A towed hydrophone array was used experimentally in recent seismic test (Appendix), but no marine mammals were acoustically detected in that short experiment. The utility of passive acoustics detection for beaked whales is extremely limited because, for most species, we do not know what sounds they make.

Some recent mitigation plans have incorporated active sonar to detect marine mammals. An active sonar system has been incorporated into the mitigation plan for the SURTASS Low Frequency Active sonar system. The Environmental Impact Statement for SURTASS LFA (Department of the Navy 2001) contains data on system design, tested effectiveness and usage as a mitigation device. A subsequent report (Johnson 2004) provides additional information on system performance. Additional data on the Scientific Solutions, Inc. IMATS (Integrated Marine Animal Tracking System) active whale detection sonar should be forthcoming soon, following tests with migrating gray whales in California during January and February, 2004.

None of the available detection methods have a high probability of detecting and identifying beaked whales. Passive and active acoustic detection must be considered experimental and untested. Because of their long dive times and cryptic surfacing behavior, visual detection will not be effective at detecting more than a small fraction of beaked whales that are in the immediate vicinity of a sound source. Mitigation plans that depend solely on detecting beaked whales will be similarly ineffective.

Sound Screening Procedures

Mitigation of stationary sources such as pile-driving or explosives can sometimes be achieved through the use of bubble screens or material screens that impede sound radiating from the source. For typically mobile sources, like ship sonars and airgun arrays, this form of mitigation is unlikely to be an option.

Aversive Alarms

Alarm signals have been proposed as a means of moving animals away from a potentially more dangerous situation. Acoustic deterrent devices (ADDs or "pingers") are low-amplitude sound sources (<150 dB re: 1 μP) that are commonly used on gillnets to reduce cetacean bycatch. Acoustic Harassment Devices (AHDs) are higher amplitude sound sources (>180 dB re 1 μP) typically used to keep seals and sea lions away from aquaculture pens, fish ladders, and other locations where they could cause damage to resources or property. ADDs have been shown to be effective at reducing gillnet bycatch of harbor porpoises (Kraus *et al*. 1997; Gearin *et al*. 2000) and other cetaceans (Barlow and Cameron 2003); however, the mechanism by which they work is not known (Kraus *et al*. 1997). Considerable evidence suggests that ADDs produce a sound that is aversive to many cetaceans (Anderson *et al*. 2001), thus the difference between "deterrent" and "harassment" devices may be artificial. Since California-based drift gillnet vessels began to use pingers in 1996 no beaked whales have been observed entangled in nets with pingers (Barlow, NMFS unpubl. data); prior to pingers, 26 beaked whales were observed caught in nets from 1991-95 (Julian and Beeson 1998). Beaked whales appear to be responding to pinger alarms by avoiding nets, so there may be some potential to use of alarms to reduce beaked whale exposure to anthropogenic sounds.

In considering the effectiveness of an alarm signal, it will be necessary to assess the type of alarm response elicited and its likelihood of reducing risk. Recently, Nowacek *et al* (2004) showed that an alarm signal altered the behavior of right whales, but the alteration (reduced diving and increased surface time) probably increased their vulnerability to vessel collisions.

3. Monitoring the Impact of Sound on Beaked Whales

In general, monitoring for impacts of sound on beaked whales has received less emphasis than mitigation measures to prevent impacts. Although it is clearly better to prevent impacts, the efficacy of all current mitigation methods is untested. It is therefore important to develop monitoring tools to directly evaluate impacts when they occur. Impacts can occur as the death or injury of individual whales or as population-wide impacts. Different forms of monitoring are appropriate for measuring these different classes of impacts.

Surveys for Dead or Injured Whales

The most direct method of monitoring beaked whale injury or death is to conduct surveys to detect dead or injured whales during or after exposure to a sound source. To date, most beaked whale strandings associated with anthropogenic sound have been detected by chance (Anon. 2001; Peterson 2003), without any dedicated search efforts. Instead of relying on chance, ship or aerial surveys could be used to detect dead or injured whales at sea, and aerial or ground-based surveys could be used to detect stranded whales on beaches. Injured whales are likely to be identified at sea only if their surface behavior is grossly changed. Direct impact assessment by detecting dead and injured whales is best for measuring the impact on individuals, but cannot easily be used to infer population-level impacts unless the population size and structure are well known.

Uncertainties in directly monitoring impacts include not knowing the probability that a dead whale will float and, if it floats, the probability that it will strand on a beach. The probability that a dead beaked whale will float is likely to be very dependent on the depth at which it dies. Experiments with freshly stranded beaked whales may help resolve these uncertainties.

The physiological effects associated with recent well-studied standings (such as the 2000 Bahamas and 2002 Canary Islands strandings) require special methods for the collection, preservation and analysis of specimen materials. As we develop hypotheses about the possible causal mechanisms of observed physiological effects it is possible that new collection and analytical methods will be needed when stranded beaked whales are detected. At present only a few individuals are sufficiently trained to perform the collections and analyses. Trained stranding response personnel and specialized collection and preservation materials may be needed to mount effective stranding responses.

Surveys to Detect Changes in Abundance

Ship or aerial surveys can be used to estimate the abundance of beaked whales (Barlow *et al*. 2004), and such estimates, if repeated over time, can be used to estimate changes in beaked whale abundance. A significant, population-wide decline in abundance may indicate anthropogenic impacts from sound or other factors (such as bycatch). This approach does not hold much promise in the short term due to the lack of precision in estimates of beaked whale population size. Taylor and Gerrodette (1993) discuss the problems associated with detecting changes in population size for rarely seen species. They conclude that rare species could go extinct before a statistically significant decline is detected. The coefficients of variation in beaked whale abundance estimates from a single survey are typically high (40-100%, Barlow *et al*. 2004, their Table 2). This lack of precision means that many years of annual surveys would be required to detect a change. The lack of any baseline abundance information for the vast majority of the world's oceans adds further to the problem of detecting changes.

Individual Identification and Mark-Recapture Studies

Many species of beaked whale are well marked with body scarring or nicks in their dorsal and caudal fins that can be used to identify individuals. Most individual identification studies are based on photographs; however, individuals can also be identified genetically. Individual identification studies have proven to be a valuable tool for the study of many whale populations (Hammond *et al*. 1990; Calambokidis and Barlow 2004) and can be used to determine residency patterns, population size, mortality rates, and reproductive parameters. Individual identification studies benefit most from a continuous series of observations over many years, however, valuable information can be gathered over shorter time periods, and abundance estimates can often be made with two seasons of fieldwork (typically separated by a year to allow randomization).

There is only one long-term, photo-identification study of Cuvier's and mesoplodont beaked whales, but, coincidentally, it is based on Abaco Island in the area of the Bahamas beaked whale strandings of March 2000. The study had begun prior to the strandings and has continued afterwards (Claridge and Balcomb 1993, 1995; Claridge et al. 2001). A complete analysis of the data from this study may give insight into the long-term effects of sound on marine mammals and may help determine whether some of the stranded animals were subsequently re-sighted after they were pushed off the beach. A similar long-term study of northern bottlenose whales (Whitehead *et al*. 1997; Gowans *et al*. 2000) also provides behavioral and ecological information that is relevant to monitoring sound impacts. Additional opportunities for long-term photo-identification studies exist and should be explored.

Controlled Exposure Experiments

The best way to monitor the effect of sound on beaked whale may be to deliberately expose whales to a known sound source while studying their behavior. Such controlled exposure experiments (CEE) are one of the most powerful tools for monitoring the response of animals to sound. The primary advantage of CEE is the high statistical power to detect a change in behavior associated with sound exposure. Opportunistic observations of sound exposures often lack power because uncontrolled variables often mask any response to sound exposure. Clearly, however, if CCE is to be used to evaluate the cause of beaked whale deaths associated with loud anthropogenic sounds, some animals may be put at risk. In the past, some environmental groups have objected to and attempted to block such experiments.

Because of their long dive times, the behavioral response of beaked whales to sound is difficult to directly observe. Recently, acoustic data-logging tags (Burgess *et al*. 1998; Johnson and Tyack 2003) have been developed that allows measurement of received sound levels, depth, and detailed behavior (orientation, roll, pitch, acceleration, fluke stroke rate, sound production, etc). The deployment of such tags on beaked whales is a critical first step in measuring underwater behavioral responses and hence enabling CEE experiments with beaked whales. The logistic problems of reliably finding and tagging beaked whales with appropriate instruments need to be resolved. Very recently, several researchers succeeded in tagging Cuvier's and mesoplodont beaked whales (Baird *et al*. 2004; Tyack *et al*., pers. comm.) and additional tagging is planned. As expertise is gained in using the tag technology, direct CEE assessment of beaked whale response to noise should be possible in the near future.

4. Risk Assessment Models

Risk assessment models are used to evaluate the exposure of marine mammals to specific sound sources. The number of marine mammals exposed to any source and their levels of exposure will depend on the characteristics of the source, but also on the density of marine mammals, their diving behavior, their distance from the source, and the local sound propagation characteristics. Risk models can be based on simplifying assumptions, such as assuming a cylindrical or spherical sound propagation model and assuming that all individuals are at the depth of highest sound levels. More complicated simulation models have been developed that reduce the number of simplifying assumptions required to estimate exposure. At least two such models have been developed and used to model risks from sound. The first is the Acoustic Integration Model (AIM) developed by Marine Acoustics Incorporated, and now widely marketed in a variety of versions (Ellison *et al* 1999). The second is the Effects of Sound on the Marine Environment (ESME) program within the Office of Naval Research, which is attempting to bring together state-of-the-art science in all the relevant fields of information to create an integrated mathematical model of risk. The ESME model accounts for uncertainty within model components, and thus allows sensitivity analyses of any of the model parameters.

Risk assessment models are, themselves, a valuable tool in assessing research/data needs. For example, one might be faced with the choice of investing a million dollars and three years in improving the accuracy of the sound field prediction in reverberant environments only to find that it only alters the outcome by 1%, whereas a ten thousand dollar investment in improved beaked whale density estimates for the same site might produce a difference of several orders of magnitude in the estimated outcome of the model. Model sensitivity therefore becomes a good guide in how to best allocated limited resources to achieve the greatest gains in certainty.

Understanding the sound exposure experienced by a diving animal is critical to risk assessment. However, until we have improved population data and improved understanding of the physical, physiological, and/or behavioral mechanisms by which sound is adversely affecting beaked whales, we will not be able to assess risk.

Conclusion

We have briefly reviewed a range of options for mitigating and monitoring the potential impacts of human acoustic activity on beaked whales. Clearly, this task is extremely difficult. Beaked whales are difficult to detect by any available method and, given their wide distribution, are difficult to avoid. The effectiveness of virtually all mitigation methods that are currently in use has not been tested for beaked whales. The number of animals exposed and the sound exposure levels can be estimated with risk assessment models, but actual risk to populations or individuals cannot be estimated without knowing the causal relationship between loud anthropogenic sounds and beaked whale strandings. We hope that by focusing attention on the problems associated with mitigating and monitoring the effect of sound on beaked whales, research will be directed to solve these problems.

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APPENDIX: Example of Seismic Mitigation and Monitoring by Lamont-Doherty Earth Observatory on the R/V *Maurice Ewing*

Increasingly, reporting requirements have been added to the Incidental Harassment Authorizations issued by National Marine Fisheries Service (NMFS) for marine mammal "takes" by acoustic harassment. Particularly good examples of such are the reports prepared by LGL Ltd. for seismic surveys and tests conducted by the Lamont-Doherty Earth Observatory on the R/V *Maurice Ewing* (LGL 2003; Smultea and Holst 2003; MacLean and Haley 2004; and Holst 2004). Here we briefly review the monitoring and mitigation methods used on four projects in 2003 and the results of their monitoring efforts. Three of the projects were actual seismic surveys, and one (LGL 2003) was a calibration study to obtain additional information on sound levels from different airgun array configurations.

All the mitigation and monitoring described here were associated with the use of airgun arrays configured with 2 to 20 airguns. Following guidance from NMFS, it was assumed that some marine mammals could be "taken by harassment" (disturbed) if exposed to a received sound level of ≥160 dB re: 1 μPa, measured on an rms basis over the duration of the pulse. The potential for injury occurs at a higher sound level; the NMFS standard at that time was that cetaceans and pinnipeds should not be exposed to pulsed sounds at received levels ≥180 dB or ≥190 dB, respectively. For the projects described here, "precautionary safety radii" were defined as 1.5 times the distance at which sounds were predicted to diminish to 180 dB for cetaceans and 190 dB for pinnipeds. The factor of 1.5X was introduced to account for uncertainty in estimating safe distances via a propagation model that was, at the time, not yet validated by empirical measurements. The safety radii used for cetaceans (1.5X the predicted 180 dB radii) varied from as low as 75 m (with two airguns) to as high as 1,350 m (with 20 airguns).

The mitigation plan for each survey included: 1) changing vessel heading and speed, when feasible, to avoid marine mammals ahead of the ship, 2) ramp-ups whenever the airgun arrays with >2 guns started firing after a period without airgun operations, and 3) power-downs or shut-downs whenever marine mammals were detected within or about to enter the applicable safety radii. In general, if all airguns were shut down for an extended period at night, airgun operations did not resume until daylight. Marine mammal monitoring was also part of the mitigation plan and was critical to mitigation strategies #1 and #3 above.

Monitoring was typically the responsibility of three biological observers who were trained to identify marine mammals and sea turtles. Typically, when the array was active during daylight hours, two observers searched with 7x50 reticle binoculars and with naked eyes while the third observer rested. Given the limited ability to sight marine mammals at night even when night vision devices (NVDs) are used, biologist observers did not search at nighttime except prior to and during ramp-ups; at those times, they searched with 3rd generation, 3X NVDs. Tests on one cruise (Holst 2004) indicated that three white milk jugs tied together were generally visible out to 50-65 m but were only visible to 1 of 3 observers at 150 m (on a bright night in Beaufort 4 conditions). During night periods when the airguns were active, bridge crew watched for marine mammals and sea turtles near the vessel as part of their normal watch duties. One marine mammal observer was on-call in case the bridge crew saw a marine mammal at night. One project (LGL 2003) had eight observers (extras were aboard for another project) and two 25x150 big-eye binoculars. On that project, daytime monitoring was done by 4 observers ... two searching with 25X binoculars and two searching with 7x50 binoculars and naked eyes, and there were no nighttime airgun activities.

Table A1 gives the hours of monitoring effort when the airgun arrays were active (including power-up time) stratified by Beaufort sea state. Marine mammal sightings when the arrays were active are summarized in Table A2. The mitigation and monitoring reports also detail the monitoring effort and marine mammal sightings during transit to the study area and at other times that the array was not active. During nighttime operations, no marine mammals were seen by the observers or reported to the observers by bridge crew.

Passive acoustic monitoring was attempted on the Gulf of Mexico project (LGL 2003). The Seamap Cetacean Monitoring System (Seamap 2002) consisted of a towed hydrophone array capable of detecting signals between 8 Hz and 24 kHz. One person aurally monitored signals and visually monitored spectrographs. Monitoring occurred for 32 hours, mostly when the array was not firing. Three visual sightings were made during periods of acoustic monitoring, but no marine mammals were detected acoustically.

Holst, M. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's TAG seismic study in the mid-Atlantic Ocean, October-November 2003. LGL Report TA2822-21 from LGL Ltd., King City, Ontario, for Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY, and National Marine Fisheries Service, Silver Spring, MD. 42 pp.

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Smultea, M. A. and M. Holst. 2003. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic study in the Hess Deep area of the eastern equatorial tropical Pacific, July 2003. LGL Report TA2822-16 from LGL Ltd., King City, Ontario, for Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY, and National Marine Fisheries Service, Silver Spring, MD. 68 pp.

Table A1. Hours of monitoring effort by marine mammal observers when airgun arrays were active (including ramp-up periods) stratified by Beaufort sea state. Average Beaufort is a time-weighted average.

	Beaufort Sea State									Average		Total
Project Area	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Beaufort**	**Reference**	**Hours**
northern Gulf of Mexico	0.0	0.0	8.8	7.8	0.8	0.0	0.0	0.0	0.0	2.5	LGL 2003	17.4
Hess Deep/ eastern tropical Pacific	0.5	0.0	0.0	13.3	38.0	38.8	8.4	0.0	0.0	4.4	Smultea and Holst 2003	99.1
Storegga Slide/Norway	0.5	8.7	25.2	33.2	56.7	59.6	61.8	18.3	1.9	4.5	MacLean and Haley 2004	265.9
mid-Atlantic Ridge	0.0	0.0	0.0	1.3	6.0	7.2	7.7	0.1	0.0	5.0	Holst 2004	22.4

Table A2. Total monitoring effort and marine mammal sightings made when airguns were active (including ramp-up periods). Animal actions are relative to the vessel, but are not necessarily reactions to the vessel or airgun array. Airguns were powered down in response to marine mammal sightings in five instances. Beaufort sea state for sightings off Norway from LGL (pers. comm.).

Project Area	**Monitoring (Hours)**	**Species**	**Group Size**	**Date**	**Distance (Meters)**	**Beaufort Sea State**	**Animal Action**	**Array Power Down?**
northern Gulf of Mexico	17.4	dwarf sperm whale	2	30-May	5,000	2	dive	No
		bottlenose dolphin	8	2-Jun	1,125	3	swim away	No
Hess Deep/ eastern tropical Pacific	99.1	unid. beaked whale (probable)	1	17-Jul	1,000	4	breaching	Yes
Storegga Slide/Norway	265.9	fin whale	1	1-Sep	3,306	3	swim away	No
		unid. whale	3	1-Sep	2,074	3	swim away	No
		unid. whale	2	1-Sep	3,306	3	swim away	No
		minke whale	2	1-Sep	3,306	3	swim away	No
		minke whale	2	1-Sep	3,306	3	swim away	No
		unid. beaked whale	2	1-Sep	2,074	3	swim away	No
		unid. dolphin	10	1-Sep	1,519	3	milling	No
		minke whale	1	4-Sep	533	4	swim toward	No
		minke whale	1	5-Sep	847	5	swim parallel	No
		minke whale	1	5-Sep	200	5	swim toward	Yes
		unid. whale	1	5-Sep	2,074	5	swim away	No
		long-finned pilot whale	7	6-Sep	200	6	swim toward	Yes
		long-finned pilot whale	25	6-Sep	277	5	swim parallel	Yes
		long-finned pilot whale	15	6-Sep	4,500	6	swim toward	No
		unid. whale	1	7-Sep	4,813	4	swim parallel	No
		unid. whale	3	7-Sep	847	4	swim toward	Yes
		unid. whale	1	11-Sep	654	2	swim away	No
mid-Atlantic Ridge	22.4	none	n/a	n/a	n/a	n/a	n/a	n/a