Canadian Science Advisory Secretariat
Examination of the Effectiveness of Measures Used to Mitigate Potential Impacts of Seismic Sound on Marine Mammals. DFO workshop, May 11-12, 2009.

Does moderate anthropogenic noise disrupt foraging activity in whales and dolphins?

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Introduction

While the primary mitigation measures associated with seismic survey sound are designed to avoid gross impacts such as TTS or physiological injury, the *Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment* also aims to prevent significant impacts on breeding, feeding, or nursing marine mammals. Determination of "significant" impacts is an ongoing challenge in relation to ocean noise, and this paper will not attempt to address that central question. As we evaluate the effectiveness of existing or proposed mitigation measures, we must also continually assess new research results and observations. Toward that end, this paper will summarize a growing body of research published since late 2007 that raises new questions about a subtle but perhaps significant behavioral response to moderate anthropogenic noise in the marine environment: the suspension of foraging activity.

These recent papers together suggest that moderate human noise may disrupt the feeding behaviors of many different species—indeed, interruption of foraging and feeding appears to be quite common, and perhaps the most biologically significant of the common behavioral disruptions observed. Reference will be made to one older study, which assessed the energetic costs of various behavioral disruptions and highlighted the relatively high energetic cost of reduced feeding time. This consideration of reduced foraging time should be considered within the context of a growing understanding that even moderate noise intrusions (120-150dB) can trigger behavioral disruptions which are not necessarily minor (see Southall, et al, 2007, for scaled severity of responses observed).

While seismic surveys were the noise source in some of these studies, this review will also include similar results from other noise sources, as well as summaries of two recent agency efforts to create systematic assessments of the impacts of moderate noise (Appendix A). The papers focused on other noise sources provide some reinforcement for the early, ambiguous indications emerging from studies of seismic surveys, while the systematic approaches could well inform the creation of models for collecting and evaluating data from marine mammal observations made in conjunction with seismic surveys. Two further appendices will briefly mention other recent research that will inform the assessment of mitigation measures and their effectiveness (Appendix B addresses the variability of sound propagation; Appendix C reports on the limits in Passive Acoustic Detection of beaked whales).

Moderate noise and suspension of foraging activity: seismic surveys

The most striking studies relating directly to seismic surveys include:

- The 5-year Sperm Whale Seismic Study (SWSS) in the Gulf of Mexico. This project monitored whales as they were exposed to sounds from a seismic airgun array; many were tracked via satellite tags (which remain on for days and tracked dozens of whales in large areas) and a few with D-tags (which remain on for hours and recorded the sounds heard and made by a handful of animals, as well as tracking their dive patterns). While the "take-away" message in media reports at the time of the release of the SWSS final report was centered on the apparent lack of large-scale effects of airguns (distribution of whales on scales of 5-100km were no different when airguns were active than when they were silent), a key observation was rarely noted: the one whale that was D-tagged and that experienced sound levels of over 160dB (164dB) remained at the surface for the entire two hours that the survey vessel was nearby, then dove to feed as soon as the airguns were turned off. The whale remained at the surface for an additional hour before the airguns were activated; there is a chance it was ill or otherwise disrupted by the tagging, rather than the airguns themselves. Another possibility is suggested by the fact that this whale's D-Tag recorded significant higher-frequency components in the airgun signals; it is possible that, at close range, these higher-frequency components would have interfered with the whale's echolocation, whereas similar sound levels at greater distances would be less bothersome. (See note in Appendix B, regarding findings from this study that sound levels of 160dB could occur up to 10km away from active airguns.) The relative lack of whales within 5km was also noted, though given the total number of observations, did not qualify as statistically significant. The authors concluded that "it is more likely than not that some decrease of foraging effort may occur" when airguns are active, at least in some individuals. Using complex statistical analysis to try to tease patterns from a limited data set, the researchers conclude that a decrease of 20% in foraging activity is likely. (Jochens, et al, 2008)

- In Angola, another study done during a seismic survey came up with a similar mix of easy to report overall effect, and suspicious secondary effect: In this case, the study simply looked at the numbers of whales seen by marine mammal observers during several months on a particular vessel. There were no apparent large-scale distribution changes (i.e., the whales did not leave the area when surveys were occurring). But strangely, more whales were seen during airgun activity than when airguns were silent; again, it appears that they were more apt to remain at the surface when the noise was occurring. (Weir, 2008)

- Another study by Weir, also done in West Africa, indicated that pilot whales showed a modest avoidance response to airgun ramp-up, while also observing another instance of milling on the surface at a range of just under and over a kilometer. (This paper also serves as a valuable survey of previous studies of the effectiveness of ramp-up procedures.) In the instance reported on here, a survey vessel gradually approached a pod of traveling pilot whales from behind, and initiated ramp-up when 900m away. The whales did not initially respond, but when the ship was 750m away, they suddenly veered 90 degrees and traveled until they were again about 900m away. At that point they milled for a few minutes, then gradually increased their distance to about 1.3km, continuing to mill at the surface and orient toward the ship as the it passed abeam of them (as the airguns continued their ramp-up procedure), after which they headed off in the opposite direction to the ship's continued movement. The author notes that it is impossible to know whether the initial movement away from the vessel was triggered by the gradual increase in the sound level reaching a point at which they decided to move away, or if the group moved when they first heard the sound, and responded to it in something like a startle response. She also notes that the movement away was limited in time and space: after the initial movement away, "despite a four-fold increase in source volume...the whales exhibited behavior best described as milling." (Weir, 2008)

- A paper from late 2007 looked at cetacean distributions near a seismic survey in the north Atlantic, where again, the overall number of marine mammals within 1-2km did not change significantly when the seismic source was 'on' compared to 'off', but it appeared that larger and apparently less vocal groups were observed when the seismic source was active. The researchers noted that "seismic surveying can apparently have a behavioral impact at a high level of statistical significance without visual observers reporting seeing fewer marine mammals". This study was a post-hoc statistical analysis of observations made at the time of the survey, and the authors note that it may suffer from some confounding variables, including lack of clear separation of different species and bathymetric conditions. (Potter, et al, 2007)

Moderate noise and suspension of foraging activity: mid-frequency active sonar

While the observations near seismic survey vessels as reported above are subtle and ambiguous, more striking are two recent studies looking at responses to mid-frequency active sonar:

A UK Defence Science and Technology Laboratory study found changes in beaked whale behavior that it termed "potentially very significant." The study took place on an un-named instrumented range where researchers can listen to whales via bottom-mounted hydrophones while sonar exercises take place;

Beaked whale calls (primarily foraging signals) dropped to a quarter of the level heard at the start of the exercise; the researchers noted that "Beaked whale species ... appear to cease vocalising and foraging for food in the area around active sonar transmissions," and noted, "Since these animals feed at depth, this could have the effect of preventing a beaked whale from feeding over the course of the trial and could lead to second or third order effects on the animal and population as a whole."
Reported in Nature, which received the report under a FOIA request,, with the authors name and location of the study removed. http://www.nature.com/news/2008/080801/full/news.2008.997.html

In Norway, similarly dramatic yet more specific reactions were seen in orcas exposed to sonar signals. In a limited Controlled Exposure Experiment (CEE), in which two orcas in a group were D-tagged, the group exposed to mid-frequency sonar signals (maximum received level was only 160dB, roughly equivalent to full-power transmissions at 10km) ceased feeding and moved rapidly away; in addition, they exhibited an unusual dive pattern, diving about twice as deep (over 60m) as normal (20-45m), including a highly unusual reversal of their ascent (coming up to 15m from the surface, then retreating again to 60m). This was the third of five dives during the 35-minute CEE; we might wonder whether they were trying to find a way to avoid the sound. (Kvadsheim, et al, 2007)

While the nature of airgun and mid-frequency active sonar sounds are very different, their source levels and propagation patterns are not so dissimilar. Both are classified in the same "Sound Type" category in Southall, et. al. (2007). The different nature of the sounds is clear: MFA sonars are centered on a higher frequency, with airgun sounds being predominantly low frequency, especially at distance. In addition, the sonar signals are far less "biotic" and thus inherently annoying in nature, containing significant "kirtosis" (distinct peaks of sound across the frequency range, associated with harshness of sound) and rise times out of synch with animals' perceptual systems, while airgun sound, though loud, is essentially a large bubble bursting, and thus more organic. However, the source levels of the two are very similar (and much louder than other anthropogenic oceanic sounds that persist over many minutes, hours, or days), and so they impose themselves on the natural soundscape over similar scales. Indeed, propagation over distance is greater for airguns sounds (thanks to their lower frequency). Airgun sounds—especially at greater distances—also have some commonality with boat sounds, which have been widely shown to disrupt foraging activity (see below). The main similarity is the shared predominant low frequency; airgun signals "blur" significantly at distance, so that they are less of a quick pulse (though they tend to remain discrete even at large distances), and they share a relatively non-startling quality, while indicating the presence of human activity.

Moderate noise and suspension of foraging activity: boats

Two recent studies looked at the effects of boat noise on dolphins and porpoises, and the results were quite dramatic. In the Mississippi sound, researchers watched the reactions of bottlenose dolphins to jetskis, and in just under half the cases, within one minute of the presence of a high-speed personal watercraft, groups that were feeding shifted to "traveling" mode. Interestingly, groups of dolphins that were already in "traveling" mode often paused and began "milling." Researchers note that "The results demonstrated an immediate, short-term change in dolphin behaviour, suggesting that an increase in the frequency of high-speed personal watercraft in this area could produce long-term detrimental effects." (Miller, et al, 2008)

Another study shows that interactions with tour boats causes dolphins to interrupt their foraging behavior, and increase milling and socializing behavior. In this case, the dolphins being studied reduced the proportion of time they spent foraging from about 35% of the time, to under 25% of the time, when boats were present. Average length of time spent foraging decreased from 10 minutes to 6 minutes when the tour boat was nearby, and once interrupted, it took the dolphins 54% longer than normal to return to foraging (14 minutes on average, instead of 9). As tour boat trips increase, the proportion of time that dolphins are disrupted is also increasing; at the study site, the dolphins spent 29% of their time in the presence of a tour boat, and since the study was completed, a second tour operator began trips in the same area. (Stockin, et al, 2008)

Energetic costs of reduced foraging

A series of papers by Rob Williams and colleagues has investigated the behavioral impacts of boat traffic on both southern and northern resident killer whales. In early 2009, a paper released by this group confirmed that foraging activity among southern resident pods is significantly reduced when boats are within 400m, largely replicating findings from several years earlier among northern resident pods, and closely matching the results reported by Stockin, above (Williams, et al, 2009, 2009).

The earlier study (Williams, et al, 2006) was accompanied by a compelling examination of the energy budgets of animals when boats were or were not present; a striking finding was that while overall energy expenditures were negligibly increased in the presence of boats (2-3% increase), the total energy taken in via feeding was reduced by more than 25%. This suggests that in situations where human noise may repeatedly disrupt feeding behavior, longer-term impacts could result. As regards seismic surveys, the key question would be how large an area the disruption occurs within, and would be particularly relevant in areas with multiple seismic surveys over the course of months.

Discussion

While many of these results remain ambiguous, the pattern of response that they suggest is not surprising, especially when considered in consort with other studies of the effects of moderate noise. Foraging activity may be suspended in the presence of moderate noise for a number of possible reasons: animals may choose to remain near the surface, where noise tends to be somewhat minimized by destructive interference off the surface; the increased noise at depth may interfere with clear reception of echolocation or cooperative feeding signals; or, prey may move away from the immediate vicinity of active survey vessels (see Popper and Hastings, 2009)

In evaluating the growing body of research into the behavioral impacts of moderate noise, we are confronted with a glaring and seemingly intractable problem: all indications are that the responses of any given species, and perhaps even any given individual, to a given received level of sound (even when from the same sound source, let alone different ones), is consistently found to be inconsistent; some responses to this quandary are summarized in Appendix A. For example, in several of the studies noted above, half the population seemed to respond rather dramatically, while the other half apparently did not. Though this might be seen as a confounding factor, the lack of a clear dose-response function need not stymie all attempts to assess or address these questions. Others (Tyack, 2008; Weilgart, 2007) have detailed some of the key aspects of this issue of variable responses. Two of the more common considerations are: a) a lack of response does not necessarily indicate that the noise is not bothersome, as animals may remain in an area when the activity taking place is not easily transferred to another location (e.g. key feeding grounds), and conversely, may respond more quickly to noise when the current activity is not crucial to the particular time and place; and b) some individuals within a population may be more sensitive to noise than others; if this is so, then these individuals may be disproportionately affected by cumulative impacts, leading to potential population-level effects.

A crucial consideration is that the energy budget impacts of foraging disruptions by seismic surveys would be most problematic in baleen whales on summer feeding grounds. In such situations, interruptions during a short and critical feeding season could have clear impacts on individual and group health. Given that there are many indications that baleen whales avoid airguns at greater distances (lower received levels) than many other species, such impacts could be regional, rather than local.

Recommendations

While our understanding of the mechanism(s) that may contribute to reduced foraging remain murky, <u>marine mammal observations taking place on or around seismic survey vessels hold the promise of providing much-needed clarification of these potential impacts</u>. Toward this end, **the establishment of consistent observation and reporting standards and the maintenance of a database of all observations would be a helpful step**.

At the same time, an important aspect of the emerging pattern of (at least occasional) changes in foraging behavior is that these effects often occur at sound levels of 170dB or less, which is generally beyond the range of visual observations on survey vessels. **Investigation of this factor, and the implication that foraging activity could be disrupted over a relatively large area, is a crucial research need**. In order to accurately assess the effectiveness of current mitigation, we must know whether there are some situations or locations in which it may be difficult for animals to successfully relocate and continue unimpeded foraging.

A proactive approach toward investigating whether more widespread disruption of foraging activity is taking place would require the use of monitors (visual and/or acoustic) at some distance around survey vessels (perhaps 2km to 10km or more). This could be especially important in summer feeding grounds of baleen whales. **While data collected in such an effort would be essential in confirming the extent of behavioral impacts (both the spatial extent, and the proportion of animals affected), it is likely to be difficult to generate funding for such investigations unless required as part of the permitting process.** Some initial sampling studies (relatively inexpensively done using small boats near survey vessels) could determine whether there are indications of such impacts, with more extensive studies proceeding only if indications of impacts are seen.

Ongoing reviews of new research examining behavioral responses to moderate noise is especially important for regulators charged with developing effective mitigation guidelines. Recent multi-agency efforts in the US and EU (Southall et al, 2007; Marine Science Board, 2008) are attempting to create frameworks within which the ever-increasing amounts of new data on behavioral responses to anthropogenic noise may be more effectively organized, utilized by stakeholders, and used to design studies to address key knowledge gaps and provide solid foundations for more advanced research in the future. **DFO staff should remain in close contact with their colleagues in the US and EU so as to assure that observations here are incorporated in these efforts, and to respond as is appropriate to new findings.**

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Appendix A: How Much Noise Does it Take to Cause Problems?

This is the $100,000 Question, and both the US NMFS and the US Navy have developed relatively new approaches to investigating the question and estimating impacts.

NMFS Noise Criteria

In 2006-7, the NMFS put together an expert panel of researchers to look at the body of research into the impact of noise on marine mammals, and to recommend "noise criteria" for use in permitting. This review was hampered, as are all "big-picture" attempts to look at this issue, by the need to extrapolate from very few studies—more often than not on species other than the ones being considered, even sometimes from terrestrial species—due to what one Navy EIS referred to as "the overwhelming lack of other information." (perhaps you've had to be immersed in this field for a few years to have that obviously well-considered phrase trigger the empathetic/frustrated guffaw it did for me…)

The NMFS team recommended a modest increase in the threshold of noise that is considered likely to cause physical injury (permanent hearing damage); these increases spurred considerable grumbling from NGOs and some researchers, but will have little practical effect, because this level of sound only occurs very close to noise sources, and most EISs lead to estimates of only a very few, if any, animals being close enough to be injured.

The behavioral response section of this report was much more fascinating, and could have far more real-world impact. Because of the wide variation in responses, the authors refrained from making any specific recommendations about noise limits to minimize behavioral disruption. Instead, they created a set of charts that are designed to be used in coming years to both organize new data and to design studies to fill in the many gaps in the data that they reveal. Each chart addresses one of five "hearing groups" and a particular sound type (e.g., one for low-frequency cetaceans and single pulses, one for low-frequency cetaceans and multiple pulses, and one for low-frequency cetaceans and nonpulses; with the same set for each of the 5 hearing groups). Into the chart, the authors placed results from all studies that have investigated the particular type of animal and sound, arranged with increasing received sound level across the top (in 10dB steps, from 80-200dB RMS), and increasing severity of behavioral change up the left side (a 0 to 9 scale, from brief or minor change, through moderate changes in swimming or vocalizing, to obvious and extended changes in behavior). Each chart shows the cumulative total of individuals observed in all relevant studies that responded at each level of severity to each level of that particular type of sound exposure. The fascination comes in seeing the wide range of responses shown in virtually every chart: in some cases, a given dB level of sound exposure includes observed reactions at every level of the scale, from no response at all to very obvious disruption; and similarly, a given severity of response (say, obvious flight) can be observed at low sound levels, but not at higher levels. The challenges to setting an absolute limit are clear.

At the same time, though, the reasons that many environmentalists (and increasing numbers of scientists) are raising concerns about widespread and systemic noise impacts is also made crystal clear. Among the most striking observations:

- Dolphin responses to boat noise: over half the extreme reactions observed (rated at Level 8: obvious or long-term avoidance of the area, prolonged separation of females and calves, prolonged disruption of mating behavior) occurred at sound levels of just 100-130dB re 1uPa RMS. These results are somewhat confounded by the fact that at the same time, a majority of the animals who were exposed to 100-120dB showed little or no response (remember, these charts are compiling data from many different studies).
- Baleen whales responses to nonpulses (which include sonar, shipping, and enduring oil and gas noise such as drilling or seafloor processing): A clear threshold appears in the data: below 110dB, virtually all observations show little or no response, but at both 110-120dB and 120-130dB, the majority of individuals observed respond at "level 6" (avoidance, brief separation of females and calves, extended changes or cessation in vocalizing, visible startle response, brief cessation of reproductive behavior).
- Baleen whales response to multiple pulsed sounds (e.g. airguns): Another dramatic threshold is seen at a moderate noise level: 60 out of 75 responses at 110-120dB were rated Level 0 (no response), while 47 out of 72 at 120-130dB were at Level 6; this clarity is somewhat muddied by a wide range of responses to sound at 150-180dB, with clusters at both Level 0 and Level 6.
- Seals and sea lions in water: the vast majority of responses to 120-130dB sound are at Level 0, and then jump to Level 4 at 130-140dB.

While there remains considerable ambiguity, in that a given level of sound can cause responses at nearly all levels of severity, from no response to dramatic avoidance or cessation of feeding or reproduction, these charts clearly show that the many animals DO react to noise levels that are far lower than what regulators have generally considered (160-180dB are common regulatory thresholds for behavioral disruption). Sonar and seismic airgun noise can remain at levels above 130dB for fifty to a hundred kilometers, while similar sound levels around underwater construction or supertankers are common at ten or more kilometers.

New U.S. Navy Approach to Estimating Behavioral Responses
(Level 2 Harassment/Takes)

This wide range of responses has spurred the U.S. Navy, in consultation with NMFS, to develop a new approach to estimating the number of animals that will react to sonar signals. Of course, the nature of mid-frequency active sonar signals is very different than the sound signature of seismic survey airguns, so the specific figures used by the Navy are not simply transferable to seismic survey mitigation measures. This section is included here as an example of a more realistic approach to estimating behavioral impact numbers, and thus to addressing the question of whether current mitigation is effective at its stated goal of minimizing disruptions in key marine mammal activities such as foraging or mating. The fundamental point is that a risk function approach can more accurately account for the moderate but significant proportion of a local population that may respond to relatively low sound levels by changing their behavior in relatively dramatic ways.

Replacing an earlier impact assessment approach based on the simplistic assumption that ALL animals exposed to 160dB will be affected, and NONE hearing sounds less intense than that will have a reaction, a "risk function" approach is being used in the current round of Navy sonar training EISs. Ideally, this approach can be tuned as new research takes place (continuing to fill in and clarify the charts mentioned above). As currently structured, the risk functions assume that a few animals will respond at 120dB, half will respond at 165dB, and nearly all will respond at 180db. *(see figure below)*

However, the "slope" of the risk function is a matter of some debate: according to some environmental advocates and researchers, the slope of the curve (which charts the percentage of exposed animals who will react as sound increases) is too steep. While it begins to chart reactions mathematically at 120dB, the line remains at virtually zero all the way up to 140-145dB, then rises steeply to nearly a hundred percent reactions at 180dB. Given the range of responses documented in Southall, et al, 2008, the very low proportions of reaction shown at 120-145dB may be questionable. To some degree, this might be insignificant if nearly all responses at these levels were very low on the severity scale (and indeed, Navy personnel stress this idea), but it is becoming more clear that moderate and occasionally even severe reactions can occur at these low levels—perhaps not commonly, but certainly more than "nearly never."

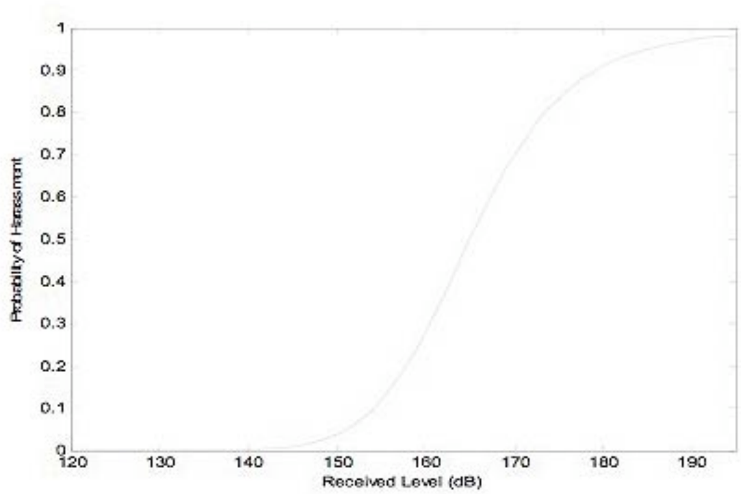

Figure 3.9-7: Risk Function Curve for Mysticetes (Baleen Whales)
Source: NWTRC DEIS, p. 3.9-72

Clarification of the slope of the risk function will be of interest to regulators of all noise sources, though such resolution may be some time away: this question is precisely the topic about which the previously noted "overwhelming lack of information" was referring.

Interestingly, as shown in the following chart, Navy estimates suggest that about half of all Level-B harassment events will occur beyond 5km, where visual observation is generally impossible, and that the majority of exposures will occur at received levels of 160-175dB, which are not insignificant levels of sound, so might be expected to trigger significant behavioral responses.

Table D-12. Behavioral Harassments at each Received Level Band from 53C

Received Level (dB SPL)	Distance at which Levels Occur in NWTRC	Percent of Behavioral Harassments Occurring at Given Levels
Below 140	51 km - 130 km	< 1%
140<Level<150	25 km – 51 km	2%
150<Level<160	10 km – 25 km	18%
160<Level<170	3 km – 10 km	43%
170<Level<180	560 m – 3 km	28%
Above 180 dB	0 m – 560 m	< 9%

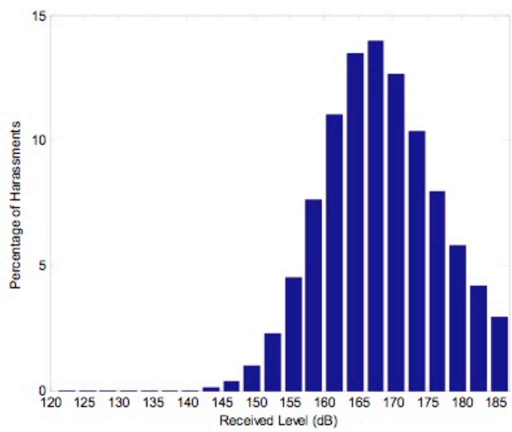

Figure D-26. Approximate Percentage of Behavioral Harassments for Every 5 Degree Band of Received Level from the 53C

Source: NWTRC DEIS, p D-50

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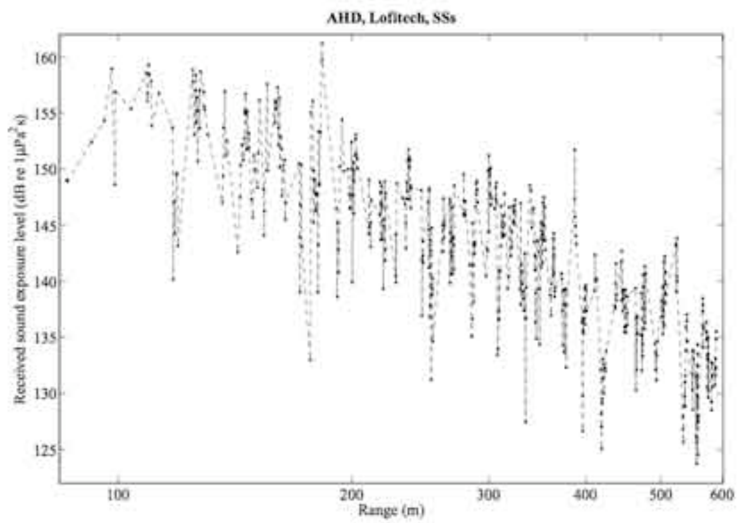
Southall, Bowles, Ellison, Finneran, Gentry, Green Jr, Kastak, Ketten, James Miller, Nachtigall, Richardson, Thomas, Tyack. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals, Volume 33, Number 4, 2007

See any of the recent Navy EISs for a discussion of their Risk Function analysis.

Appendix B: Variability of sound propagation and received levels

Given the increasing concern among biologists about behavioral disruptions triggered by noise, it is extremely important to acknowledge that real-world exposures can vary quite dramatically, primarily due to sounds traveling multiple pathways and constructively interfering in unpredictable ways.

Pinger Study Illustrates Extreme Variability of Real-world Sound Propagation
A very recent study (Shapiro, 2009) was designed to investigate why acoustic harassment devices, or pingers, on fishing nets do not always succeed in keeping dolphins away. The researchers made a series of recordings around pingers of several different types, and found that the received sound levels did not simply increase as they came closer, but fluctuated dramatically; thus, animals approaching the nets may not have clear sense of how far away they are. The study offers a fascinating glimpse into the real-world factors that will often confound simple geometric or spherical-spreading models generally used to predict sound exposure levels around any sound source. The researchers suggest that many factors likely contribute to the variation: changes in directivity of the source, subtle differences in source level for each ping, and, most influentially, as a result of the constructive and destructive interference of direct, surface-reflected, and bottom-reflected sound waves.



This graph offers a good picture of the degree of variation commonly found in the field. Note a routine variation of 10-15dB, with some more dramatic shifts: at 400m, the sound shifted from around 127dB to over 150dB; and again, at just under 200m, from just above 130dB to over 160dB (around a general average at that distance of perhaps 150db).

SWSS confirms peaks in received levels beyond 10km
An important finding of the multi-year SWSS was that the actual received levels of sound did not match those expected based on the spherical or geometric spreading models generally used to predict sound exposures and safety radii. Several factors were noted, especially that any given airgun blast results in a series of noise arrivals at a distance as the sound travels different direct and

reflected pathways, and that surface ducts can allow sounds to travel further than expected. At times, received levels reached over 160dB (peak to peak) at ranges over 10km; most models assume sounds fall below this level by 2km or so from the survey vessel.

More specifically, SWSS researchers (DeRuiter et al, 2006) found that sound reflections from the surface and sea floor created areas of increased sound intensity at ranges of 4-8km, so that “Regulation based on inappropriate application of geometric spreading law to calculate the extent of exposure zones could result in exposing animals to higher-than-intended noise levels." A related study (Madsen, et al, 2006) noted that that "The relative strength of pulses arriving on different paths vary with range and depth of the diving whales, but the absolute received levels can be as high at 12km as they are at 2km." None of the whales tagged made deep dives closer than 4km from the array, where sound levels could be expected to be especially high, and the team encouraged investigations at closer range in the future.

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Appendix C: Passive Acoustic Detection of Beaked Whales from a Moving Platform

Beaked whales seem particularly sensitive to many types of sound; their responses to active sonar are well known; they have been involved in the only stranding events (ambiguously) associated with seismic surveys; and they have also been shown to be extremely responsive to Acoustic Harassment Devices (Caretta et al, 2008: beaked whale by-catch in gillnets equipped with pingers dropped to zero over eleven years, whereas no other species showed such an absolute change). Detection of beaked whales as part of seismic survey mitigation is especially important, as key beaked whale habitat occurs in the Scotian Shelf region where oil and gas exploration is expected to increase.

An important recent study (Zimmer, et al, 2008) should inform all plans to adopt Passive Acoustic Detection (PAD, also known as Passive Acoustic Monitoring) for beaked whales. Beaked whales spend very little time at the surface, with foraging dives that last an hour or more, including about 30 minutes of active echolocation at the feeding depth. Visual detection is very difficult, so the possibility of using PAD/PAM is an attractive complement to visual spotting.

However, beaked whale high-frequency foraging clicks attenuate rapidly. According this study, acoustic modeling suggests that in "good conditions," e.g. wind speed of 2 m/s, a hydrophone close to the surface should detect beaked whales with a high probability within .7km. At the other end of the detection range, no whales would be detected at distances greater than 4km, except in very low ambient noise or unusually good propagation conditions. The detection curve generated by the models suggests roughly 50% detection when whales are 1.5-3.5km distant. When the researchers substituted some actual dive profile data obtained in D-Tag studies, detection probability may rise somewhat, with 80% detection being possible at distances of 1.5-2.5 km. Detection is complicated by the fact that the sound of the clicks is highly directional; only clicks directed nearly directly toward the receiver will be heard at the modeled distances, but echolocating whales do scan in many directions, so at least some clicks from any whale should be detected. Finally, the relatively quiet interval between deep foraging dives can be as long as 110 minutes, meaning that listening time should be roughly 140 minutes to have a high probability of detection if beaked whales are present. This, in turn, suggests that a slow-moving vessel (such as gliders or drifting buoys) will be more successful than a faster-moving active sonar or seismic survey vessel. (That is, if detections are only going to occur within roughly 4km, the listening platform should remain in a relatively similar area during the 2-hour-plus PAD session.)

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