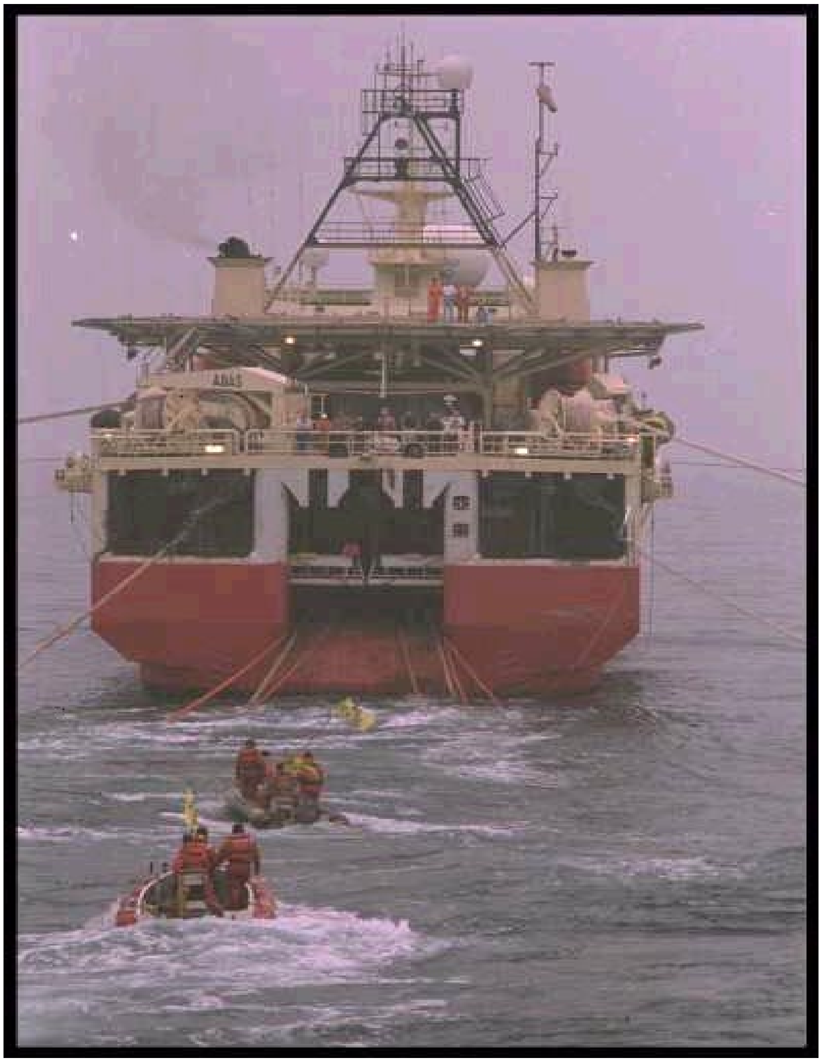
SONIC IMPACT:
A Precautionary Assessment of Noise Pollution from Ocean Seismic Surveys



GREENPEACE

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Abstract

Ocean noise pollution has become an increasingly controversial and studied topic in recent years. Attention to research and development of Naval low frequency sonar weaponry and the ever increasing scale of marine seismic surveys for oil exploration have raised significant concerns and scientific questions about the impact on ocean creatures and ecosystems, particularly marine mammals. Seismic surveys used in oil exploration and geological studies utilize airguns to produce explosive impulses of sound directed toward the ocean bottom. Echoes produced by these impulses are recorded and analyzed to provide information on sub-surface geological features for academics and the oil and gas industry. Both ocean researchers and the public have become concerned about ways that sounds created by the airguns may impact ocean creatures.

While it is generally assumed by industry that the risk of physiological damage is low, there are many uncertainties in our understanding of both sound transmission and the biological effects of sound "pollution" in the ocean. In addition, the complexities of acoustics science and inconsistencies within the research community in terms of measuring systems, has made it difficult for lay people concerned about seismic surveying to assess existing research and data.

Here we provide a primer for the non-scientist on current knowledge about airguns, their impacts and acoustic sensitivity of ocean-dwelling creatures. This report concludes that given the glaring holes in our knowledge of this subject, there is a need to take a precautionary approach to regulation of anthropogenic sound in the seas and that a series of suggested mitigation methods and research programs be undertaken in consort with future seismic surveys.

Foreword

The outer continental shelves of every continent could not be farther from public consciousness in most cases and the oil and gas industry would just as well keep it that way. The coastal oceans are a broad frontier for development of new oil and gas reserves. Seismic surveys are a major tool used by industry to map potential oil reserves in these areas. Seismic surveys utilize airguns, or rather air cannons, to produce explosive impulses of sound directed toward the ocean bottom producing echoes that are recorded and used to assess the sub-surface geology.

These tests are massive, covering vast areas of ocean with thousands of blasts going off every few seconds in some cases over the course of days, weeks or months. The noise pollution from these tests can currently be heard literally across oceans.

Researchers and the public have become concerned that sound created by the airguns may adversely effect ocean creatures. While it has been assumed that the risk of physiological damage is low, there are many uncertainties in our understanding of both sound transmission and its biological effects. The marine mammals and other potential victims of seismic tests are invisible unless they wash up on shore. Death is not the only damage endpoint as animals may suffer loss of hearing, bodily harm as well as disruption of feeding, mating and migration.

Greenpeace, the concerned public and the research community will not stand by as these endangered creatures are harmed or displaced by seismic testing or other noise pollution in the oceans. As a first step to bring public awareness to this issue, we determined it critically important to collect and review the limited amount of existing scientific research about noise in the oceans and its impact on marine mammals. In addition, the research had to be presented in a way that non-scientists would be able to access it, evaluate it and when possible, communicate their concerns in an informed way.

This report provides a primer for the non-scientist on current knowledge about seismic airguns, their impacts, and acoustic sensitivity of ocean dwelling creatures. The report discusses the need for a precautionary approach to regulation of human-made sound in the seas: and presents suggested mitigation measures and research to be undertaken to avoid damage from future seismic surveys. Greenpeace's report, Sonic Impact, references past sonar-related stranding incidents and points to the possible long-term effects on the health of marine mammal populations.

This debate is far from over. Currently, the U.S. government is skirting its responsibility under the Endangered Species Act to protect a recently discovered resident population of sperm whales in the Gulf of Mexico, right in the middle of rapidly expanding oil and gas development. Will we wait until the whales wash up on our beaches or will we forge a new US and indeed global energy policy that prioritizes clean renewable energy sources over oil and gas exploration - one that safeguards our beaches and coasts from oil drilling hazards, helps solve global warming and safeguards safe, clean drinking water and clean air?

Around the world, the oil industry is striking out onto the Continental Shelf in search of new oil reserves to tap to quench our endless thirst for oil. Oil exploration off the coast of West Africa, Eastern Russia and in the Arctic continues daily with little or no safeguards for the ecosystems and creatures of those regions. This global problem deserves global attention and indeed global regulation and oversight.

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1.0 Introduction

Over the past several years, the specter of whales washing ashore[1] and fleeing in panic[2] after exposure to Navy mid-frequency active sonar systems has focused new scrutiny on the impacts of human-made sound on ocean creatures. While Navy sonars are designed to be heard over vast distances, they are typically operated for relatively short periods at a time. By contrast, industrial oil and gas exploration ships have been deploying seismic survey airguns that are similar in intensity, often for weeks or months at a time, with relatively little public concern. Partly in response to the concern raised by the high-powered sonar systems, since the fall of 2002 both governments and the courts have begun to more closely question seismic survey projects. It seems that a new standard is emerging, whereby both courts and permitting agencies are leaning toward the "precautionary principle," leading to decisions that tend toward caution and protection when conclusive proof of safety is absent.

This is a radical shift from past standards, which held that clear proof of harm was needed to halt new human activities. In October 2002, a Federal Court stopped a geologic research project in the Sea of Cortez when two beaked whales were found dead, despite a lack of undeniable evidence that the seismic activity was responsible[3]. The scientific community was somewhat shocked that the court would act on such circumstantial evidence, while environmental advocates cheered the court's willingness to not wait for more definitive proof, which (given that minimal biological assessment takes place during geology projects) would likely be in the form of more dead whales. During 2003, the Canadian government slowed a proposed geological research project off their west coast[4], and is giving a similarly close look to an oil and gas survey off Cape Breton planned for the winter of 2003-4[5]. The Australian government refused to issue permits for a survey near a marine park, citing precautionary dictates.[6] And in late November, the Bermudan government refused to issue a permit for seismic geologic surveys off its coast, citing concerns for impacts on marine mammals.[7]

Some observers have complained that the public, press, and even courts are misinterpreting the Marine Mammal Protection Act and National Marine Fisheries Service regulations governing "small takes" by incorrectly asserting that "take" means to "kill" marine mammals, while in fact "takes" include any sort incidental exposure of animals to human activity that may cause behavioral changes, including simply creating sounds that they may hear (such exposure is termed "level 2 harassment" under the statutes). The fact is that the public, press, and courts are beginning to realize that "harassment" in the form of exposure to excessive sound is something worth being concerned about, and are calling on regulators to address such "harassment" as defined. **This reflects a desire on the part of many citizens (as well as a growing number of researchers) that our regulations should not simply protect sea creatures from physical harm, but should reflect a consideration and respect for their right to hunt, rest, and travel through the oceans without being subjected to excessive human noise**.

Simply put, our desire to search for oil should not trump ocean creatures' ability to survive and thrive.

In the U.S., driven by an energy policy that centers on developing new sources of fossil fuels, there is a push for more exploration in the few territorial waters that are not subject to offshore drilling bans. The Gulf of Mexico and the Beaufort Sea, on Alaska's North Slope, are the two primary offshore development areas where new seismic surveys are likely to take place (though Canadian exploration certainly can impact American waters and wildlife). It is not at all clear that American regulatory agencies are prepared to join in the present global move toward a more precautionary approach to permitting. Indeed, current application of regulatory standards seems inconsistent, with activities in the Gulf of Mexico receiving a lower level of oversight than the policies established in the Beaufort Sea (see Section 5.4 below). In addition, recent changes in the language of the Marine Mammal Protection Act (included as a part of the 2004 Defense Authorization Bill) have established permitting standards for the military and researchers that are *less* precautionary than existing rules.

The impacts of seismic survey airguns have been quite thoroughly studied by both government and industry. The reports that result from these studies are fairly consistent, and tend to show that whales, dolphins, fish, sea turtles, and squid are all clearly impacted by seismic activity[8]. The danger of gross physiological damage is relatively low, apparently an issue only at very close range (and possibly in unusual topographic situations). There are clear avoidance responses in all species at ranges of one to several kilometers; it is likely that the sounds are audible and may mask important communication or perceptual cues at much greater ranges. The general response to these results has been to allow seismic surveys fairly free reign; airguns are shut down only when cetaceans are seen at very close range (100m to 1km, depending on the size of the air gun array and species of concern in the area); localized disturbance of fish or whale movements is considered to be of negligible effect (the assumption is that the creatures will simply move far enough away to not be harmed). The generally accepted exposure level for sea creatures is 180dB re $1\mu Pa^2$, which compares fairly well (if a bit loosely) to accepted terrestrial limits for impulse noise[9] and observed behavioral responses of marine mammals and other ocean species[10]. Distances under 1km are, conveniently enough, within the range that allows ship-board observers to spot whales (at least whales at the surface). This rough correlation, however, should not blind us to the many indications that the 180dB threshold, reflecting an area 1-2km around the survey ship, may be set a bit too high.

Indeed, current standards for acceptable exposure are based largely around a dramatically elevated threshold: the effects of human sounds on marine creatures are considered acceptable unless they cause dramatic physiological damage or are likely to diminish a species' long-term survival or reproduction rates. Imagine if the noise standards in our cities and workplaces allowed any sounds that did not threaten the survival of our species! Our human-exposure standards are based on avoiding long-term hearing damage. While it is very difficult, if not impossible, to determine thresholds of sound exposure that cause hearing damage in animals, surely there is room for developing standards that are more sensitive to other species' needs than those currently in place.

Although this report will provide a summary of the current state of our knowledge, it is important to realize that all the research that has been done to date still offers only an extremely limited picture of the extent and impact of human noise in the oceans, and of the functioning of ocean creatures' acoustic perceptual systems. Research scientists certainly do their best with what they have to work with, but there is a widely recognized lack of solid data in nearly all aspects of ocean acoustics[11]. Potter/Delory (1998) raise this point clearly:

> "Marine mammals are perhaps the hardest mammalian group to study. **Virtually all relevant aspects of their biology (including sensory capabilities, undisturbed behaviour and its adaptive significance, distribution and abundance) are only poorly understood**. Conducting marine mammal research at sea is always difficult and costly. . . Given such a background of ignorance, it is extremely difficult to even establish a meaningful framework for estimating the impact of noise on these animals."

For this reason, it's crucial to remember that the observations and studies that have taken place provide just some starting points for understanding, and that there is much more to be learned about the acoustic experience of ocean creatures. Just as it is imprudent to make sweeping conclusions based on current knowledge, likewise it is important not to lose sight of the idea that human activities in the ocean are likely having effects that are not yet recognized. Since many marine species are experiencing severe population declines (e.g., most fish species), or are in the tenuous process of recovery (e.g., many cetacean species), it is essential to act with caution, knowing that any errors we make now in assessing the ecological impacts of our actions could easily lead to biologically critical population stresses, including limited genetic diversity or extinction.

What are the uncertainties that we should bear in mind as we survey current research? There is much local variability in how far sound travels in the ocean, and a dramatic lack of knowledge about the biological effects of sound on wild creatures.

Acoustic propagation (the physics describing the way sound travels through the water) is relatively well understood yet highly variable, with water depth, seafloor composition, temperature, and salinity all playing roles. Most studies of how sound introduced into the sea by seismic surveys will decrease over distance are based on mathematical models; while often being good approximations, these predictions have too rarely been followed up with direct measurements (funding for such field studies is difficult to come by). Propagation in deep-water areas, where much of the new exploration is taking place, is relatively well understood: powerful sounds can travel extremely long distances while remaining significantly louder than the ambient background noise of the sea.

Meanwhile, very little is known about the physiological or behavioral responses of cetaceans, fish, and other sea life to sound. We have no direct knowledge even of the hearing range of large marine mammals, and there is ample reason to suspect that our land-based conception of "hearing" (centered on the ears and on perception of discrete frequencies of sound) offers only a very partial picture of the acoustic perception of water-based creatures. It seems possible that many or most sea creatures perceive sonic vibrations throughout their bodies, and are capable of sensing minute changes in acoustical energy, beyond our perceptual imagination or scientific measurements.

In surveying the existing research on seismic surveys, it's easy to get lost in a sea of numbers, charts, and conclusions. The abstractions generated by models of acoustic propagation, threshold sound levels, and predicted consequences can lead to both a false sense of security (it's not killing the whales) and false sense of uncertainty (there's no way to know what the animals are experiencing). Strangely, both responses lead to similar action, or more commonly, inaction.

As an antidote to the torpor that can be imposed by the deluge of data, it is especially revealing to step back and listen to what researchers say about their own experiences in the field. These "anecdotal" reports from people who have grounding in the objective data may be especially eye- (and ear-) opening:

> The authors have been in the North and Norwegian Seas on many acoustic experiments, and **listening to the raw output from hydrophones deployed from the research vessel, the entire soundscape is often dominated by the repetitive 'boom...boom...' of distant geophysical surveying.** This incessant cacophony, an acoustic equivalent to the fabled 'Chinese water torture' deeply disturbs some individuals who are exposed to the sound over long periods. Perhaps it does the same to whales. . . Recently, attempts were made to monitor baleen whales off the West Coast of the British Isles using a SOS US array of (deep-water) hydrophones. **Levels of background noise were so high in the summer months due to oil-related seismic surveying that monitoring had to be abandoned for long periods**. . . **One can only assume that baleen whales' ability to monitor (their) acoustic environment might be similarly compromised by such noises.**
>
> -Potter, Delory (1998)[12]

The increased concern about seismic testing is taking place in a context of realizing that all forms of ocean noise need closer scrutiny[13]. High intensity sonar, seismic airguns, and explosions related to industrial or military activities are simply the loudest forms of human noise, and therefore ones of special concern. Chronic exposure to high levels of shipping noise and construction activity are also part of the picture. Darlene Ketten, perhaps the world's foremost authority on cetacean hearing systems, stated at a marine mammal health conference that **"a surprisingly large number of stranded animals, nearly 50 percent, show evidence of some form of auditory compromise or pathology that correlates with low to profound hearing loss in other species."** (Ketten, 2002) While bearing in mind that human noise is far from the only possible source of such physiological damage (parasites, infections, and trauma from natural sources or other animals could all be factors), this is surely cause for pause.

The issue of human noise in the ocean raises a complex debate with a mix of ethical questions and compassionate concerns. For this reason, closer attention should be given to the confusions caused by both the variety of measurement systems used by researchers, and the tendency of laymen to not take into account the ways that sound is measured and experienced differently in the denser medium of water, compared to our familiar experiences in air. **As laymen are asked to meet the science community on common ground, at the same time it is also valid and important to encourage researchers, regulators, and the courts to acknowledge the scope of uncertainties in our knowledge, and to act in ways that take into account the profound risks of causing irreparable harm to sensitive natural systems and populations whose future survival is tenuous.** Again, it is especially useful to listen to scientists who are beginning to voice concerns about the implications they see underlying the dry data of their final reports. In the words of Hal Whitehead, a marine mammal expert at Dalhousie University in Halifax, commenting on the Cape Breton seismic survey plans, "My message is that we know very little and the risks are very great. We should proceed very cautiously."[14]

2.0 Seismic primer

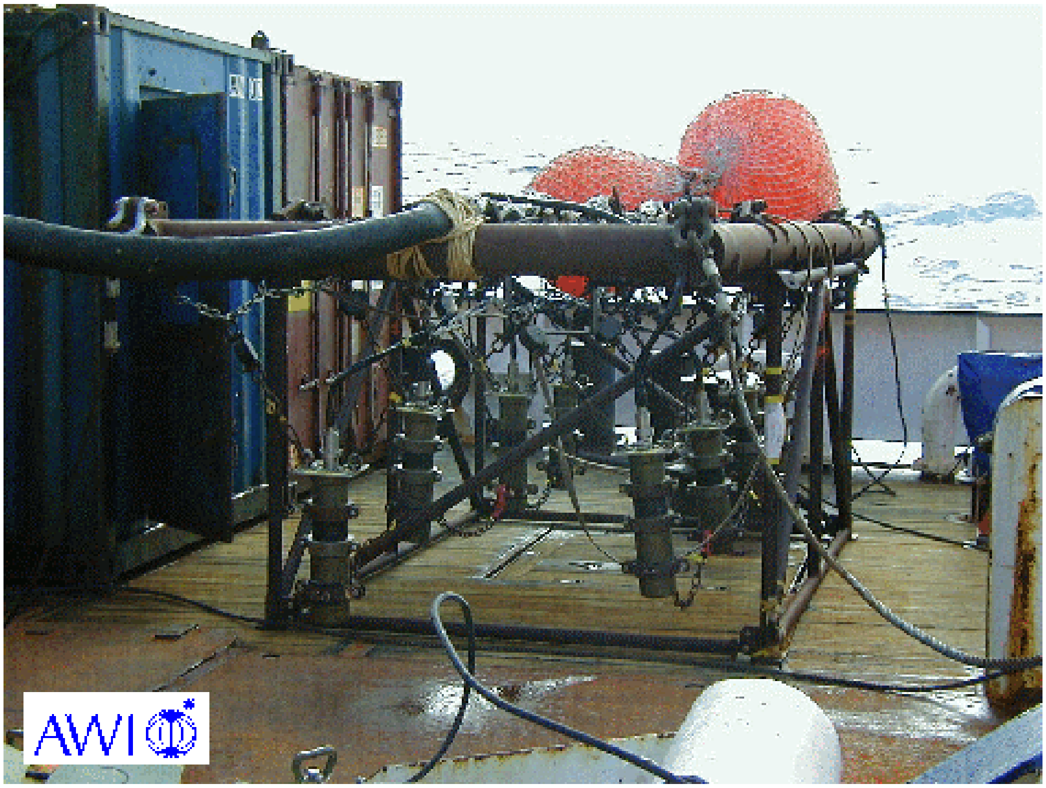
2.1 Functionality

2.1.1 How they work

Seismic airguns generate sound impulses by expelling bubbles of air; single airguns (often used in basic geological surveys, especially ones that are simply mapping sea floor profiles) expel from 30 to 800 cubic inches of air per shot. (From this range of size, you may be able to imagine that while some guns are small enough to be held in your hands, others could more accurately be considered air cannons.) For oil and gas exploration, air gun arrays are used. Arrays consist of 12-48 individual airguns synchronized to create a simultaneous pulse of sound, outputting a total of 3000-8000 cubic inches of air per shot. During seismic surveys, shots are typically fired every ten to sixty seconds;

surveys can last from a few days to several months. The sounds are so powerful because the survey is attempting to generate echoes from each of several geologic boundary layers below the bottom of the ocean; results can show geologically significant information as deep as 40km down[15].

Until 1993, most surveys were 2D; this means they used one array of airguns (or, in the earlier days, dynamite tossed overboard at regular intervals) to generate the sound pulse, and a single "streamer" of hydrophones to receive the echoes. More modern 3D surveys use multiple arrays, and multiple hydrophone streamers (stretching several kilometers behind the ship and over 1km wide), to create much more detailed maps of subsurface geology.



Airgun array on board the Polarstern, a research vessel doing geological surveys in the Weddell Sea, of Antarctica
http://www.awi-bremerhaven.de/GPH/www_weddell_tectonics.html

An airgun array being fired during a marine geophysics research project off the coast of Nicaragua
http://es.ucsc.edu/~silver/MarineGeophysics.html

2.1.2 Where they are used

Seismic surveys are carried out primarily by the oil and gas industry, and secondarily by research geologists studying topics ranging from plate tectonics and climate change to gas hydrates and ancient meteor impacts. Continental shelves are by far the most common areas for surveys; among the zones that have been subject to ongoing interest are the North Sea, the Gulf of Mexico, and areas around Alaska, Australia, Venezuela, the Canadian Maritimes, and Brazil. Most of the United States coastline and "outer continental shelf" is currently off-limits to oil and gas drilling, and thus (apart from Alaska and the Gulf of Mexico) US waters are not subject to many surveys; a proposal to mandate a survey of US coastal waters was floated during the 2003 Congressional session, but did not prevail.

Most surveys are conducted before development leases are bid on, in order to identify likely oil and gas reservoirs. After issuance of a lease, the lessee will generally do both low-power, high-resolution surveys to determine best placement of oil rigs and pipelines, as well as deep-penetrating 3D seismic surveys, aimed at discovering previously unnoticed reservoirs in the lease area. During the 40-year life of the lease, repeated surveys are done to track fluid flows within the reservoirs (these repeated 3D surveys are referred to as 4D data). Areas not surveyed since the development of 3D technology in the early 1990s, are often re-surveyed to take advantage of the increased resolution now obtainable.[16]

2.1.3 Frequency spectrum as related to ocean creatures

It is important to consider not only the intensity of sound being output by airguns, but also the frequency band(s) within which the sound is loudest. Each ocean species vocalizes, and presumably preferentially perceives sound, in a particular range of frequencies; these ranges differ greatly between species. Larger whales are likely the most susceptible to direct impact by the relatively low frequency output of airguns, since they make the most use of low frequency bands themselves.

Calls or perception of surrounding environment can be obscured by "acoustic masking" from sounds in similar frequency ranges. The most dramatic masking is caused by sounds within .1 to .2 octaves of the sound of interest (be it a call or the sound of prey or predators). However, some masking can take place in frequencies further from the source of the interference, with increasing interference as the intensity of the interfering sound increases (Potter, 1998).

Baleen whales (humpback, blue, fin, grey) are too large to have been studied in captivity, so vocalization patterns must be examined to determine a sense of their range of hearing; it appears that frequencies from 20-500Hz are especially important, with some components of their calls occurring up to 8kHz (8000Hz). Toothed whales (dolphin, orca, beaked, sperm) are focused on higher frequency sounds, from 100Hz to a bit over 100kHz, with a special concentration of sensitivity in the 10-70kHz bands. Seals respond to sounds ranging from roughly 300Hz-80kHz (Richardson, et al, 1995).

Seismic air gun arrays output a rather broadband low-frequency sound (i.e., not a single "tone" or "chord", but rather a noise composed of an undifferentiated range of tones). Peak output is generally in the range of 50Hz, with a secondary peak appearing in the 150-200Hz range, and continuing decreasing peaks up to almost 1kHz[17]. There is often a "ghost notch", or reduction of output intensity in the 100-125Hz range, due to "destructive interference" from sound reflecting off the surface. The primary frequency range used to

Note on Hz:
The frequency of sound waves is measured in the number of pulses or cycles per second, or hertz (Hz). Low frequency sounds range from just a few cycles per second, up through tens and hundreds of cycles per second. A level of 1,000 Hz or 1 kilohertz (1kHz), is often considered a threshold into mid-frequency sound. Humans can hear sounds ranging from 20 Hz to 20,0000 (20kHz). Most airgun noise occurs in the range below 1kHz.

analyze the sub-surface geology is 3-100Hz; this is the most dominant and usable frequency band that bounces back up toward the surface[18].

There is considerable transmission of sound in somewhat higher frequencies, as well. McCauley (2000) made direct measurements of a commercial airgun array's sound output that shows clearly audible sound in frequencies ranging up to 1000Hz (1kHz), and Goold (1998) mentions airgun effects up to 8kHz. The end result of all this is that, given the relatively extreme source levels of airgun sound, even creatures whose hearing is not centered on the lower frequencies can hear and are affected by the sound of seismic surveys.

2.1.4 Short and long duration sound/rise times

In general, most creatures respond more dramatically to sustained sounds than to transient ones. This is partly because our perceptual systems take some time to process and react to sound. Studies with marine mammals tend to bear this out; whales may (depending on habituation) show avoidance to sustained sounds at around 120 dB re 1μPa, while avoidance to short-durations sounds (like airguns) begins at 140-150dB re 1μPa[19].

However, this tendency is perhaps somewhat countered by the relatively "unnatural" waveforms of some human-generated sounds. Impulse noises, such as caused by explosions and airguns, have faster rise-times than most natural sounds, far faster than vocalizations, and somewhat faster than even seaquakes. This faster rise time can trigger a reaction that would more likely be expected to a louder noise[20]; this may account for initial startle or early avoidance maneuvers at sound levels as low as 125 dB re 1μPa[21].

2.2 Measurement issues

There are several measurement issues that have caused much confusion in debates and research about ocean noise. Some of these—such as the differences between sound in air and water—have compromised laymen's ability to intelligently communicate their concerns to scientists and regulators (likewise, this confusion can at times cause undue concern in the lay population). Others—such as the plethora of measurement systems used in research studies—have made it difficult to analyze, interpret, and compare results from different studies.

2.2.1 Decibels in air and water

First off, a primer on the decibel system: decibels (dB) do not measure an absolute amount of sound, but rather represent a proportional increase above an arbitrary reference level of sound intensity. Each increase of 10dB represents a 10-fold increase in the sound's intensity; thus 140dB is ten times more intense than 130db, and 150db is one hundred times more intense. However, 140dB it is not ten times louder than 130dB; our perception of relative loudness decreases as sound intensity levels go up. To some degree, this matches the logarithmic scale of decibel measurement, so that a sound of 150dB will tend to sound about half again as loud as a sound of 100db. However, there is much individual subjectivity in perceived loudness, as well as no real knowledge of how other species perceive loudness. Also, when considering a sound's impact on sensitive acoustic perceptual systems (i.e., ears or other organs and systems), the relative intensity is perhaps more important than the perceived loudness.

Comparing dB measurements in air and water involves two different measurement corrections. One of them is purely a numerical shift, while the other is more complicated, involving both mathematical and physical differences. The result of both corrections can at times make estimating the impact of sound in the water a difficult task. Adding to the situation is the fact that our tools perceive specific physical qualities of sound waves, and our measuring systems then abstract this information into quantifiable values, while the experience of sound (by either humans or other animals) is far more complex, involving physical responses that are more diverse, subtle, and integrated than those captured by our sound-measuring tools, as well as subjective responses to sounds that are both individual and unquantifiable. Despite these uncertainties, there are some straightforward and important corrections that scientists use in order to make the measurement of sound in water more closely align with the physical experience of the listener.

The first adjustment is a simple 26dB difference, related to the arbitrary reference level from which the sound intensity is measured. The air reference level is "dB re 20µPa" (µPa is a unit of measuring sound pressure, the micro-Pascal), which is the limit of human audibility (that is, humans can only hear sounds that have a pressure of at least 20µPa). In water, where the human hearing system is inefficient (because our eardrum does not respond well to the added pressure), it doesn't make sense to count dB in relation to human audibility threshold, so it is instead measured from an arbitrary level of 1µPa. Since micro-Pascals and dB are related logarithmically, this means that a sound of a given intensity will be measured as being 26dB higher in water than in air. So (considering only this first correction factor), a sound measured at 126dB in water will only be as loud as a sound that measures 100dB in air. The two sounds are experienced identically.

The second adjustment is a bit less cut and dried. Because water is much more dense than air, water has higher impedance, so sounds of equal measured pressure will (because of the physics and math of impedance), be measured at 36dB higher in water. However, this time, the difference is not purely mathematical, as in the reference pressure correction. To some degree, the sound as experienced in water will feel louder—if you were in a bathtub listening to sound at 90dB, and then moved the speaker underwater, it would be measured as 126dB; unlike the previous correction, though, the sound would indeed feel stronger when experienced underwater, as well as being measured louder. Since this is a subjective experience, it is very difficult to quantify to what degree the 36dB measurement difference is actually experienced physically as an increase in sound intensity.

Since subjectivity is such a slippery slope, and researchers are by nature comfortable with the abstractions of measurements and mathematics, it is generally accepted in ocean acoustics that sounds of equal pressure (in the respective reference units) can be considered 62dB higher in water than in air (26dB plus 36dB). This means that when a sound is reported as 206dB in water, it will correspond to a sound measuring 140dB in air. When trying to imagine the impacts of sounds reported in ocean acoustics studies, it is crucial to keep this correction in mind (while also remembering that the subjective experience of the sound may be a bit louder than the correction implies).

2.2.2 Inconsistent measurement systems used by researchers

More surprising than the forgoing discussion of dB differences is the fact that there is no generally accepted measurement system for use in studies of underwater sound. Several systems are in use, each with its own advantages and relevance to the impacts of sound on animals; again, similar sounds result in significantly variable dB measurements, depending on which measuring system was used. Strangely, many literature surveys complain that all too often, studies do not sufficiently clarify which system is being used, making comparisons between studies difficult; in recent years, this difficulty has been more widely recognized, so that while there is still no agreed upon standard approach, at least researchers communicate more clearly which one they are using.[22]

The three most common systems of measurement are:

- Peak levels / peak-to-peak, mean peak, or zero-to-peak (measured in units of dB re 1μPa^2; though often by convention the ^{2} is omitted). This considers the change in amplitude (pressure) of a sound wave from the lowest to highest point on its waveform. It is relatively easy to measure, and may be especially relevant to concerns about direct physical damage to tissues, since it is the best reflection of the physical displacement likely to occur in tissue with the passing of a sound wave. In addition, peak measurements are less time-dependant than the following methods, which is appropriate for short-duration sounds such as airguns. However, especially as sound is measured at more distance from the source, reflection of the sound waves off the sea's bottom and surface, along with differences in the speed at which sounds travel through different layers of the sea, create a situation where the received sounds are arriving along countless different pathways, making their waves interfere with each other. This interference can decrease or increase the intensity of the waves arriving at the receiver; accurately predicting the actual peak values is virtually impossible in many cases.

- Root-mean-squared or mean-squared-pressure levels (units of dB re 1μPa). This measures the total sound intensity, then divides it by the length of the signal. It is also useful biologically, because our perception of a sound's intensity takes place over time, not instantaneously. Acoustic power, intensity, and energy are proportional to the mean squared pressure. However, measurements based on this system are difficult, since it is not always easy to precisely identify when a sound starts and stops, especially at some distance from the source, where individual sound impulses are blurred and often can be confused with existing background sounds (at the lowest frequencies, "headwaves" traveling faster along the bottom of the ocean, also complicate the timing). This problem can tend to cause researchers to over-estimate the length of the sound, thereby under-measuring the RMS value.
- Measurements of the signal's energy (units of dB re 1μPa^2.s). Like RMS values, energy measurements do not depend so directly on the specific waveform of the received sound. After extensive comparisons of the many approaches to measurement and prediction, McCauley (2000) built on earlier work by Malme et al (1996) to develop a formula that has proven effective in measuring the energy of a signal; simply stated, it involves a correction of mean squared calculations to account for the difficulty in determining signal duration. He found that, compared to the above systems, measurements of what he termed "Equivalent Energy" provided the most reliable indication of a signal's intensity in a wide variety of situations (water depth, distance downrange, etc.).

While McCauley's Equivalent Energy approach proved to be effective at accurately measuring sound in a variety of situations, in order to provide more useful comparison to other systems, and to better estimate the effects that are best measured by the other systems, a conversion factor was obtained, based on direct measurements in the field. **For an airgun array in the open ocean, RMS values averaged about 13dB higher than Equivalent Energy values, while peak-to-peak values averaged 28dB higher.** Bear this in mind as the propagation of airgun sounds is described in Section 2.3 below.

Note: Each of the above systems presents measurements based on a signal's total broadband energy (generally using the 1/3 octave band standard to create the subsets which are summed or averaged); most commonly, these energy levels are plotted against distance, to show how the received level falls as it travels. At times, they are stated with reference to the range of frequencies being measured (generally the range within which the sound had significant energy). It is also common to present sound data as "sound pressure density spectra" levels. In this approach, the sound pressure or intensity is broken down and plotted separately in smaller frequency band chunks; the resulting graphs show the sound level (in units of dB re 1μPa^2 /Hz) plotted across the frequency spectrum, from 1Hz to a relevant number of kHz. This approach is useful to analyze the tones at which a broadband sound is most powerful; it can also highlight the general bands within which animal sounds or anthropogenic sounds carry the most energy. As related to seismic airgun signals, sound pressure density spectra levels tend to highlight the ways that airgun sounds are especially intense in frequencies below 100Hz, while carrying continued but declining energy up to 1kHz. McCauley (2000) and others often present density spectra data as well as broadband energy data, either by plotting the sound level at a given distance against the frequency spectrum, or by adding a color scheme that allows presentation of three variables: frequency spectrum, dB levels, and distance.

2.2.3 Consideration of various exposure regimes in testing

Studies of the impacts of seismic airguns have similarly used a variety of experimental models, or "exposure regimes," each of which offer advantages and disadvantages; it is often difficult or even impossible to extrapolate effects from one approach to another.

The three prime exposure regimes that have been used to date are:

- Caged trials: Here animals are put in cages in the sea, and the seismic source is moved in relation to the cage. Offers careful control of exposure levels and relatively easy observation of reactions; responses are likely somewhat altered by the caged environment. Very useful for determining precise levels of sound that cause physical damage.
- Controlled approaches in the field: Using a single gun or small array, researchers move toward or past wild pods or schools, and watch for responses. Offers relatively good control over sound levels being tested, and more realistic simulation of the passing of a commercial survey ship. Observation of responses can be difficult. No measure of exposure history (i.e. habituation to noise) of specific animals.
- Monitoring of responses to commercial operations: Boat, plane, or shore-based observations of the reactions of wild creatures to an operating seismic survey. Gives best look at response and recovery times from actual surveys. Can be used to verify either exposure models or response predictions generated by other exposure regimes. No control exposure levels; very difficult to observe reactions, especially at long distances from survey ship.

While there is no definitive "preferred" technique, it is important to consider which regime was used as we compare results. Many studies involve no (or few) direct sound measurements. A surprising amount of research is based solely on mathematical and physical modeling, making predictions of sound propagation on which deployment and mitigation procedures are then founded. The McCauley (2000) study is one of the few to have made comprehensive direct sound measurements in the field during a commercial seismic survey[23].

2.3 Overview of source levels and received levels at various ranges

Source levels of airguns and arrays are generally reported at 1m from the array. In general, commercial airgun arrays output sound in the range of 218-228dB (equivalent energy; increase by 13dB for RMS, 28db for peak to peak). These figures from McCauley (2000) compare fairly well with measurements reported by Caldwell (2000) of 240-246dB (peak to peak).

The sound emerging from the airgun is directed downward; sound levels measured to the side (which is the sound that is of most interest, as this is what travels through the water to affect animals at distance) is lower by a factor of 12-20db, at least nearby the vessel[24]. Also, depending on the type of airgun array, horizontal sound levels are loudest either fore-and-aft (2D array) or abeam (3D array) of the ship; this variation is in the range of 2-8dB (McCauley, 2000, p51).

2.3.1 Variability in transmission loss and received levels

Sound is absorbed, scattered, and spread as it moves outward from its source. Researchers look at all of these as factors in "transmission loss," or the reduction in the sound level as it travels. The received level at any given distance is the source level, less transmission loss.

In the simplest models, assuming cylindrical or spherical spreading, the received level decreases simply by virtue of the sound energy being spread over a larger and larger surface area the farther from the source it is. In both spreading models, there is a relatively rapid decrease in the received dB level at close range, followed by a leveling off of the dB value out to many tens or hundreds of kilometers. High frequency sounds quickly fall victim to transmission loss (especially absorption and scattering), while low frequencies can travel vast distances at still-audible levels (see Section 2.3.2 below); in the ideal situation, the transmission loss of a 100Hz sound will nearly level off at about 100dB, so that an airgun noise (over 200dB at the source) will remain over 100dB a thousand kilometers or more away[25].

There are a number of factors that influence how loud a sound will be as distance increases.

2.3.1.1 Quieter near surface

Observations of the responses of many marine creatures near seismic surveys or noise sources indicate that they often take advantage of a "sound shadow" that exists near the surface of the sea. As sound waves bounce off the surface of the water from below, they interfere with themselves "destructively," meaning that the high point of the direct wave combines with the low point of a reflected wave to cancel each other out (similar to the way noise-cancellation headphones work). In this case, the cancellation is far from perfect, so there is no "zone of silence," but received levels can be significantly lower near the surface, offering refuge to animals escaping dangerous or annoying sound levels below.

2.3.1.2 Shallower water propagation is worse

In deep waters, sound waves can travel relatively undisturbed, so that transmission loss is mainly a factor of distance (and to some degree, time: gradients of temperature and salinity can influence the speed of the sound waves and thus affect the waveform patterns that are received). In shallow waters, however, the distance between the water's surface and the sea floor is too small for the sound waves, and they begin to break up and become scattered, greatly reducing their received levels if the bathymetry (seafloor topography) is rugged or varied, but allowing for excellent propagation if the seafloor is flat, as a wave guide is created.

2.3.1.3 Hard bottom/soft bottom radically different

The composition of the seabed plays a significant—and hard to predict—role in horizontal sound propagation. Hard surfaces reflect most of the sound energy, while soft surfaces absorb/scatter the sound. So, transmission loss is greater in areas with soft surfaces. Unfortunately, the sea bed often contains patches of both hard and soft areas, making it very difficult to model likely transmission loss, and thus received levels. To take this one step further, models from any one area are likely to be of limited value in another place.

2.3.2 Examples of measured propagation at various ranges

McCauley (2000) made direct measurements of the received levels around an active seismic survey vessel, at distances of 1km to 50km. At each distance, there tended to be about a 10dB variation in received level, likely the result of localized transmission loss differences. The two instances of greatest divergence from the overall transmission loss trends were both identified as being related to specific factors (a received level higher than predicted being related to being abeam the ship, where the source level was higher, and a received level lower than predicted being related to an upslope propagation path that increased transmission loss).

Distance	Mean received level (dB re 1 μPa^2.s, equivalent energy) (increase by 13dB for RMS, 28dB for peak to peak)
1km	160dB
2km	150
3km	145
4km	140
5km	137
10km	125
20km	116
30km	110
40km	106
50km	103

Current regulatory consensus is that received levels of over 180dB (peak to peak) are likely to cause significant impacts on sea creatures; this compares to 152dB in equivalent energy. According to these measurements, then, the zone of significant impact will be out to almost 2 km from the ship. Behavioral, and likely perceptual, impacts are likely at far greater distances (see Section 3.2 below)

2.3.3 McCauley exposure modeling over time

While most studies have focused on the effects of exposure to a given level of transient sound, McCauley (2000) took the analysis a step further, creating a map showing the cumulative exposure likely over the course of a full seismic survey, whatever its duration (generally a few days to a few weeks, occasionally a few months). This is most relevant to resident species, which may be exposed to the full survey; migratory species would pass through in a relatively short time.

The exposure model looks at how many individual air gun shots would be received at a level of 155dB re 1µPa^2.s (equivalent energy) or higher over the course of a four-month survey. The results are sobering: an area roughly 60km by 90km in size would be subject to 40,000 shots at this biologically significant level (over 300 per day on average). An area of about 150km by 120km would experience 20,000 shots, and an area of 240km by 200km would hear 1000 shots in the course of the survey.

An area roughly 60km by 90km in size would be subject to 40,000 shots at this biologically significant level (over 300 per day on average).

While this is an unusually long and wide-ranging survey, leading to exceedingly high numbers of shots over the threshold, McCauley's exposure modeling approach would provide similarly useful insight for smaller surveys measured on the scale of shots over 155dB re 1µPa^2.s per day, or per hour, in the area being surveyed. It is likely that this sort of detailed analysis of cumulative impacts could be used to adjust survey boundaries in ways that would protect resident species from highly disruptive repeated exposure.

It should be noted that industry sources offer substantially lower estimates of the cumulative impacts. Caldwell (2002) focuses on the maximum exposure of any one animal to high levels of sound, assuming that it will tend to move away rather than linger in the vicinity of the seismic vessel; his figures suggest an animal may hear 40 shots above 180 dB re 1µPa over the course of 6.5 minutes "once a day or so for a few days."[26]

2.4 Other sources of noise in the oceans

2.4.1 Natural sources of high-intensity sound

Many observers have noted that the sea is full of loud sounds, both ongoing and episodic.[27] Among the most dramatic sources of natural ambient noise are wave action, sea-quakes (earthquakes in the sea floor), and whale vocalizations. The evolutionary adaptations that allow ocean creatures to withstand these sounds is considered an indication of their ability to cope with similarly loud human noises. In fact, most natural sources are quite a bit lower than the source levels of seismic arrays: high seas measure a peak of 140dB re 1µPa^2 at low frequencies under 10Hz, dropping to 90db at 100Hz, and continuing down from there. Seaquakes have been measured at 130dB re 1µPa^2 at around 10Hz, and less elsewhere in the frequency band; other measurements of seaquakes range much higher, with estimated source levels[28] of up to 240 re 1µPa^2, and received levels of up to 204dB[29]. Heavy rain can create a higher frequency (over 1kHz) noise of 80dB re 1µPa^2. While these levels can surely influence the background ambient noise significantly, and so reduce the distance at which seismic noise is audible and disruptive, localized disturbance from repeated airgun shots is clearly far louder in most cases (and far more persistent in the case of seaquakes).

Whale songs and calls are often quite loud. Many species have been measured in the range of 130-228dB re 1µPa (not clear if peak or RMS). The loudest sources are high-frequency echolocation clicks of toothed whales, which attenuate rather quickly. Low frequency baleen whale calls are often 170-180dB re 1µPa. Individual whales have been observed within 100m of companions singing at peak intensities.

By comparison, the two loudest sources of sound in the sea are explosions and seismic survey airguns, both with source levels of up to 240dB re 1µPa, with low frequency active sonar just behind at 235dB (NRC 2003).

Whatever the levels of sound produced by whales, we must again refrain from making the leap to thinking that we can thus know how they respond to loud sounds:

> Arguments that marine mammals, simply by nature of their size and tissue densities, can tolerate higher intensities are not persuasive. First, mammal ears are protected from self-generated sounds not only by intervening tissues (head shadow and impedance mismatches) but also by active mechanisms (eardrum and ossicular tensors). **These mechanisms do not necessarily provide equal protection from externally generated sounds largely because the impact is not anticipated as it is in self-generated sounds.**
> -Ketten (2001), testimony to U.S. House Resources Committee.

2.4.2 Overall ambient noise in the sea, including human noise

There are good indications[30] that the overall background ambience of the seas has increased 10-20dB over the past hundred years, mostly due to long-range transmission of shipping noises (though possibly also sea state noises caused by wind and waves has increased some as well, due to climate change or natural cyclical factors). In some areas, such as the west coast of the US, the increase has been measured at 10dB since the 1960s (Andrew, 2002).

There have been many theoretical studies of how far a sound would be audible above the background ambient noise "floor."[31] Ambient noise in the sea includes wave and wind noise, snapping shrimp, shipping, and animal sounds. Outside the surf zone along shorelines, ambient noise is often as low as 35-70dB re 1 μPa^2; during times of high wind and storms, wave noise alone can increase to over 80db. Dense animal or shipping noise can peak as high as 140 dB re 1 μPa^2 at low very frequencies (below 10Hz), 100 dB re $1\mu Pa^2$ at frequencies up to 1kHz, and 60 dB re $1\mu Pa^2$ at frequencies over 1kHz. Other more recent studies[32] have shown individual supertankers being as loud as 189dB re $1\mu Pa^2/Hz$ at low frequencies, with most large ships having individual source levels between 160 and 180db re $1\mu Pa^2/Hz$.

It is important to bear in mind that airguns are not the sole sources of sounds loud enough to propagate audibly over tens or hundreds of kilometers. By far the most dominant source of marine noise is shipping. Some observers consider the added sounds introduced by any intense human source other than shipping to have negligible added effect, mainly because there are far fewer sources of airguns than there are ships.[33] Once again, we are faced with the question of whether airguns should bear added scrutiny simply because they are among the very loudest specific sources of sound. It can be argued that an airgun at 50km[34] is no louder than a supertanker at 15km; beyond these distances, their effects are similar. It remains, though, that airguns with source levels well over 200 dB re $1\mu Pa^2$ will have substantially more local impact than other, even modestly less intense sound sources, while joining other extreme sound sources (ships, whales, etc.) as part of the audible noise at greater distances.

2.5 Is it valid to compare the intensity of sounds in water and air?

While, as discussed above, it is difficult to compare the experience of sound in the water with the experience of sound in the air, it can still be somewhat helpful to offer a few points of reference to bear in mind as we traverse the gauntlet of decibels over the next several pages[35]. The following chart can give a rough sense of how common human sounds in air may sound *to humans* underwater:

Sound source	dBA[36] re 20μPa at 1m in air	dB re 1μPa^2.s in water[37]	dB re 1μPa in water[38]
Conversation	60dB	109dB	122dB
Leaf Blower	90dB	139dB	132dB
(90dBA: OSHA permissible exposure limit; prolonged exposure causes permanent hearing loss; hearing protection required; NIOSH requires hearing protection at 85dbA; SEE FOOTNOTE ON dBA ABOVE)			
Chain Saw	100dB	149dB	162dB
(100dBA: short exposure can cause permanent hearing loss)			
Indoor crowd noise	110dB	159dB	172dB
OSHA ceiling	115dB	165dB	177dB
(115dBA: no employees may be exposed without hearing protection)			
Jet takeoff	130dB	179dB	192dB
Pain threshold	140dB	189dB	202dB
(140dBA: OSHA ceiling for impulse noises and NIOSH ceiling for all noise, with or without protection SEE FOOTNOTE ON dBA ABOVE)			

For many reasons, comparisons such as this are only really valid when comparing how the same species, in this case, humans, would perceive a sound. Every species (and, to a lesser degree, every individual) has its own "frequency response curve"; that is, we each hear certain frequencies much more easily than others. Humans, for example, do not hear low frequencies very well; a 63Hz sound measured at 100dB sound will sound to us as though it is only 74dB, while a 2kHz, 100dB sound will indeed sound like 100dB. Every species has its own range of hearing where sounds are perceived optimally, and likewise ranges where sounds are not perceived as well. Of course, when dealing with exceptionally high intensity sounds, physiological damage (and perhaps behavioral responses such as avoidance) may be caused even when we are not hearing the given frequency very well.

Please do bear in mind that given all the translations involved (from these individual species differences, to the many measuring scales and conversions mentioned above), **it is difficult to make any definitive claims about how sea creatures may respond to any given dB level. At best, an underwater dB rating is a decent estimate of the sound's physical power, and a somewhat useful benchmark by which to make informed guesses about its possible effects.** This is why scientists tend to rely on behavioral responses and observed physiological damage caused by ocean-based sound, and to avoid making direct comparisons with human hearing, and especially human safety thresholds, in the air.

That being said, **it is especially important to base our decisions about operational safety, mitigation, and regulation on careful observation of the actual responses of many species at a range of distances from seismic survey vessels, rather than to over-rely on ideas about the danger of specific dB levels or on models of how we think that the dB level will change as the sound moves out into the ocean environment.** As we will see, researchers do use dB measurements as a tool in determining thresholds of effects; when measured in the field, this can provide a more concrete handle on the animals' reasons for responding the way they do, despite the cross-species uncertainties in how a given dB level is perceived. We will also see that many studies are based on observed responses at various distances, without regard to received dB levels (at times, such observations are paired with models of likely sound propagation, and more rarely, with measured sound readings); such studies offer less concrete data and more uncertainties as to the reasons for the observed responses. Both approaches offer valuable information; the most useful insight with which to inform our decisions about operational standards is likely to follow from a judicious use of all data, within a context of appreciating the limits of each approach.

3.0 Effects on marine life

A wide variety of studies have shown that cetaceans, fish, squid, and turtles respond to seismic airgun sounds. Not surprisingly, louder sounds lead to increased response: low levels of exposure generally elicit modest changes in swimming behavior, while increasing sound levels lead to avoidance and/or startle responses. More surprising is that **significant behavioral responses happen for all these creatures at 143-152dB re 1 μPa^2.s (equivalent energy; 172-180db peak to peak). McCauley observes that "the hearing systems of baleen whales, sea turtles, fishes and squid are fundamentally different, yet the received air-gun level range over which responses seem to become significant is within 10 dB for these diverse groups** (McCauley, 2000, p188)." At this point, the reasons for this convergence can only be speculative; they may involve unknown evolutionary pressures, or a limitation in hair-cell mechanics in a wide range of ear systems (tiny hairs in ears are responsible for primary perception of sound).

Avoidance and startle responses to air gun sounds seem to begin in the range of 2-15 km, depending on the species and the situation. Current standard operating procedures which call for shut down of airguns when whales or dolphins are within 100m to 1km of the ship are designed primarily to avoid causing physiological damage at close range; this criteria, while usefully concrete, is also somewhat arbitrary. There is mounting evidence of consistent and meaningful avoidance on the part of many species at much greater distances, which deserves closer consideration in setting operational standards. Apparent contradictions are also observed where dolphins choose to swim with airgun arrays for extended periods of time[39], and humpback whales approach survey vessels, apparently curious about the sounds[40]. These observations do not necessarily imply that the exposure is not harmful, or discount the importance of the overall tendency to avoid such sounds.

3.1 Physiological Effects

Many observers are especially concerned about the possibility that human sounds may cause direct physiological damage to the tissues of ocean creatures. While this is of course does happen at times (see sections below), and is the worst-case scenario, we should be cautious about putting too much emphasis on this specific and grossly obvious effect of sound.

Physiological damage is exceedingly difficult to observe and study; generally, only dead specimens would yield this information. Partial impairment of physiological systems will be especially hard to discover, either because the individual remains in the wild, albeit in a compromised condition, or because the damage is not readily obvious upon discovery of a body.

Beyond this, though, is the fact that many physiological effects may not involve tissue damage, but rather the ways that intense sound impairs or interferes with the proper functioning of a creature's acoustic perceptual system. Virtually all studies of the physical effects of sound focus on the hearing systems of fish and smaller cetaceans; this is a sensible starting place, since we have a pretty good understanding of these systems in humans and other land animals. However, it is likely that water creatures' relationships with sound involve far more than their ears. The implications of this open a far wider doorway for study and understanding of the effects of anthropogenic sound in the oceans.[41]

The bodies of ocean creatures have acoustic impedance very close to water (while of course our watery bodies are very different than the air that surrounds us). This leads to the suggestion that sounds can easily enter their bodies and be perceived in ways we may not initially imagine; we could say that their sense of touch becomes an auditory sense. Indeed, fishes respond to pressure gradients with both their "lateral lines" (running down their sides, and containing hairs and cellular structures similar to those found in the ears of terrestrial animals) and swim bladders (which are sometimes used for sound production, and in some species are connected by a set of bones to the fish's inner ear). Our sound-measuring tools all measure pressure gradients, as does the fishes' lateral line. But fish also have particle motion sensors, and they respond to subtle phase differences using both systems (and so join instantly in schooling movements or respond to the disturbance on the surface caused by food source such as an insect or piece of plant or animal tissue).

Whales and dolphins, like fish, do not have outer ears (they would cause turbulence) or eardrums (which would not withstand the extreme pressure changes underwater). It seems that toothed whales perceive sound largely though coupling of the lipids in the jaw to the inner ear, with some recent indications that bone conduction also plays a role. The melons of toothed whales (also filled with lipids) surely play a central role in sound production, and possibly some perceptual role as well. Since many toothed whales are small enough to study in captivity, we have quite a body of knowledge about the structures and frequency sensitivity of their auditory systems, though our understanding of how they work and respond to the acoustic world of the ocean is still speculative. By contrast, our understanding of the hearing systems of baleen whales, which are centered on perception of low frequencies, is almost purely speculative, based on observing their behavior from a distance and trying to comprehend strange organs that bear little resemblance to those we know from land creatures more interested in middle and higher frequency sounds.

> The properties of water create sensual realms outside of our perceptual grasp. Water is not as homogeneous as air; it has density and pressure gradients that vary widely with turbidity and turbulence, salinity and temperature. You might imagine an underwater environment as a rich mélange of blending densities, all telling of the motions of eddies and tides, turbulence, and the trails of micro-currents left by the movements of sea animals within it. These swirling nuances of density affect the transmission of acoustical energy in water, allowing animals a sense of current, thermal and chemical characteristics with perceptions tuned into these conditions.
> (Stocker, 2004)

It is probably obvious from this discussion that our consideration of the physiological impacts of anthropogenic sounds must include more than discussion of gross tissue damage. To appreciate the ways that powerful human sounds (which saturate large areas of the ocean with powerful acoustical energy) may affect the finely-tuned and integrated acoustic and tactile senses of water creatures will require us to step outside the frameworks of our own perceptual systems. It is natural that our scientific inquiries are based in what we know, yet it is important to remember that to understand other creatures with very different perceptual skills, we will need to expand the horizons of our inquiry.

To appreciate the ways that powerful human sounds (which saturate large areas of the ocean with powerful acoustical energy) may affect the finely-tuned and integrated acoustic and tactile senses of water creatures will require us to step outside the frameworks of our own perceptual systems.

3.1.1 Pathological direct damage

There is very little evidence of direct tissue damage caused by seismic surveys. This can be partly attributed to the standard procedure of gradually ramping up the sound, and the constantly moving vessel, both of which tend to make the appearance of airgun noise be gradual enough to allow animals to avoid intense exposure. It is also clear that we have virtually no direct observations about the short or long-term physiological effects on wild creatures, since they cannot be examined. Evidence from beached whales and dolphins does tend to show some long-term hearing loss, with up to half showing some physiological compromise[42], though the sources of this damage are not easily discernable.

However, in the past year, some troubling results have begun to appear. Cetaceans exposed to high-level mid-frequency sonar have been found (after beaching and dying) to have a bewildering array of tissue damage. Some individuals have hemorrhaging in the ears, others have lesions caused by bubble formation and/or bubble expansion in other tissues, including liver, lungs, and blood[43]. The mechanisms for these forms of tissue damage are not yet fully understood, and most of the victims have been beaked whales, with a few dolphins affected as well. While there is no evidence that seismic airguns can cause similar damage, these early indications of unexpected physical trauma caused by high-intensity sound bear close scrutiny.[44]

The only controlled study to date that shows clear tissue damage from exposure to airguns involves pink snapper (McCauley, Fewtrell, Popper, 2002). In this caged exposure study, a single airgun was moved toward and away from the fishes several times over the course of a two and a half hour trial, exposing them to sound in the range of 145-180 dB re 1μPa (mean squared pressure). The fish experienced severe damage to the sound-sensitive hair cells in their ears, and in contrast to earlier studies, there was little or no regeneration of these cells over time. The main caveat to this study is the obvious one: had the fish not been caged, they likely would have swum away. Nevertheless, it raises for the first time a clear mechanism by which exposure to elevated sound levels can cause permanent damage to fish ears.

3.1.2 Temporary Threshold Shift

It has long been observed in people and terrestrial animals that exposure to loud sound for extended periods can cause our hearing sensitivity to decrease. That is, the threshold for hearing goes up, so that we no longer hear sounds that we normally can faintly notice. This is known as a Temporary Threshold Shift. It can cause significant impacts in the ability to hear distant or faint acoustic signals of importance.

Relatively little study has taken place with ocean creatures[45], but some studies seem to indicate that there is evidence of some TTS with fish, though the amount of temporary hearing loss is far less dramatic than that seen in birds or mammals.[46]

3.1.3 Increased stress

While there have been several studies that have shown increases in stress, as measured by a variety of physiological indicators, in terrestrial animals, very little has been done with ocean creatures in this regard. The one study in the literature involves captive beluga whales, and showed no stress response to recorded offshore oil rig sounds at received levels of up to 153 dB re 1μPa, though the researchers cautioned against extrapolation to wild belugas, which would likely be exposed to such sounds for longer periods. (Richardson, 1995) It is possible that recent advancements in temporary tagging could be used to explore this question.

3.2 Behavioral

As noted above, behavioral changes are clearly seen in many species encountering seismic survey sounds. At the same time, there appears to be little evidence of dramatic changes in behavior or migration patterns in areas subject to survey activities. The general assumption has been that any behavioral changes are short-term and have negligible impact on species survival. Summaries of behavioral change will be presented below; however, it is again useful to keep some perspective on the degree of confidence we may rightly assume about such studies[47]:

> There have been no direct studies to investigate whether or not repeated man-made noise pollution in an area can lead to long term disturbance and exclusion from habitat. However, some authors have drawn attention to examples where **repeated loud noise events do not appear to have caused animals to desert areas of preferred habitat. We should be reticent in taking much comfort from these observations however.** Firstly, such observations tend to be qualitative rather than quantitative; they are rarely backed up by surveys or analysis to show what the population levels might have been in the absence of airgun noise. Secondly, **the option of moving to different habitats or changing migration routes may be a far more drastic undertaking than many imagine.** There may be strong reasons why an alternative route or habitat cannot be found. . . **It may also be the case that animals are not able to appreciate the potentially damaging consequences of exposure to noise. There are innumerable examples of humans willingly exposing themselves to damaging levels of noise, workers using power tools and teenagers in dance clubs to mention two. The damaging effect of transients can be particularly difficult to assess.** Because the auditory system integrates sound over about 0.5 seconds, **transients that are much shorter than this (such as a pulse from an airgun) may not "sound" particularly loud.** For a number of reasons, marine mammals may be unable to take what might seem to a human observer to be the obvious course of action to alleviate the effects of a localized noise such as an airgun array or large approaching vessel. This could be due to an inability to correctly appreciate the situation on the part of the marine mammals, or a failure on our part to understand the biology of the animal concerned.
> -Potter/Delory, 1998

> Behavioral perturbations are not assessed here but a concern is noted that they are an equal or potentially more serious element of acoustic impacts. While auditory trauma, particularly from short or single exposures may impair an individual, that is unlikely to impact most populations. Long-term constant noise that disrupts a habitat or key behavior is more likely to involve population level effects. In that sense, **the question of individual hearing loss or animal loss from a single intense exposure is far less relevant to conservation than a more subtle, literally quieter but pervasive source that induces broad species loss or behavioral disruption.**
>
> -Darlene Ketten, testimony before House Resources Committee, 2001.

3.2.1. Avoidance/stand-off/swimming behavior changes

The most commonly observed behavioral changes are avoidance (changing course to avoid close travel past a sound source; this can include moving away, or continuing to come closer at an oblique angle), stand-off (coming no closer to a sound source), and change of swimming patterns (speeding up, startle responses, increased disorderly swimming).

Bowhead whales, residents of Arctic waters, appear to be among the most sensitive to airgun sounds[48]. Initial behavioral changes were seen up to 8km away, at received levels of 142-157 dB re 1μPa, and bowheads started moving actively away from the survey vessels at ranges from 3-7.2km. Rapid swimming away began at 152-178 dB re 1μPa, with activity clearly disrupted for 1-4 hours afterwards. Some subtle effects, such as changes in surfacing and blowing rates, were apparent up to 54-73km from an active airgun array, where received levels were as low as 125 dB re 1μPa.

Grey whales have shown pronounced avoidance responses at 2.5km (received level 170dB re 1μPa)[49], with less consistent or dramatic responses suspected at received levels of 140-160dB re 1μPa. Some subtle behavioral changes in surfacing patterns seemed to persist for more than an hour after seismic shooting ceased.

Note that in each of these species, clear behavioral responses are common at levels far below the current 180dB re 1μPa threshold, and often far beyond the 1km radius considered the industry standard "exclusion zone".

In each of these species, clear behavioral responses are common at levels far below the current 180dB re 1μPa threshold, and often far beyond the 1km radius considered the industry standard "exclusion zone."

Migrating humpbacks encountering an active seismic survey[50] showed avoidance at 4-5 km (received level 140dB re 1μPa^2.s / 168dB re 1μPa^2 peak-to-peak). The stand-off range appeared to be about 3km (received level 144-151dB re 1μPa^2.s).

Controlled exposure trials with a group of resting cow and calf humpbacks showed much lower tolerance for airgun sounds: avoidance was seen at received levels of 97-132dB re 1µPa^2.s and stand-off at levels of 116-134dB re 11µPa^2.s. This would translate to avoidance of an airgun array at 7-12km. **It is clear that in most circumstances, whales would prefer to remain at distances that are significantly farther than current mitigation measures are designed to accommodate.**

Responses of sperm whales, a species of special concern in the Gulf of Mexico, are less clear. Until recently, research has been focused on gathering basic population distribution data; observations of responses to airgun sounds have been more opportunistic, and less methodical, than those cited above[51]. Federal regulators noted in 2002 that "the effects of noise (on sperm whales) are virtually undocumented and, unlike a potential event such as an oil spill, represent the results of normal industry activities.[52]" Though sperm whales vocalize at higher frequencies than baleen whales or the bulk of airgun noise, seismic survey sounds do at times cause some responses. Sperm whales have been observed in the Gulf of Mexico apparently moving away, to as far as 50km, when surveys began[53], though this has been contradicted by other studies; likewise, some (but not all) sperm whales in the Indian Ocean ceased calling in the face of seismic pulses that were 10-15dB above the background ambient noise, produced by a survey over 300km away[54]. Most research in the Gulf of Mexico, though, has shown surprisingly little dramatic response in the face of thousands of miles of seismic surveys being shot over the past three decades. It is unclear whether this is a consequence of low sensitivity or habituation to seismic sound, or reflects a high motivation to remain in the area. During the MMS-sponsored GulfCet II study on marine mammals, the cetacean sighting rate did not change significantly when seismic exploration signals were audible. Likewise, passive acoustic surveys to monitor sperm whale vocal behavior and distribution in relation to seismic surveys in the northeast Atlantic revealed few, if any, effects of airgun noise[55]. A multi-year study of sperm whale responses to sound is underway in the Gulf of Mexico at this time; preliminary results will be released over the coming year[56]. However, the cumulative impact of seismic surveys conducted in recent decades will be nearly impossible to assess.

Other families of sea creatures

McCauley (2000) studied responses of several non-whale species exposed to sounds from a single airgun in caged trials. Sea turtles showed increased swimming activity at 155dB re 1µPa^2.s (168dB re 1µPa^2 mean squared pressure), and erratic swimming patterns at levels above 164dB re 1µPa^2.s.

Squid showed increasing startle responses (jetting away from the sound) at levels above 145-150dB re 1µPa^2.s, and a tendency to slow their swimming at levels over 155dB re 1µPa^2.s. They also showed a tendency to move to the top of the water, where the received levels were lower.

Caged fish trials showed classic "c-turn" startle responses and a tendency to gather together in tight groups at the bottom center of the cage at levels above 145-150dB re 1μPa^2.s.

Again, thresholds for responses indicate that current mitigation standards, based solely on avoiding physiological harm, may need to be reconsidered.

Engås et al (1996) stands as the most definitive study to document what has long been observed by fishermen: when seismic surveys are taking place, the fish leave. Engås noted **reductions in catch rates of cod and haddock up to 18 nautical miles from the survey area** (which was 3 x 10 nautical miles in size); acoustic mapping of the survey area showed a 45 percent reduction in fish numbers during the shooting, with numbers continuing to drop after shooting finished, to a total decline of 64 percent. Catch rates within the survey area fell 68 percent; in surrounding areas, catch rates fell 45-50 percent. Virtually all the larger cod (over 60cm) left the shooting area; among haddock, there was still some evidence of larger fish still being caught, though at a reduced proportion relative to before the survey. Catch rates at greater distances from the survey showed increasing proportions of larger fish. The study followed fish numbers via both catches and acoustic mapping for five days after the survey; while there was some return of fish (and proportionately more larger fish) during this time, stock numbers were still well below the starting point after five days of quiet.

Engås et al (1996) stands as the most definitive study to document what has long been observed by fishermen: when seismic surveys are taking place, the fish leave.

3.2.2 Acoustic Masking

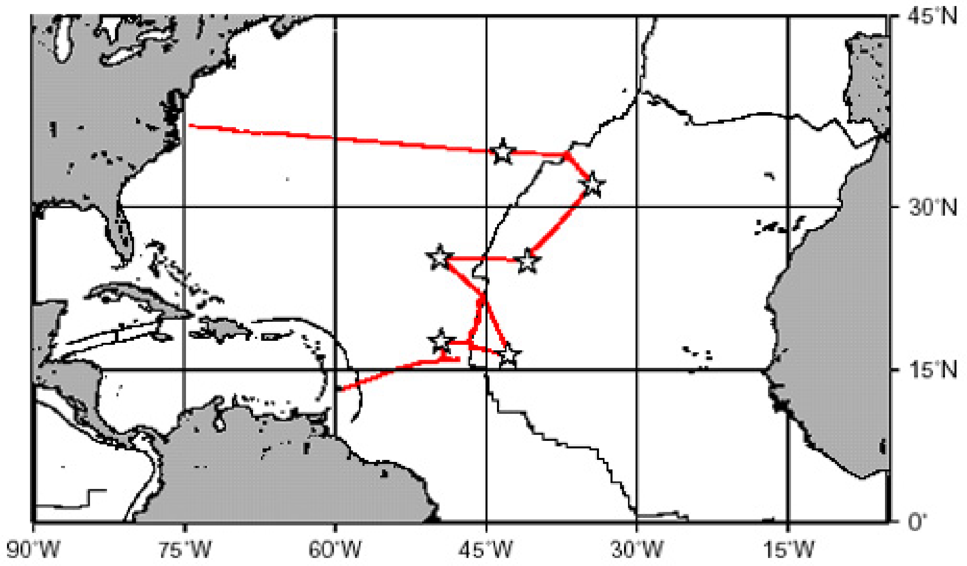
Masking of communication or of important auditory cues about predators or prey will generally only happen when the airgun sounds are louder than the background ambient noise levels. At greater distance, the airgun sounds are not totally gone; they simply melt into the (now slightly increased) background ambient noise.

Masking is most dramatic on sounds very close in frequency; when the frequency of, say, a vocalization, is far from the frequency of a noise source, then the vocalization will remain clear even when the noise is somewhat louder. While airguns discharge predominantly low-frequency sound, it is still considered a broad-band source, in that it does contain elements in a wide range of frequencies. It is also loud enough to remain distinctly audible, even at distances of tens to hundreds of kilometers.

Obviously, airgun sounds that start at over 200 dB re 1μPa^2 at the source are far above the ambient background (see Section 2.4.2 above). Even as transmission loss reduces the received levels rapidly over the first few kilometers, they remain clearly audible, often dominant in the soundscape. Even 100dB transmission loss, as can be expected in low frequencies (below 1kHz) over about 100km in deep water, and over 10-100km in shallower water,[57] can often leave airguns clearly louder than the background ambient noise. It is both theoretically likely and often observed that seismic sounds are prominent in the soundscape at ranges of tens to hundreds of kilometers, far beyond the range at which they may cause physiological damage or obvious behavioral changes. We can only guess at what effects this may have on the communication and acoustic perception of ocean creatures.

Given the lack of clear data on how the long-range audibility of airguns may mask biologically important communication or perception, some excerpts from research reports that address this issue will perhaps give the best sense of what it going on below the surface.

> There will be many situations when there is **significant biological advantage for an animal to be able to detect very faint sounds**. Indeed this is believed to have been the evolutionary pressure for the creation of sensitive hearing, so there is the potential for harmful masking to occur at very great ranges.
> Potter/Delory (1998)
>
> Even at 8 km range seismic power was still clearly in excess of the high background noise levels (featuring mainly the noises of the survey ship) up to 8 kHz.
> Goold (1998)
>
> Toothed whales hearing is relatively poor in low frequencies, but there is sufficient energy in the output of airgun arrays at frequencies of 200-500Hz to make them **audible at distances of 10-100km**
> Harwood, Wilson (2001)
>
> The PMEL autonomous hydrophone array deployed in the central Atlantic Ocean recorded at least three different airgun sources from around the Atlantic Basin, sometimes simultaneously. The most frequent origin locations were near Nova Scotia, Canada, Northeast Brazil, and Northwest Africa. **Airgun signals dominate approximately 75% of the annual data recordings.**
> PMEL/NOAA website, airgun page



This map shows the placement of the hydrophone array that has been dominated by airgun signals from Brazil, Novia Scotia, and Africa.
Map from Smith (1999)
http://humm.whoi.edu/projects/cruisereport1999.pdf

3.2.3 Masking of perception: ambient noise imaging

A new field of study that has emerged in the past five years or so is pointing toward a heretofore unimagined use of sound in the underwater environment. It appears that the ambient noise of the sea may "illuminate" the underwater environment much as light illuminates terrestrial landscapes. Researchers have developed systems that can begin to "see" objects in the underwater landscape by complex processing of the jumble of sound waves that make up the ambient background noise. Using the early processing systems developed so far, it seems that ambient noise imaging is most useful in relatively close ranges (less than 500m), and that high-frequency sounds provide the best resolution. Suspicion is increasing (though so far unfounded by any direct evidence) that many ocean creatures may use similarly subtle processing systems to decode changes in ambient noise patterns in order to identify individual fish or schools of prey, or to navigate through underwater topography. These sorts of very subtle acoustic sensitivities could be disturbed by loud transient sounds, which may be likened to a bright spotlight sweeping across our face as we try to see our surroundings. (Caveat: while this is a very intriguing line of research, and may develop into a new and powerful form of passive monitoring, imagining such abilities in sea creatures is by far the most speculative and unsubstantiated moment you'll encounter in this report.)

3.2.4 Disruption of rest

Perhaps one of the most overlooked aspects of anthropogenic noise impacts is the disruption of rest periods important to migrating, or even generally moving, ocean creatures. By easily falling back on the idea that creatures can simply swim away from the bothersome noise, we may neglect to appreciate that "swimming away" takes valuable energy and attention.

McCauley (2000) clearly noted that humpback whales at rest were far more easily disturbed by airgun noise, than whales that were intently migrating; resting whales showed avoidance behavior at greater distances and lower received levels of sound[58]. (See section 3.2.1 above)

3.3 Food chain impacts

There is little direct knowledge of the impacts of sound on creatures lower on the food chain, such as krill or plankton. It is known that some crustaceans have rudimentary auditory structures, and it is quite likely that most or all ocean beings make use of tactile/auditory perceptions in some way. Robert McCauley, who has studied the sound impacts of seismic sources on larger creatures, and has acknowledged the lack of data on of the use of sound by prey such as krill, was aghast at plans to allow a survey in an important blue whale feeding area: "It beggars belief that we can allow this to happen when we don't know the impact," McCauley was quoted in the local press, "Krill also have sophisticated sensory systems. The noise effects on blue whales and krill and their interactions, have not been investigated."[59]

4.0 Discussion

4.1 Concrete effects

We must always stay aware of the fact that extreme human sounds have effects on ocean creatures on a continuum of scales. Gross physiological damage is the most dramatic, but it may be a tragic mistake to stake our ocean's future on implementation rules that are built primarily on avoiding such damage. The current standard of simply assuring that marine mammals are far enough away to avoid sounds of over 180dB deserves closer scrutiny.

Likewise, we must be cautious about assuming that driving fish, cetaceans, or any other creature away with our sound is always a "negligible" impact. There is ample evidence that a wide variety of ocean creatures choose, when possible, to avoid sounds much less intense than 180db re 1 μPa^2. The fact that occasionally an individual may remain, or approach, closer should not blind us to the evidence of those that retreat.

And finally, it is crucial to remember that the acoustic sensibilities of ocean creatures are incomprehensibly more sensitive than we can imagine based upon our own experience. It is nearly certain that repetitive human sounds which are vastly louder than the ambient background at their source, and that remain audible at great distances, are having effects that we cannot understand.

4.2 Ethical considerations

While of course we cannot refrain from all activity in the ocean because of our lack of understanding of how it may affect bodies and senses that are very different than ours, we can and should bear in mind our degree of certainty or uncertainty about the effects of our actions.

We humans like to set ourselves apart from the rest of nature. Yet our special qualities are not just our power of reason and inquiry, but also our ethical sensibilities. To enter the sea as truly human, we must combine our efforts toward practical and concrete measurement of highly disruptive effects with a curiosity, respect, and consideration for the beings that live there. Obviously, seismic surveys are but one of many factors in the human sound presence in the ocean realm; while it may seem unfair to single airguns out for closer scrutiny, it is also natural that such extreme examples of human activity will be the first to stir the deeper questions that must be faced.

Is death of whales the threshold that triggers us to stop? Is the disruption of a school of fish's feeding activity enough to give us pause? Is it acceptable to cause annoyance, irritation, or confusion in wild species across tens, hundreds, or thousands of square kilometers of the sea? By what virtue do we claim the right to so dominate the soundscape?

Such questions may not have concrete or easy answers. Yet it is time that we begin to ask them, and in so doing, to challenge ourselves in new and important ways. The understandings that may come from such inquiries promise us the opportunity to continue to thrive in this place, in relationship with a diverse and healthy natural world. Indeed, such questions represent a natural maturation of the self-awareness about the unintended effects of our actions that gave rise to the first environmental regulations. While our regulations can serve to slow unthinking or even intentional destruction, consideration of ethical questions such as these lead us toward a strong, long-term relationship with the rest of our planetary companions.

4.3 Precautionary principle

The recurring theme of choosing our actions with mindfulness of the uncertainties of our understanding leads to the application of the Precautionary Principle. Rather than charging ahead with new actions, accepting limits only when presented with incontrovertible proof of harm being caused, the Precautionary Principle holds that we should proceed with caution, and set our standards such that we can be assured of doing no harm to other creatures or living systems. Or more simply put, that we err on the side of caution in the absence of a full understanding of the impacts of our actions.

There is ample historical evidence that our rush to progress tends to carry with it unintended and unforeseen consequences. **Especially in situations where the survival of species hangs by relatively tenuous threads, the precautionary principle makes ecological and biological sense.** The depleted state of global fisheries, the ongoing recovery of cetacean species from the brink of extinction, and growing concerns about the health of the ocean ecosystem as a whole, all point toward a need to take each action with mindfulness of a picture very much bigger than an individual survey area and more long term than most current knowledge allows.

Thompson, et al (2000) have shown that the precautionary principle can mean the difference between survival and extinction for populations on the edge. It is likely to take 10 to 30 years to notice small but significant 1-5% annual declines in population. The chances of survival once the decline is noticed drop rapidly as it takes longer for us to notice problems. A precautionary management criteria can greatly increase the opportunities for species survival, by minimizing negative impacts during the decades it may take to know how the population is doing. **This is especially important, given our current systemic questions about the ocean's vitality and the low rate of population recharge in larger species.** Potter (1998) notes that "Sperm whales, for example, are thought to have a fecundity rate only four percent above natural attrition. If this is the case, even a marginal decrease in fitness for life of this species could result in total extinction in the future."

Regarding the effects of seismic surveys and industrial development in the Gulf of Mexico, the National Marine Fisheries Service Biological opinion (NOAA, 2002) stressed the fragility of the stock of sperm whales in the Gulf: "NOAA Fisheries believes sperm whales may be vulnerable to adverse effects of acoustic harassment from seismic activities, construction and operation noise, or pollution resulting from activities associated with the proposed action (p28). . . . Even though sperm whales are abundant on a world-wide scale (Reeves and Whitehead 1997), because their potential rate of reproduction is so low and because those found in the Gulf of Mexico are believed to be a small (Nmin=411) resident stock, even small negative impacts of noise resulting from activities associated with the proposed action could cause population declines (p37)." Given such profound concerns, proceeding in a precautionary manner would be the prudent choice.

5.0 Calls for action

5.1 Case by case analysis and modeling

Because of the great variability in transmission loss across different sorts of ocean floor profiles, and the small but significant variation in the output levels of individual air gun arrays[60], we follow McCauley (2000) in calling for case-by-case modeling of likely propagation patterns: **"at present, predicting the horizontal**

sound propagation from any specified air-gun array source needs to be done on a case by case basis. . . **Accurately predicting levels at specified ranges and water depths requires modeling of the source and local environment."**

We also encourage the use of cumulative effects modeling such as developed by McCauley (2000) and described above, to better adapt each survey's operations to fit local biological and geophysical conditions. Such case-by-case procedures may help to ameliorate the effects of current uncertainties, which can lead to seemingly excessive regulatory hurdles for very small single-gun site surveys.[61]

5.2 Require "best practices" mitigation measures

Many innovative approaches to mitigation and monitoring are emerging from researchers and regulatory agencies worldwide[62]. A "best practices" approach to mitigation would include:

- Use of the lowest possible power array to meet local conditions and obtain information being sought.
- Extend ramp-up times where turtles are present; 30 minute ramp-ups are minimal and 60 minutes preferable, to accommodate turtles' relatively slow swimming speeds. Engås (1996) evidence also suggests that smaller fish would benefit from slower ramp-ups.
- Adapt the sequencing of seismic lines to account for any predictable movements of fish across the survey area.
- Consider establishment of a larger exclusion zone to reduce behavioral effects, especially on species with tenuous populations. It may be that observed behavioral disruptions will be better addressed by a 2-5km radius, rather than the current 1km radius. In the same way, the current 180 dB re $1\mu Pa^2$ standard for acceptable received levels of sound (based on avoiding physiological damage) may need to be adjusted downward to avoid behavioral disruption.
- Consider cumulative impacts over time in permitting and effects modeling; include consideration of seasonal and historical impacts from other activities (shipping, military, industrial, other seismic) in the specific survey area and nearby region. Develop databases that track the history of seismic and other industrial activities, using GIS mapping.[63]
- Require passive acoustic monitoring[64]: can complementing visual observations by identifying animals vocalizing beneath the surface, down to the sea bottom. Passive acoustic monitoring can also extend the zone of effective observation, which would be important should we choose to apply a more precautionary approach to acceptable received sound levels.
- Incorporate Environmental Effects Monitoring into all active seismic surveys. EEM should include measurement of received sound levels at ranges of 1-25km, as well as both visual and passive acoustics monitoring of the responses of marine mammals, fish, and other species present in the area.

These "best practices" would require a greater investment in time and money from companies conducting seismic surveys; a small price to pay for increased protection. Over time, as our knowledge increases, it is likely that we will be able to design both technologies and implementation strategies that can reduce these added costs associated with seismic surveys.

5.3 Establish more coordinated oversight of seismic surveys and of noise in the ocean in general.

5.3.1 Formation of a Commission charged with developing coherent operational and mitigation policies regarding seismic surveys.

An independent, government funded commission is called for, to coordinate efforts specifically directed at better understanding the impacts of seismic testing and development of improved mitigation and monitoring measures. Such a commission must have high standards of transparency and accountability, to remain free from charges of bias or influence by industry. It is possible that the National Science Foundation studies planned to begin in 2004 (see Section 5.3.2 below) could catalyze this effort.

5.3.2 Follow through on calls for better coordination of research into ocean noise impacts in general.

Recent reports from the National Research Council, the Whale and Dolphin Conservation Society, and the Office of Naval Research have all called for stronger coordination and commitment to carrying out much-needed research into the impacts of noise in the sea. Such basic information as a "sound map" charting worldwide noise levels and a "sound budget" which attempts to set caps on total noise so that vulnerable areas will be protected, are still only in the conceptual stage.

Several existing programs are attempting to address either sound-related research needs, or better coordination among government, academic institutions, and industry. These efforts all need to be given high priority in funding decisions; likewise, the coordination efforts should all be encouraged to include data on sound and noise in their missions, in order to more quickly obtain the global baseline data that is so sorely needed. The National Research Council Ocean Studies Board recently called for a single Federal agency to oversee and coordinate these important efforts. [65] We second that desire for better oversight.

Among the existing efforts that can be coordinated to study noise issues are:

- Marine Mammal Commission. Mandated by Congress to hold a series of noise pollution workshops in 2003-4.[66]

- National Research Council, Ocean Studies Board. Laid out an ambient noise research agenda in their 2003 report.
- NOAA. Plans to begin work on a noise budget.[67]
- National Oceanographic Partnership Program[68] (NOPP). Links oceanographic research efforts into regional and national coordination networks. Current focus is on sea state info (temperature, wind, waves, etc) with some indirect efforts on fisheries and species monitoring.
- Consortium for Oceanographic Research and Education (CORE)[69]. Oversees NOPP and other oceanographic initiatives, including the Census of Marine Life, which also could put added focus on acoustics research.
- US Integrated and Sustained Ocean Observing System (IOOS)[70]. This effort, a sub-set of the NOPP program (itself a subset of CORE) includes in its formal mission "managing resources for sustained use" and "restoring healthy ecosystems." IOOS appears to be doing the practical work of coordinating regional data collection networks, but is not including sound data as a priority.
- National Science Foundation. Has committed $1 million for research into the effects of seismic surveys on marine mammals.[71]

While it appears that the responsibilities of CORE, NOPP, and IOOP are bureaucratically nested, the apparent redundancy reinforces the Ocean Studies Board's call for a coordinating entity.

5.4 Research in need of industry and government support

There are several areas in which investment in research could lead to better monitoring of biological effects and/or lower-impact technologies for conducting surveys. Government and industry should share the burden of increasing our knowledge in the following areas:

- Use of ambient noise imaging as an added passive monitoring tool, in an effort to observe animals beneath the surface that are *not* vocalizing.
- Use of temporary tags to gather information on received levels of sound, as well as physiological indicators of stress. Development of the least invasive tags is preferred, likely focusing on suction-cup tags that remain attached for hours, rather than skin-piercing tags that remain attached for days or weeks. Free-floating acoustic monitoring devices that are not attached to animals can also provide important information about received sound levels in and around survey areas.[72]
- Studies of the acoustic perception and use of sound by species at the bottom of the food chain. This is important both to balance the current focus on charismatic larger sea creatures, and to assure that feeding patterns of larger species are not disrupted.
- Development of technologies to reduce the source levels of airguns. These efforts could include limiting the frequency output (range) of airguns to better avoid frequencies important to marine species, development of

techniques that can adjust sound levels during the survey, to maintain the most modest sub-surface penetration necessary, development of more sensitive hydrophones or improved data analysis algorithms that could discern the needed geological information in much weaker echoes, use of bubble-curtains to provide some sonic baffling near the source, and investigations of lower power sound-generating technologies including evacuated spheres[73] or other now-experimental techniques (this would involve a degree of industry cooperation, as new techniques may be considered proprietary). Research could also be encouraged toward developing geological interpretation techniques that could make use of surveys which do not penetrate so deeply into the ocean-bottom crust; alternatively, such lower-power surveys could become the norm, with very site-specific return surveys to probe more deeply into areas of special promise.

5.5 Uniform application of regulatory procedures (Gulf/Beaufort)

There are two areas within US territorial waters that have been subject to seismic surveys and oil and gas development in recent years. One is the Beaufort Sea, north of Alaska, and the other is the Gulf of Mexico. Exploration in the Beaufort has declined in recent years, while the Gulf of Mexico has seen significantly more seismic survey activity, especially targeting deep-water areas.

In the Beaufort, after failing to gain drilling access to the Arctic National Wildlife Refuge (ANWR), the oil industry was given increased access to lease areas in the nearby National Petroleum Reserve as well as royalty relief incentives for companies (exempting specified volumes of oil from royalty payments, tied into wholesale prices for oil). This is expected to lead to an increase in drilling, and perhaps to more offshore surveys, which have slowed to a trickle (rarely more than one a year, and often none).

The Gulf of Mexico has been subject to a continuing barrage of seismic surveys over the past thirty years. Between 1969 and 1999 about 900,000 miles of survey lines were shot by seismic survey crews; since 1994, about 150,000 square miles have been mapped by more advanced 3-D seismic surveys[74]. Royalty relief measures passed during the 1990s led to a massive upswing in surveys and drilling in deepwaters in the Gulf. On average, during the late 1990's over a hundred survey permits were issued per year, largely reflecting the 7-9 year cycle of repeat surveying, along with a desire to utilize newer state of the art techniques and equipment. Minerals Management Service (MMS) planners project that these numbers will drop during the 40-year lease cycle currently being planned.[75]

This activity has been subject to relatively modest levels of oversight. Only in 1990 did the MMS begin to actively collect data on marine mammal populations, and in 2003 it first applied to the NMFS for small take permits allowing seismic surveys to harass marine mammals. Meanwhile, MMS and NMFS studies have repeatedly raised warnings about the cumulative impacts of airgun noise on local species:

> As the oil and gas industry moves into deeper water along the continental slope in its continuing search for extractable reserves, information is needed on the distribution, abundance, behavior, and habitat of cetaceans, especially large and deep-water species in the Gulf of Mexico. . . The first large-scale vessel surveys to assess marine mammal distribution and abundance in the Gulf were conducted by the NMFS beginning in 1990. Much of what we've learned regarding the Gulf's marine mammals is a result of the GulfCet Program, funded largely by the MMS. **Despite recent studies of distribution and abundance, we know little about the natural history and ecology of pelagic cetaceans in the Gulf of Mexico.**[76]
> -MMS website, 2003
>
> Although any one seismic survey is unlikely to have long-term effects on any cetacean species or population, available information is insufficient to be confident that seismic activities, collectively, would not have some effect on the size or productivity of any marine mammal species or population.
> -MMS Eastern Planning Area EIS, 2002
>
> Until more conclusive results on the effects of seismic activities on sperm whale behavior are obtained, NOAA Fisheries believes that precautionary measures to prevent harm to sperm whales should be taken to reduce the likelihood of any adverse effects to individuals or populations.
> -NOAA Fisheries Biological Opinion, 2002

In 2002, MMS issued new mitigation standards, including requiring marine mammal observers and establishment of a 500m exclusion zone (i.e. requiring airguns to cease firing when marine mammals are within 500m). However, the MMS, which worked closely with the International Association of Geophysical Contractors in developing its mitigation measures, rejected NMFS recommendations to use a larger exclusion zone and suspend operations in times of poor visibility, including darkness.[77]

Meanwhile, the MMS's Environmental Impact Statement for the Central and Western Planning Areas of the Gulf[78] (focus of over 90% of development) gives little attention to sound issues. After the NMFS identified debris, vessel traffic, and airgun noise as potential sources of "takes," MMS's EIS included mitigations for debris and traffic, but not for noise; they likewise provided estimates/projections of ship traffic, helicopter trips, platforms to be constructed, but not of surveys[79]. The "Impacts on Marine Mammals" section of the EIS had only this to say about noise: "There is no conclusive evidence whether anthropogenic noise has or has not caused long-term displacements of, or reductions in, marine mammal populations." (p70)

Since 1994, oil and gas exploration in the Beaufort area (along Alaska's North Slope) has required NMFS issued "small take permits" in order to harass marine mammals, in the form of Letters of Authorization (LOAs). These LOAs are issued contingent on permittees following NMFS-approved mitigation plans designed to assure negligible impacts; among the restrictions in place in the Beaufort is seasonal suspension of operations during the bowhead whale migration.

The NMFS has yet to officially place seismic survey activities under its Small Take Authorization Program, even though there has long been concern about marine mammals and seismic testing in the Gulf, and Small Take permitting regulations are in use in the Beaufort Sea. Despite the vastly greater level of exploration and drilling activity in the Gulf of Mexico, until 2002 the MMS issued permits in the Gulf without NMFS involvement; and once embarking on the required Endangered Species Act consultations, MMS chose to adopt weaker mitigation measures than those recommended in the NMFS Biological Opinion.

On March 3, 2003, the Minerals Management Service (MMS) finally formally petitioned the NMFS to allow authorization for petroleum companies to harass small numbers of marine mammals, principally the sperm whale, incidental to conducting seismic testing in the Gulf of Mexico. As it stands now, the wheels are slowly turning to bring management in the Gulf up to the standards long used in the Beaufort, whereby NMFS must issue LOAs with binding mitigation plans, before MMS can issue its permits. The issuance of NMFS permits for small takes (primarily harassment of individual animals) is pending, awaiting a Programmatic Environmental Assessment prepared by the MMS, and its evaluation by NMFS. This EA, or an expanded EIS, will be adapted or developed by NMFS, and will form the basis for future activities in the Gulf. However, until this process is complete, Gulf industrial development is continuing on the current system, by which permits are issued by MMS, along with Notices to Lessees (NTLs). These NTLs contain MMS mitigation requirements, though as noted above, such requirements represent minimal oversight and are not subject to NMFS approval.

On March 3, 2003, the Minerals Management Service (MMS) finally petitioned the NMFS to allow authorization for petroleum companies to harass small numbers of marine mammals, principally the sperm whale, incidental to conducting seismic testing in the Gulf of Mexico.

It is striking that MMS has allowed such extensive development to continue, when even its own reports confirm that our knowledge of marine mammals in the Gulf is both recent and lacking in detail. Given that permanent resident sperm whale populations were unknown until recently. vague assumptions based on the fact that sperm whales are still in the area after decades of exposure to surveys, and that they appear to respond only modestly to seismic activity, are not acceptable as foundations of policy. Without historic data or better current monitoring, we are operating in the dark. It is crucial that future industrial activities in the Gulf of Mexico are carried out under the combined auspices of the MMS and NMFS. The NMFS's biological expertise is essential in assuring that exploration and development activities do not cause further harm to local marine species.

5.6 Moratorium on new surveys

It is clear that the regulation of seismic testing is based on assumption and hope rather than clear established science or even a modest application of the Precautionary Principle. This thinking has resulted in a rampant disregard for safeguards laid out in the Marine Mammal Protection Act (MMPA) and has created a major discrepancy in regulatory policy between seismic testing activities in the Beaufort Sea and the Gulf of Mexico. It is the responsibility of the Bush Administration to acknowledge the obvious confusion within the current system, and to halt all seismic activities in the Gulf of Mexico until a uniform standard of implementation of the MMPA and improved, consistent mitigation standards are adopted.

5.7 Reinstate and reaffirm stronger protections during reauthorization of the MMPA in the next congressional session

Despite strong protests from Senator Olympia Snowe (R-ME), whose subcommittee is scheduled to address re-authorization of the MMPA this year, the Senate and House both included negative language in the recent Defense Authorization Bill that has dramatic, direct effects on regulation of noise impacts on marine mammals. As regards sound, the two changes that are most relevant are:

- Rewriting the definition of harassment. Currently, any military action that constitutes an "annoyance" to marine mammals and has the "potential to disturb" the animals is prohibited. The Pentagon has changed the definition of harassment mean anything that has a “significant potential to injure” or is “likely to disturb " animals. This puts the onus on scientists to prove such impacts and is a move directly away from precautionary standards.
- Expanding the “small take” permitting process so that a single permit can cover large numbers of animals (e.g., whole local populations) and large

areas, rather than the current language, which requires each permit to cover a specified geographic region and small numbers of animals.

In both cases, the changes point us firmly away from precautionary standards, and toward the precipice of causing rapid, hard-to-document population stresses, at a time when more, rather than less, caution is demanded. The House seems poised to affirm these changes in its re-authorization debates. Prevention of these environmental roll-backs and harmful rule changes will depend on steadfast efforts in the Senate. This year's amendments to the MMPA explicitly apply only to "military readiness activities," so do not affect other noise sources, such as seismic surveys, but vigilance will be required to assure that such changes are not extended to other arenas, such as commercial seismic surveys.

5.8 Support clean energy alternatives to fossil fuels and strengthened conservation efforts

Although the purpose of this report remains to highlight the urgency of the threat seismic testing poses to marine mammals as well as other ocean animals, it cannot go unmentioned that the necessity for seismic testing is born out of an antiquated energy policy. Today's clean energy technology is progressing towards increased use of renewable sources of energy, which means it is only a matter of time until oil and natural gas technologies become obsolete. The fact that seismic testing is threatening our ocean ecosystems provides just one more reason to work towards ending our dead-end dependence on fossil fuels.

6.0 Conclusion

The planet's oceans are in crisis and the human burden on our ocean ecosystems is increasing by the day. Marine mammals are especially in need of help and it is vital that the laws currently in place to protect them, such as the Marine Mammal Protection Act, are fully implemented.

But the oceans and the life within them will not be saved through government action alone. The petroleum industry has a reputation for being a highly influential force within the U.S. government and perhaps tremendous public pressure is the only hope left for enforcing environmental values on industry. As drilling in the Gulf of Mexico spreads further and deeper into ocean waters, the risks increase for more species to be harmed by seismic surveys.

Current scientific knowledge of the effects of anthropogenic noise on marine animals is woefully inadequate. This creates an urgent need for advancing research into noise with high standards of scientific and public accountability. This research must remain unbiased and free from interference from the energy industry or other influenced parties.

Today the ocean remains a mix of unparalleled beauty and tragic threats. We watch as the environment continues to pay the price for the steadily encroaching human imprint on nature. Greenpeace is committed to protecting the oceans and the many endangered marine animals that inhabit them and to that end we will continue to do everything within our power as a nonviolent agent of change to end unnecessary and destructive ocean threats such as seismic testing.

But Greenpeace alone cannot turn such a devastating tide. With this report we hope to contribute in a minor way by highlighting the reality of this threat. Our government and corporate actors must be willing to show leadership on protecting the environment and take responsibility for ensuring that our oceans will remain places of wonder and beauty for generations to come.

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[7] Lamont-Dougherty project, source: Environmental News Service, 11/17/03

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[8] See Section 3 below for details; Richardson (1995) and McCauley (2000) provide comprehensive summaries.

[9] See Gausland (2000).

[10] See McCauley (2000).

[11] This is noted in National Research Council (2003), among other places. Potter/Delory (1998) raise this point clearly: "Marine mammals are perhaps the hardest mammalian group to study. Virtually all relevant aspects of their biology (including sensory capabilities, undisturbed behaviour and its adaptive significance, distribution and abundance) are only poorly understood. Conducting marine mammal research at sea is always difficult and costly.. . Given such a background of ignorance, it is extremely difficult to even establish a meaningful framework for estimating the impact of noise on these animals." (p8)

[12] Note that this is a non peer-reviewed conference presentation.

[13] National Research Council (2003) has led the call for more and better-coordinated research. See press release at http://www4.nationalacademies.org/news.nsf/isbn/0309085365

[14] Corridor Research project; The Canadian Press, 11/13/03, http://www.canada.com/search/story.aspx?id=3157e062-08c6-4480-8f5f-053e1b2db3c4

[15] See ESCOOT website, http://www.geosurv.gov.nf.ca/ecsoot/tfunck/z-40km.html (40km), http://www.geosurv.gov.nf.ca/ecsoot/tfunck/z-20km.html (20km)

[16] This summary of operations is based on info in MMS (2003).

[17] National Research Council, 2003

[18] Caldwell and Dragoset, 2000

[19] See Richardson (1995), p297-299

[20] Stocker, personal communication

[21] See Richardson (1995), p 298

[22] There is an added factor of confusion, but this one can be, for now, relegated to the footnotes. Richardson (1995) notes that not all studies are careful to note the sampling bandwidths used to generate pressure density spectrum curves; these bandwidths are crucial, as they allow other researchers to convert the results in ways that allow useful comparisons between studies. Likewise, McCauley (2003) notes that there was an optimal sampling rate for recording the output of airgun arrays, and that this optimal rate would change for different arrays and different locations.

[23] See Richardson (1995) for an overview of other studies of note, including several studies of behavioral responses of bowhead whales by Richardson, Malme, and Ljungblad (individually and in teams) in the Beaufort Sea and of grey whale responses by Malme and Ljungblad, all during the 1980's. These included both opportunistic observations and controlled exposure in the wild. There is a surprising dearth of studies on toothed whales.

[24] Caldwell (2000) and McDonald (personal communication, 2003). At distances greater than twice the depth of the water, reflected sounds tend to increase horizontal received levels to within a few decibels of calculated propagation of vertical source levels.

[25] National Research Council (2003), Figure 1-4.

[26] Caldwell, 2002, p77

[27] Figures in this section are from Richardson (1995) and National Research Council OSB (2003).

[28] Estimated by APPEA, an Australian oil and gas trade association; see http://www.appea.com.au/Publications/factsheet1.asp

[29] Estimated by McDonald (personal communication) See. McDonald, M.A., Webb, S.C., Hildebrand, J.A., Blue and fin whales observed on a seafloor array in the Northeast Pacific, J. Acous. Soc. Am.,98(2), Pt. 1, 712-721, 1995.

[30] See National Research Council (2003), Chapter 2. Ross (1987) found to a 12-14dB increase in low-frequency noise in the period between 1950 and 1975, and projected it to increase another 5dB by the end of the century. Extrapolating back to the beginning of the century, it seems likely the increase has been at least 20dB.

[31] The following discussion is based on figures in Cato (1997), as referenced in National Research Council (2003), and Richardson (1995).

[32] Also referenced in National Research Council (2003): RANDI model as referenced in Emery (2001) and Mazzuca (2001)

[33] This line of reasoning informed the debate on the ATOC experiments in the mid 1990s. See especially National Research Council (2000)

[34] These are very rough estimates, presented to suggest the relative difference, and similarity, in the sounds as received at distance.

[35] In-air sound levels (RMS) taken from Berger (2003), OSHA standards from comparison chart of noise regulations: http://www.aearo.com/html/industrial/pdf/comparechart.pdf

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[36] Adding a straw that will hopefully not break our camel's back, dB levels in air, when being rated in order to judge effects on human hearing, are weighted to better match our frequency sensitivity. Since our hearing is not very sensitive at lower frequencies, the absolute dB value of lower frequency sounds is REDUCED by this weighting system (to reflect the fact that, due to our poor sensitivity, they sound less loud to us). There are a couple of weighting sytems in use; dBA, or "A-weighted" is the one most commonly used when setting safety thresholds. A-weighted values are lower than absolute dB levels in frequencies below 1kHz, the range we are most interested in. The corrections are much higher at the lowest frequencies, and become smaller up to1kHz, where there is no correction applied (26dB are subtracted at 63Hz, 16 decibels are subtracted at 125Hz). By contrast, we do NOT create weighted dB scales for each ocean species; though each species does have its own frequency response curve (ie can more easily hear certain frequencies, with others at which sounds appear quieter than their absolute value); rather, we are content with absolute dB measurements. The bottom line of all this is that if we want to compare the sound of, say a jet take-off on land measured in dBA with the sound of seismic airguns underwater in unweighted dB(peak, mean, or energy), there is a case for adding roughly 25dB to our water values when considering frequencies under 100Hz, and 15dB if considering frequencies 100-200Hz (these are the frequency ranges in which airgun energy is its highest). Of course, if our point is to create a comparison that shows how we might hear a sound in air and water, then there is no need to consider this correction, since low frequency sounds in water will likewise need to be weighted to suggest how human ears would perceive them (ignoring the fact that our eardrums are generally very poor sound conductors in higher pressures of underwater…). For many reasons, comparisons such as this can only be valid when comparing how the same species, in this case, humans, would perceive a sound. Thus for this chart, we are only making the previously noted mathematical corrections for the different dB references, density of water, and differences between ocean sound measuring systems. Please do bear in mind that, given all the translations involved, all parties are on very thin ice in making any definitive claims about how sea creatures may respond to any given dB level. This is why scientists tend to rely on behavioral responses and observed physiological damage caused by ocean-based sound, and to avoid trying to make these sorts of comparisons with human hearing, and especially human safety thresholds, in the air.

[37] Difference calculated using 62dB standard correction, less 13dB correction of mean to equivalent energy, to match the figures above.

[38] To be as modest as possible in these comparisons, this column adds the full 62dB correction to create a comparable RMS level in water; figures for peak levels would be higher by 15dB.

[39] Mark McDonald, personal communication.

[40] McCauley (2000) notes that the sound signature of airgun pulses closely resembles that of a breaching humpback falling back into the water.

[41] The following section owes much to the review of animal hearing that is included in Michael Stocker's work-in-progress, Hear Where We Are.

[42] Darlene Ketten, perhaps the world's foremost authority on cetacean hearing systems, stated at a marine mammal health conference that "a surprisingly large number of stranded animals, nearly 50%, show evidence of some form of auditory compromise or pathology that correlates with low to profound hearing loss in other species." (Ketten, 2002)

[43] See Jepson, et all (2003) and NMFS report on Bahamas stranding (http://www.nmfs.noaa.gov/prot_res/overview/Interim_Bahamas_Report.pdf)

[44] In late November 2003 a series of strandings of sperm whales, pilot whales, and dolphins in southeast Australia, Tasmania, and New Zealand coincided with seismic surveys 300-500km away. The great distance stretches the limits of possible causality, yet a stranding of sperm whale mothers and calves last year during a similar survey raises the question of whether there may be a connection, possibly indirect. See article: http://www.smh.com.au/articles/2003/12/05/1070351793772.html

[45] The most work has been done with pinnipeds, measuring TTS in response to airborne sounds.

[46] See Aquatic Bioacoustics Laboratory summary of research, with chart, http://www.life.umd.edu/biology/popperlab/research/intensesounds.htm

[47] Note that both of the following excerpts are from non peer-reviewed presentations, reflecting a more speculative tone on the part of the researchers.

[48] Summarized in Richardson (1995), p 297

[49] Studies by Malme (1984, 1985, 1986, 1988) and Ljungblad (1982) summarized in Richardson (1995), p293.

[50] Figures in the next four paragraphs based on McCauley (2000)

[51] The MMS GulfCet program has been gathering population data since 1990. In 2001, a long-term study was initiated, led by Peter Tyack of Woods Hole, that is designed to measure sperm whales' responses to controlled sounds in a more systematic way.

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[52] Minerals Management Service Environmental Studies Program project description, http://www.gomr.mms.gov/homepg/regulate/environ/ongoing_studies/gm/GM-01-04C.html

[53] Richardson (1995), referencing Mate et al, 1994

[54] Richardson (1995), referencing Bowels et al, 1994

[55] These studies are referenced in MMS (2002), citing David et al (2000) on the GulfCet study, and Swift et al (1999) for the Atlantic study.

[56] An annual report is due to be published in December 2003. For a description of the research, see http://www.gomr.mms.gov/homepg/regulate/environ/ongoing_studies/gm/GM-01-04C.html

[57] Richardson (1995), p346.

[58] As noted above, controlled exposure trials with a group of resting cow and calf humpbacks showed much lower tolerance for airgun sounds: avoidance was seen at received levels of 97-132dB re 1μPa^2.s and stand-off at levels of 116-134dB re 11μPa^2.s. This would translate to avoidance of an airgun array at 7-12km.

[59] The Standard, 2/14/03; http://the.standard.net.au/articles/2003/02/14/1044927789927.html

[60] McCauley (2000) found a variation of up to 9dB re 1μPa^2.s in the intensity of individual shots; averages over time were fairly consistent, but this variation around the mean "again. . . exemplified the difficulty of predicting the received air-gun level for a specified air-gun array and the requirement for a detailed study of the source and environment." (p172)

[61] See USGS Soundwaves newsletter (11/1999): Report on the regulatory and mitigation process and costs for a geology survey off the California coast using a small (40 cubic inch) airgun: http://soundwaves.usgs.gov/1999/08/fieldwork2.html

[62] See Canadian and UK reports on mitigation measures: Department of Trade and Industry, UK (2003), Turnpenny, et al (2002)

[63] The UK has initiated such a project, with maps available on a publicly-accessible website, www.ukdeal.co.uk.

[64] Passive Acoustic Monitoring utilizes listening devices to eavesdrop on vocalizations beneath the surface; systems have been developed that can identify a large number of species based on such acoustic data. Active Acoustic Monitoring, using low-power sonar, can locate animals that are not vocalizing, but species identification is difficult, and these systems add, in a modest way, to the acoustic pollution of the area. Especially if we are trying to gauge the behavioral effects of an ongoing seismic survey, passive systems are much preferable. There are some situations, such as assessing the behavioral responses of fish or of cetaceans at moderate distances from a survey, where an active acoustic system could be used as in Engas (1996) to estimate changes in the numbers of animals in an area.

[65] See press release: http://www4.nationalacademies.org/news.nsf/isbn/0309085365

[66] John Hildebrand, MMC science advisor, personal communication

[67] Malakoff (2001)

[68] http://www.coreocean.org/Dev2Go.web?id=220628&rnd=5987
NOPP includes U.S. Navy, National Oceanic and Atmospheric Administration , National Science Foundation, National Aeronautics and Space Administration, Department of Energy, Environmental Protection Agency, U.S. Coast Guard, U.S. Geological Survey, Defense Advanced Research Projects Agency, Minerals Management Service, Office of Science and Technology Policy, Office of Management and Budget
Department of State,U.S. Army Corps of Engineers

[69] http://www.coreocean.org/

[70] http://www.oceans.us/

[71] Reported in settlement to lawsuit brought against NSF in regards the 2002 survey in the Gulf of California. See http://geophys.seos.uvic.ca/cassis/Eos.html

[72] For example, see description of PANDA system, a lightweight easily deployable acoustic monitoring system that can remain in place for months at a time: http://www.arl.nus.edu.sg/objects/PANDA_MTS_2003.pdf

[73] "Imploding acoustic sources offer potential advantages in terms of operation depth, ease of field operation, bandwidth for shallow reflection purposes, and a significantly reduced bubble pulse presence. While their *peak* energy output may be relatively high, …their overall energy output is generally low. However, the ability to detect a light globe implosion at 1.2km range is promising." Hoffman 2000

[74] Minerals Management Service (2000)

[75] Minerals Management Ser vice (2002b)

[76] From MMS website, http://www.gomr.mms.gov/homepg/regulate/environ/marmam/gulfcet4.html

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[77] According to the Oil and Gas Journal, 8/19/02, the IAGC was engaged in an active dialogue with MMS in order to bring the new regulations in line with standards in force in other regions, including the North Sea.

[78] Minerals Management Service (2002). Gulf of Mexico OCS Oil and Gas Lease Sales: 2003-2007, Central and Western Planning Areas, Final Environmental Impact Statement. OCS EIS/EA MMS 2002-052. Vol. I, 674pp, Vol II, 180pp.

[79] It is likely that surveys will be better addressed in the Programatic EA for Geological and Geophysical Exploration, which is still in process. However, it appears that MMS is skirting the issue at present.