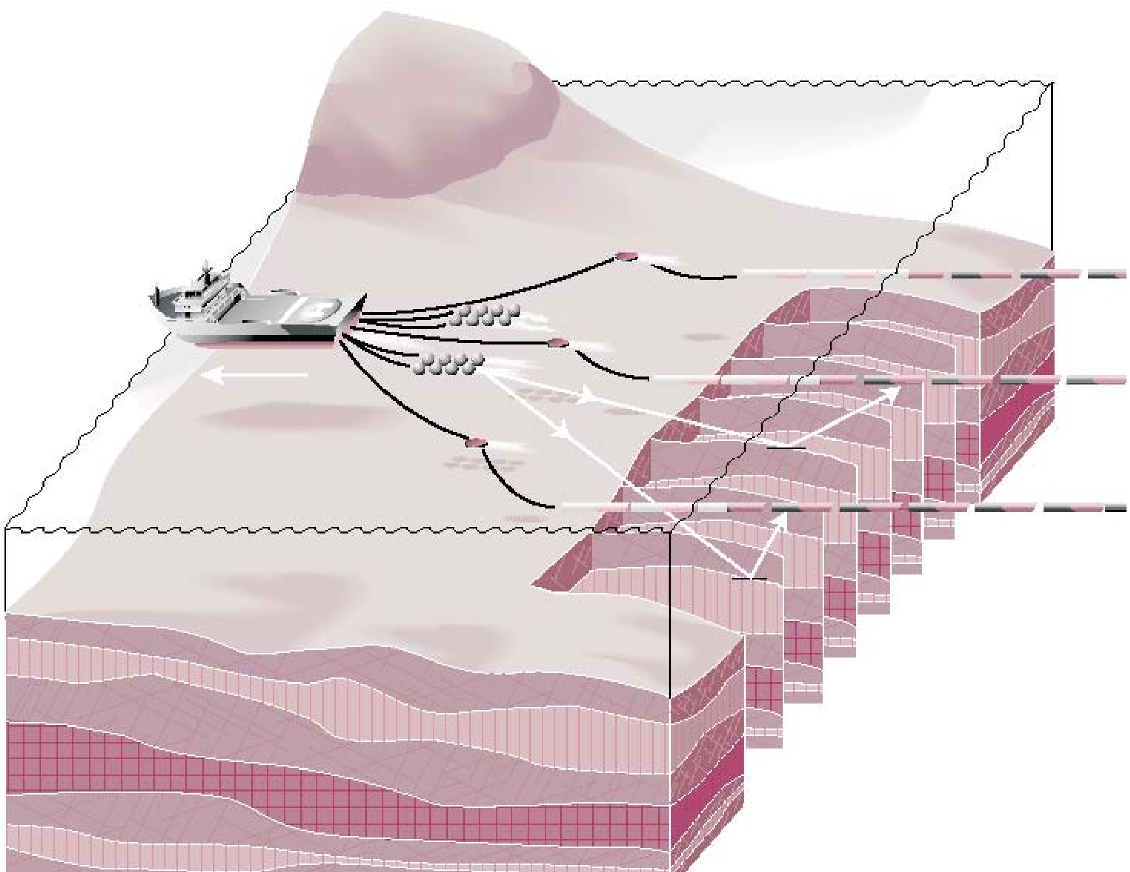
British Columbia
Ministry of Energy and Mines

Sonar versus Seismic:

What are the Differences?



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Seismic versus sonar: what are the differences?

Introduction

The prevalence of human produced noise in our coastal waters, and its effect on marine-mammals and fish, are topics of growing public concern in British Columbia. Many groups, including environmentalists, fishermen, whale-watch tour operators and First Nations, all have, for various reasons, an interest in protecting our oceans from the effects of noise pollution. In particular, two very different sources of human produced ocean noise have become the focus of keen public concern: **seismic airguns** and **naval sonars**. This article explains, in plain language, some of the basics of underwater noise, the fundamental differences between noise generated by airguns and naval sonars, and scientists' current understanding of how noise can affect marine wildlife.

Underwater Sound: Frequency, Loudness and Decibels

Water transmits sound much more efficiently than air. Sound is everywhere in the world's oceans, and originates from many sources, such as storms, animals, earthquakes, commercial shipping, marine construction and even clouds of bubbles. Water also transmits sound far better than it does light, which is why many marine organisms rely on their hearing to find prey, avoid predators, and to communicate. Every human activity in the ocean generates sound. Furthermore, excessive noise in the ocean presents the potential problem of noise pollution. So how do scientists measure ocean noise? Before continuing, it is necessary to introduce two important acoustic concepts: *frequency* and *loudness*.

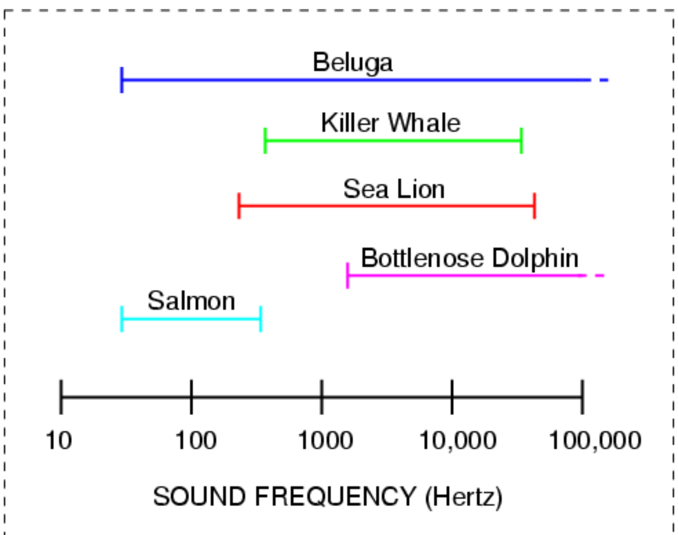

***Figure 1**: Diagram illustrating the differences in hearing ranges between various kinds of marine wildlife.*

Frequency is measured in cycles per second, or Hertz (abbreviated Hz), and is analogous to musical pitch; high-pitched sounds contain high frequencies and low-pitched sounds contain low frequencies. Natural sounds in the ocean span a huge range of frequencies: from earthquake noise at 5 Hz to Harbour porpoise clicks at 150,000 Hz. These sounds are so low or so high in pitch that we cannot even hear them; acousticians call these *infrasonic* and *ultrasonic* sounds, respectively. A single sound may be made up of many different frequencies together. Sounds made up of only a small range of frequencies are called "*narrowband"*, and sounds with a broad range of frequencies are called *"broadband"*; airguns are an example of a broadband noise source and sonars are an example of a narrowband noise source.

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When considering the influence of various kinds of noise on the marine environment, it is necessary to understand that different kinds of marine life are sensitive to different frequencies of sound. Most dolphins, for instance, have excellent hearing at very high frequencies between 10,000 and 100,000 Hz. However, their sensitivity at lower frequencies below 1000 Hz is quite poor. On the other hand, the hearing sensitivity of most fish is best at low frequencies between 100 Hz and 1000 Hz. Thus, fish might be expected to suffer more harmful effects from loud, low frequency noise than would dolphins.

The loudness of sound, both underwater and in air, is generally measured in decibels (abbreviated dB). A very important point to recognize is that **decibels underwater and decibels in air are not the same and cannot be directly compared**. In fact, due to the different densities of air and water, and the different decibel standards in water and air, a sound with the same intensity (*i.e.*, power) in air and in water would be approximately 63 dB quieter in air. Thus a sound that is 160 dB loud underwater would have the same effective intensity as a sound that is 97 dB loud in air. Additionally, because underwater ears are physiologically different from our own, the comparison in decibels would still not be adequate to describe the effects of this noise on a whale.

When sound travels away from its source, its loudness decreases as the distance travelled by the sound increases. Thus, the loudness of a sound at its source is higher than the loudness of that same sound a kilometre distant. Acousticians often refer to the loudness of a sound at its source as the *source level* and the loudness of sound elsewhere as the *received level*. For example, a Humpback whale 3 kilometres away from an airgun with a source level of 230 dB may only be exposed to sound that is 160 dB loud. Thus when one discusses the loudness of sound in the ocean, source levels and received levels must not be confused

Marine Seismic Surveys and Airguns

Marine seismic surveys are conducted all over the world by exploration companies searching for deposits of oil and gas below the seabed. Seismic surveys typically receive quite a bit of public attention, because they generate a significant amount of noise in the ocean environment. Noise from a seismic survey may have the potential to harass or injure marine wildlife, especially marine mammals. But why do seismic surveys generate so much noise, and what purpose do they serve?

Seismology is the science of using sound and vibration to probe the structure of the Earth. In a seismic survey, sound pulses are projected into the earth's crust and the echoes of those pulses are used to create images of layers of sediment, rock and hydrocarbons. Modern, marine-based seismic surveys use large arrays of *airguns* to project sound pulses down into the seabed. Long *streamers* of sensitive hydrophones (underwater microphones) are used to detect echoes of the airgun pulses from the sub-bottom layers. The airguns and streamers are towed from a large survey vessel, which may be at sea for months at a time, constantly firing its airguns (every ten seconds or so) over an area where there are suspected hydrocarbon deposits.

Airguns are the primary source of environmental noise from a marine seismic survey. An airgun is a hollow metal cylinder that generates pulses of sound by releasing bursts of highly pressurized air into the water. In effect, an airgun is like an underwater "pop-gun".

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Airguns are usually combined into an array, and fired in unison to make a louder pulse that penetrates deeper into the seabed. Airgun noise is broadband, and is made up of low frequencies, from about 10 Hz to 3000 Hz. Airguns are designed to emit low frequency pulses, because only very low frequency sounds can penetrate deep into the earth.

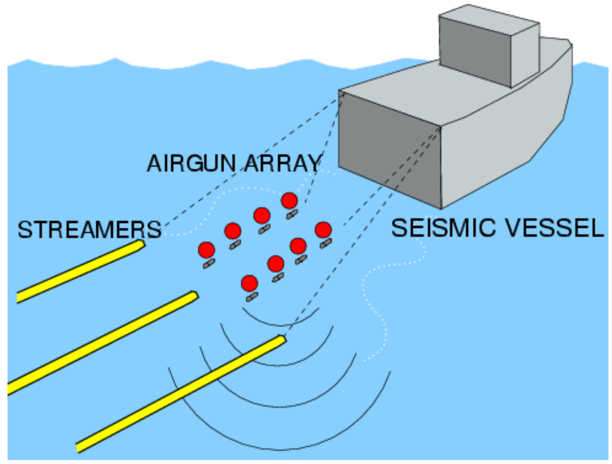

Figure 2: *Illustration of a seismic survey vessel towing an airgun array and streamers. While surveying, seismic pulses generated by the airguns are projected into the sea-bottom. Reflections, from beneath the sea-bottom, are detected by sensitive hydrophones in the streamers and used to locate oil and gas deposits.*

Large airgun arrays are often quoted as having peak source levels as high as 250 dB, which is extremely loud. However, an often-misunderstood point is that most of the energy from an airgun array actually travels straight downward. In fact, the sound levels off to the side of an airgun array may be 20 dB less than the down-going sound level (depending on the size and layout of the array). However, the sound travelling horizontally away from airguns is nonetheless loud, and may still present a possible risk to marine wildlife.

Scientists have studied the effect of airgun noise on marine organisms, both in the lab and in the wild. Recent laboratory experiments concluded that fish exposed to airgun noise at very close range, at peak levels of up to 210 dB, suffered permanent hearing damage. No similar laboratory exposure experiments have been performed with airguns and marine mammals, but dolphins exposed to simulated noise from distant explosions (similar in nature to airgun noise, though much louder) were not observed to sustain any hearing loss at peak sound levels of up to 215 dB. These results are consistent with the hypothesis that airgun noise is likely more disturbing to those animals that are able to hear it, and less so to those who can't. Baleen whales (*e.g.*, Humpbacks, Blues and Greys) whose hearing is best at infrasonic and low frequencies may be more affected by noise from airguns than dolphins who have poor low frequency hearing.

In the wild, animals are seldom exposed to such extreme sound levels from airguns. A number of scientific studies have observed the behaviour of marine mammals in the wild, in response to seismic survey activities. Groups of whales have been observed to intentionally avoid airgun surveys, especially when exposed to sound levels above 160 dB. In addition, whales may cease calling or change their diving patterns in response to exposure from airgun noise. It has even been suggested that whales modify their migration paths in reaction to periods of intense airgun activity.

The seismic industry now employs various mitigation measures to decrease the potential impact of airgun surveys on marine wildlife. Many seismic surveys, in Canada and in the US, have marine mammal observers aboard to watch for whales, dolphins and seals close to an operating seismic vessel. Many survey operators will voluntarily shut down an operating airgun array if a marine mammal is sighted within a few kilometres range. As well, when beginning a survey line, many operators, rather than firing all of their guns immediately, will "ramp up" their airgun arrays (gradually increasing the loudness over 5–

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10 minutes) in order to warn off nearby marine life. In some jurisdictions, for example the U.S., the law requires such mitigation measures.

Navy Sonar Systems

Navy sonars are used for an entirely different purpose than airguns, and thus generate a completely different kind of noise. Naval sonars are designed for three primary functions: submarine hunting, mine hunting and shipping surveillance. There are two classes of sonars employed by navies: *active* sonars and *passive* sonars. Passive sonars generate no noise at all (they locate submarines and ships merely by listening for them) and are therefore not a concern. Active sonars, in contrast, can generate a considerable amount of high intensity noise and are of definite concern, with regards to their affect on marine wildlife.

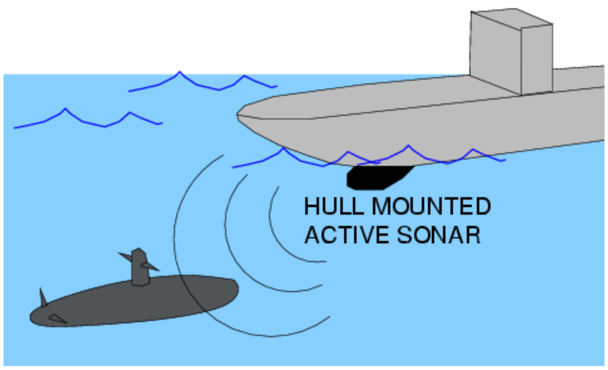

Figure 3*: Illustration of a submarine-finding sonar system aboard a naval destroyer. Sonar pulses are projected into the water by an active sonar mounted on the ship.s hull. Reflections of the sonar pulses are used to discover the location of enemy submarines.*

The largest naval active sonars are typically carried aboard naval destroyers whose specific role is hunting submarines. The U.S. Navy operates many of the most powerful and sophisticated sonar systems in the world today, but most other navies, including Canada's, employ similar active sonar systems as well. Naval sonars operate on the same basic principle as fish-finders (which are also a kind of sonar): brief pulses of sound, or "pings", are projected into the ocean and an accompanying hydrophone system in the sonar device listens for echoes from targets such as ships, mines or submarines.

Pigeonholing sonar noise can be difficult for two reasons: there are many different navy sonar systems in use, and their capabilities are generally classified knowledge. A single destroyer will often carry an entire suite of sonar systems, each with a different source level and operating frequency. However, some broad statements about naval active sonars are possible:

1. Naval sonars are typically narrowband sources. Often their pulses will be at a single frequency, or swept over a narrow range of frequencies about a central frequency.
2. Naval sonars operate over a very wide range of frequencies, between 100 Hz and 100,000 Hz.
3. Sound from naval sonars is directed *horizontally* away from the source vessel, rather than *downwards*, as in the case of airguns.
4. Ship and submarine finding sonars are typically high-powered (*i.e.*, have high source levels) for detecting targets at long range. Exact source levels are, unfortunately, classified.

The effects of naval sonars on marine wildlife have not been studied as extensively as the effects of airguns. In the Caribbean, avoidance reactions were observed for Sperm whales exposed to mid-frequency submarine sonar pulses, in the range 1000 Hz to 10,000 Hz. Recently, the US Navy sponsored tests of the effects of low-frequency active (LFA) sonar noise, between 100 Hz and 1000 Hz, on Fin, Blue and Humpback whales. The tests demonstrated that whales exposed to sound levels up to 155 dB did not exhibit significant disturbance reactions, though there was evidence that Humpback whales did alter their vocalization patterns in reaction to the noise. Given that the source level of the Navy's LFA is reported to be in excess of 240 dB, the possibility exists that animals in the wild may be exposed to sound levels much higher than 155dB.

There are claims of some military sonar tests being followed by mass whale strandings. However, links between sonar tests and some mass strandings have only recently been proven. In one case in 1996, documented in the journal Nature, a mass stranding of 12 Cuvier's beaked whales in the Mediterranean was statistically linked to nearby military tests of LFA sonar with 99% probability. Additionally, the US Navy acknowledged responsibility for the beaching of another 14 Beaked whales in the Bahamas in 2001 (see Suggested Reading). This is not to say that naval sonar tests are the only probable cause of mass whale strandings; many mass strandings are not related to noise pollution at all. Though the specific motivations are still a mystery to scientists, groups of whales may beach themselves in response to a variety of environmental stresses.

Differences Between Airguns and Sonars

Both airgun arrays and naval sonars have the potential to harass, and even injure, marine wildlife. However, differences in the nature of these sources and the way they are operated have a significant effect on the probability that wild animals will be harmed by their use. The most important distinctions are:

1. Since naval sonars operate over a much wider frequency range than airguns, there is a greater potential for affecting a wider variety of marine species.
2. Because sound from naval sonars is often directed horizontally away from the source, there may be a larger overall zone of influence inside which marine life may be affected.
3. Less is known about the effects of high-powered sonars on marine life than the effects of airguns, since military activities, such as sonar tests, are necessarily subject to less public scrutiny than civilian activities, such as seismic surveys.

The last point is, perhaps, the most important. Without a greater understanding of the effects of naval sonars on the marine environment, scientists cannot say, with certainty, what are the specific risks associated with their use.

Mitigation Measures

In Canada regulators require operators of any high-powered acoustic source, be it an airgun array, active sonar or demolition charge, to obtain a permit to operate and to take appropriate steps to reduce the risk to the marine environment. The following mitigation steps are required and have been adopted by seismic operators around the world as a code of practise:

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1. Taking care not to operate a high powered acoustic source near an area where threatened species are known to congregate.
2. Being aware of the source level and operating frequency of an acoustic system, as well as the size of possible zones of influence around that system (*e.g.*, ranges where animals are likely to be harassed or injured).
3. Employing "soft-starts", *i.e.*, a gradual ramp up of the sound level, to scare off any marine life before operating at full power.
4. Watching for marine mammals and fish in the immediate vicinity of an acoustic system, prior to operation, and shutting down when animals are spotted within pre-determined zones of influence.

Thus, when operated with care, airgun arrays, should not pose a threat to marine life.

Some Links for Further Reading

Marine Mammals and Human-Made Sound
http://birds.cornell.edu/brp/HumanMadeSound.html

University of Rhode Island: Animals and Sound in the Sea
http://omp.gso.uri.edu/dosits/animals/intro.htm

IAGC Article: Airguns and Marine Mammals
http://www.iagc.org/public/gom/gom6.pdf

Scientific American Article: Sound Judgements: Will a Powerful New Navy Sonar Harm Whales?
http://www.sciam.com/article.cfm?articleID=00082EB7-0903-1C6F-84A9809EC588EF21

SURTASS LFA Environmental Impact Analysis
http://www.surtass-lfa-eis.com/EIA/index.htm

National Academies Press: Ocean Noise and Marine Mammals
http://www4.nas.edu/news.nsf/isbn/0309085365?OpenDocument

Strategic Environmental Research and Development Program:
Conservation Programs
http://www.serdp.org/research/Conservation.html

IAGC Article: Male sperm whale behaviour during exposures to distant seismic survey pulses
http://www.iagc.org/public/gom/Madsen_revised.pdf

Whale and Dolphin Conservation Society: Oceans of Noise
http://www.wdcs.org/dan/publishing.nsf/allweb/48A0C8D9C559FA0680256D2B004027

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