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Backgrounder

Seismic Surveys at Sea:
The contributions of airguns to ocean noise

Contents:

Scope of the Industrial Airgun Presence
Primer on Seismic Surveys and Airguns
Recent Research on the Effects of Airgun Noise
Reports on Ocean Noise

The Story in a Nutshell:
In the wake of recent whale beachings, ocean noise is receiving increasing scrutiny from government agencies, the courts, and academic researchers. While Navy sonars have been the focal point of public concern and legal actions, research released in 2004 points to noise from airguns used in seismic surveys carried out by the oil and gas industry as a key and largely untracked contributor to global ocean noise. The largest seismic survey in history is about to commence along much of the coast of India; it is scheduled to include up to 13 vessels, and will last from November 2004 to June 2005.

Airguns are as loud as the Navy sonars, but they are much more common and ongoing, typically blasting every 10-20 seconds for days or weeks at a time. There are about a hundred commercial seismic survey vessels worldwide, and their activity is increasing the overall background noise in the sea to levels that are likely making long-range whale communication difficult. Even thousands of kilometers from active surveys, field researchers have found airgun noise to be the dominant feature in the soundscape. This past summer, the International Whaling Commission called for public notice of industrial surveys and independent monitoring of their biological impacts.

Beyond marine mammals, a 1996 study in Norway showed that airguns lowered fish catch rates over a 2,000 square mile area, and 2004 studies have demonstrated that airguns can cause long-term injuries in snow crabs and implicated surveys in the beachings of squid that died from unexplained internal injuries. While seismic surveys have been taking place for decades, changes in industry practices (including exploration on the continental slopes where sound may bounce into long-range sound channels, and increasing use of 4D (repeat) surveys during the life of active reservoirs) may be responsible for the recent burst of reports from biologists concerned about their effects. Surveys are especially common in the North Sea, off the African and South American coasts, the Gulf of Mexico, the South Pacific, and the Indian Ocean.

Scope of the Industrial Airgun Presence:
How many commercial survey vessels are out there?

Estimates given by biologists and geologists range from 50-100 ships worldwide, with 2-20 active on any given day.

The most concrete data I've found:

- 105 seismic survey ships counted in the trade journal OffShore's 2003 survey, not counting the biggest company, WesternGeco (at least 11); the survey may include "non-streamer vessels" (not sure what they are, support ships that are not making or measuring sound?)
- Over 90 ships in operational condition, 15-20 active on any given day (Tolstoy R/V Ewing calibration paper, 2004)
- Each year there are about 20 MMS-permitted 3-D seismic surveys in the U.S. Gulf of Mexico. (US Minerals Management Service, Programmatic Environmental Impact Statement for Gulf of Mexico Geological and Geophysical Activities, 2004)

Primer on Seismic Surveys and Airguns

What are Airguns? Seismic surveys utilize arrays of airguns to produce powerful sound waves; sudden releases of pressurized air bubbles create the sound source, with up to 20 guns fired in synchrony, while "streamers" of hydrophones listen for echoes. Using sophisticated acoustic processing, these echoes can provide information about geological structures up to 40km below the sea floor. Seismic surveys are used by academic geologists to study plate tectonics and sedimentation patterns that hold clues to historic climate change patterns, and by the oil and gas industry in its search for new hydrocarbon deposits and the monitoring of reservoirs as they are emptied.

Human Noise Sources in the Sea: Over the past several years, public and legal attention regarding ocean noise has focused on military sonar systems such as the Low Frequency Active Sonar (successfully challenged in the US and now used only in limited training ranges) and the Mid Frequency Active Sonar (widely deployed by several countries and NATO, and implicated in several strandings of beaked whales in which evidence of acoustic trauma were present). In the past year, two much more common sources of human noise have received increased scrutiny. Shipping is the most omnipresent source of anthropogenic noise in the sea, though not nearly as loud as sonar or airguns; overall, shipping is blamed for a 10-20dB increase in the backgound noise in the sea throughout the world since 1950 (which translates to a 100x to 1000x increase in the intensity of background noise). Meanwhile, seismic surveys utilizing airguns create noise nearly as loud as the military sonars, but continuing every 10-15 seconds for days or weeks at a time.

A handful of seismic survey ships worldwide are contracted by academic institutions for their studies. Academic surveys use anywhere from 1 to 20 airguns in their arrays; it is quite common for these surveys to use 3-12 guns. The standard "safety radius" is 500-1000m, though it can be less on small-array projects, or more (up to 3000m) in certain shallow-water situations; operations stop when whales are in or approaching this distance from the ship. Occasionally, these studies move beyond "pure science" and can involve data collection designed at least secondarily for assessing the potential for energy development.

Meanwhile, there are somewhere in the range of a 50-100 industrial ships equipped with airguns, with 20-30 active at most times, and one or more surveys underway worldwide on most days. Industrial surveys are far more apt to use full-power 20-gun arrays (academic surveys typically make more of an effort to use smaller arrays when possible); however, the standard safety radius is just 500m. Industrial seismic surveys have been taking place worldwide since the 1970s; activity peaked in the late 1980s to mid 1990's, though a new generation of higher resolution technologies and a trend toward ongoing seismic monitoring of active reservoirs is fueling an increasingly bullish attitude in the industry.

In recent years, industrial exploration has extended farther out to sea, onto the continental slopes, where reflections from the slope may tend to project sound out towards deep water and the SOFAR channel (a layer of the ocean that traps low-frequency sound and transmits it over long distances), adding to global noise pollution.

Also, it is becoming much more common to conduct "4D" surveys, which are repeat surveys over producing oil and gas fields, designed to monitor reservoir depletion and fluid movement, in order to better site wells and maximize the utilization of each reservoir. The North Sea has been the site of many 4D surveys, and the industry considers the Gulf of Mexico fields now "mature" enough to benefit from the same.

Impacts on nearby ocean life. A well-established body of research indicates that marine mammals tend to avoid active seismic survey vessels, often exhibiting avoidance behavior at ranges of 5-30km; however, it is not uncommon for whales or dolphins to approach closer to operating airguns, whether out of curiosity or because of a biological need to be where they are. In 2002, two beaked whales (the family whales that has proven most susceptible to sonar impacts) were found dead along a shoreline near where an academic survey was underway; they were too decomposed to determine a cause of death, but the incident became the first case of a survey being stopped by the courts due to animal safety concerns. Wild fish stocks similarly avoid active seismic surveys; several studies since 1990 have shown that fish catches decrease by 50% or more in areas of up to 2000 square miles during seismic surveys; there is also evidence that fish egg viability is decreased by long-term exposure to low frequency noise. There has been very little study of the effects of airguns on more sedentary bottom-dwellers, or on plankton and other foundations of the food chain. Recent studies of caged fish and snow crabs have shown that both can sustain physiological damage when airguns pass overhead.

Industrial seismic surveys have been in operation worldwide for decades, with relatively few reports of obvious harm to sea life. In general, regulatory agencies and airgun operators proceed under the assumption that fish and whales will move away from airguns, and thus will avoid direct physiological harm. Given the several decades-long history of seismic surveys, and the lack of evidence of massive die-offs, this assumption is likely largely correct (even taking into account that many animals may sink rather than beach if injury leads to death). However, the biological effects of displacement/harassment by noise are not well studied, and there is some evidence of long-term hearing damage in cetaceans (based on studies of beached dolphins, both living and dead, about half of which show signs of compromised auditory systems--likely caused by a combination of age, toxins, and exposure to chronic airgun or ship noise, or incidental exposure to louder noises such as explosives).

Underlying much of the concern among both scientists and the public are biological and ethical questions about frequent harassment by human noise; does our need for new oil supplies trump ocean creatures' needs for acoustic space in the seas? Given the tenuous

revcovery of cetaceans, and the global decline in most fish species, calls are increasing to limit additional stressors on these fragile populations of sea life.

Long-range sound transmission: a recent realization. During 2004, bioacousticians have begun reporting that airgun noise from distant surveys along the coasts of South America and Africa can be the dominant sounds in some mid-Atlantic study sites, at times making it difficult or impossible to hear the whales or seaquakes they are trying to study. Airgun noise is over 200dB (often 230db) at the source, drops quickly to under 180dB (usually within 50-500m, depending on source level and local conditions), and continues to drop more gradually over the next few kilometers, until leveling off at somewhere near 100dB. At this level, the sound can travel for hundreds or thousands of kilometers; in many or most locations, 100dB is significantly louder than the existing ambient background noise, so the airguns raise the background noise to this level, potentially masking local biological calls and signals. Such effects have been noted at ranges from 1300-3000km from active surveys. These sounds are primarily low frequency, so at long distances, the effects are most pronounced for larger species such as the great whales and some fish that use low-frequency sounds; many fish and the toothed marine mammals such as dolphins, seals, and sperm whales, use higher frequencies in their communication.

At the International Whaling Commission 2004 meetings and at 2004 meetings of the US Marine Mammal Commission's Advisory Committee on Sound, research has been presented that suggests human noise can shrink the area in which whales can communicate with each other by two to four orders of magnitude (that is, when the sea is especially loud, their effective communication area is one hundredth to one ten-thousandth the size that it would be in the absence of human noise).

Regulation and monitoring of seismic surveys. Some countries have begun to take a harder look at airgun noise; during 2004, Mexico has rejected some permits for both academic and industrial surveys, and Brazil is prohibiting surveys near a key marine reserve. Still, worldwide awareness of the long-range acoustic effects of surveys is only beginning to develop.

It is not clear how the international community might regulate noise effects at such long ranges. To date, mitigation measures and operational standards for seismic surveys have been largely aimed at assuring that no marine mammals or sea turtles are directly exposed to airguns at close range.

Most seismic surveys begin with a "ramp up" period, typically 30 minutes, during which the airguns are turned on a few at a time, so that any marine mammals or large fish in the area will be forewarned and have time to move away (smaller fish and turtles may need more time, and of course slow-moving bottom creatures are unlikely to flee). Similarly, as the ships move along their survey lines, their slow approach allows time for animals to move.

In the US, Europe, and Australia, safety zones are routinely established around operating seismic survey vessels, with on-board observers watching for animals entering this zone, which ranges from 150m to 3km, depending on the intensity of the airgun arrays and local sound propagation properties. Most commonly, the safety radius is 500m to 1km; outside of this zone, sounds are generally considered to be less than 180dB, the threshold where physical damage is considered likely. (There is an undercurrent of uncertainty within the research community about whether these thresholds are backed by solid evidence, but they have become de facto standards.)

Since ocean noise by its nature a trans-national problem, initiatives are underway to formally include noise as a "pollutant" under international treaties such as the UN Law of the Sea. Toward this, other regional, national, and state ocean policy agencies have begun to address ocean noise questions, driven by concerns about sonar and shipping, to which seismic surveys must surely be added. Examples of this include the International Whaling Commission actions in 2004, the State of California Action Strategy for ocean policy, and actions in the European Union parliament.

What Can be Done?

Responses to the increasing concerns about the effects of seismic surveys range across the entire spectrum of possible actions. At one end of the spectrum is the "business as usual" response, which relies on the long history of airguns with little dramatic evidence of problems. For example, the US Minerals Management Service recently released a draft Programmatic Environmental Impact Statement for survey activity in the Gulf of Mexico, which is content with the current 500m exclusion zones. At the other end of the spectrum are calls for a moratorium on surveys and legal challenges that have stopped several surveys in their tracks during 2004.

Modest proactive steps have taken place within some permitting agencies, including the US National Oceanic and Atmospheric Administration (NOAA) and the UK Department of Trade and Industry (DTI), both of which have begun calling for use of "passive acoustic monitoring" (listening for whales, rather than relying solely on visual monitoring, which is well-known to spot only a small fraction of whales present), and at times enforcing larger exclusion zones (up to 3km in certain situations).

The more dramatic suggestions made by the IWC deserve wider application. In addition to calls for public information about industrial surveys (so that agencies can better consider the cumulative impacts of many surveys in one area), the IWC strongly recommended that surveys be accompanied by "continuous" biological effects monitoring, extending before, during, and after all surveys. The costs of such monitoring have severely limited the academic community in its ability to do these comprehensive studies. While requiring industry to fund a wide range of biological effects studies would add to the cost of oil exploration, it should be considered a viable and prudent option at this time. The industry has funded some of the most important studies to date; there remains a pressing need for more comprehensive research. Given that seismic surveys are the most common extreme noise source in the sea, it is reasonable to require commercial survey companies to fund the research needed to determine their long-term and long-range effects on sea life.

2004 Research on the Effects of Airgun Noise

Squid Show Signs of Acoustic Trauma - Several beachings of giant squid along the coast of Spain have raised concerns that their deaths may have been caused by exposure to loud sounds, possibly seismic survey airguns. Unusual numbers of stranded squid appeared during seismic surveys in both 2001 and 2003, according to researcher Angel Guerra. None had signs of superficial damage, but all had internal injuries. Ear damage was present in all specimens, with further organ and tissue damage in some. "No one has ever seen this before in giant squid," says Guerra, who fears there might be many more victims. Local fishermen also reported seeing large numbers of dead fish floating at sea during the surveys. These were the first seismic surveys in the area, but Guerra says the surveyors, led by geologists from the University of Orviedo and affiliated with the Spanish oil company Repsol, plan to continue in 2005. Source: New Scientist, 9/22/04
http://www.newscientist.com/news/news.jsp?id=ns99996437

Snow Crabs Show Damage From Airguns - The first controlled study of snow crabs exposed to an active seismic survey has revealed a surprising amount of physiological damage. Crabs, which were caged on the seafloor as airguns passed 40meters above them, exhibited tissue and organ damage, slightly poorer reproduction, and an increased number of lost legs. Canadian Department of Fisheries and Oceans researchers, who did the study, noted that there was no significant change in mortality or feeding patterns in crabs exposed to airguns, but that hemorrhaging and membrane detachment in the crabs' ovaries was noted, and that the condition intensified between December (when the crabs were exposed to the airguns) and May. Similarly long-lasting and worsening effects were also detected in the hepatopancreas, which functions like a liver in a crab, with abnormal cell structure, swelling and stress detected. While the scientists cautioned that temperature differences or handling in the cages may have been responsible for some of the physical damage observed, and called for further study, environmental groups expressed shock at the results and called for consideration of an immediate moratorium on seismic testing.
Sources: Halifax Herald, 10/2/04
http://www.herald.ns.ca/stories/2004/10/02/f292.raw.html
Halifax Herald, 10/7/04 (more on various interpretations)
http://www.herald.ns.ca/stories/2004/10/07/fBusiness195.raw.html
Sierra Club Press Release, 10/4/04
http://www.sierraclub.ca/national/media/item.shtml?x=740

International Whaling Commission Scientific Committee, 2004 meeting:
Full Report on the Mini-symposium on Anthropogenic Noise:
http://acousticecology.org/docs/IWC56-noisesymposium.doc
Section of Scientific Committee Report addressing the Noise Symposium and Recommendations (which was unanimously adopted by the full IWC membership):
http://acousticecology.org/docs/IWC56-SCReportNoiseSymposium.doc

> **Regarding seismic surveys**, **the SC and IWC endorsed a set of detailed protocols for mitigation and monitoring near seismic surveys**, including access to information regarding timing, distribution, and extent of surveys (both planned and historic patterns) in critical habitats or potentially critical habitats, continuous acoustic monitoring of critical habitats before, during, and after seismic surveys, and independent monitoring of critical habitats to evaluate displacement or disruption of important behaviours (further specified to mean "independent and highly experienced shipboard marine observers and a monitoring system and platform that are independent of the seismic source vessel and seismic support vessels"). These (and several other) recommendations were commended to member countries for adoption, and requested to be passed on to representatives of the oil and gas industry and geophysical academic teams and relevant government committees and agencies.
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> The SC report noted that seismic surveys have been shown to cause displacement of whales from their feeding grounds both off Sakhalin Island, and off the coast of Brazil. The Committee commended Brazil for its work to protect critical marine habitats from noise exposure, and "views with great concern the impacts. . . from exposures to seismic sound impulses, particularly with respect to threatened populations such as the western gray whale."
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> **Sound from seismic survey airguns increased the measured ambient noise levels of a blue and fin whale feeding area in the North Atlantic by two orders of magnitude (a 100-fold increase).** (Christopher Clark, Cornell) This increase, observed throughout a nearly hundred thousand square kilometer study area (200x400 nautical miles), was nearly continuous for days at a time; such long-range effects contrast with typical effects modeling, which focus on areas very near the survey vessels and consider the effects of a single seismic shot lasting only a fraction of a second.
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> Questions were raised about the effects of such chronic elevated noise exposure on searches for prey, and finding suitable mates. Roger Payne presented additional information on the role of infrasound in maintaining whale "heards." He hypothesised that baleen whale populations might live in acoustic contact throughout an ocean basin where very long-range communication can take place; elevated levels of low frequency noise could very well disrupt such long-range communication, with potentially dramatic effects of reproductive success and

thus population vitality. **In certain Northern Hemisphere ocean regions the area in which a fin whale can hear a compatriot has decreased by four order of magnitude (ie, calls can be heard in an area one ten-thousandth as large as previously).** Payne noted that in spite of great efforts to find them, there are no known breeding grounds for open ocean populations of fin whales, suggesting that there may be no need for fin whales to meet *en masse* at particular times and places, if they are able to get together, simply by calling and listening for each other over great distances—they may indeed have no breeding grounds simply because they are not necessary.

New Research:
Low-frequency whale and seismic airgun sounds recorded in the mid-Atlantic Ocean
(Nieukirk, Stafford, Mellenger, Dziak, Fox. J. Acoust. Soc. Am., Vol. 115, No. 4, April 2004. P. 1832-1843)

(From Discussion section):
Since this hydrophone array was deployed, the periodic impulses produced by seismic exploration vessels operating around the Atlantic basin were the dominant signal detected.

Concern over the potential effects of anthropogenic noise on marine life has been such that the National Research Council of the (U.S.) National Academy of Science has commissioned three studies on this topic to date (NRC 1994, 2000, 2003). Although seismic airgun arrays are designed to direct the majority of emitted energy downward through the seafloor, their sound emission horizontally is also significant (NRC, 2003). Airgun survey vessels were often located 3000 km or more from our array (Fig. 1), yet airgun pulses were still clearly recorded on each hydrophone. The broadband frequency range and repeated firing of these guns make them a major contributor to the low-frequency sound field in the North Atlantic.

Airgun activity in shallow water has been shown to significantly damage the ears of fish (McCauley *et al.*, 2000) and has been implicated in the stranding of beaked whales (Malakoff 2002; NRC 2003). Its effect on the baleen whales studied here is unknown; possible effects include masking of conspecific sounds, increased stress levels, changing vocalizations, and ear damage (Richardson *et al.*, 1995). Most of the seismic vessels we located were operating in marine mammal habitat, including that of the critically endangered northern right whale.

Airgun pulses were recorded year-round but were most common from late spring through fall. This pattern is the opposite of the peak occurrences for all baleen whale calls. It is possible that the seasonal patterns seen in baleen whale calls are due to airgun interference: that is, the calls are produced in the summer months but obscured by airguns. However, because calls are detected during some months of frequent airgun occurrence in the fall, because the repetition rate of airguns is such that most whale sounds can be detected between pulses (Fig. 8), and because the data were visually inspected, we don't believe that many calls were missed due to interference (cf. Clark and Charif, 1998).

(From Results section):
Sounds associated with seismic airguns were recorded routinely on all hydrophones, and trends were similar in the

two years (Fig. 7). Typically airguns were heard every 10–20 s (Fig. 8). Although airgun sounds tended to dominate recordings during the summer months, loud whale vocalizations could still be detected during intense airgun activity (Fig. 8). Occasionally the array recorded airguns from more than one location, masking cetacean sounds and on four occasions making the spectrogram data impossible to use. The high received level of these impulses on multiple hydrophones made it possible to estimate the locations of the ships conducting the airgun surveys. During the summer months, airguns operated off Nova Scotia, Canada, probably in support of exploration in the Sable Island region (Fig. 1). From spring through fall seismic vessels, presumably commercial, were located working off the coast of western Africa and northeast of Brazil. Seismic vessels operating in other areas of active exploration, such as the North Sea and the Gulf of Mexico, were not observed by this array due to bathymetric blockage.

Reports on Ocean Noise:
SEE ALSO: www.AcousticEcology.org/science.html

Seismic Surveys: What We Don't Know Can Hurt - A research overview by Acoustic Ecology Institute Executive Director Jim Cummings, commissioned by Greenpeace, 2004.
http://acousticecology.org/oceanairgunexecsumm.html

Impacts of Anthropogenic Sound on Marine Environments - Paper by Michael Stocker, commissioned by Earth Island Institute, with a special focus on the use of sound by fish and mollusks and a brief overview of natural and biological noise in the oceans.
http://www.msa-design.com/FishEars.html

Ocean of Noise - The UK-based Whale and Dolphin Conservation Society has released a 165 page report, available on its website; its primary focus is on taking action to protect sea life from damaging impacts.
http://www.wdcs.org/dan/publishing.nsf/allweb/64543E9BBF9860D780256D2D00331176

Ocean Noise and Marine Mammals - From the Ocean Studies Board of the National Research Council, a US-government funded institute, this is an overview of existing research. Its tone is predictably cautious (the press release is titled, accurately enough: Impact of Noise on Marine Mammals Remains Unclear), mentioning concerns but stopping short of raising alarms, though it does make urgent calls for further study. Among its especially useful sections is an overview of natural noise sources in the oceans.
http://www4.nationalacademies.org/news.nsf/isbn/0309085365

US Marine Mammal Commission Sound Program – Sponsoring a series of plenary sessions and workshops on ocean noise. The page for each past event includes links to papers on the topic of the event (which have ranged from shipping to international law and general noise issues).
http://www.mmc.gov/sound/

For more information on ocean acoustics, including important discussions of dB measures in the sea and air, and natural sources of loud underwater sound, see: http://www.acousticecology.org/oceanacoustics.html