

AEI Special Report:

Ocean Noise 2009
Science, Policy, Legal Developments



Photos:
Scripps HARP autonomous recorder: Sean Wiggins
Seaglider: University of Washington
Ocean observatory schematic: NOAA

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About the Acoustic Ecology Institute

In this, AEI's fourth annual overview of ocean noise, we take a simpler approach than in the last couple of years. This time, we include brief overviews of two ongoing areas of attention — seismic surveys and active sonars — as well as a recap of the most interesting research from 2009. For the first time, we feature in-depth "AEI Resource Collections" on two key topics, shipping noise and passive acoustic research platforms. For those of you new to ocean noise issues, I'd recommend reading this recap along with the 2008 version, which has more detail in some key areas that are given only a brief look this year.

As ever, the Acoustic Ecology Institute's primary mission is to "translate" complex science and regulatory developments for the general public. AEI does not engage in direct advocacy activities, though our work is inspired by a desire to encourage mindful and respectful co-habitation with other species, and to further our society's re-integration with the natural world. Toward this end, AEI's Special Reports, news and science blog/feed, and lay summaries of new research, along with our ongoing conversations with agency managers, researchers, the press, NGOs, and industry and Navy staff, focus on clearly understanding the state of current science, and providing integration and context to help the public and press cultivate informed understanding of the issues.

Introduction

2009 was a relatively calm year in the world of ocean noise, as compared to the past couple of years, which saw legal fireworks culminating in a Supreme Court sonar ruling, a series of comprehensive reports from agencies in the US and EU, and a noticeable increase in marine scientists urging more caution in our use of noise in the sea. See AEI's previous annual reports for more on all that excitement¹; this year's recap focuses more on emerging themes that reflect the ongoing maturation of the field of ocean acoustics, as agencies, NGOs, and major ocean "noise-makers" focus more on solutions than on arguments.

Even as the dramatic but relatively rare sonar-related strandings occupied public and legal center-stage over the past few years, scientists and agency staff, as well as many NGOs, have been putting most of their attention on the far more **widespread effects of chronic and moderate anthropogenic (human-created) noise**. Much of the environmental concern about the current round of Navy sonar EISs focuses not on potential strandings and deaths of a few animals, but on properly assessing the effects of these exercises of thousands of animals that will be close enough to hear and change their behavior in response to sonar signals. Likewise, nearly all the concerns about seismic surveys have settled down to questions about behavioral responses of populations exposed to surveys noise on a regular basis, or during biologically important times of year.

The most widespread source of chronic ocean noise is clearly global shipping. Three years ago, the possible biological effects of shipping noise were just beginning to appear on the radar of regulators and the shipping industry; in 2009, the world's primary forum for agreements on shipping standards, the International Maritime Organization, began formally addressing the question. A series of international workshops have opened up lines of inquiry and dialogue that seem to hold real promise of actually reversing the steady rise in the ocean's background ambient noise that has accompanied increases in global shipping since the 1960s.

¹ See http://acousticecology.org/spotlight_oceannoise2008.html
http://acousticecology.org/spotlight_oceannoise2007.html and
http://acousticecology.org/spotlight_oceannoise2006.html

The most exciting development in 2009, though, took place outside the regulatory arena. **After several years of preliminary research and prototype testing, passive acoustic monitoring has come of age.** A high-profile project in Stellwagen Bank National Marine Sanctuary continues to lead the way, generating ground-breaking visualizations of the acoustic ecologies of ships and whales outside Boston harbor, while a steady stream of new research techniques and technologies have generated ever-cheaper platforms for short and long-term listening at sea. The result of all this will be a vast increase in our ability to know where human sounds are most problematic, and what areas are most important to marine species.

This AEI Spotlight Report will get you up to speed on each of these important topics, and look ahead at the likely themes of 2010's research, regulatory, and legal developments in the realm of ocean noise.

Naval Active Sonars

Mid-Frequency Active Sonar

EISs continue to roll out, as Navy and public stay in some old ruts

In response to legal challenges and increasing controversy over the effects of active sonar transmissions on marine life, in 2006 the US Navy initiated the process of developing Environmental Impact Statements for each of the offshore Training Ranges where mid-frequency active sonar is used. Most of these ranges have been hosting training missions, including mid-frequency active sonar, for many years, and the current EISs generally propose sonar activity at or just slightly above that which has been taking place there already. EISs for the three ranges where the vast majority of training takes place (Atlantic, Southern California, and Hawaii) were completed in 2008, with three more reaching completion in 2009 (three smaller ranges within the Atlantic province). Three more final EISs should come at any time now, covering training ranges in the Northwest (Washington, Oregon, northern California), Gulf of Mexico, and Marianas Islands (western Pacific).

EIS timeline and links, in AEI Special Report: Active Sonar Systems:
<http://acousticecology.org/sractivesonars.html#Anchor-49575>

Two contentious ranges are bringing up the rear in this EIS process. The Gulf of Alaska Maritime Exercise Area Draft EIS was released in late 2009, and has raised many concerns due to the importance of Alaskan offshore habitat for many species of whales. In particular, the Gulf of Alaska DEIS calls for active sonar exercises to take place there for the first time. As the Navy completes the final EIS, it has already applied for the necessary Incidental Harassment Authorizations from NMFS, which has announced plans to issue permits to cover a five-year period beginning in December 2010.

Navy Gulf of Alaska EIS website: <http://www.gulfofaskanavyeis.com/>

AEI news post on Alaskan press coverage and NMFS intent to issue permits: <http://aeinews.org/archives/729>

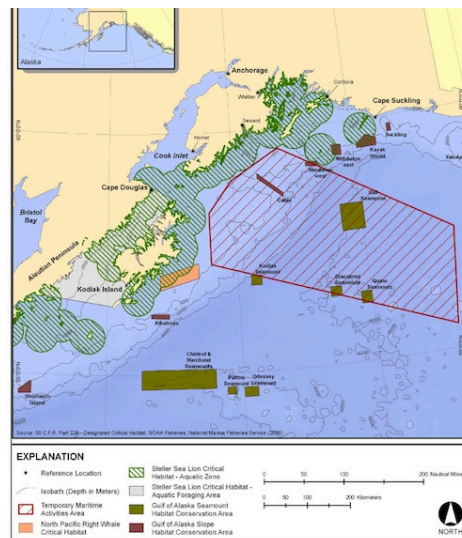


Figure 1-2. Critical Habitat and Habitat Conservation Areas in Vicinity of the Temporary Maritime Activities Area

Alaska Maritime Exercise Area (red crosshatches) and nearby designated critical habitats (sea lion: green hatched; Right Whale, orange; seamount habitat conservation areas, dark green; slope habitat conservation areas, maroon). **Note distance scales at lower right: top, 200 miles; bottom 200km** Image: US Navy

Also stirring up a hornet's nest is the Navy's final EIS for its long-planned third instrumented training range, this one off the Atlantic coast and called the Undersea Warfare Training Range (USWTR). The final EIS chose a site 50 miles off the coast of northern Florida; the issue is that **a key winter birthing and**

nursing ground for the critically endangered North Atlantic right whales is along the coast nearby. In the EIS, the Navy agreed to take extra precautions to avoid ship strikes when the whales are in the region, but refused to limit its sonar activities during those months, saying that their exercises will be far enough away (tens of miles) to pose no danger to the whales. **In January 2010, a consortium of environmental groups challenged the plan in federal court**; as has often been the case, the challenge is focused on the process by which the permits are being issued: in this case, the Navy has received permits to construct the range, but plans to hold off until closer to the planned 2014 opening of the range to apply for operational permits, a separation that the lawsuit claims is not allowed under the MMPA. The States of Florida and Georgia have also expressed concerns about the planned location's effects on right whales.

Press release announcing lawsuit, with links to states' views:

http://www.humanesociety.org/news/press_releases/2010/01/court_navy_right_whale_012810.html

AEI news coverage of the USWTR DEIS: <http://aeinews.org/archives/246> and <http://aeinews.org/archives/251>
Georgia questions "considerable speculation" in Navy assessments: <http://aeinews.org/archives/265>

Throughout the EIS-completion process at various ranges, both the Navy and local citizens have travelled well-trodden paths of rhetorical excess. While the specifics have shifted from the time that AEI assessed the contentious relationship and mutual hyperbole of the Navy and NRDC legal and public relations battles in the mid-2000's², much remains familiar. At root, the Navy continues to downplay the effects of sonar, while many environmentally-oriented members of the public exaggerate the dangers. While no simple formulation can truly capture the subtleties and paradoxes evident in the still-limited direct evidence of sonar's impact on marine mammals, it is probably fair to note that mid-frequency sonar is used routinely on over 300 ships worldwide, in addition to the contentious American training missions along the US coastlines, with very few signs of catastrophic impacts on whales. At the same time, each year new research reveals **more reasons to be concerned about cumulative and chronic behavioral impacts** from an array of human noise sources, evidence that the Navy is slow to incorporate in its assessments.

On the conservation side of the equation, NRDC's early emphasis on the few examples of whales dying after exposure to sonar has metamorphosed into a widespread public hysteria that is far out of step with current understanding or the present emphasis of the professional environmental community³. One especially entertaining (or maddening) example emerged in mid-2009, as the Northwest Training Range DEIS was being discussed in public hearings.⁴ A widely-disseminated online statement made the common mistake of equating "takes" with deaths (in fact, any minor behavioral response qualifies as a take), and spread **inflammatory language such as: "The United States Navy will be decimating millions of marine mammals and other aquatic life, each year, for the next five years**, under their Warfare Testing Range Complex Expansions in the Atlantic, Pacific, and the Gulf of Mexico... The NMFS approvals will have a devastating impact upon the marine mammal populations worldwide and this last Navy permit, which is expected to be issued in February 2010, for the "taking" of more than 11.7 million marine mammals in the Pacific will be the **final nail in the coffin for any healthy populations of sea life to survive.**" Less dramatic, but similar, concerns were raised at many of the public hearings addressing regional EISs; in most places, many members of the public were concerned about widespread deaths of marine mammals, despite the fact that the Navy was proposing little if any increase in sonar activity⁵. Since the public had never been allowed to comment before, it all seemed new to many people.

However, we must hasten to add that while the millions of planned "takes" won't be leaving the seas devoid of marine life, these same numbers have become central to more reasoned concerns with the

² See <http://acousticceology.org/srSonarFactCheck.html> for points of contention and over-statement on both sides, and see <http://acousticceology.org/sractivesonars.html> for more general information on the sonar systems and legal challenge timelines.

³ The NRDC itself is a good example of the evolution of NGO concern away from deaths and toward behavioral impacts.

⁴ The Peterson Perspective, 8/10/2009:

http://www.californiaskywatch.com/documents/htmldocs/pp_marine_mammals_to_be_decimated_by_US_Navy.htm

⁵ See <http://aeinews.org/archives/132>

Navy's approach to its EISs. While each EIS is customized to consider the marine mammal populations in its own area, the fundamental attitudes and approach to the NEPA requirement of assessing several alternatives is sadly consistent across all of the EISs. **Three of the Navy's underlying themes are of particular concern to many observers in the NGO and scientific communities:**

- A stubborn insistence that it needs access to every square mile of every training range for sonar exercises. Claiming a need for full flexibility of movement during exercises and access to the full range of underwater landscapes, the Navy has consistently rejected any alternatives that set especially biologically rich areas off limits to sonar training. Since the entire east coast and most of the west coast of the US are part of ranges, this stance is hard to understand.
- Related to the first problem is the fact that the Navy is relying on very rough population numbers, so that likely actual encounters with whales are basically impossible to predict. This is not the Navy's fault; our current population surveys are just not all that specific. So, the Navy uses numbers that reflect a large regional population of animals (e.g. the North Atlantic), and "assumes" they are spread evenly throughout the entire range, an assumption that everyone knows is false; this likely overestimates takes in most areas, since whales are, in fact, not present at any given time, yet it also is sure to underestimate the numbers of whales impacted when concentrations of whales ARE present. (This last point also undermines the ability of the Navy to truly assess the benefits of putting important habitat off-limits, as their models do not generally show those areas as having more animals.)
- The Navy has attempted to address the wide range of received sound levels that can trigger behavioral responses in some minority of a population by improving its method of estimating behavioral takes by using of a "risk function curve." This approach counts a decreasing proportion of whales as likely to change their behavior down to 120dB, which is a more realistic assessment than their previous method⁶; however, the curve itself is based on a very limited set of studies, resulting in a curve that in fact **counts nearly no impacts below 140dB, thus standing in stark contrast to the current "state of the art" report on behavioral impacts, released in late 2008⁷**. Most scientists involved in these esoteric studies expect the risk function to change substantially in the next few years; until then, the Navy's current approach is likely vastly underestimating the numbers of whales making small behavioral changes. This may or may not be that important (the changes are indeed rather minor), but in some populations, such as the 300 remaining right whales, small impacts could be critically important to avoid.

See AEI's detailed analysis of the USWTR EIS, which includes a focus on the risk function curve's limitations: <http://aeinews.org/archives/251>

There are some promising signs that some of the shortcomings in the Navy's approach will indeed be addressed; we'll discuss this below. But first, we'll take a brief look at what's been going on with the newer, more powerful low-frequency sonars.

Low-Frequency Active Sonar

2008 settlement kept LFAS in Western Pacific;

New Supplemental EIS (SEIS) aims to restore access to other oceans

LFAS policy was basically stagnant in 2009, as we await the Navy's Draft Supplemental EIS, the first step toward expanded operations after two more ships are outfitted with LFAS in 2011 or 2012. There was a bit of excitement in the spring, though, when China raised a fuss about the continuous presence of US LFAS (active sonar emitting) and SURTASS (passive receiver) ships off its coast near a major Chinese Naval base. The Chinese object to surveillance activity within its EEZ (Exclusive Economic Zone), which

⁶ They formerly used a "step-function," setting a sound level (often 160dB) at which in which all animals were considered likely to change behavior when the sound was louder, and none when it was lower.

⁷ In the most recent comprehensive collection of research into the behavioral responses to noise, in Southall, et al. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. Aquatic Mammals 33(4), 2007, a series of charts summarizes past studies, with many moderate behavioral responses noted at sound levels of 120-140dB.

extends 200 miles from each country's coast; the US contends that such activity is only barred within the 12-mile territorial waters zone.

See AEI's coverage of this brouhaha:

March: <http://aeinews.org/archives/128> June: <http://aeinews.org/archives/197>

August talks between the US and China: <http://aeinews.org/archives/362>



USNS Impeccable, one of two US LFAS-equipped ships deployed in the Western Pacific (*US Navy photo*)

In late 2007, the Navy completed a Supplemental EIS⁸ to cover its newer Low-Frequency Active Sonar system (LFAS), and received permits allowing it to deploy its two (and later four) LFAS-equipped ships around the world. LFAS, as you may remember, is an active sonar system that uses, as the name suggests, low frequency sound waves; its effective listening range is dozens to hundreds of miles, and the signals can be audible even thousands of miles away. (Mid-frequency active sonar, deployed on hundreds of ships worldwide, has an effective listening range of tens of miles, and can be heard for somewhat over a hundred miles). NRDC challenged the permits on the grounds that the EIS had not sufficiently considered the impacts on animals in biologically important habitats, and in early 2008, a federal judge ordered to two sides to commit to working out an agreement (and, perhaps in a bit of judicial humor, asked for them to report to her about their plans for negotiations on Valentines Day!). In August 2008, an **agreement was announced that would keep the Navy's two LFAS ships in the Western Pacific (where, in fact, the Navy had kept them since the EIS was released, to monitor Chinese and North Korean subs), and keep them out of some biologically important areas.**

In response, the Navy has initiated a second Supplemental EIS, which will attempt to assess the concerns raised by NRDC, especially three topics:

- The need for larger coastal buffers (especially extending the current 12-mile limit in areas where the coastal shelf is wider than that)
- Formally excluding LFAS from more areas of biological importance, including migration corridors, breeding and calving grounds, and feeding grounds
- Cumulative impacts of LFAS exposure combined with exposure to MFAS

In the SEIS scoping announcement they asked interested parties to submit suggestions for areas that should be protected from LFAS impacts. The Navy has not released a projected timeline for completion of the Supplemental EIS, but I suspect that we should expect a Draft SEIS in 2010. This would allow the final SEIS **to be completed by the time that the Navy is planning to launch its next two LFAS-equipped ships in 2011; it is likely that these ships would be ideally deployed in areas other than the Western Pacific**, and thus the need to move beyond the current status quo of being limited to that region.

Federal Register Notice: <http://edocket.access.gpo.gov/2009/pdf/E9-1041.pdf>

⁸ The original EIS had been challenged in court by NRDC and others, and had resulted in a court-mediated agreement that the Navy's LFAS ships would be restricted to a defined area in the western Pacific where few whales live. The SEIS allowed the Navy to operate worldwide; a legal challenge to this first SEIS led to an agreement to stay in a broader area of the western Pacific, including the waters off China.

NMFS LFAS Letter of Authorization, Aug 2009-Aug 2010:

http://www.nmfs.noaa.gov/pr/pdfs/permits/lfa_loas_2009.pdf

Navy LFAS website: <http://www.surtass-lfa-eis.com>

With much less fanfare, the UK Royal Navy has continued to deploy LFAS systems, known as Sonar 2087, on at least six vessels, operating in unknown parts of the sea⁹.



Sonar 2087 on a UK Navy Type 23 Frigate

Photo: <http://www.armedforces.co.uk/futureprojectimages/sonar2087m.jpg>

Signs of Sonar Sanity

Scientists, NOAA step up and speak to the bigger picture

Two recent developments offer signs that the ten-year process of coming to grips with the impacts of active sonars on marine life may be reaching a tipping point that will apply pressure on the Navy to design its sonar training operations with less of a broad brush, taking into account more specific and localized conditions.

In April, at a workshop on sonar mitigation organized by the European Cetacean Society, **a diverse group of international marine scientists signed on to a resolution which called clearly for sonar exercises to take be limited to relatively limited areas** and to increase protective distances from sonar for beaked whales to the point that behavioral impacts will be negligible (which could well be several miles, beyond the range of visibility). The statement represented the shared expertise of 14 scientists, including some working for conservation groups (NRDC's Michael Jasny and WDCS's Sarah Dolman), several researchers who have been relatively outspoken with their concerns about noise (Andrew Wright, Michel André), and notably, two fairly cautiously mainstream long-time marine acoustics researchers (UK's Peter Evans and WHOI's Peter Tyack).

Download the ECS statement: http://www.service-board.de/ascobans_neu/files/ac16/AC16_39_ECS_SonarResolution.pdf

AEI's summary of the resolution: <http://aeinews.org/archives/158>

And, in January 2010, **NOAA Administrator Jane Lubchenco announced a series of sweeping new initiatives designed to vastly improve NOAA's ability to effectively regulate sonar activities**. Until now, NOAA Fisheries has effectively rubber-stamped Navy operational and mitigation plans, generally developed in consort by the Navy and NOAA. The new initiative will jump-start some key research initiatives (including more detailed population assessments and a global sound-budget effort, both aimed at identifying key biologically rich areas), and commits NOAA to active participation in ongoing talks between the Navy and NRDC to work out continuing disputes. Lubchenco notes that "NOAA's

⁹ See <http://www.armedforces.co.uk/projects/raq3f8d4e1b8587c> and <http://www.thalesgroup.com/Pages/PressRelease.aspx?id=11162> ; there have been no known impacts on whales, though by and large, no one is looking.

participation will enhance these discussions and help resolve differing views....I also expect the Navy to be open to new ideas and approaches to mitigation that are supported by the best available science.” Elsewhere, **Lubchenco stressed that “Protecting important marine mammal habitat is generally recognized to be the most effective mitigation measure currently available.”** All this leads many observers to a cautious optimism that NOAA may impose some limits on sonar operations as it issues future permits.

Download the NOAA statement: http://www.nmfs.noaa.gov/pr/pdfs/permits/lubchenco_letter.pdf

AEI’s summary of the statement: <http://aeinews.org/archives/656>

Key new sonar research, news, and resources

Controlled exposure experiments, whale hearing, routine use of sonar

MED09 Controlled exposure study of “naïve” beaked whales fails to tag any whales, but demonstrates powerful new mobile passive monitoring system

A five-week beaked whale Behavioral Response Study in the Mediterranean concluded in early September with a mixed bag of results: while researchers were unable to affix D-tags to any beaked or pilot whales, they were quite successful in using a new mobile Passive Acoustic Monitoring system which could be very useful in years to come. This system of two towed arrays with two hydrophones each, giving **four separate receivers, allowed very accurate localization of calls;** they also deployed some passive “sonobuoys” to further extend the listening network. These techniques **could offer many of the robust capabilities for tracking animals during sonar use that has previously been limited to the Navy’s few instrumented ranges** (large areas with hydrophones permanently mounted on the sea bottom)¹⁰. The study was largely aiming to track “naïve” whales’ responses to low to moderate levels of mid-frequency active sonar sounds using D-tags on the animals; previous Behavioral Response Studies using such “controlled exposures” have taken place on Navy instrumented ranges where the local populations are presumably familiar with sonar sounds, so they may respond differently than whales who have not heard these sounds before. However, due to many periods of rough seas, as well as the inherent difficulties of finding, getting close to, and attaching tags to beaked whales (who dive for over an hour and come to the surface only briefly), no D-tags were deployed on whales, and no controlled exposures took place. However, **a document prepared before the cruise, summarizing previous BRS results, is well worth reading;** see especially page 8, which includes a detailed analysis of beaked whale responses to sonar and orca sounds: in both cases, **the whales cut short foraging dives, but returned to the surface more slowly than normal, not more steeply as is sometimes assumed, and they clearly moved directly away from the sounds.**

Pre-cruise BRS summary: <http://www.whoi.edu/files/server.do?id=50783&pt=2&p=58448>

AEI detailed summary of cruise, with many links to various cruise blog posts: <http://aeinews.org/archives/445>
See also these resources on Behavioral Response Studies in general:

A great collection of conference presentations, at Brandon Southall’s website: <http://www.sea-inc.net/science/>

AEI post on Navy News article/press release on Behavioral Response Studies: <http://aeinews.org/archives/310>

NOAA study disproves lunar connection in 2004 Hanalei Bay incident; sonar link remains

New research suggests that an apparent coincidence that had perhaps let the Navy off the hook for the 2004 incident in which over 150 agitated melon-headed whales appeared in a shallow Hawaiian bay during a large biannual naval exercise is not as simple had been initially suspected. On the same night, an aggregation of the same species appeared in a bay on the western Pacific island of Rota, spurring speculation that the whales in both places were perhaps following prey into the bays on a bright moonlit night. The new study found that the western population often rests in bays, while the Hawaiian population does not; in addition, on this night and morning the Rota whales were indeed resting, while the Hawaiian whales were highly agitated. The author suggests that the whales just happened to be near the mouth of the bay when sonar operations commenced, sending them scurrying for refuge.

Much more detailed AEI summary of this paper: <http://aeinews.org/archives/294>

¹⁰ It should be noted that the usefulness of any system that is trying to listen for beaked whales is limited by the fact that most of the beaked whale vocalizations are relatively high frequency, so that they only travel a short distance before fading from audibility. It is hard to hear beaked whales beyond 1.5km, and nearly impossible beyond 4km.

Minke whales appear to flee sonar in the Mediterranean

Two UK environmental and research organizations that were monitoring whale activity during a recent NATO naval exercise report that **minke whales were seen fleeing along the surface while their hydrophones were picking up loud mid-frequency active sonar signals**. Observers from the Hebrides Whale and Dolphin Trust saw “two minke whales within an hour displaying unusual and worrying behaviour. At the same time they heard military sonar on the hydrophone – sometimes so loud that they could not keep the headphones on. The whales were both moving in the same direction at high speed, regularly leaping clear of the water. This behaviour, known as ‘porpoising’, is more typical of dolphins and rarely seen in undisturbed whales.”

AEI post on this event, with links to several first-hand accounts: <http://aeinews.org/archives/179>

What do beaked whales hear?

Finneran, Houser, Base-Guthrie, Ewing, Lingenfelter. Auditory evoked potentials in a stranded Gervais' beaked whale (*Mesoplodon europaeus*). *J. Acous. Soc. Am* 126(1), July 2009. 484-490.

This study took place with a stranded beaked whale that was euthanized after three days in captivity; it was very ill (organ failure due to bacterial infection) throughout. Since beaked whales seem to be more affected by Naval mid-frequency active sonar, the study was designed to see whether beaked whale hearing is more sensitive than other closely related families of cetaceans. The results find a hearing sensitivity curve that is similar to those of dolphins and orcas, with no indication of greater hearing acuity. The highest frequency that could be heard was 80kHz (though this could be limited by hearing impairment in this individual, as one earlier study of this species found good sensitivity than at 80kHz, and did not test higher). Highest sensitivity was found at 40kHz (i.e. the animal can hear sounds at this frequency when they are relatively faint--higher and lower frequency sounds must be louder to be heard) No tests were done using frequencies below 20kHz; mid-frequency active sonar ranges from 2-10kHz.

Ed. note: This study received peculiar treatment in the press; most articles seemed to imply that the results indicate that beaked whales do not even hear mid-frequency sonar. This is a strange interpretation, since other research clearly shows beaked whales altering their behavior when sonar signals are present; most strikingly, at the US Navy's instrumented range, beaked whale call rates drop dramatically during sonar exercises, and Navy researchers assume they leave the area.

SEL Metric Does Not Simplify TTS Assessment

Mooney, Nachtigall, Breese, Vlachos, Au. Predicting temporary threshold shifts in a bottlenose dolphin (*Tursiops truncatus*): The effects of noise level and duration. *J. Acoust. Soc. Am.* 125 (3), March 2009.

This study, from one of the leading researchers investigating Temporary Threshold Shift (TTS; temporary decline in hearing sensitivity) after exposure to loud noise in dolphins, calls into question one of the key advantages of the Sound Exposure Level metric. SEL measurements are designed to measure total sound exposure over a given period of time; simply stated, SEL remains constant when sound intensity increases while duration decreases (e.g., twice as loud for half as long should result in "equal energy", or the same SEL). The assumption was that SEL offered an "equal energy" metric that could allow biologists and ocean regulators to set a SEL threshold that would apply to many types of noise exposure, from steady shipping noise to periodic repeated pulses of airguns or sonar to very short bursts of noise from pile-driving. However, this study indicates that a given SEL dB level (arrived at via a mathematical equation combining sound energy from many noise pulses over time) did not seem to induce TTS in the single captive dolphin used in this study. As with other metrics, higher SELs were required to induce TTS with shorter duration sounds. By extension, the hypothesis that TTS is caused by a given level of sound energy (the "equal energy" hypothesis) is called into question. The relationship appears to be logarithmic, rather than linear. In this study, the sound source was short (20ms) digitally generated tone bursts.

Mid-Frequency Sonar Must Be Very Loud/Close to Trigger TTS

Mooney, Nachtigall, Vlachos. Sonar-induced temporary hearing loss in dolphins. *Biology Letters*, doi: 10.1098/rsbl.2009.0099

The same team more recently found the same difficulty with using SEL to predict TTS when using a recording of a US naval mid-frequency active sonar; **short duration MFA "pings" had to be ramped up to a SEL of 214dB (equivalent to 203dB SPL rms) to induce a modest temporary loss of hearing sensitivity (TTS) of 6dB, which faded rapidly back to normal hearing levels in 20-40 minutes, a higher SEL than had**

induced TTS using longer duration sounds in the above study. This was the first hearing test on dolphins to use actual mid-frequency active sonar signals; previous studies had used sonar simulations or tones at similar frequencies. *Ed. note: The usual caveats are in order here, as a long-time captive dolphin may not hear as well as his wild relatives; it is often assumed that captive dolphins are less sensitive both physiologically (hearing loss from age or living in noisy pens) and behaviorally (habituated to noise, and given food to remain in the test area), though the relative lack of clear studies on wild animals makes this assumption difficult to confirm.*

AEI summary of this paper, with links to press reports, which tended to hype it as evidence of sonar deafening dolphins, with the Navy, by contrast, suggesting it proves sonar impacts have been “vastly over-estimated”: <http://aeinews.org/archives/142>

US to sell MFA sonobuoys to Pakistan

The United States and Pakistan are cooperating in a new initiative to supply the Pakistani Navy with 445 sonobuoys, including mid-frequency active sonar units used to detect quiet submarines. It is not clear what subs would be the target for this program (the “Taliban Navy” and “Taliban Airforce” are often tossed out by bemused observers as the only likely mutual threats), or how carefully they would be deployed in regards to marine mammals.

Source: Domain B, 3/9/09: http://www.domain-b.com/defence/general/20090309_taliban_air_gorce.html

A reminder that MFAS is used routinely outside of training exercises

After suspending the use of mid-frequency active sonar training activities in Puget Sound in the wake of an incident in 2003 in which sonar sounds appeared to agitate a group of orcas, the Navy confirmed this week that a new regional sonar training plan will keep future sonar training off the West Coast, and out of inland waterways. Chris Dunagan at the local Kitsap Sun gives the announcement his usual thorough coverage, including context from the past, as well as zeroing in on **a key passage in the Navy’s public statement:** “Any use of high- or mid-frequency active sonar for training purposes in Puget Sound would be beyond the scope of this permit,” the statement says. “However, **outside of this permit, active sonar is used within Puget Sound for safety and navigation; testing; maintenance; and research, development, test and evaluation (RDT&E).**” An incident in January of 2009, during which mid-frequency active sonar was heard through a night, was part of RDT&E activities. Likewise, a stranding off southern California in 2006 triggered an unusual statement that suggested that it may have been caused by routine, rather than training, use of active sonar¹¹.

Kitsap Sun article: <http://www.kitsapsun.com/news/2009/jul/29/navy-declares-limits-on-sonar-use-in-puget-sound/>
Dunagan explores the question of these multiple activities a bit more in an accompanying blog post:

<http://pugetsoundblogs.com/waterways/2009/07/30/some-sonar-questions-are-answered-others-remain/>

AEI summary of January event: <http://aeinews.org/archives/147>

Overview of current Navy sonar systems and upgrade plans

The 2009 Navy Program Guide includes two sections of interest on sonar systems.

Download 2009 Program Guide: <http://www.cffc.navy.mil/Navy%20Program%20Guide%202009.pdf>

Page 82-86 details Anti-submarine warfare (ASW) integrated systems including LFAS and MFAS, with the latter including details of a two-year software upgrade cycle and a four-year hardware upgrade cycle.

Page 98-99 details the passive acoustics systems on submarines, including towed hydrophone arrays.

And last, but far from least:

Sea-Inc Website Launched; instantly becomes the go-to site for ocean acoustics research updates

After leaving his long-time post as head of NOAA Fisheries ocean acoustics program in mid-2009, Brandon Southall formed a private research institute, Southall Environmental Associates, Inc. **SEA-Inc’s new website offers a wealth of information on all of the key ongoing research initiatives that Southall is involved in, and a blog that covers other ocean acoustics developments.**

<http://sea-inc.net/>

¹¹ At the time, a Navy spokesman said that the nearest ship using mid-frequency active sonar was 62 miles away the previous day, and was not part of the exercise. Source: LA Times, 2/22/08
<http://www.latimes.com/news/printedition/california/la-me-dolphin22feb22,1,6511399.story>

Seismic Surveys

Academic surveys trigger oversized outrage New LDEO/NSF survey vessel faces intense scrutiny on several projects

There was very little public attention on seismic surveys this year, and also fewer new research studies. It's becoming somewhat less common for the public to lump air gun sounds in with sonar, though at times there still appears to be a lack of appreciation for the differences between the two.

The biggest story this year was that the new academic survey vessel, the *R/V Langseth*, was dogged by local environmental groups as it undertook surveys in Taiwan and British Columbia. The *Langseth* is owned and operated by Columbia University's Lamont-Doherty Earth Observatory (LDEO)¹², funded primarily by the National Science Foundation, with research carried out by various university-based geologists and geophysicists.

In both 2009 cases, local groups raised objections with host-country permitting authorities, and forced some changes in operations at the eleventh hour. To be fair, the public participation process in other countries is nowhere near as transparent as we are used to in the US, and the last-minute nature of the complaints is likely largely due to lack of advance notice, though no doubt it was partly a factor of small groups with limited funding scrambling to action to avert perceived threats.



R/V Marcus G. Langseth Note high marine mammal observation platform (Photo: LDEO)

In both Taiwan and BC, the objecting groups engaged in some rather over-the-top rhetoric, reaching out to the global environmental community to solicit comments to authorities; however, these urgent action alerts seemed designed to inflame public opinion, more than to engage in constructive dialogue with project planners or regulatory authorities¹³.

The Taiwanese survey was extensive, with the *Langseth* in the region for most of April through July¹⁴. The research was focused on the seismic plate dynamics that gave rise to the island of Taiwan, which is

¹² See <http://www.ldeo.columbia.edu/research/office-of-marine-operations> and http://strs.unols.org/Public/diu_schedule_view.aspx?ship_id=10012&year=2010

¹³ The first round of public comment-solicitation in Taiwan was more grounded, largely focused on urging the survey to avoid near-shore areas where endangered species were likely to be exposed to bothersome noise; this effort was successful, as noted below in the main narrative.

¹⁴ The TAIwan Integrated GEodynamics Research (TAIGER) study has been in the planning stages for several years. For more on its goals, see <http://www.ig.utexas.edu/research/projects/taiger/> The final revised NOAA permit is here: http://www.nmfs.noaa.gov/pr/pdfs/permits/taiger_iha_modified.pdf And, an article in Time magazine is here: <http://www.time.com/time/world/article/0,8599,1926457,00.html>

one of the best examples of forces that have shaped continental margins throughout earth's history. In response to concerns raised by both military and environmental groups, the survey was re-designed in March so as to remain 20km off the coast of Taiwan (it was originally planned to come as close as a mile from shore). A major environmentalist concern was the risk of exposing a small and highly threatened population of *Sousa chinensis* (humpbacked dolphin) to high sound levels because of the survey's proximity to the species' coastal habitat. The revised track lines, moving far offshore, removed the threat of potentially dangerous sound levels (over 180db, enough to easily disrupt behavior, and perhaps to cause temporary hearing loss if animals were very close). Nonetheless, local activists pressured scientists to further modify the survey in the weeks it was near Taiwan.

The BC brouhaha was far more unexpected and out of proportion to the dangers. This survey was designed to study the geology of a deep ocean vent system, which is designated as a (relatively tiny) Marine Protected Area. Protests from a local environmental group expressed outrage that an MPA would be targeted for a seismic survey, ignoring the fact that the very purpose of the survey was to understand the unique geology of these important ecosystems. In addition, the public rhetoric claimed that the survey would threaten key whale habitat, though the MPA's designation was unrelated to whales, and the whales in question would likely be largely far north along the Alaskan coast at the time of the survey (which was chosen largely to avoid times of whale concentrations in the area). The bottom line was that the public outcry led to the establishment of an unrealistically-large "safety zone" of 7km, which is impossible to monitor. In the end, **the Langseth's marine mammal observers did not see a single whale during the cruise.**

The irony of the situation is that **while nearly a hundred oil and gas industry survey vessels operate around the world, with virtually no public scrutiny, the single ship doing valuable geology research¹⁵ is incessantly attacked by environmental activists.** The LDEO seismic survey team is by far the most precautionary of the survey operators, and in particular monitors all whale activity in the area around the ship, to gather more data on the various behavioral responses to airguns that are seen—by contrast, industry surveys routinely claim to be unable to spare the extra time and effort to do any more than assure whales are outside the safety zone, which is generally 500 meters. In addition, the LDEO surveys work to reduce their soundprint in the area, shooting the airguns just enough to get the data they need but avoiding acoustic overkill; for example, in BC, the airguns were shooting only once every 3-4 minutes, as compared to once every 10 to 20 seconds as in industry surveys.

AEI coverage of Langseth survey controversy in BC: See <http://aeinews.org/archives/326>

Offshore oil and gas seismic surveys

Industry continues to search for the last hidden oil reserves

While anyone who understands the manifold dangers of mounting atmospheric carbon may raise an eyebrow — or rip out a hunk of hair by the roots — at the idea that our future prosperity demands that we continue to seek out, deploy development technology, bring to market, and (five or ten years down the line) burn the oil and gas that lies in the ever more difficult to reach parts of the ocean that are not already tapped and providing today's fuels, the fact is that new offshore oil and gas exploration is continuing around the world. East Africa and Indonesia have joined the North Sea and Gulf of Mexico as centers of major offshore activity, with the Indian Ocean, South China Sea, and Brazil all booming as well. Meanwhile, Norway, Russia, the US, and Canada are all eyeing the melting Arctic, and the US is moving toward new exploration off the Atlantic coast.

Some positive signs of increasing environmental planning and sensitivity

Once we accept that offshore exploration is not screeching to a halt in a global wave of carbon clear-headedness, we can look around and see that the oil and gas industry is continuing to increase its efforts to be aware of and minimize the acoustic impacts of its ongoing exploration activities.

¹⁵ Most of the NSF-funded studies are looking either at plate tectonics, in order to understand earthquake risk in dangerous coastal zones, or studying historic sedimentation as markers of climate change throughout earth's history.

In March, the **Canadian Department of Fisheries and Oceans convened an expert panel to assess the effectiveness of the DFO's current seismic survey mitigation measures**, which AEI Executive Director Jim Cummings was invited to be a part of. By all accounts, the collaborative and cooperative tone of this meeting was a big step forward, in comparison to similar multi-stakeholder panels in recent years. Canadian and US agency staff, oil and gas company employees, seismic survey and environmental assessment contractors, marine biologists, and environmental organization representatives shared a room for two days of presentations and discussion. Granted, the stakes were lower than in some similar meetings (such as the two-year Marine Mammal Commission attempt to come to consensus on ocean noise issues), which made it easier for all participants to step off their firm positions, but the tone was positive.

AEI's post on the DFO panel: <http://aeinews.org/archives/173>



DFO workshop, facilitated by Jake Rice. Photo: Bill Lang

A few months later, a **workshop on Alternatives to Seismic Surveys was also attended by a wide spectrum of participants, including oil and gas industry staffers.** Participants considered¹⁶ how airguns could be made safer, and how seismic surveys could be reduced or replaced by quieter alternatives. It is clear most of these new technologies are not presently able to replace airguns. However, workshop panelists identified several ways in which noise in the ocean from seismic airguns might be significantly mitigated with little or no effect on the quality of data acquired, including methods by which “waste sound” (higher frequency than useful for the exploration purposes) might be reduced. Peak sound levels required for exploration might be significantly reduced by increasing receiver density and sensitivity (some of which is already being done), spreading the source energy out over time, and moving sources and/or receivers closer to the seafloor. Panelists also discussed promising new technologies that are completely silent but can still lessen the amount of seismic data required to reduce the economic risk of hydrocarbon recovery, such as controlled source electromagnetic and passive seismic techniques. **Download workshop report:** <http://www.sound-in-the-sea.org/oceanos/download.php?id=19>

Another useful step this year was the **development of a Marine Mammal Observer reporting form that could become a global standard.** The form, developed by the E&P Sound and Marine Life Joint Industry Program¹⁷, a research effort funded by a consortium of oil and gas companies, was adopted as the official reporting form for all UK-based seismic surveys. It is hoped that other jurisdictions will use it as well. Current use of several different non-standardized forms makes it difficult, if not impossible, for agency staff or researchers to compile observation data in order to learn more about patterns of marine mammal behavior around seismic survey vessels.

See MMO form (xls): http://www.jncc.gov.uk/docs/Marine%20mammal%20recording%20forms_rev02.xls

See MMO deck worksheet (doc): http://www.jncc.gov.uk/docs/Deckforms_rev02.doc

This note of caution didn't come from the oil and gas industry, but bears notice: Einar Svendsen, research director at the Norwegian Institute of Marine Research noted that fish stocks have rebounded nicely in Norwegian waters, but that increasing oil and gas exploration activities could pose a danger. According to Nature.com¹⁸, he **strongly advised that no seismic surveys be conducted during the spawning season,**

¹⁶ The rest of this paragraph is adapted from the initial conference report on the Okeanos website; a full report is forthcoming; keep an eye on this page: <http://www.oceanos-stiftung.org/oceanos/sound.php?id=41>

¹⁷ <http://www.soundandmarinelife.org/>

¹⁸ http://blogs.nature.com/news/blog/2009/01/arctic_frontiers_the_fish_are.html

and, in particular, that petroleum activities stay clear of the major spawning areas around the Lofoten Islands.

US continental shelf is eyed for new exploration, leases — sometime

Responding to several years of pressure from some east coast states eager for new sources of revenue, the US Department of Interior is continuing to move forward on the possibility of re-opening the Outer Continental Shelf to oil and gas development. The Bush administration included the possibility of lease sales in the current 5-year cycle (which ends in 2012), and the Obama team has not shut that door, though it is moving more slowly than some in the oil and gas industry would like. They have not committed to offering leases in the current round, and in January Interior Secretary Ken Salazar announced that the Department is initiating a Programmatic Environmental Impact Statement (PEIS) process to assess the effects of renewed seismic surveys on the Outer Continental Shelf¹⁹. This is likely to be an extended process (similar PEISs in recent years have taken 2-4 years to complete), but is clearly necessary, for both legal reasons and to be environmentally responsible, before surveys commence. The American Petroleum Institute responded to this plan with contempt, accusing Salazar of “fast-tracking” wind and other alternative energy development while “kicking the can down the road” for oil and gas; however, this ignores the fact that offshore renewable energy went through its own PEIS process in the past several years; the PEIS was completed in 2008.

Research highlights: air gun noise

Moderate seismic survey noise linked to increase in blue whale calling

L. Di Lorio and C.W. Clark. Exposure to seismic survey alters blue whale acoustic communication. *Biology Letters* doi:10.1098/rsbl.2009.0651

Download paper: <http://rsbl.royalsocietypublishing.org/content/early/2009/09/17/rsbl.2009.0651.full.pdf+html>

This study found that a seismic survey in wide bay at the mouth of the St. Lawrence Seaway caused blue whales feeding and socializing nearby to double or triple their call rates. The calls were near-range communication signals, rather than the long, loud songs that are heard over hundreds of miles. The research was meant to simply learn more about these social calls, but during the study, their recordings began to pick up the pulses from a seismic survey. “The whales made more calls on days when the testing was happening. It seems they are having to repeat themselves in order to not lose information,” said lead researcher Lucia Di Lorio. During the four days in which survey sounds were heard, the whales also increased their call rates when the sparkers were audible than when they were not, and tended to rapidly increase call rates when the sounds appeared. The results were especially surprising, since the survey in question was using a much lower-power sound source (sparkers) than the airguns used in most surveys. The electronic sparkers top out at only 190dB, rather than the 230-240dB of airguns. Sparkers are slightly higher frequency as well, but still solidly centered in low-frequency bands of 30-450Hz, primarily 60-250Hz, very similar to airguns, and matching key blue whale communication frequencies. The authors conclude by noting that “This study suggests careful reconsideration of the potential behavioural impacts of even low source level seismic survey sounds on large whales. This is particularly relevant when the species is at high risk of extinction as is the blue whale.”

Read more detailed AEInews summary (includes a skeptical note sent by a long-time ocean acoustics expert, who wonders if the increased calls were more an indication of interest in the novel sounds): <http://aeinews.org/archives/396>

Measuring Air Gun Propagation from New NSF Research Ship R/V Langseth

Tolstoy, Diebold, Doermann, Nooner, Webb, Bohnenstiehl, Crone, Holmes. Broadband calibration of the R/V Marcus G. Langseth four-string seismic sources. *Geochemistry Geophysics Geosystems*, Vol. 10, Number 8. August 2009.

Download paper: http://web.mac.com/drbohn/MG_NCSU/Publications_files/Tolstoy_langsethG3.pdf

¹⁹ The Bush administration announced a PEIS just before leaving office, but Salazar called for a longer comment period, and apparently the process did not move forward (even the Bush proposal noted that funding was not in place to actually DO the PEIS). For some recent press coverage of the new initiatives, see <http://www.chron.com/dispatch/story.mpl/business/6835125.html> and <http://canadafreepress.com/index.php/article/19961> See also this note on a comprehensive OCS survey that passed a key Senate committee this year, though apparently did not make it into law: <http://aeinews.org/archives/211>

This study marks the primary calibration of the new seismic survey vessel managed by Columbia University's Lamont-Doherty Earth Observatory (LDEO) and often chartered by the National Science Foundation for academic surveys. The Langseth's air gun arrays are different than those on the previous vessel, the R/V Ewing, as it uses four identical 9-gun linear arrays of somewhat smaller air guns, rather than up to 20 separately towed and larger air guns. Tests were run in a deep water site and a shallow water site, since sound propagation varies considerably with depth. Sound levels were calculated using both 90% RMS (re 1uPa) and SEL (re:1uPa2s). The resulting exposure radii (safety zones to prevent exposure at the given level) are as follows:

dB threshold RMS	deep site	shallow site
190	300m	300m
180	600m	1.1km
170	1.2km	3.7km
160	2.7km	12.5km

dB threshold SEL	deep site	shallow site
190	N/A	N/A
180	300m	400m
170	500m	1.5km
160	2.1km	21.7km

Interestingly, actual received levels at distances over 3km at the deep site were below the slope of the statistical "line" the data created at closer ranges; thus the very distant exposure radii are likely over-estimates. As has been widely noted in recent years, sound energy was concentrated in the 10-300Hz range (120-150dB energy spectral density at 1km), but continued to have significant energy up to 1kHz (100-120db shallow, 90-110dB deep) and 20kHz (60-80dB shallow, 20-60dB deep). Of special note in this study is the further clarification that, contrary to previous assumptions, differences between RMS and SEL are not consistent, but rather vary greatly with water depth. Reverberations in shallow environments create a smaller difference (about 8dB) than in deep water (about 14dB).

Fin Whales Seem to Avoid Seismic Survey

Castellote, Clark, Esteban. Mediterranean fin whale migration movements altered by seismic exploration noise. Presentation at Acoustical Society of America, May 2009.

This study took place in the western Mediterranean, off the coasts of Spain, France, and northwestern Italy; its main purpose was to simply identify seasonal patterns of fin whales and better understand their migratory movements, using the now-common Cornell Marine Autonomous Recording Units (MARU), which are deployed for weeks or months, and then "pop up" for recovery. By chance, a medium-sized academic seismic survey took place in the vicinity of the recorders for ten days, from 8-17 December 2006, using 5 typical air guns and 4 small "sleeve" guns, totaling 1555 cubic inches. The resulting **changes and in fin whale call rates strongly suggest that they shifted their migratory path**, though given the limited perspective offered by two MARUs deployed near each other, and the fact that understanding of normal migratory pattern is limited, the study is not conclusive.

During the ten days before the survey began, whale calls were heard fairly regularly; during the first three days of the survey, it appears that whales vocalized more, while moving to a different position relative to the recorders. The call rate was most dramatically higher on the 2nd day of the survey: whale calls were heard for over 20 hours, rather than the 6-8 hours that was more typical before and after the survey (some non-survey days peaked at 12-14 hours). The researchers note a dramatic change in bearing (angle at which most of the calls came from) during this peak early in the survey, which was followed by a dramatic drop in calls, to zero on the 4th day of the survey, and continuing at zero or close to it for two weeks after the survey was completed; presumably the whales moved out of range of the recorders (the peak in call rates may represent more whales being temporarily closer as their route shifted). By the beginning of January, whale calls sporadically rose again to near the levels before the survey, and, by January 7th, became more consistent, and back to the bearing that had been noted before. **The researchers cite a few other studies that have shown displacement or changed vocalizing patterns near**

surveys, to bolster their sense that this study should be added to that emerging body of research suggesting behavioral effects that are not fully accepted yet by the scientific and industrial communities.

Harbor Porpoise TTS, Behavioral Response at Moderate Airgun Noise Levels in Lab Tests

Lucke, Seibert, Lepper, Blanchet. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. *J. Acoust. Soc. Am.* 125 (6), June 2009.

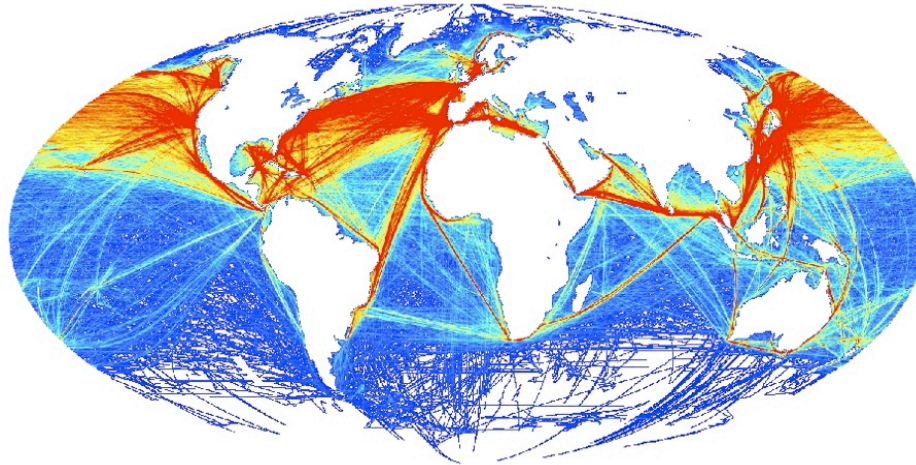
Field researchers have observed for years that harbor porpoises appear more sensitive to noise than most other cetacean species, moving away from noise sources at greater distances than typically considered problematic (belugas and bowhead whale mothers are also more behaviorally sensitive to noise). This study was the first that measured harbor porpoise auditory sensitivity in the lab, using Auditory Evoked Potential measurements (brain-wave scanners that note auditory brain activity), and the results confirm that **this species' avoidance behavior occurs at relatively low sound levels, and may be linked to a similarly low threshold of TTS (temporary hearing loss)**. The test animal was a wild-born ten-year old porpoise who has lived in captivity in Denmark for most of his life; the testing facility is open to the sea, so background noise (ranging roughly from 60-80dB pressure spectral density) is dominated by local shipping sounds. A single small (20 cubic inches) airgun was used as the sound source, gradually moving closer until a TTS was observed at one of the 3 tested hearing frequencies (4, 32, and 100kHz). The airgun source sound was, as is typical, loudest at low frequencies (max of 150dB SPL at 300Hz), but had significant energy at higher frequencies as well (100-110dB SPL from 2kHz to 5kHz), at the relatively close range used in this test (14-150m).

The key finding was that the airgun sounds caused TTS in the 4kHz hearing range at received levels of 165.5dB SEL (202.1dB peak to peak); perhaps more importantly, recovery was quite slow, with reduced sensitivity (i.e., sound had to be louder than normal to be heard) still measured at 29 hours post-exposure. Based on the pattern of recovery, the researchers estimate that the animal's hearing returned to normal at about 55 hours. Also striking was the clear avoidance of the airgun sounds exhibited by Eigil, the test animal. While there was **no apparent avoidance during initial exposures at 145dB SEL (174dB peak to peak), at levels above this, he tried to move away, and eventually resisted being placed in the exposure station** (a small part of the pool where he was constrained during the actual tests, and where received level from the airguns was highest). This avoidance of the testing location continued for the rest of the 4.5 months that the tests continued.

Current US regulatory measures, while still evolving, have zeroed in on a proposed TTS threshold of 198Db (SEL) for both single impulses and multiple impulses; this is based on earlier TTS studies of bottlenose dolphins and belugas. The authors of this paper point out that these "mid-frequency" cetaceans may well have different hearing sensitivity thresholds than "high-frequency cetaceans" such as the harbor porpoise; thus, this study provides new information that could inform regulatory thresholds for seismic surveys and pile-driving (during construction of wind farms, bridges, or piers) in harbor porpoise habitat. The US Navy, in estimating the numbers of animals that will be behaviorally affected by sonar training, has been singling harbor porpoises out as more sensitive to disruption, and assuming that any animal exposed to 120dB will potentially change its behavior to some degree.

AEI Resource Collection: Shipping Noise

Since the National Marine Fisheries Service (NMFS) and Marine Mammal Commission (MMC) first addressed shipping noise in symposia in 2004 and 2005, the **question of what to do about the steady increase of background ambient noise in the oceans, primarily consisting of shipping noise, has been addressed with increasing urgency by scientists and regulators.** The shipping industry has been very responsive to the concerns, with both the US Chamber of Shipping and German shipping organizations actively participating in international discussions about the topic.



Global shipping traffic, as mapped during a comprehensive analysis of human impacts on the worlds' oceans. For more on this important and rather shocking study, see:

<http://globalmarine.nceas.ucsb.edu/> and <http://www.nceas.ucsb.edu/GlobalMarine>
Image source: <http://ebm.nceas.ucsb.edu/GlobalMarine/impacts/transformed/jpg/shipping.jpg>

In this section of our report, we will **step back from our focus solely on 2009, and provide an annotated collection of the key reports on shipping noise that have been issued in the past five years.** Each of these includes background and practical ideas that are being fleshed out in the course of ongoing research and policy work on the national and international levels. We'll begin with the most current and potentially widest-impact work, in the International Maritime Organization's Marine Environmental Protection Committee.

IMO Addresses Shipping Noise

In 2008, the International Maritime Organization (IMO) accepted a proposal from the US, with strong backing from Australia, Germany, and other European nations, to **initiate a "high priority work item" aimed at reducing the impacts of shipping noise, with the goal of coming up with voluntary ship-quieting technologies, as well as potential navigational and operational practices.**²⁰ The IMO sets the ground rules for international shipping, including regulating pollutants and designating shipping lanes; adding noise to its management toolkit is a major step forward.

The IMO's work on shipping noise is taking place within its Marine Environmental Protection Committee (MEPC); the MEPC charged a Correspondence Group (CG) to begin addressing the topic "Noise from Commercial Shipping and its Adverse Impacts on Marine Life." The CG's initial reports indicate that it will largely defer consideration of impacts (recognizing that this sort of research is ongoing worldwide), in

²⁰ See http://www.AcousticEcology.org/onc/IMO_MEPC_2008ShipNoiseProposalAndDecision.pdf

favor of focusing more directly on mechanical and operational changes that could be made by ship builders and operators and that could reduce the amount of shipping noise introduced into the oceans as a whole, and perhaps areas of particular biological importance in particular. During 2009, several documents have been issued by the MEPC²¹ and the CG, each of which is worth taking a look at.

First report of the Correspondence Group on Noise

Download: http://AcousticEcology.org/docs/IMO_MEPC59/19_April09_WGreport.pdf

Issued in April, this 25-page document briefly sets the framework for the CG's work, and provides **an excellent and comprehensive introductory overview of the current state of knowledge about various noise sources in ships**, including a list of previous research documents considered fundamental by committee members. Of particular interest, the CG clarified its focus as follows:

- The options for quieting technologies generally fall into two basic areas: hull/propeller design (cavitation) and underwater radiated noise from machinery; the initial and primary focus of the CG's efforts is expected to be in issues related to propeller cavitation, since it's known to be a significant (and often dominant) source of vessel noise.
- After addressing quieting technologies, other issues may be pertinent such as the overlap of dense shipping and migratory pathways and establishing integrated underwater noise monitoring systems
- We are working on the basis for developing non-binding, technical guidelines. Our goal is to develop practical, effective guidance on solutions that can reduce the incidental introduction of underwater noise from commercial shipping in turn reducing potential adverse impacts to marine life.

IFAW Submission:

Reducing underwater noise pollution from large commercial vessels

Download: http://AcousticEcology.org/docs/IMO_MEPC_59/19/1_May09_IFAW_submission.pdf

This is a six-page summary of a report commissioned by the International Fund for Animal Welfare (IFAW), which **reviews the technologies that may be used to reduce noise from the loudest commercial vessels**. In addition to summarizing the key contributors to ship noise, the report stresses that there appears to be a 20-40dB variation in the noise output from ships of similar sizes. This suggests that **it should be possible to focus quieting efforts on the noisiest ships; indeed, it is likely that the loudest 16% of ships are responsible for 40% or more of the total sound energy added to the world's oceans by commercial ships** (IFAW's press release claimed these noisiest few ships could contribute as much as 50-90% of current total shipping noise). Among the key research priorities identified in the report are developing a standard method of analyzing ship noise (the ISO Technical Committee on Ships is at work on this already), and developing guidelines to help identify the potentially noisiest large commercial ships.

The full 44-page IFAW-funded report, conducted by Renilson Marine Consulting, is available from IFAW at: http://www.ifaw.org/Publications/Program_Publications/Whales/asset_upload_file262_53989.pdf

Marine Environmental Protection Committee (MEPC) Report, July 2009

In its report to the full IMO, the MEPC included a short section acknowledging the above two submissions, and "instructed the Correspondence Group to take into account the issues presented by IFAW," as well as **inviting IMO "Member Governments to encourage a review of their merchant fleets in order to identify vessels" that may be most ripe for efficiency improvements that could also reduce noise**. The CG's work is currently scheduled to continue as a part of the MEPC's agenda through at least the next three MEPC meetings, taking place in March and October 2010, and July 2011.

The work at the IMO should be considered within the context of a broad spectrum of ongoing research addressing the effects of anthropogenic noise on marine life. While the CG on noise, and the MEPC,

²¹ The US Coast Guard is one of the US representatives to the IMO and the MEPC, and is maintaining a web page that provides agendas and links to the full MEPC reports, though not the Correspondence Group work. See <http://www.uscg.mil/imo/mepc/default.asp>

may look more closely at specific impacts when considering the cost-effectiveness of some noise-reducing proposals, perhaps the most relevant current research is that which is beginning to shape a new understanding of the ways that moderate increases in background noise can drown out whale communication. It will likely be difficult to quantify specific impacts caused by reduced communication effectiveness, but **AEI encourages those interested the effects of shipping noise to pay particular attention to new metrics such as “listening areas,”** summarized below (p. 35) in the New Research section of this report.

This work is summarized in two detailed AEInews posts:

The first summarizes the key new paper released in 2009 and introduces the metric of “communication space,” which is greatly reduced by nearby ships: <http://aeinews.org/archives/626>

The second focuses on some new graphics from researchers that illustrate the masking of routine communication by commercial ships: <http://aeinews.org/archives/741>

Shipping noise reports, 2005-9

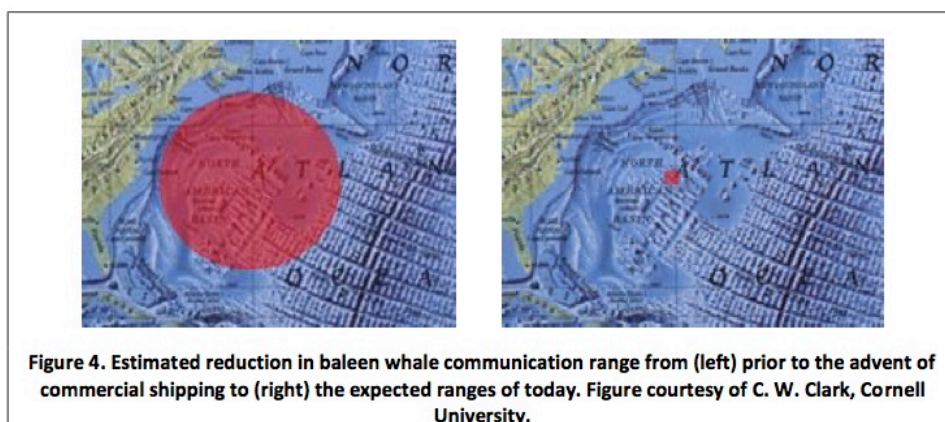


Figure from Okeanos 2008 International Workshop report

NOAA/MMC 2004 International Symposium: Shipping Noise and Marine Mammals

Final report: http://www.nmfs.noaa.gov/pr/pdfs/acoustics/shipping_noise.pdf

This is the meeting that got the ball rolling, bringing together agency staff, scientists, and representatives from the shipping industry to consider the acoustic “unintentional consequences” of increased global shipping. Technical sessions included:

- Trends in the Shipping Industry and Shipping Noise
- Effects of Noise on Marine Life
- National and International Response to the Marine Noise Issue
- Developing Technologies for Monitoring Marine Noise
- Vessel Quieting Technology: Application and Benefits

The final report, while far less detailed than those that came later, laid the foundation for ongoing consideration and discussion of these important topics.

NOAA 2007 International Symposium on Vessel Quieting

Southall, B. L. and A. Scholik-Schlomer. 2008. Final report of the NOAA International Conference: “Potential Application of Vessel-Quieting Technology on Large Commercial Vessels,” 1-2 May, 2007, Silver Spring, MD, U.S.A.

Final report, issued in 2008: http://www.nmfs.noaa.gov/pr/pdfs/acoustics/vessel_symposium_report.pdf

All the presentations from this symposium are available as pdfs at:

<http://www.nmfs.noaa.gov/pr/acoustics/presentations.htm>

NOAA shipping noise website: <http://www.nmfs.noaa.gov/pr/acoustics/shipnoise.htm>

For this symposium, the focus was more engineering oriented, and participants included noise control specialists, shipping industry representatives, and scientists, with additional perspectives including those of recreational divers and pollution control.

Okeanos 2008 International Workshop on Shipping Noise and Marine Mammals

Wright, A.J. (ed) 2008. International Workshop on Shipping Noise and Marine Mammals, Hamburg, Germany, 21st-24th April 2008. Okeanos - Foundation for the Sea, Auf der Marienhöhe 15, D-64297 Darmstadt. 33+v p.

Download report: http://www.sound-in-the-sea.org/download/ship2008_en.pdf

See article from the Marine Technology Reporter: <http://www.okeanos-stiftung.org/okeanos/download.php?id=9>

The German conservation organization Okeanos was a co-sponsor of the 2007 NOAA ship quieting symposium, and followed up on its own with meeting in April 2008 that returned to **broader questions of the effects of shipping noise on marine mammals, and made a particular effort to involve members of the international maritime transport industry, particularly ship builders and architects** (it was held in Hamburg, a capital of ship owners and operators, representing 36% of the world's containership fleet). The symposium report includes two thematic "background papers" and brief abstracts of each presentation. Of particular note is that **the workshop participants agreed to call for initial global action to reduce shipping noise by 3dB in 10 years and 10dB in 30 years relative to current levels**²². This is especially important, since research over the past few years indicates that shipping noise has been INCREASING at roughly those rates over the past five decades; turning this trend around would be a major boon for ocean wildlife.

Conservation reports with shipping components, 2008-9

International Union for the Conservation of Nature (IUCN)

Ameer Abdulla, Olof London (editors). 2008. Maritime traffic effects on biodiversity in the Mediterranean Sea: Review of impacts, priority areas and mitigation measures. Malaga, Spain: IUCN Centre for Mediterranean Cooperation. 184 pp.

Download: <http://data.iucn.org/dbtw-wpd/edocs/2008-042-1.pdf>

A comprehensive report on Mediterranean shipping from the International Union for the Conservation of Nature and Natural Resources includes a long section in the early pages on noise impacts. Due to the concentration of shipping, **ambient noise in the Mediterranean is 40dB higher than in relatively shipping-free regions** such as the Sea of Cortez. Among the recommendations are that "Much effort should be devoted to developing a legal framework within which underwater noise is recognized and regulated as a threat," and the **advocacy of MPAs that are designed to provide acoustic protection to critical and productive habitats, where "noise levels should not be allowed to exceed ambient by more than a given value, including noise from sources located outside the MPA."** In addition, the report stresses the importance of moving rapidly to develop regional hydrophone networks with which to monitor noise and develop current "noise budgets," as well as the need for expanded research using new non-invasive methods to examine hearing sensitivity and changes due to noise exposure in wild animals, and analysis of stress hormones in response to noise. **The authors of the report forge important new ground as they summarize: "In addition to defining which impacts should be avoided or mitigated, we also need to draw up a model of 'acoustic comfort' that we should guarantee to animals, at least over sufficiently extensive protected areas.** This is a novel concept. It means we should define the (near to) zero-impact noise level that a habitat should have for each type of marine life."

United Nations Environment Program (UNEP)

Also in 2008, the United Nations Environment Program (UNEP) meeting of the **Convention on Migratory Species (CMS) adopted a statement calling on member states to, among many other clauses, "endeavour to control the impact of emission of man-made noise pollution in habitat of vulnerable species and in areas where marine mammals or other endangered species may be concentrated,"** and to "consult with any stakeholder conducting activities known to produce underwater noise pollution with the potential to cause adverse effects on marine mammals and other biota, such as the oil and gas industry, shoreline developers, offshore extractors, marine renewable energy companies, other industrial activities and oceanographic and geophysical researchers." Since many countries in the world who are parties to the

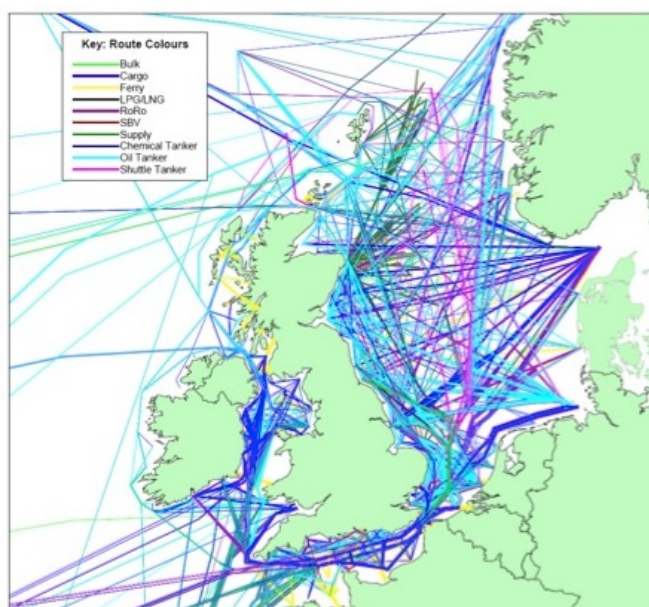
²² More specifically, it called for these reductions in the 10-300Hz band, the low frequency sound that is most dominant in ship noise, and that travels the greatest distances, accumulating to increase background ambient noise levels across ocean basins.

UNEP and CMS do not currently pay much attention to ocean noise issues, this could be a useful development.

Download: http://www.AcousticEcology.org/onc/UNEP_CMS_noiseresolution2008.doc

OSPAR Addresses Underwater Noise in Europe, North Atlantic

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the OSPAR Convention) dates from the 1990s and has been ratified by Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Sweden, Switzerland and the United Kingdom and approved by the European Community and Spain. Two related studies were published in 2009, which “lay the scientific basis for OSPAR to design future management measures in order to tackle this emerging source of pollution. This pioneering work will inform the current debate on energy levels, including noise, that can be introduced into the marine environment, one aspect of the European Commission’s Marine Strategy Framework Directive. Further OSPAR work on noise will be undertaken in advance of an Environment Summit for The North-East Atlantic in September 2010.”



Major shipping lanes in the North Sea

Source: Rijkswaterstaat, The Netherlands, via OSPAR report

OSPAR Assessment of the environmental impact of underwater noise

Download:

http://www.ospar.org/documents/dbase/publications/p00436_JAMP%20Assessment%20Noise_final.pdf

This report notes: “There is a reasonably long and successful history of quieting both surface and sub-surface military vessels to reduce their acoustic signature and thus vulnerability to detection by enemy passive acoustics. Additionally, commercial applications of ship quieting technology, are rapidly advancing in such areas as acoustic research vessel design, ferries, and environmentally-sensitive cruise ships,” and suggest familiar approaches to minimizing noise from commercial shipping, including reducing cavitation and routing and speed restrictions.

OSPAR Noise Background Document: Overview of the impacts of anthropogenic underwater sound in the marine environment

Download:

http://www.ospar.org/documents/dbase/publications/p00441_Noise%20Background%20document.pdf

This more detailed report includes a section dedicated to shipping noise²³ and includes some useful references to specific effects of shipping noise, including:

²³ The shipping noise section of this report was written by Leila Hatch of Stellwagen Bank National Marine Sanctuary and Brandon Southall, formerly of NMFS and now an independent researcher.

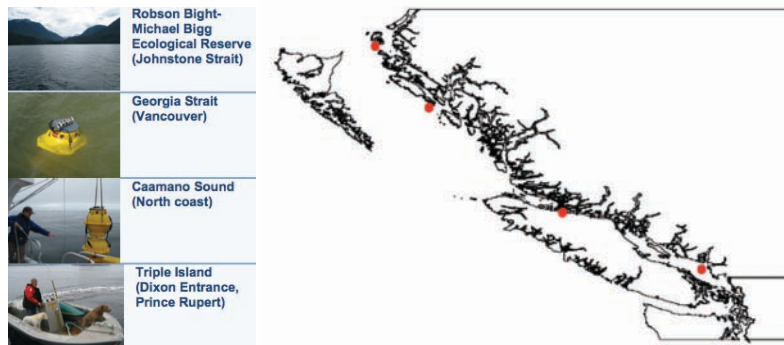
- Behavioral and vocal changes in the presence of passing vessels
- Cuvier beaked whales suspending foraging as a cargo ship passed
- Possible long-term hearing loss and stress responses in the presence of chronic shipping noise
- Studies suggesting that fish may experience stress and hearing impairment when exposed to noise from small boats and ferries
- The effects of masking in reducing communication and listening areas

And, this section concludes with this obvious but often ignored note: “Due to the long range transmission capabilities of shipping noise, mitigation must also address shipping noise impacts experienced by populations relatively distant from highly trafficked areas.”

The revolution in passive acoustic monitoring

Over the past few years, a revolution has been brewing in the ocean acoustics research community. **Hydrophones have been finding more and more ways into the world without being suspended from boats or connected to recorders via long cords.** Flash storage using far less energy than anything before is providing much longer recording times using very little battery power. And most exciting, engineers are developing ever more versatile platforms to carry these hydrophones, data storage, and associated hardware across and into the ocean for longer and longer periods of time without human intervention.

The possibilities inherent in these breakthroughs are only beginning to be imagined. Among the first major research projects utilizing the new technologies is the widely-publicized work in Stellwagen Bank National Marine Sanctuary, which tracks individual whales and ships in real time, helping to avoid collisions as well as contributing to new insights about communication masking. Getting less attention, but equally exciting, are projects like Deep Sound, which is sending hydrophones into the deepest parts of the world's oceans, and a multi-year project measuring ambient ocean noise in several places along the British Columbian coast, in part to see whether there are significant differences in shipping noise.



Summer-season recording locations off the BC coast

Images: Rob Williams

As the hardware behind such recording systems continues to offer more bang (data) for the buck, and the platforms on which they are deployed get simpler and cheaper, **the long-time dream of being able to listen in on the world's oceans with enough "ears" to create comprehensive sound maps is within reach.** We will be able to learn just how much the acoustic ecology of busy ports is dominated by shipping noise, and more importantly, identify coastal areas where the soundscape remains rich and dynamic. Ocean planners will have access to localized, seasonal "sound budgets" that can inform the Marine Spatial Planning process that is beginning to unfold around the world. All this while students and scientists are given the opportunity to listen in on habitats and animals that have long been "agua incognita." When combined with the simultaneous development of other observing systems also deployed for autonomous surveying (cameras, chemical sensors, etc.), we find ourselves on the cusp of a great age of exploration and understanding in the sea.

Recent research papers: two acoustic monitoring reviews

Two papers published as part of the special issue of Marine Ecology Progress Series (MEPS) on ocean acoustics research offer a good starting place for getting up to speed on these new possibilities.

Overview of new autonomous ocean noise recorders for use in small and large areas

Van Parijs SM, Clark CW, Sousa-Lima RS, Parks SE, Rankin S, Risch D, Van Opzeeland IC. Management and research applications of real-time and archival passive acoustic sensors over varying temporal and spatial scales. Mar Ecol Prog Ser, Vol. 395: 21-36, 2009

Download: <http://www.typepad.com/articles/theme/m395p021.pdf>

Very good overview of the full spectrum of recent research using acoustic recorders, including both archival systems (deployed for weeks to years, with data downloaded periodically) and real-time systems

(in which data is available on an ongoing basis remotely). Includes discussion of acoustic systems deployed in Brazil, Antarctica, the US, and Norway, as well as a series of studies using towed hydrophone arrays in the Pacific. The authors stress the importance of the different research designs and baseline information necessary to effectively study behavior that takes place on different spatial scales, and suggest adaptation of long-standing terminology used in other fields to discuss relevant oceanic scales (synoptic scales for regional marine areas of >2000 km², mesoscale as areas between 1 and ~2000 km² in size and microscales as areas <1 km²).

The importance and the flexibility of these new technologies is well expressed in the paper's conclusion: "Archival and real-time passive acoustic arrays are now among the lowest cost approaches for mesoscale monitoring of marine areas and can be used to monitor vocal marine life in areas difficult to survey by traditional visual methods. Fixed autonomous passive acoustic arrays sample continuously for prolonged periods of time, allowing assessment of seasonal changes in distribution and acoustic behavior of individuals without introducing into the environment the types of disturbances generated by the presence of survey vessels or aircrafts. Unlike more traditional visual methods, passive acoustic technologies can survey in darkness and remain active during adverse weather conditions. Further, the ability to retrieve and redeploy archival Acoustic Recording Units provides a level of flexibility in data acquisition that is not available with other fixed long-term monitoring systems."

Acoustic recording tags

Johnson M, Aguilar de Soto N, Madsen P. Studying the behaviour and sensory ecology of marine mammals using acoustic recording tags: a review. Mar Ecol Prog Ser, Vol 395:55-73, 2009.

Download: <http://www.typepad.com/articles/theme/m395p055.pdf>

A related, though far more limited, line of research involves temporarily placing recorders on animals themselves; this allows researchers to hear what animals hear, while tracking their dive patterns in relationship to the sounds heard or made by the animals. It is still very hard to successfully place these suction-cup tags on to animals, so the datasets are tiny, though very illuminating. This paper reviews the history and current status of this line of research.

Identifying animals on recordings: Moving past data crunch

While the promise of wide deployment of the following recording platforms is very exciting, the ease of gathering "acoustic data" comes with a daunting challenge: how to make use of the information in the recordings. There will be — and already are — **too many hours of recordings to have people listen to; even if they could, the sounds are often faint, or jumbled together, and identifying individual species can be very difficult.** To help with this, several different software packages are in use, each of which aims to automate the detection of particular species of interest. Such software is also widely used in terrestrial acoustic monitoring, where bats or birds or insects are the stars of the recordings.

The two leading ocean acoustics automated detection programs are PAMGUARD, being developed by the Joint Industry Program²⁴, and Ishmael, developed by NOAA²⁵.

²⁴ <http://www.pamguard.org/home.shtml>

²⁵ <http://www.pmel.noaa.gov/vents/acoustics/whales/ishmael/>

AEI Resource Collection: Technologies and Platforms for Remote Recording

Stationary recorders – permanent deployment

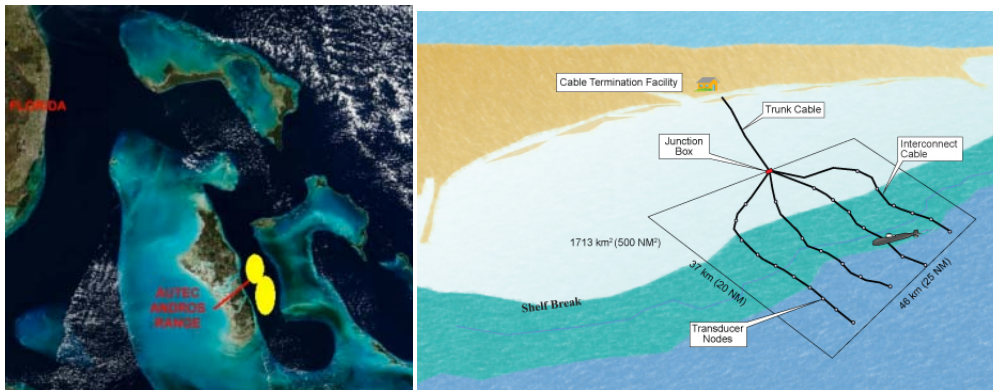
Navy SOSUS platforms

Beginning in 1961, the US Navy operated a network of bottom-mounted hydrophones known as the Sound Surveillance System (SOSUS), primarily designed to track Soviet submarines. Since 1991, the Navy has made declassified SOSUS data available to government and university marine scientists. The system listens in on long-range low-frequency sounds traveling in the deep sound channel; the data is currently used for monitoring whales and seaquakes, as well as for some acoustic thermometry (tracking temperature patterns in the ocean).

http://www.pmel.noaa.gov/vents/acoustics/sosus_apps.html

Navy instrumented ranges

The US Navy operates two instrumented ranges, one in the Bahamas²⁶ and one off the Southern California coast²⁷. Each of these ranges has a variety of instruments, including hydrophones, permanently mounted on the sea bottom over an area of about 500 square miles (equivalent to a 20 miles by 25 miles rectangle). A third such range is proposed off the coast of northern Florida²⁸.



L: AUTECH in the Bahamas; R: schematic of proposed USWTR in the Atlantic

The ranges are mostly used to monitor and provide assessment and feedback in onsite training missions, though they are have more recently been used to listen for the presence of marine mammals, especially beaked whales. Some academic research has taken place in AUTECH; however, even though the research was in support of Navy research priorities (tracking the responses of beaked whales to sonar signals), the researchers had some difficulties in scheduling time on the ranges in the limited period during which they were in the region.

Ocean observatories

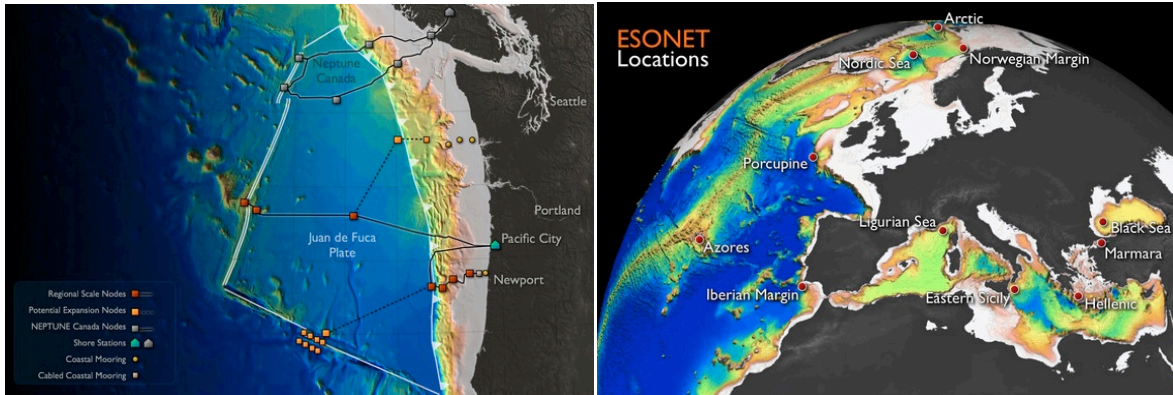
For the research community, **the most exciting long-term permanently deployed acoustics research projects are likely to be based at one of many new Ocean Observatories. On the planning board for the past decade or more, the first of these permanent observatories are now online, with more due to become operational every year.**

²⁶ Atlantic Undersea Test and Evaluation Center (AUTECH), 500 square miles: <http://www.npt.nuwc.navy.mil/autec/> and <http://en.wikipedia.org/wiki/AUTECH>

²⁷ Southern California Offshore Range (SCORE), including the 670 square mile Southern California Anti Submarine Warfare Range (SOAR): <http://www.globalsecurity.org/military/facility/score.htm>

²⁸ Undersea Warfare Training Range (USWTR): http://projects.earthtech.com/uswtr/USWTR_index.htm
And see also coverage on p.4 in the Sonar section of this report

Ocean Observatories will contribute to a full array of science topics, including plate tectonics, climate studies and planetary gas cycling (e.g., carbon dioxide and methane), and monitoring physical, chemical, and biological interactions that support—and result from—the life cycles of the constituents in the biological food chain. At the same time, **many (though not all) observatories are also installing hydrophones that will contribute to marine mammal monitoring as well as larger-scale understanding of the ocean's soundscapes.**



Regional scale ocean observatory nodes off BC, WA, and OR (left) and Europe (right)

Images: <http://www.ooi.washington.edu/>

Canada's NEPTUNE observatory (Northeast Pacific Time-series Undersea Network Experiments) is currently on the forefront at sharing its data, via a website launched in December, dubbed Oceans 2.0. Three of its seven "nodes" feature hydrophones, at depths of 100m, 400m, and 1000m. So far, no audio is available on Oceans 2.0, but it is due to come on line soon.

NEPTUNE site, with access to Oceans 2.0: <http://www.neptunecanada.com/>

NEPTUNE goes live, with link to Oceans 2.0: <http://www.neptunecanada.com/news/news-details.dot?id=20604>



NEPTUNE instrument node heading to sea (left) and one location's instrumentation (right)

Images: <http://oceannetworks.ca/assets/images/lodbrog%20crane%20with%20TRF.jpg> and <http://www.neptunecanada.com/sensors-instruments/>

For more information on global ocean observatories, see:

Consortium for Ocean Leadership ocean observatories page:

<http://www.oceanleadership.org/programs-and-partnerships/ocean-observing/>

University of Washington Interactive Oceans site, with info on all major regional plans:

<http://www.ooi.washington.edu/portal/Observatories>

Excellent 5-minute video from NEPTUNE on ocean observatories:

http://www.youtube.com/neptunecanada#p/u/6/oi46_D-BgtA

Nice big graphic of cyber-infrastructure:

<http://ucsdnews.ucsd.edu/graphics/images/2004/LookingFig1.jpg>

Oregon State University planning:

http://www.oregonlive.com/environment/index.ssf/2009/09/part_of_vast_ocean_observing_n.html

Eastern Consortium of ocean observatories: http://www.whoi.edu/mvco/other_data/ECCOO/index.html

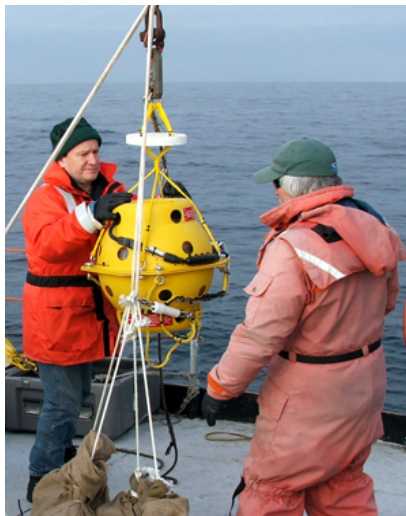
European Ocean Observatory Network: <http://www.eurosites.info/>

Stationary recorders – temporary but extended deployments

Cornell MARU

Cornell's Marine Autonomous Recording Unit (MARU), or "pop-ups," have become the best-known of the new technologies, and are in use in research projects around the world. **Pop-ups are anchored to the ocean floor to record the sounds of marine mammals within a pre-set range of frequencies.** When the hard drive is full, a signal is sent to the device to cut loose from its tether and "pop-up" to the surface. A radio frequency transmitter then sends out a signal that allows scientists to find and retrieve the device, and download the data. The MARUs in use at Stellwagen are equipped with transmitters that allow real-time monitoring of recordings, as well.

MARUs are capable of storing up to 90 continuous days of data. They generally are designed to listen for low-frequency sounds, and are used especially for research focused on baleen whales and shipping. For example, the MARUs in Stellwagen record from 10Hz to 1kHz, though other units listen to 2kHz.



A Cornell MARU

Image source: http://www.nefsc.noaa.gov/press_release/2006/buoy1.jpg

To learn more about the use of this system, see the following web resources:

Cornell pages on pop-ups:

<http://www.birds.cornell.edu/brp/hardware/pop-ups>

<http://www.birds.cornell.edu/brp/hardware/autonomous-recording-units>

<http://www.birds.cornell.edu/brp/hardware/tagging-and-monitoring>

<http://www.birds.cornell.edu/brp/brp-projects-around-the-world>

Stellwagen pages of note:

http://stellwagen.noaa.gov/science/passive_acoustics_noise.html

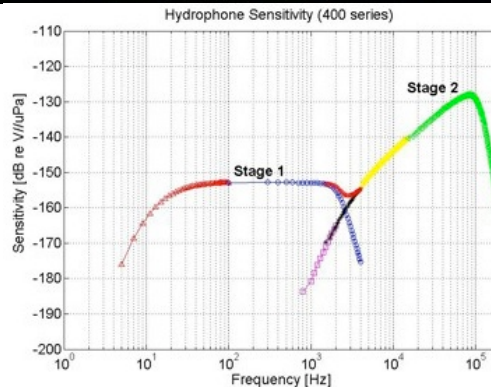
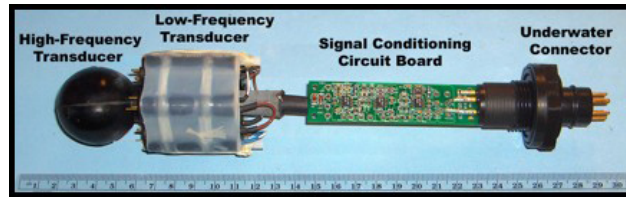
http://stellwagen.noaa.gov/science/passive_acoustics_current.html

Right whale listening network (with close to real-time whale detection info): <http://www.listenforwhales.org/>

Scripps HARP

The Marine Physical Laboratory at Scripps Institution of Oceanography (SIO), in collaboration with SIO's Whale Acoustics Lab and the University of California at San Diego, has developed the High-frequency

Acoustic Recording Package (HARP), along with the earlier ARP, which focuses only on lower frequencies. **These units record at a broader range of frequencies than the MARU units**, and are capable of storing 55 full days of data (soon to double, with the replacement of hard drives with flash drives). Like the MARUs, HARPs are anchored to the ocean floor, and retrieved for data collection. The dual hydrophone system records from 10Hz to 100kHz, allowing it to monitor for a wide range of sea life simultaneously.



HARP hydrophones: 2 stages, wide frequency response

The Stage 1 sensitivity curve is adapted to minimize the effects of high ambient noise levels at lower frequencies

For more on the HARP system, see:

Scripps main HARP pages: http://cet.uscd.edu/technologies_AutonomousRecorders.html

Excellent interactive map of worldwide projects: http://cet.uscd.edu/projects_Main.html

T-POD, C-POD

This European system is somewhat similar to the Scripps and Woods Hole pop-ups, though it has a more specialized purpose: identifying the species-specific click-trains emitted by dolphins and porpoises as they hunt fish. The PODs (PORpoise Detectors) are used to do population surveys²⁹, and to assess the impacts of noise sources such as wind farm construction³⁰.

Developed by Chelonia Limited³¹, T-Pods sample a number of distinct frequencies between 9 and 170kHz in sequence; the newly improved C-POD continuously samples the full 20-160kHz range, and utilizes a replaceable SD memory card allowing for extended re-deployments.

See Chelonia presentation on current and future uses of PODs:

http://www.bfn.de/habitatmare/de/downloads/vortraege-yod/24-Nick_Trogenza.pdf

T-POD being readied to monitor for harbour porpoises and bottlenose dolphins

Photo: <http://www.devonwildlifetrust.org/images/uploaded/cetacean/acoustic2.jpg>



²⁹ See <http://www.devonwildlifetrust.org/index.php?section=cetacean:acoustic>

³⁰ See <http://www.chelonia.co.uk/eia.htm> and also two studies summarized on p.38 in the Research section of this report.

³¹ See <http://www.chelonia.co.uk/>

Stationary recording platforms – short term deployments

Sonobuoys

Buoys equipped with hydrophones are used by researchers as well as by the Navy as part of its anti-submarine warfare systems (some of the Navy buoys emit mid-frequency active sonar signals, while others are simply part of the listening systems that receive sonar signals or listen for submarine sounds). They are generally considered to be expendable units (i.e., they are not picked up after deployment; they sink after they stop receiving data).

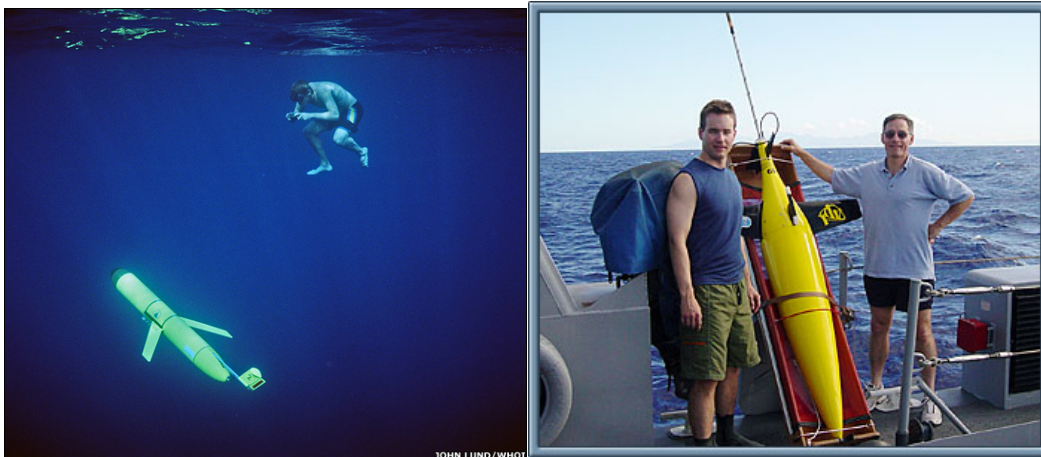
As an example, Scripps uses two types of Sonobuoys in its research³². Omnidirectional sonobuoys have hydrophones that can register signals up to 20 kHz, but cannot determine the location of the sound source. DiFAR (Directional Fixing And Ranging) sonobuoys also have an omnidirectional hydrophone for recording sound, but it is limited to frequencies lower than 2.5 kHz. However, DiFARs also have 2 pairs of direction sensors, which along with an internal compass can determine the bearing of the sound relative to the sonobuoy. With 3 or more sonobuoys in the water it is possible to pinpoint the exact location of the sound source. This can then be correlated to visual observations of the species of marine mammal in that location, along with behavior and grouping information.

For more on the Scripps sonobuoys: http://cetus.ucsd.edu/technologies_Sonobuoy.html

Mobile recording platforms – long term/long distance deployments

Diving Thermal Gliders: Seaglider and Slocum Glider

These winged “autonomous underwater vehicles” (AUV) have been in use for several years, though **this year the Seaglider was outfitted for the first time with a hydrophone.** On its initial listening voyage, it heard beaked whales off the Hawaiian coast³³. **Among the many acoustic applications for gliders could be providing acoustic monitoring near and during sonar exercises away from instrumented ranges; gliders have been used to monitor salinity and temperature during Navy exercises, but so far, not to listen for whales.** They could also provide long-term regional acoustic monitoring as part of a global sound mapping/sound budgeting effort, and could play a role in improving our knowledge of the ranges of various marine mammals.



The Slocum Glider at sea; Seaglider ready to be deployed

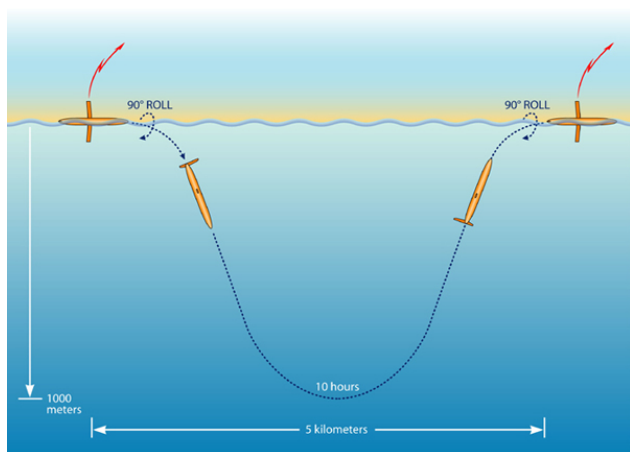
Images: WHOI, University of Washington

³² See http://cetus.ucsd.edu/technologies_Sonobuoy.html Again, Greeneridge is the developer of at least some of these: <http://www.greeneridge.com/technology.html>

³³ See AEInews coverage of this mission at <http://aeinews.org/archives/483> and earlier coverage of glider research at <http://aeinews.org/archives/189>

Three designs are most widely used in oceanography, and each are largely affiliated with one research institution in consort with a commercial company that spun off to market the units. The Slocum Glider originated at Woods Hole Oceanographic Institute, and is marketed by Webb Research³⁴, while the Seaglider is centered at the University of Washington and sold by iRobot³⁵. And, the Spray Glider was developed at Scripps, and is now sold by Bluefin Robotics³⁶. They operate in comparable manners, making slight changes in their mass by moving water or oil in and out of the units as they move into colder water during their dives. Each can contact a satellite upon surfacing, sending data and receiving new instructions as needed. All can operate for months at a time, covering thousands of kilometers at sea; in September, a UW team claimed that their 9-month mission had doubled the previous endurance record for autonomous vehicles³⁷.

There is a major limitation, however, in that the small changes of buoyancy that “drive” the unit up and down, and therefore forward; the “payload” must be quite light in order to not interfere with these subtle changes. Therefore, instrument packages must weigh less than 3.5-5kg. As noted, acoustics is still a new field for glider research; generally, gliders are outfitted with traditional oceanographic sensors, including CTD sensors (Conductivity, Temperature, Depth), fluorometers, Acoustic Doppler Profilers, back scatter sensors, ISUS (Nitrate) units, altimeters, and acoustic modems for communicating with subsurface moorings.



L: Sample dive profile of the Spray Glider, similar to those of other gliders as well
 (note compressed scale in graphic: actual is 1km dive, 5km horizontal range, in 10 hours) Image: WHOI
R: Seaglider “phones home” at top of its dive Image: Wiki commons

For a good overview of the main thermal glider designs, see this article from the Marine Technology Society Journal, in 2004 (note that designs have improved since then, notably with advancements in thermal driving of the buoyancy systems, rather relying on batteries):
http://www.pord.ucsd.edu/~rdavis/publications/MTS_Glider.pdf

A more recent article appeared in the Marine Technology Reporter, Oct 2009; see page 28:
<http://dwp.marinelink.com/pubs/nwm/mt/200910/>

And, this 2009 presentation offers a look at the sorts of research currently taking place with gliders:
http://www.mtsociety.org/pdf/sections/Ocean%20Glider_Pat%20Cross.pdf

³⁴ See <http://www.webbresearch.com/thermal.aspx> and http://www.earthexplorer.com/2009-03/Slocum_glider_generates_scientific_payload_in_undersea_data.asp

³⁵ See <http://www.irobot.com/sp.cfm?pageid=393> and <http://www.apl.washington.edu/projects/seaglider/summary.html>

³⁶ See http://www.bluefinrobotics.com/bluefin_glider.htm and <http://spray.ucsd.edu/pub/rel/index.php>

³⁷ See http://www.apl.washington.edu/projects/seaglider/new_note_seaglider.html

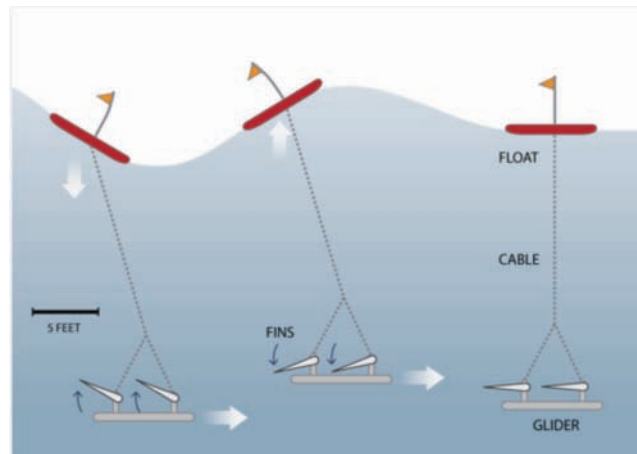
Wave glider

This is a **new, simpler, and far cheaper platform for long-term excursions at sea**. Rather than aiming for underwater dives, this **“persistent surface vehicle”** is more of a rectangular surfboard with solar panels on top, and instruments suspended below along with its ingenious drive mechanism, which utilizes the rise and fall of waves for propulsion. Also **unlike the larger thermal gliders, the Wave Glider began as a platform for acoustic monitoring**; it was invented by two Silicon Valley engineers to provide a quieter platform for listening to whales than a hydrophone near shore³⁸. While hydrophones are not heavy, it is also worth noting that the Wave Glider’s propulsion system will not be significantly hampered by carrying larger payloads than are possible with the diving gliders; of course, any recordings or other data collection may also be limited by being kept relatively close to the surface.



The Wave Glider is rapidly evolving as it moves into commercial development

Images: Liquid Robotics



The Wave Glider is propelled by fins that “flap” as the surface unit goes up and down waves

Images: Liquid Robotics

For more on the Wave Glider:

See the Liquid Robotics website: <http://www.liquidr.com/products.aspx>

And see this hour-long lecture: <http://www.youtube.com/watch?v=Cq4G2ciXjZI&fmt=18>

³⁸ See February 2009 NY Times article on the wave glider:
<http://www.nytimes.com/2009/02/24/science/24wave.html>

Mobile recording platforms – short term deployment

Another approach to acoustic monitoring is to design units for specific, short-term deployment situations. Of course, the old-fashioned hydrophone-on-a-cord is the simplest version of this approach. This section of the report could likely get out of hand pretty easily, so I'll limit myself to just a quick summary of a few basic innovations.

Acoustic tags

Once again, the great east-west Oceanographic Institute rivalry between Woods Hole and Scripps is in play, with the east coast player getting most of the popular press (reminding me of claims of the sports media's "east coast bias" in college hoops). **Both WHOI and SOI have developed suction-cup tags that are placed on whales, and which can record received sound levels while tracking the animal's movements; ideally, researchers can correlate behavioral responses to received sound levels.** In practice, while the results from acoustic tag studies are incredibly dramatic and at times exciting, there is a continuing struggle to successfully tag enough whales to get large enough data sets to make meaningful predictions. With N=1 or N=4 (i.e., one or four whales tagged and responding to the target sound), it's hard to make any substantial claims or conclusions; instead, we have gotten a series of compelling indicators and hints.

D-Tags

In use since 2003, the Woods Hole D-tags³⁹ have been used in many of the controlled exposure experiments (CEE), also known as Behavioral Response Studies (BRS), in which researchers attempted to assess animal responses to sounds from seismic surveys and mid-frequency active sonar⁴⁰. They've also been very useful in assessing normal beaked whale dive and vocal behavior.



D-tag on pole, ready to be attached to a whale (or the photographer)

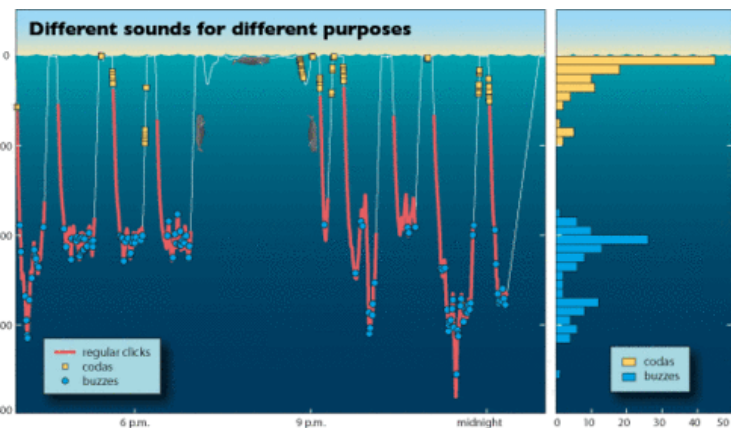
Photo, Marcus Ballardini:

http://www.who.edu/cms/images/tag&boat_LigNOPP04_Ballardini_cropped2_47459.jpg

Beaked whale dives patterns, and three distinct sounds made by the whale, over the course of about 10 hours

communication codas: yellow
echolocation clicks: red
prey-capture buzzes: blue

Graphic: WHOI; image source:
http://twistedphysics.typepad.com/cocktail_party_physics/images/2008/01/02/v43n2tyack2en_8668.gif



³⁹ See <http://www.who.edu/page.do?pid=39337>

⁴⁰ For cruise reports and conference presentations about BRS studies in the Bahamas and the Mediterranean from 2007-9, and plans for future studies, see Brandon Southall's research page at <http://www.sea-inc.net/science/>

Bioacoustic Probe (B-probe)

This is the Scripps version⁴¹, designed by Greeneridge Sciences,⁴² and has also been in use since 2003. They've been used primarily to learn more about diving and vocalization behavior in blue, fin, and humpback whales; a comparable unit has been used to listen in on pinnipeds on shore as well as in the water.



B-probe on whale

photo John Calambokidis, Cascadia Research Source: http://cet.uscd.edu/technologies_AcousticTag.html

Towed Hydrophone Arrays

Finally, an array of hydrophones towed behind a vessel is often used in Passive Acoustic Monitoring by seismic survey vessels, and by researchers. While unlike the other platforms featured here, all of which are designed for autonomous (unmanned) recording, arrays are of course cabled; but I felt their role in monitoring for marine mammals made them worth mentioning. There are challenges, most notably masking of animal sounds by the noise from the vessel itself as well as flow noise over the hydrophones, but these are increasingly being addressed by better design and software that can tease the animal sounds out of the other noises.

As noted above (p.8-9), a recent NOAA research project in the Mediterranean demonstrated the potential of a specially designed array of four hydrophones, towed behind a quiet research vessel, to localize animals in the area with good precision⁴³.

⁴¹ See http://cet.uscd.edu/technologies_AcousticTag.html

⁴² See <http://www.greeneridge.com/technology.html> and http://www.acousonde.com/downloads/Acousonde_Brochure.pdf

⁴³ See this AEInews blog post for more details: <http://aeinews.org/archives/445>

Other Research of Note in 2009

While sonar and seismic research were covered in their own sections above, the following research reports are also worth your attention. When available, I include links to either the AEI news post on the study, or to the lay summaries of new research page at the main AEI website, where you'll find a longer summary of each of these (and many more).

Routine ways to stay current with AEI's science coverage

Bookmark and visit the lay summaries page: <http://AcousticEcology.org/scienceresearch.html>

Check the science subset at AEI news: <http://aeinews.org/archives/category/science>

Get the full RSS or email feed from <http://AEInews.org>

Breakthrough technique measures how much ocean noise reduces whales' communication area

Clark, Ellison, Southall, Hatch, Van Parijs, Frankel, Ponirakis. Acoustic masking in marine ecosystems: intuitions, analysis, and implication. *Mar Ecol Prog Ser*, Vol. 395: 201-222, 2009.

Download paper: <http://www.int-res.com/articles/theme/m395p201.pdf>

This paper proposes a clear and strikingly rigorous set of new metrics that will allow researchers and ocean planners to have a much more practical picture of how numerous noise sources combine to create cumulative impacts on acoustic habitat. The new approach centers on the **"Communication Space" of individual animals, as well as groups, and provides an intuitively obvious way to both visualize and assess the effects of ocean noise – by delineating the area in which an animal can hear or be heard by others of its species.**

This was one of the most exciting papers published this year, and I heartily encourage you to read the whole thing, and to check out AEI's detailed summary of it at: <http://aeinews.org/archives/626>

Bias in military (and conservation) funded ocean noise research

Wade, Whitehead, Weilgart. Conflict of interest in research on anthropogenic noise and marine mammals: Does funding bias conclusions? *Marine Policy* 34 (2010) 320-327.

In the United States, **the US Navy funds about 70% of the research into the effects of ocean noise on wildlife (and half, worldwide)**. For many years, conservation groups have questioned whether this preponderance of funding is skewing research results, whether by constraining the types of questions being studied, or by leading researchers to downplay negative impacts of noise in order to continue receiving funding. The authors of this new study report a significant correlation between Navy funding and results reporting "no effect" of noise, based on their analysis of several wide-ranging reviews of ocean noise science, and of the primary research papers cited in these reviews. While the data behind their conclusion is clearly explained, the results don't look nearly as clear-cut to me; I question the comparability of the five reviews used, and while the trends in primary papers is more obvious, it's hard to ignore the fact that the majority of military-funded papers still found that noise had effects. Indeed, as the authors make clear, it's the conservation-funded reviews and primary research that is most clearly one-sided in its results (though there are good reasons for this, also fleshed out by the authors and in AEI's commentary below). In AEI's view, studies like this – and indeed, reviews such as those considered here – are diligent exercises in quantifying an issue that has become, for all practical purposes, an exercise in divergent world views and beliefs talking at and past each other. Of special note is that the authors did not find any strong trend toward bias of results reported by independent, academic researchers receiving Navy funding for research studies - these studies showed a similar proportion of effect and no effect results as studies funded by neither the military nor conservation groups (though when comparing military-funded studies with all the others, including conservation-funded, a non-statistically significant trend of 1.64 times more "no effect" findings was observed).

Again, AEI's summary is very detailed, including some of the key graphs from the paper: <http://aeinews.org/archives/545>

Fish Acoustics: New Frontier in Biology

One of the leaders in fish bioacoustics, Rodney Rountree, wrote a **great overview piece in the Marine Technology Review on groundbreaking work being done in fish biology using Passive Acoustic recording systems**. The article does a wonderful job of introducing the various approaches being taken to recording

freshwater and oceanic fish. The most exciting aspect of this work is that **until quite recently, very few biologists even considered fish as vocal or acoustic creatures** (the emphasis was on chemical/smell and mechanical/tactile sensitivity). As Rountree notes, "currently most biological sounds recorded in marine and aquatic habitats are unknown due to the lack of study and a lack of comprehensive sound catalogues." It's *agua incognita*! **To enter this fascinating new acoustic world, Rountree has compiled three distinct yet complementary overviews:**

The article in MTR is on Page 40 of this pdf version of the issue:

<http://www.mtronline.net/MTIssues/mt200811o2.pdf>

You can download his 42-page "e-book" nominally written for children, but in fact a wonderful layperson overview of the history and current discoveries in fish acoustics; it's full of links to websites:

<http://fishecology.org/soniferous/Listening%20to%20fish%20children's%20book%20final%20wlinks.pdf>

Rountree's academic website <http://FishEcology.org> has a page that is full of fish sounds, including a slew of unidentified sounds: <http://fishecology.org/soniferous/justsounds.htm>

Excellent Review of the Effects of Human-Generated Sound on Fish

Popper and Hastings. The effects of human-generated sound on fish. *Integrative Zoology* 2009; 4: 43-52

This recent review is a great place to get up to speed on the current state of our knowledge regarding the effects of human sound on fish. It begins by sketching a sense of the "natural" and 21st-century aquatic world's acoustic nature, and proceeds to **review various possible physiological and behavioral effects of human sounds ranging from sonars to pile-driving, seismic surveys, shipping, and even research vessels themselves**. The authors note that a significant challenge to improving our understanding of the behavioral effects of noise sources is our inability to observe wild fish over large enough areas (fish-finding sonars can only see fish out to a few hundred meters, not enough to observe possible avoidance of noise sources). As is usually the case with ocean noise issues, the concerns about noise and fish far exceed the ability of our limited data to discern possible effects. As the authors note, "Because of a striking paucity of well-designed and controlled experimental data, very little is actually known...Human-generated sounds, even from very high intensity sources, might have no effect in some cases or might result in effects that range from small and temporary shifts in behavior all the way to immediate death."

A special theme section entitled "Acoustics in Marine Ecology" was published in the journal *Marine Ecology Progress Series* in 2009. This compilation of empirical and review papers includes an introduction and overview of the relevant issues, along with a call for new research paradigms and funding strategies, as well as manuscripts in three general subject areas: (1) the use of passive listening systems to measure and monitor marine ecosystems; (2) active acoustic technologies to explore habitat use and predator-prey behavior; and (3) impacts of anthropogenic sound on the marine environment.

To see the Table of Contents, with links to abstracts and full papers, see:

<http://www.int-res.com/abstracts/meps/v395/>

Of special note are:

Bejder L, Samuels A, Whitehead H, Finn H, Allen S Impact assessment research: **use and misuse of habituation, sensitisation and tolerance in describing wildlife responses** to anthropogenic stimuli

Clark CW, Ellison WT, Southall BL, Hatch L, Van Parijs SM, Frankel A, Ponirakis D Acoustic masking in marine ecosystems: intuitions, analysis, and implication

Hatch LT, Fristrup KM No barrier at the boundaries: implementing regional frameworks for noise management in protected natural areas

Hildebrand JA Anthropogenic and natural sources of ambient noise in the ocean

Van Parijs SM, Clark CW, Sousa-Lima RS, Parks SE, Rankin S, Risch D, Van Opzeeland IC Management and research applications of real-time and archival passive acoustic sensors over varying temporal and spatial scales

See AEI summaries of several of these papers: <http://acousticecology.org/scienceresearch.html>

Humpbacks avoid boat noise at nearly 5 miles

Sousa-Lima and Clark. Whale sound recording technology as a tool for assessing the effects of boat noise in a Brazilian marine park. *Park Science* 26:59-63.

Download paper: <http://www.nature.nps.gov/ParkScience/index.cfm?ArticleID=270&Page=1>

See AEI summary on this page: <http://acousticecology.org/scienceresearch.html>

Using an array of pop-up recorders, this study was able to **track eleven individual singing humpback whales and monitor their movements in response to four separate approaches by a tourist boats** in the

Abrolhos Marine National Park off Brazil, in the main humpback breeding grounds in the southwest Atlantic. Nine of the eleven whales moved away from the boat; of these, four continued singing and five stopped singing (these did not resume singing for at least 20 minutes). Six of the nine began moving away while the boat was more than 4km (2.5mi) away; this distance was chosen as the onset of the "exposure" period, since it had been previously shown to be the median distance at which humpbacks respond to boats. In fact, the mean distance at which the nine whales began moving away was 7.5km (4.7mi); previous studies have suggested that 8km is the greatest distance at which humpbacks would exhibit avoidance, with some studies suggesting they would not move until boats were within 300 meters.

Offshore wind farms: impact area on porpoises is small during operation, but potentially over 20km during construction

These two papers, from related research teams, assessed the impacts of construction and operation of wind farms in Europe on local populations of harbor porpoises and harbor seals.

Tougaard, Henriksen, Miller. Underwater noise from three types of offshore wind turbines: Estimation of impact zones for harbor porpoises and harbor seals. J. Acoust. Soc. Am. 125 (6), June 2009. 3766-3773.

Underwater noise was recorded from three different types of wind turbines in Denmark and Sweden. The authors note that **virtually all airborne noise from the turbine blades is reflected off the surface of the water**, while vibrations from the machinery are transmitted through the tower and into the foundation, from where it radiates out into the water column and seabed. In general, turbine noise was only measurable above ambient noise at frequencies below 500Hz, with total SPLs of 109-127db re 1uPa rms, measured at 14-20m from the turbines' foundations. By comparing measured sound levels with audiograms of harbor seals and harbor porpoises, the researchers determined that the sounds were only slightly audible for the porpoises at ranges of 20-70m, whereas harbor seals may hear the sounds at ranges of 100m to several kilometers. As a bottom line, researchers suggest that behavioral changes are very unlikely in harbor porpoises except at very close ranges, while seals may have some behavioral reaction out to a few hundred meters. For both species, masking is predicted here to be low to non-existent (due to differences between vocalization frequency patterns and the predominantly low-frequency turbine noise), and the sound is not strong enough to cause physical injury, no matter how close the animals are.

Tougaard, Carstensen, Teilmann, Skov, Rasmussen. Pile driving zone of responsiveness extends beyond 20km for harbor porpoises (*Phocoena phocoena* (L.)) (L). J. Acoust. Soc. Am. 126(1), July 2009. 11-14.

This study took place **during construction of an offshore wind farm in the North Sea**. Acoustic T-PODs were placed in the wind farm and in two locations outside the wind farm, at 7 and 20km away. During pile driving operations, which generate high-intensity impulsive sounds (235dB peak-peak), detections of harbour porpoises declined at all listening stations. (The baseline was detections during construction, but without pile driving activity taking place) The declines were not dramatic (within the 95% confidence bars in most cases, barely beyond them in some cases), but were consistently found. There was no clear difference in detection rates at 7 and 20km, which implies that the displacement effect extends well beyond 20km. The differences inside the wind farm were minimal when pile driving was occurring, though total detections were lower inside the farm than outside at all times, suggesting that animals inside the construction zone were individuals who were more acclimated or tolerant of the ongoing construction noise.

Safety Thresholds for Ocean Noise Should Address Character of Signal, Not Just Loudness

Michael Stocker. The importance of incorporating signal characteristics in the evaluation of noise exposure impacts on marine life. Acoustical Society of America presentation, May 2009.

Download paper: http://ocr.org/research/criteria/Signal_characteristics_in_noise_exposure_metrics.pdf

This paper is a literature review that presents evidence suggesting that **our current reliance on simple amplitude (dB level) limits as the foundation of noise-exposure guideline for sonar and other ocean noise sources may not provide the assumed protection for animals**. The author proposes several other characteristics of sound signals that may have biologically relevant effects that contribute significantly to possible injury or behavioral responses to human sound. Current safety thresholds are largely based on hearing tests with captive dolphins. A striking graphic in this paper shows the wide variability in these lab-based results from one species, with reported hearing thresholds varying by up to 50dB. This could well be due to large individual variations in hearing health among captive dolphins; the author stresses as well that the simple sine-wave-based signals used in most hearing tests may not be especially relevant to

cetacean hearing. He notes that predominant natural ocean noises (waves, rain, etc.) are relatively simple sine-like sounds, so that ocean species may in fact be adapted to NOT hear them as well as sounds important to communication or which are threats. He concludes his overview of existing hearing studies: "It is clear that animal hearing systems are not just 'auditory frequency bins' but include complex ways of discriminating the characteristic differences between biologically useful signals, 'safe sounds,' and 'pernicious sounds.'" He then cites studies from Holland that have used various non-sinusoid signals to determine discomfort levels, and associated "discomfort zones" related to various signal differences; and, studies indicating that signals with high "kurtosis" (variability in sound levels and harmonic content) produce greater physiological damage than similarly-loud sounds with low kurtosis.

The author concludes by noting that current regulations are based on simple lab auditory threshold tests that are favored because they are easily replicable, but which "only demonstrate the subject's sensitivity to the test signal and do not necessarily reflect the subject's auditory thresholds to the range of signals that they might encounter in their own habitat." He suggests that **exposure criteria should be modified to reflect characteristics known to enhance behavioral responses or increase the risk of physiological injury**; he proposes evaluation of the following signal characteristics:

- Rise time of impulse signals
- Periodicity of intermittent signals
- Kurtosis, evaluated three ways: FFT of spectral distribution, amplitude variability, and spectral variability (kurtosis is, in lay terms, a measure of the variability or complexity of the frequency components of a signal)

Ocean Acidification Not Likely to Increase Ambient Background Noise

Reeder, Chiu. Ocean acidification and its impact on ocean noise level: An analysis using empirical and physical models of acoustic transmission loss. Presented at ASA October 2009 meeting.

Udovydchenkov, Duda. Ocean noise level change in response to ocean acidification. Presented at ASA October 2009.

These two papers take a closer look at the widely-noted ocean noise implications of increasing ocean acidification (a combination of factors related to global warming is triggering a steady increase in the ocean's pH, which decreases sound absorption). When the acidification results were first released there was much speculation that shipping noise would propagate farther, resulting in cumulative ambient noise increases throughout the oceans. These two papers, presented at this fall's Acoustical Society of America meeting, both come to the same conclusion: **low frequency noise will not be significantly increased due to ocean acidification; rather, the primary changes will occur at mid-frequencies**. This calms concerns about shipping noise, but may (over time) lead to slightly larger areas being impacted by mid-frequency active sonar, some acoustic harassment devices used by fish farms, noise from recreational boating, and other mid-frequency noise.

Rather than simply looking at the effects of sound absorption, both papers assessed the combined effects of many factors in sound propagation: seabed attenuation and boundary effects, waveguide physics, and the distribution of pH and absorption through different depths of water. The first paper looked at shallow water, a surface duct, and deep ocean, and found that the maximum change in noise transmission occurs at about 2kHz, with no significant change below 800Hz. The second paper notes that at low frequency, little sound is absorbed anyway, so pH-related absorption effects are much smaller than all the other effects, and that at high frequencies, sound does not propagate very far, also minimizing effects of decreased absorption; the authors note that effects can be sizable at middle frequencies. (*Ed. note: for both papers, pre-conference abstracts do not quantify the mid-frequency effects; details will follow after the presentations and with later publication of results.*)

Right Whales Experience Dramatic Variations in Noise During Annual Movements Along North American Coast

Parks, Urazghildiiev, Clark. Variability in ambient noise levels and call parameters of North Atlantic right whales in three habitat areas. J. Acous. Soc. Am. 125 (2), February 2009.

This study used pop-up recorders to examine ambient noise conditions and right whale calls in three of the species' annual habitats: The Bay of Fundy, Cape Cod Bay, and the coast of Georgia. While the variability of calls was subtle, there was **some indication that louder call patterns were in response to the peak sound in an area, rather than the overall noise level**. However, the seasonal variability of noise

experienced by this population is the key finding here. Overall sound levels were highest during the summer season spent in the Bay of Fundy, and lowest in the winter off Georgia. Likewise, **the percentage of time that the habitat was "loud" (ambient noise over 105dB re 1uPa in the 50-350Hz frequency range of right whale contact calls) varied dramatically:** in the Bay of Fundy, it was loud 85-95% of the time, in Cape Cod Bay it was loud 53-63% of the time, and off Georgia it was loud only 20-30% of the time. **While the quiet is surely appreciated during calving time in Georgia, the high proportion of noisy times in the Bay of Fundy could impede summer social interaction, perhaps including mating.** The population of North Atlantic right whales is precarious, and slowly decreasing; the researchers conclude with the urgent observation that "Locating the mating grounds for right whales and quantifying the noise occurring in their breeding areas may be crucial in understanding how increases in ambient noise may limit the range of communication signals that are vital for successful reproduction."

Orcas Increase Volume of Calls in Synch With Increasing Boat Noise

Holt, Noren, V. Veirs, Emmons, S. Veirs. Speaking up: Killer whales (*Orcinus orca*) increase their call amplitude in response to vessel noise. *J. Acous. Soc. Am.* 125(1), January 2009.

This study found that **Southern Resident killer whales, who are nearly always within earshot of boat traffic, increase their call amplitude by 1dB for every 1dB increase in background noise levels.** Call amplitudes ranged from 133-174dB re 1uPa (mean 155dB), while background noise (measured in the 1-40kHz band) ranged from 98-123dB (mean 110dB), as nearby boat counts ranged from 1-46. Of course, source levels of calls vary, based on the type of call; still, there was a significant correlation between call source level and background noise for all call types. The detailed analysis was restricted to the one call type with the largest sample size. It appeared that call amplitude was relatively unaffected until background noise reached 105dB, though the researchers note a small sample size below that level, and suggest further investigation to see whether there is a threshold at some point. Above 105dB, calls increased 1dB for each 1dB of increased boat noise. Interestingly, they found no increase in duration of calls; an earlier study had found that calls were longer in noisy conditions. The researchers suggest that this difference may be due to differences in study design, or due to the fact that the current study site did not provide any "no boat noise" conditions (i.e., perhaps call duration increases at the first appearance of background noise, with call amplitude increasing with the noise).

Boats Reduce Foraging Time in Orcas

Lusseau, Bain, Williams, Smith. Vessel traffic disrupts the foraging behavior of southern resident killer whales *Orcinus orca*. *Endangered Species Research*, Vol. 6: 211-221, 2009.

This recent paper continues a line of research undertaken by this team over the past several years, which investigates the ways that boat traffic changes orca behavior, with a special focus on foraging activity (a 2004 paper by these researchers suggests that reduced foraging is the most significant impact on an animals' energy budget; ie, the extra energy used in, e.g., avoidance is much less significant than the much larger decrease in energy received when foraging is reduced). As in their study of the northern orcas of BC, and in line with studies by others of delphinid species in other parts of the world, this study found that orcas around San Juan Island reduced their time spent foraging by about 20% when boats were within 400m (from 76% of the time to 60% of the time). They had hoped to identify behavior patterns when 100m, 400m, and 1000m or more from boats; unfortunately, in the San Juan Islands, boat traffic is nearly constant, and there were very few opportunities to observe orcas with boats more than 1000m away. In the end, the authors show a clear affect with boats within 100m and 400m, as well as an apparently smaller affect when boats were within 1000m. The authors note that it is possible that the 400m affect is mainly caused by boats not far beyond 100m (a study with finer spatial analysis would be needed to clarify this). Nonetheless, they show that the **current whale watching standard of remaining 100m away is not sufficient to avoid disrupting the key foraging behaviors of orcas.**

Related: Number of Vessels May Play Larger Role than Proximity of Vessels

Williams, Bain, Smith, Lusseau. Effects of vessels on behavior patterns of individual southern resident killer whales *Orcinus orca*. *Endangered Species Research*, Vol. 6: 199-209, 2009.

This companion paper by the same research team does not address foraging, but rather looks at overall behavioral effects of the same boat traffic measured in the above study. They find that behavioral changes such as swimming speed and directness of travel path changed slightly in response to boats, and in general, they found that **changes were more correlated to the number of boats within 400 yards than by the proximity of the boats, whereas current whale watching standards address only how close**

each boat is, rather than total numbers of boats. They also note that, given the difficulties in finding clear patterns within this noisy environment, it may be hard for managers to feel that the data is solid enough to warrant additional protections. However, the authors conclude with the observation that it appears that **this population is food-limited** (many researchers consider declining salmon runs to be a primary factor in population stagnation and sometimes dips), **and suggest that reducing the ambient noise levels would improve the whales' ability to find the limited food that remains in the region.** *Ed. note: This paper's focus on numbers of vessels corresponds well with the Holt paper directly above, which finds overall ambient noise is closely tied to the number of boats in the vicinity.*

Soundscapes, Acoustic Daylight, and Fish Hearing

Richard Fay. Soundscapes and the sense of hearing in fishes. *Integrative Zoology* 2009; 4: 26-32.

This fascinating review offers a wide-ranging consideration of the implications of a simple observation: goldfish have an acute sense of hearing, though they do not vocalize or engage in any known sound communication. What are they listening to? Fay introduces several key lines of research into fish hearing, some dating from the 80s, and some from the past decade. His own research, along with that of several others, has demonstrated that fish can isolate multiple sound sources (though studies cited are limited to two distinct sounds, rather than much more complex mixes of sound). From there, **Fay suggests that fishes' sensitivity to particle motion in water, via their lateral lines, provides them the ability to engage in what in human perception is termed "auditory scene analysis," or the perception of a complex environment by distinguishing the many sound sources and their motion through the soundscape.** The most intriguing suggestion in the paper is less solidly fleshed out: that fish make use of reflections of ambient sound to build this "auditory scene." That is, ambient noise can act as "acoustic daylight," with subtle differences in the echoes of the overall ambient sound bouncing off specific objects being a source of perception (as light reflects off objects to create visual perception). Fay mentions one study in which goldfish were shown to be able to perceive a single point source of delayed (as if echoed) signal in a noise field; this was apparently done with artificial noise sources, though the researchers (and Fay) propose that it represents an ability of goldfish to perceive the fish bladder of another fish re-radiating ambient noise. This may well be true, though this (and one other related study that showed fish using echoes from self-produced sound) do not yet cross the chasm of showing that fish process complex acoustic scenes by using reflections of ambient noise. Yet the point of this review is not to "make a case" for these higher order perceptual abilities, but rather to open our minds to the likely fact that fish listen to much more than simply communication signals, which has been overlooked due to our "profound ignorance of the other possible sounds and sources that probably have biological significance to fish," and to suggest that "environmental soundscapes (are) most probably important sources of information." This more modest first step is clearly successful here, opening the way to future studies of the undoubtedly subtle and complex sensory world of fishes.

Yet Another Study Shows Dramatic Decrease in Dolphin Foraging Near Boats

Antonella Arcangeli and Robert Crosti. The short-term impact of dolphin-watching on the behaviour of bottlenose dolphins (*Tursiops truncatus*) in western Australia. *Journal of Marine Animals and Their Ecology*. Vol 2, No. 1. 2009.

Download paper: <http://www.oers.ca/journal/Volume%202/200921arcangeli.pdf>

Over the past few years, a steady trickle of new studies have indicated that many species may decrease foraging activity in the presence of boats. In many situations, it can be difficult to have enough sightings without boats to create a data set large enough to have statistically significant results (e.g., orcas in the Pacific northwest, or dolphins in the Mediterranean). Also, the presence of the observation boat can confound results. This study took place in a bay near Bunbury, 200km south of Perth, western Australia, a location where these limitations could be overcome. The weather conditions in summer are generally calm, allowing excellent observing conditions, with the observation inflatable's motor often shut down; observations were only made in quite calm seas (Beaufort 2 or lower). A large local population of dolphins offered plenty of data, and the population is generally stable in place, engaging in a series of regular behaviors over relatively prolonged timeframes. Behavior "without" boats present was noted when no boats (other than the observation inflatable) were within 350m; behavior "with" boats present was noted when four boats came within 150m. (*Ed. note: it would be interesting to consider the data when four boats were 150-350m distant, to assess whether the observed effects extend to greater distances*). Over the course of 65 hours of observation by a single observer, 1028 3-minute behavioral samples were taken, 781 with no boat (average duration 69 min.), and 247 with a tour boat present (average duration 47 min.).

As usual with such studies, several behavioral states were analyzed: Traveling, Socializing, Resting, Milling, Feeding, and Diving. All showed some change in the presence of boats, with Traveling, Milling, and Diving all increasing in the presence of boats, and Socializing, Feeding, and Resting decreasing. Of these, the most relevant to an animal's energy budget all were negatively affected: Traveling increased from 27% of the time to 46%, Resting decreased from 31% to 20%, and **by far the largest energetic impact was seen in Feeding, which reduced from 20% of the time to just 7.6% of the time, a 62% decrease**. This is the most dramatic decrease in feeding seen in such studies (others have tended to find a 25-35% decrease in foraging). This may indicate that the relatively localized population had plenty of time to eat when the boats were not present, and chose to either leave or play with the boats when they were present. The study did look at attraction/deterrence, finding that in 20% of cases, dolphins moved closer to the boats, while in 28% of encounters, they moved away (about half the time, there was no spatial difference, though behaviors may still have changed). The Discussion section of this paper includes an unusually detailed comparison of the findings and the contexts of this and several similar studies, as well as consideration of the ways that in other settings, where human activity is more prevalent, these behavioral changes could have longer-term, population-level impacts.

What to Keep an Eye (Ear) on in 2010

Sonar issues

- **Legal:** will the courts intervene to stop construction at USWTR until environmental analysis is completed?
- **LFAS:** watch for the release of the Draft SEIS coming from the Navy, as it prepares to expand LFAS operations into oceans around the world
- **Regulatory:** how will NOAA's recently-announced new initiatives play out in 2010? It's likely that at least one of the proposed workshops will be organized for this year, and that ongoing talks between the Navy and NRDC, with NOAA offering its input, will be somewhat fast-tracked by the lawsuit mentioned above.

Marine Spatial Planning

As the Obama administration moves toward completion of its ocean policy and planning blueprint, it's becoming clear that the new kid on the block has grown into a dynamic young adult, ready to change the shape of ocean planning forever. Marine Spatial Planning (MSP) is taking a central role in the ocean task force's work, and [a recent symposium on MSP put together by NOAA's Office of National Marine Sanctuaries offers a great introduction to the power of this approach.](#)

At its root is a simple idea, one we're very familiar with after decades of zoning on land: let's identify which areas offer the best opportunities for fulfilling each of our goals and needs in the sea, then use this information to focus each activity in areas where it will have the least cumulative impact on other priorities. Where are the regions most important for each species' reproduction and feeding? Which areas have the best possibilities for wind energy? Where is shipping concentrated? How about recreational diving and near-shore boating? Navy training, underwater cables, key fishing grounds, and all other ocean uses are mapped into layers, from which we can make informed choices about where to focus each activity.

MSP symposium website, with links to presentations: http://sanctuaries.noaa.gov/news/msp_symposium.html

Council for Environmental Quality Ocean Policy Task Force interim MSP Framework:

<http://www.whitehouse.gov/administration/eop/ceq/initiatives/oceans/interim-framework>

AEI summary of key presentations at NOAA Sanctuaries MSP workshop: <http://aeinews.org/archives/504>

Offshore renewable energy

This will be a growing area of interest and impact assessment in the coming years. Among the topics on the radar are:

Wind farms

- **Construction noise:** Pile driving of turbine foundations creates very loud sounds, which can injure or kill fish at very close range, and displace cetaceans (to distances of a few to several tens of kilometers). While the impacts are temporary, there is some concern that as construction increases, some regions may have audible noise in large proportions of coastal habitat. Deep offshore floating turbines will require less extensive pile driving.
- **Possible impacts of electromagnetic fields** from transmission cables (more likely to have some effect on fish and smaller ocean creatures).

For more on offshore wind issues, see

Working Waterfront article:

<http://www.workingwaterfront.com/articles/Fathoming-What-are-the-marine-impacts-of-offshore-wind-turbines/13667/>

Deep offshore planning surges in Maine: <http://aeinews.org/archives/472>

Tidal turbines

These turbines sit in the water, and are driven by the movement of water as the tide goes in and out. An interesting point was brought up this year: the turbines need to be designed to be loud enough for fish to hear and avoid, but quiet enough to not create widespread acoustic footprints.

<http://aeinews.org/archives/108>

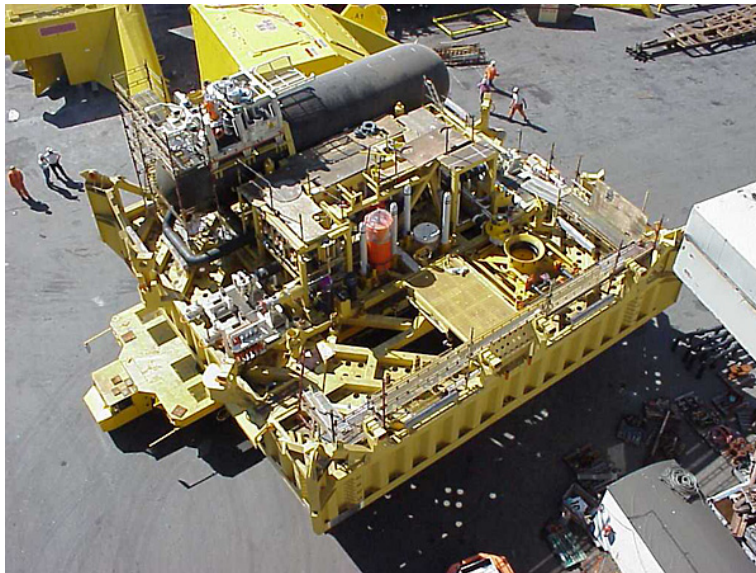
Offshore industrial activity

Seafloor mining

The mining industry is looking more actively at the vast opportunities available if they can tap into the three quarters of the earth's surface that is under the oceans. A new generation of undersea technology, developed in part by the oil and gas industry, is opening this door that was previously mostly a dream. Undersea crawlers, remotely operated vehicles with robotic arms, and subsea processing units are all key to the new mineral rush that may be starting. The Woods Hole Oceanographic Institute magazine Oceanus ran a good piece on the history and current plans in this realm⁴⁴; much of the focus has been on undersea vents, where biologists are concerned about impacts on rare species (extinct or dormant vents may have the same minerals with far less active communities of life). Meanwhile, the International Maritime Minerals Society has released a new draft of its Code for Environmental Management of Marine Mining⁴⁵, and is accepting comments through April 15, 2010⁴⁶. The draft code has some fairly progressive provisions, including leaving corridors to facilitate biological re-establishment after mining, and leaving nearby similar areas untouched to serve as research/environmental controls; the code makes no mention of assessment of the noise footprint of mining, which is bound to be locally significant.

Subsea oil processing

In order to decrease the risks of surface extraction spills the industry is developing a suite of seafloor processing technologies. This equipment includes pressurizers and injectors used to pressurize and inject seawater into the well to force petroleum out; separators and de-sanders which separate mud, drilling muds, water, and sand from the petroleum; and booster pumps which help distribute product over longer distances and bring it up to the surface. All of this equipment operates under extreme pressures (as much as 100 atmospheres or 1400 psi at the sea floor). Many also generate huge pressure – up to 5000 psi. These physical conditions will naturally generate large amounts of noise. While noise measurements of this equipment have not been published, one industry worker commented that “they are real screamers.” Currently there is no assessment of the biological impacts of this new noise on marine habitats.



Subsea oil separator

Photo: National Energy Technology Laboratory, US Dept. of Energy

Ocean Conservation Research has prepared a paper that explains the need for research to clarify what the acoustic imprint of these technologies may be: <http://ocr.org/research/impacts/SeafloorProcessing.pdf>

⁴⁴ See <http://www.whoi.edu/oceanus/viewArticle.do?id=62986§ionid=1000>

⁴⁵ See http://www.immsoc.org/IMMS_downloads/PAV_Code_082109_KM_082509.pdf

⁴⁶ email to Verlaan AT hawaii DOT edu

New Outer Continental Shelf Seismic Surveys

See coverage above (page 14-15). The Programmatic Environmental Impact Statement is unlikely to come out until 2011 or beyond, but the scoping period this year will likely create some buzz.

Academic surveys by LDEO

If the past is prologue, then it won't be too surprising to see environmental groups target some of the seismic surveys undertaken by Columbia University's LDEO, in consort with the National Science Foundation-funded geophysics researchers at other universities. Among upcoming surveys that may trigger scrutiny are one in May in the Marianas Trench of the western Pacific, and two in the summer in Alaskan waters. Coverage of 2009 LDEO operations, above on page 12-13, may provide some context if controversy erupts again this year.

About the Acoustic Ecology Institute

The Acoustic Ecology Institute was incorporated as a 501(c)3 organization in 2004. Since then, AEI has developed a reputation as an honest broker of information and resources regarding sound-related environmental issues. Generally steering clear of advocacy-oriented activities, AEI focuses on providing clear information on science and policy issues via a news digest, lay summaries of new research, and a series of comprehensive special reports on key topics, all available free of charge at <http://AcousticEcology.org> and <http://AEInews.org>. Our work on ocean noise issues has garnered enthusiastic responses from top agency staff and field researchers, journalists, NGOs, Navy staff, and oil and gas industry managers.

AEI is primarily the work of Jim Cummings, a writer and editor who has covered environmental, science, and socially responsible investing topics since the early 1980s. He was an invited plenary speaker at the Alberta oil and gas noise control conference in 2007 and 2009, and an invited participant and presenter for the Canadian Department of Fisheries and Oceans expert committee on Seismic Survey Mitigation Effectiveness in 2009. In 2007, he was the guest editor of a special double issue on Ocean Noise for the *Journal of International Wildlife Law and Policy*.

For more on AEI, see <http://acousticecology.org/press/index.html>

To receive occasional news updates (3-4 times/year), contact Jim Cummings
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<http://www.AcousticEcology.org/sractiveonars.html>

AEI's main website *Coverage of ocean, wildlands, urban issues, as well as recent science and comprehensive resource links (research programs, advocacy organizations, government agencies).*

<http://www.AcousticEcology.org/>