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Dessau, September 6-7, 2006

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Umwelt Bundes Amt

Für Mensch und Umwelt

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Dr. Heike Herata

Dessau, February 2007

International Workshop

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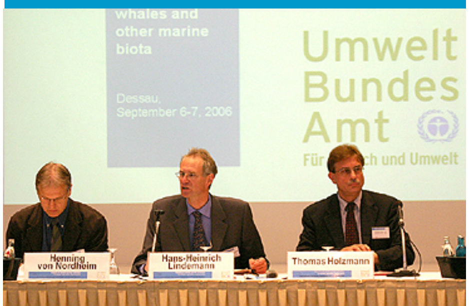

Proceedings

Umwelt Bundes Amt

Für Mensch und Umwelt

Contents

Workshop Agenda

Tuesday, September 05, 2006

	Arrival at the Hotel Steigenberger "Fürst Leopold" Welcome to Dessau
18:30	*Optional: Guided tour through the new building of the Federal Environment Agency*
20:00	*Optional: Informal dinner ("get together") at "Zum Alten Dessauer" (a local brewery pub)*

Note: All oral presentations are limited to 20 minutes plus 10 min. for discussion!

Wednesday, September 06, 2006

08.30	Registration
09.00	**Welcome address** Thomas Holzmann, Vice President of the Federal Environment Agency, Dessau, Germany
	Introduction: The Federal Environment Agency in Dessau; Scope of the workshop; technical notes Hans-Heinrich Lindemann, Federal Environment Agency, Dessau, Germany Henning von Nordheim, Federal Agency for Nature Conservation, Putbus, Germany
	1. General introduction to the issue of marine seismic surveys and their potential impacts on marine biota Chair: Hans-Heinrich Lindemann, Federal Environment Agency, Dessau, Germany
09.45 – 10.15	**1.1 Contribution of seismic survey activities to the overall ocean noise budget** John Hildebrand, Scripps Institution of Oceanography, University of California San Diego, La Jolla, USA
10.15 – 10.45	**1.2 Overview on seismic survey activities in the Southern Ocean** Monika Breitzke, Alfred-Wegener-Institute for Marine and Polar Research, Bremerhaven, Germany
10.45 – 11.15	*Coffee break*
11.15 – 11.45	**1.3 Report on the IWC-Workshop "Review of the Potential Impacts of Seismic Surveys on Cetaceans". Pre-Meeting of the IWC Environmental Concerns Sub-Committee, 24-25 May, St. Kitts, West Indies** Howard Rosenbaum (author), Wildlife Conservation Society, USA Wolfgang Dinter (presenter), Federal Agency for Nature Conservation, Germany
11.45 – 12.00	**Discussion and Summary by the Chair**
12.00 – 13.30	*Lunch break*

2. Different seismic sound generators and their characteristics on acoustics
Chair: Heinrich Miller, Alfred-Wegener-Institute for Marine and Polar Research, Bremerhaven, Germany

13.30 – 14.00	**2.1 Physical basic principles of sound propagation from seismic sources in the marine environment** John Hildebrand, Scripps Institution of Oceanography, University of California San Diego, La Jolla, USA
14.00 – 14.30	**2.2 Sound generators used in industrial surveys** Alec Duncan, Centre for Marine Science & Technology , Curtin University of Technology, Perth, Australia
14.30 – 15.00	**2.3 Sound generators used in scientific seismic surveys – calibration and modeling** Monika Breitzke, Alfred-Wegener-Institute for Marine and Polar Research, Bremerhaven, Germany
15.00 – 15.15	**Discussion and Summary by the Chair**
15.15 – 15.45	*Coffee break*
15.45	**3. Impacts on Whales** Chair: Wolfgang Dinter, Federal Agency for Nature Conservation, Putbus, Germany
15.45 – 16.45	**3.1 Vocalisations of baleen whales and their reaction to seismic noise** Christopher Clark (author), Cornell University, Ithaca, USA Peter Tyack (presenter), Woods Hole Oceanographic Institution, Woods Hole, USA
16.45 – 17.15	**3.2 Vocalisations of toothed whales and their reaction to seismic noise** Peter Tyack, Woods Hole Oceanographic Institution, Woods Hole, USA
17.15 – 17.45	**3.3 Diving behaviour of whales and their reaction to seismic noise** Peter Tyack, Woods Hole Oceanographic Institution, Woods Hole, USA
17.45 – 18.00	**Discussion and Summary by the Chair**
18.30	*Evening Bus Tour to Wörlitz Castle in Wörlitz Garden, UNESCO's World Cultural Heritage (approximately 2 hours), afterwards Dinner*

Thursday, September 07, 2006

08.30	**4. Impacts of seismic surveys on other marine biota** Chair: Henning von Nordheim, Federal Agency for Nature Conservation, Putbus, Germany
08.30 – 09.00	**4.1 Impacts of seismic surveys on seals** Jonathan Gordon, Sea Mammal Research Unit (SMRU), University of St Andrews, St Andrews, Scotland
09.00 – 09.30	**4.2 Impacts of seismic surveys on fin fish** Arthur N. Popper, Center for Comparative and Evolutionary Biology of Hearing, University of Maryland, College Park, USA
09.30 – 10.00	**4.3 Impacts of seismic surveys on giant squid** Angel Guerra, ECOBIOMAR, Instituto de Investigaciones Marinas (CSIC), Vigo, Spain
10.00 – 10.15	**Discussion and Summary by the Chair**
10.15 – 10.45	*Coffee break*

5. Risk Analysis for airguns/airgun-arrays used for academic purposes
Chair: Axel Friedrich, Federal Environment Agency, Dessau, Germany

10.45 – 11.15	**5.1 Risk analysis – how to structure risk assessments of acoustic sources** Olaf Boebel, Alfred-Wegener-Institute for Marine and Polar Research (AWI), Bremerhaven, Germany
11.15 – 11.30	**Discussion and Summary by the Chair**

6. International Measures of Mitigation (under discussion, recommended, or in force)
Chair: Axel Friedrich, Federal Environment Agency, Dessau, Germany

11.30 – 12.00	**6.1 Overview on potential mitigation measures** Sarah Dolman (author), Whale and Dolphin Conservation Society (WCDS), Chippenham, United Kingdom Carsten Brensing (Co-author and presenter), Whale and Dolphin Conservation Society (WCDS), Berlin, Germany
12.00 – 12.30	**6.2 Short description of national situations** Michael Jasny, Natural Resources Defense Council, Vancouver, Canada
12.30 – 12.45	**Discussion and Summary by the Chair**
12.45 – 14.00	*Lunch break*

7. Detection of Whales before and during use of airguns
Chair: Anita Künitzer, Federal Environment Agency, Dessau, Germany

14.00 -14.45	**7.1 MAPS: Marine Mammal Perimeter Surveillance - experiences and improvements** Olaf Boebel, Alfred-Wegener Institute for Marine and Polar Research (AWI), Bremerhaven, Germany
14.45 – 15.45	**7.2 Acoustic detection and surveillance – experiences and improvements** a) Walter Zimmer, NATO Undersea Research Centre (NURC), La Spezia, Italy b) Peter Tyack, Woods Hole Oceanographic Institution, Woods Hole, USA
15.45 – 16.15	**Discussion and Summary by the Chair**
16.15 – 16.45	*Coffee break*

16.45 – 17:30

8. General Discussion and Summary
Chair: Heike Herata, Federal Environment Agency, Dessau, Germany
Wolfgang Dinter, Federal Agency for Nature Conservation, Putbus, Germany

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Results of the Workshop

Heike Herata
Federal Environment Agency, Dessau, Germany

Abstract

The international "Workshop on the Impacts of Seismic Exploration Activities – particularly on whales and other biota" organised by the German Federal Environment Agency in Dessau, Germany, on 6 and 7 September 2006 brought together a wide expertise. All participants appreciated the intensive exchange of scientific information particularly concentrated on academic seismic surveys and the Antarctic environment.

After a general introduction to the issue on marine seismic surveys and their potential impacts on marine biota different seismic sound generators and their characteristics on acoustics were introduced. The workshop specially focused on the impact of so-called airguns/airgun arrays.

The workshop has delivered new and substantial information on the evaluation of seismic activities. One important result was that seismic surveys significantly contribute to noise in the marine environment. Furthermore, there are still great gaps in knowledge on the impacts of seismic surveys on different marine species groups.

It was clearly shown that seismic survey activities may lead to changes in the behaviour of **whales**; however, different whale species react differently. Baleen whales are low-frequency specialists that are adapted to long-range communication in a low-frequency ambient noise notch, and react differently, too. Grey whales show avoidance of seismic sources during migration. Bowhead whales in the Arctic presumably avoid seismic sources when feeding. Behavioural disruption from seismic surveys was observed in baleen whales and many toothed whales, but not in sperm whales. The biological significance of these behavioural effects, however, and whether these observations can be transferred from northern hemisphere waters to the Antarctic, remains unknown for many cases.

Seismic surveys can also have an impact on other marine species. Noise of moderate intensity and duration is sufficient to induce TTS (temporary threshold shifts) in **seals**. Observations suggested that ramp up in open water might reduce the risk of hearing damages in seals. Also behavioural responses of northern hemisphere seal species to seismic exposure trials have been recorded. More over, seismic surveys are suspicious of impacting **fish**. Temporary hearing losses were observed in some species of tested freshwater fish.

Stranding events of **giant squids** recorded during 2001 and 2003 appeared to be spatially and temporally linked to geophysical prospecting using airgun arrays. Revealed tissue and organ lesions and the relation of these effects to physical, physiological, and behavioural effects in cephalopods exposed to seismic noise, and to strandings require further investigation, in small scale experiments as well as in the field.

Mitigation measures when shooting airguns, either potential, recommended or already in force at national levels were also discussed. There is an urgent need to strengthen and standardise mitigation measures and to investigate their effectiveness. It was recommended to work towards regional guidelines which should be applied throughout the world, wherever

surveys take place. More over, well-planned and properly conducted long-term monitoring studies with appropriate control populations for measuring effects were strongly recommended. It was also clearly stated, that there is a need for broader measures for cetacean protection. This will only be possible on the basis of access to future seismic survey plans, funding for long-term cetacean baseline and monitoring programs, determination of the location, furthermore the protection of critical habitats, and appropriately conducted stranding research.

One session dealt with different methods for the detection of whales. It was shown that visual observation is necessary, but labour-intensive. More over, visual observers need to be well trained and motivated. Infrared cameras are a promising observation tool, but which needs further development. Disadvantages of infrared techniques are the short range of 1 km and the need for good weather conditions. Passive acoustic observation can be a necessary complementary method to optical methods Disadvantages are a noisy environment and if individuals do not vocalise. Active acoustic observation is possible, but expensive and the possibility of potential effects on marine biota from active detection devices is not known. It was recommended to combine visual and passive acoustic detection if necessary, since they are complementary.

Further investigations are needed in order to clarify whether and which impacts on the Antarctic environment as a result of academic seismic surveys must be suspected and therefore have to be avoided or have to be mitigated with which methods (precautionary principle). All information and evaluation should be used for the preparation of an environmental assessment for academic seismic surveys under the provisions of the Protocol on Environmental Protection on the Antarctic Treaty. Further work is required to reconcile differences in field observations, to assess biological significance of the effects and to develop and test the efficiency of appropriate mitigation procedures. There is also a need of long-term monitoring of the effects of academic seismic surveys and an improvement of mitigation measures.

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Welcome address

Thomas Holzmann
Vice-President of the Federal Environment Agency,
Dessau, Germany

I am glad to welcome you to the international "Workshop on the Impacts of Seismic Exploration Activities – particularly on Whales and other Biota" at the Agency's new headquarter in Dessau, in the Federal State of Saxony-Anhalt.

I must frankly say that you chose a beautiful convention site here at the "Steigenberger Fürst Leopold Hotel" but an even more beautiful and impressive site is located right next door: the brand new headquarter of the Federal Environment Agency at Dessau which some of you might already have seen yesterday evening. We are proud to say that this building is unique in its environmental performance, such as:

- Energy-efficient and environmental friendly heating and cooling, e.g. solar supported cooling system and photovoltaic system,
- Geothermal energy exchange,
- Environmentally and health compatible building materials
- Etc.

Those who haven't seen the building yet are invited to have a look at it for example during lunchtime or whenever you can spare some extra time for "ecological sightseeing".

Aside from a beautiful building, we have of course a scientific and administrative mission:
The motto of the Federal Environment Agency is "FOR HUMAN WELLBEING AND THE ENVIRONMENT". It sums up the objective of the work of its staff of over 1200. Established in 1974, the Agency is Germany's largest environmental authority. Together with the Federal Agency for Nature Conservation and the Federal Office for Radiation Protection, it is attached to the German Ministry for the Environment, Nature Conservation and Nuclear Safety and provides the scientific base of Germany's environment policy. It is also the contact point for citizens in environmental and health protection questions. Legislature and the Federal Government have given the Agency many and varied functions.

The most important ones are:

- scientific support to the federal government (Federal ministries of environment, health, research, transport, building and urban development, among others),
- implementation of important environmental legislation (inter alia emissions trading, authorisation of chemicals, medicinal products and pesticides, ***authorization of Antarctic activities organised in or proceeding from Germany in the Antarctic***)
- Information of the public (The Agency gives for example gives practical advice on environmental issues, publishes data on the state of the environment and informs about air quality in Germany on a same-day basis).

The Federal Environment Agency sees itself as a kind of early-warning system that identifies and assesses potential future adverse impacts on humans and the environment in a timely manner. It also makes its knowledge available to other state, municipal and private institutions. Its activities are not focused on Germany only. International activities are gaining in importance because many environmental problems can only be tackled within a transnational framework. Therefore, the Agency also co-operates with more than 300 international bodies and sends representatives to numerous international conferences. It is German partner and contact point of international organisations such as the World Health Organization (WHO).

The **Agency's experts** partly do research in in-house laboratories and measure air quality at own measuring stations. They also award research contracts to scientific organisations and institutes in Germany and abroad. They work in a transdisciplinary manner. Environmental problems are thus considered from different angles including economic and social aspects. The Agency's scientists propose solutions to environmental problems to the relevant federal ministries.

The Federal Environment Agency currently has a **staff** of over 1200 who work at a total of eleven locations, including seven measuring stations of the Agency's own measurement network. Since May 2005, 750 of the total staff are being based at the new headquarter in Dessau. About half of the staff graduated from university or a college of applied science. Biology, chemistry, law, sociology, medicine – the Agency has a broad scientific base. It runs the largest environmental library in German-speaking countries and operates various databases.

5 Divisions and 1 central functions department exist in our office. All divisions work on a broad spectrum of topics. **Division I** for example deals with Environmental Planning and Sustainability Strategies including the cross-cutting issues Energy/Climate protection, Transport and Agriculture. It devises proposals for sustainable development in Germany and the European Union.

One of the parts of Division I is the section on “Protection of the Antarctic”. The Federal Environment Agency is the German competent authority for issuing permits of activities organised in, or proceeding from Germany in the Antarctic according to the Protocol on Environmental Protection to the Antarctic Treaty. In this context we have, inter alia, to assess the impact of seismic surveys on the marine environment, topic of our meeting.

I hope that this Workshop will give significant insights for the national as well as for the international level of the implementation of the Protocol on Environmental Protection to the Antarctic Treaty. I wish you a pleasant stay in Dessau and I hope that the discussion will be open, intensive and fruitful.

Introduction

The Federal Environment Agency in Dessau - Scope of the Workshop

Hans-Heinrich Lindemann
Federal Environment Agency, Dessau, Germany

Abstract

The Federal Environment Agency is the German competent authority for issuing permits of activities organised in, or proceeding from Germany in the Antarctic according to the Act Implementing the Protocol of Environmental Protection to the Antarctic Treaty (AIEP). The main tasks are the Authorization of German activities in the Antarctic (Articles 3-12 AIEP). Additional tasks comprise Monitoring (Article 14 AIEP), Waste management (Articles 21-28 AIEP) and Reporting (Articles 13, 15 and 40 AIEP). According to the AIEP (Article 4 (3)) the Federal Environment Agency shall, on the basis of existing documents judge whether the activity gives cause to suspect:

- less than a minor or transitory impact;
- a minor or a transitory impact; or
- more than a minor or a transitory impact

on the assets to be protected set forth in Article 3 (4) of this Act. The Federal Environmental Agency shall inform the applicant of its judgement and on how to proceed further.

Environmental Impacts of seismic activities on the assets to be protected are discussed controversial and this is one of the reasons why we organised this Workshop. We want to obtain scientific knowledge:

- about physical and technical basic principles of sound propagation from seismic sources in the marine environment,
- about the contribution of seismic survey activities to the overall ocean noise budget, and
- for the evaluation of the impacts from seismic survey activities on marine biota (whales, squid, fin fish, fish larvae, plankton).

The focus of the workshop should be on academic seismic surveys with the aim of using this information for the preparation of an environmental assessment under the provisions of the Protocol on Environmental Protection on the Antarctic Treaty. More over, information exchange is needed on potential mitigation measures recommended or applied at the international level when shooting airguns. We expect to get significant insights into the subject and the most recent findings to assist the implementation of the Protocol on Environmental Protection to the Antarctic Treaty.

1. General introduction to the issue of marine seismic surveys and their potential impacts on marine biota

1.1 The Contribution of Seismic Sources to the Anthropogenic Ocean Noise Budget

John A. Hildebrand
Scripps Institution of Oceanography
University of California San Diego, USA

Ocean noise is generated by a variety of human activities including: commercial shipping, seismic surveys associated with oil and gas exploration and academic research, naval operations, and fishing activities. At low frequencies (5 – 300 Hz) commercial shipping and seismic surveys are the dominant sources of anthropogenic noise. Low frequency sounds propagate especially well, contributing to basin scale increases in background noise. At mid-frequencies, (3 – 50 kHz) naval and commercial uses of sonar are the dominant source of anthropogenic noise. These frequencies attenuate more rapidly as they propagate, resulting in a contribution to local and regional scale background noise. These sources of ocean noise are becoming both more pervasive and more powerful, increasing background noise levels and peak sound intensity levels.

Seismic surveys are an important contributor to the anthropogenic ocean noise budget at low frequencies (Hildebrand 2005). Seismic surveys are the primary technique for finding and monitoring reserves of fossil-fuel and are used extensively by the oil industries. In addition, seismic surveys are used by research scientists to study tectonics and history of the seafloor crust. Arrays of airguns are the sound-producing elements in seismic surveys (Dragoset 2000). Airgun arrays produce sound by venting air at high pressure into the water, generating a high source level with most energy in the low frequency band (5-300 Hz), and with lower levels at higher frequencies. A single airgun pulse lasts about 20-30 milliseconds. To yield high intensities, multiple airguns are fired with precise timing to produce a coherent pulse of sound. Arrays of airguns are designed to direct sound energy downward toward the seafloor, and apparent source levels are about 6 dB lower for other directions. Oil industry airgun arrays typically involve 12 to 48 individual guns, and operate at pressures of 2000 psi. They are dispersed over a 20 m by 20 m region, and are towed about 200 m behind a vessel. About 90 ships operate airgun arrays for the oil and gas industry worldwide (with about one-quarter of them firing their airguns on any given day). There are about 80 additional ships that are capable of operating airguns for academic and other research, some of these vessels maintain substantial schedules of airgun operation (e.g. ~150 day/year for R/V Ewing), although many of these vessels conduct seismic surveys on an occasional basis.

The source level output from an airgun array is proportional to its operating pressure, the number of airguns, and the cube root of the total gun volume. Industry airgun arrays typically have more airguns, but may have lower total source volume than those used by academic researchers. For consistency with the underwater acoustic literature, airgun-array source levels are back-calculated to an equivalent source concentrated into a one-meter-radius volume, yielding source levels as high as 259 dB peak re 1µPa @ 1 m output pressure

(Greene and Moore 1995). These estimates of effective source level predict pressures in the far-field of the array, but in the near-field the maximum pressure levels encountered are limited to 220-230 dB peak re 1μPa, owing to the distributed nature of the airgun array source.

Airguns are towed at speeds of about 5 knots and are typically fired about every 10 seconds. A seagoing seismic-reflection survey often includes a series of parallel passes through an area by a vessel towing an airgun array as well as 6-10 seismic receiving streamers (hydrophone arrays). A recent industry practice is the use of repeated seismic reflection surveys for "time-lapse" monitoring of producing oil fields, called "4-D" surveys.

Industry offshore oil and gas exploration and construction activities occur along continental margins. Currently active areas include northern Alaska, eastern Canada, the U.S. and Mexican Gulf of Mexico, Venezuela, Brazil, West Africa, South Africa, North Sea, Middle East, northwestern Australia, New Zealand, southern China, Vietnam, Malaysia, Indonesia, and the Sea of Okhotsk. New areas of exploration include the deepwater U.S. Gulf of Mexico and deepwater West Africa, both of which have seen increasing activity in the past 5 to 10 years. Academic airgun surveys are conducted in a greater variety of settings, such as in extremely deepwater and in tectonic settings not associated with fossil-fuels. A recent study of ambient noise in the North Atlantic suggests that airgun activity conducted along the continental margins of North America, South America and Africa propagates into the deep Atlantic Ocean and is a significant component of low frequency background noise (Nieukirk et al. 2004). Sounds from airguns were recorded almost continuously during the summer, originating at locations over 3000 km from the receiving hydrophones. In the North Pacific Ocean, seismic surveys are less prevalent and they are not thought to be a dominant anthropogenic noise source.

Commercial shipping is a major contributor to background noise in all the world's oceans (Ross 1976). The low frequencies generated by commercial ships propagate especially well in the oceans, contributing to basin scale increases in noise. Distant ships contribute to the background noise level over large geographic areas. The sounds of individual vessels are often spatially and temporally indistinguishable in distant vessel traffic. Ships generate noise primarily by propeller action (cavitation), propulsion machinery, hydraulic flow over the hull, and flexing of the hull. Individual ships produce noise primarily in the low frequency band (5-100 Hz), but also with lower source level at higher frequencies. Peak spectral densities for individual commercial ships range from 195 dB re $\mu Pa^2/Hz$ @ 1 m for fast moving (20 knots) supertankers, to 140 dB re $\mu Pa^2/Hz$ @ 1 m for small fishing vessels. Shipping vessel traffic is not uniformly distributed. Major commercial shipping lanes follow great circle routes or coastlines to minimize the distance traveled. Dozens of major ports and megaports handle the majority of the traffic, but hundreds of small harbors and ports host smaller volumes of traffic. Vessels found in areas outside major shipping lanes include fishing vessels, military ships, scientific research ships, and recreational craft – the last typically found near shore. Vessel operation statistics indicate steady growth in vessel traffic over the past few decades, with an increase both in the number of commercial vessels and in the tonnage of goods shipped.

Sonar systems are used by naval and fishing activities to probe the ocean. They seek information about objects within the water column, at the sea bottom, or within the sediment. Sonars are used for detection, localization, and classification of various targets (*e.g.* the ocean floor, plankton, fish, submarines). For purposes of discussion, sonar systems can be categorized as low-frequency (< 1 kHz), mid-frequency (1 – 20 kHz), and high-frequency (> 20 kHz). Sonars used for locating submarines use low and mid frequencies (100 Hz – 20 kHz) at high source levels to detect targets at long distances. Most commercial sonars use high frequencies (3 – 100 kHz) and have moderate to high source levels. Sonars used for locating small objects like fish require higher frequencies to provide detailed resolution at relatively short distances, but these high frequencies attenuate rapidly. Commercial sonars used to detect and study the ocean floor use mid- to high frequencies (3 kHz – 50 kHz). During their operation sonars tend to emit sound a few percent of the time, and listen for returning echoes the rest of the time. Under some conditions, however, sound from a sonar may reverberate to produce elevated noise levels between pulses.

Naval sonars are used for target detection, localization, and classification. They generally cover a broader frequency range and operate with higher source levels than civilian sonars. They are operated during both training exercises and combat operations. Low Frequency Active (LFA) sonars are used for ocean-basin-scale surveillance; they are designed to allow submarine tracking over scales of many hundreds to thousands of kilometers. Specialized support ships are used to deploy LFA sonars, which consist of arrays of source elements suspended vertically below the ship. The U.S. Navy's Surveillance Towed Array Sensor System (SURTASS) LFA sonar uses an array of 18 projectors operating in the frequency range of 100 - 500 Hz, with 215 dB re 1µPa @ 1 m source level for each projector (Johnson 2002). These systems are designed to project beams of energy in a horizontal direction. The effective source level of an LFA array, when viewed in the horizontal direction, can be 235 dB re 1µPa @ 1 m or higher. The signals transmitted include both constant-frequency (CF) and frequency-modulated (FM) components. A transmission sequence can last 6 to 100 seconds, with a time between transmissions of 6 to 15 minutes and a typical duty cycle of 10 to 15 percent. Signal transmissions are emitted in patterned sequences that may last for days or weeks.

Mid-frequency tactical Anti-Submarine Warfare (ASW) sonars are designed to detect submarines over several tens of kilometers. They are incorporated into the hulls of submarine-hunting surface vessels such as destroyers, cruisers, and frigates. There are 117 of these sonars on U.S. Navy ships currently in active service, and equivalent systems in other navies bring the worldwide count to about 300 sonar systems (Watts 2003). The AN/SQS-53C is the most advanced surface ship ASW sonar in use by the U.S. Navy. The AN/SQS-53C sonar generates frequency-modulated pulses of 1-2 second duration in the 1-5 kHz band, at source levels of 235 dB re 1µPa @ 1 m or higher (Evans and England 2001). This sonar has a nominal 40-degree vertical beamwidth (dependant upon frequency), directed 3-degrees down from the horizontal direction. The AN/SQS-53C is designed to perform direct-path ASW search, detection, localization, and tracking from a hull mounted transducer array of 576 elements housed in a bulbous dome located below the waterline of the ship's bow. These systems are used to track both surface and submerged vessels, with range settings of up to 60 km.

Nearly all of the 90,000 vessels in the world's commercial fleet and many of the 17 million small boats owned in the US are equipped with some form of commercial sonar. Commercial sonars are designed for fish finding, depth sounding, and sub-bottom profiling. They typically generate sound at frequencies of 3 - 200 kHz, with only a narrow frequency band generated by an individual sonar system. Source levels range from 150-235 dB re 1µPa @ 1 m. Commercial depth sounders and fishfinders are typically designed to focus sound into a downward beam. Depth sounders and sub-bottom profilers are designed to locate the sea-bottom and to probe within the sea-bottom (respectively). They are operated primarily in nearshore and shallow environments. Fish finders are operated in both deep and shallow areas.

High power sonars can be achieved by constructing arrays of sensors on the hull of the vessel. For example, multibeam echosounding systems (e.g., SeaBEAM or Hydrosweep) form narrow directional beams (e.g. 1-degree beamwidth) and are used for precise depth sounding. Using hull-mounted arrays of transducers, these systems can achieve 235 dB re 1µPa @ 1 m source levels and are typically operated at 12-15 kHz in deep water, and at higher frequencies (up to 100 kHz) in shallow water. They may ensonify a swath of a few 10's of km along the track of the ship. In addition to multibeam sonars, oceanographers use low-frequency sound sources with to map the physical properties of the ocean (*e.g.*, Acoustic Thermometry of Ocean Climate project).

The fishing industry has developed sound sources to keep marine mammals away from fishing gear or aquaculture facilities (Olesiuk et al. 2002, Barlow and Cameron 2003). Acoustic Deterrent Devices (ADDs) and Acoustic Harassment Devices (AHDs) are mid- to high-frequency sound sources used to intentionally modify marine mammal behavior. ADDs or “pingers” typically produce low sound levels and are used to discourage marine mammals from approaching fishing gear. Pingers are intended to warn animals of the presence of a net or other fishing gear. Pingers reduce the bycatch of marine mammals by altering them to the presence of an entangling object. These are typically low-power devices with source levels of 130 – 150 dB re 1 µPa @ 1 m which emit brief pulses. Alternatively, AHDs emit tones or pulsed frequency sweeps at higher source levels and are used to keep seals and sea lions away from aquaculture facilities or fishing equipment, to which the animals are attracted as a food source. The idea behind AHDs is that they keep marine mammals away by introducing a local acoustic annoyance. AHDs are used to reduce depredation by marine mammals on caught or cultured fish. These are high-powered devices with source levels of 185 – 195 dB re 1 µPa @ 1 m. Both pingers and AHDs have frequencies in the 5 – 160 kHz band, and generate pulses lasting from 2 – 2000 msec. To reduce habituation, a single device may transmit with a variety of waveforms and time intervals.

The anthropogenic sound sources discussed above may be summarized by sound-pressure-level and other parameters. Naval LFA-sonars and seismic airgun arrays both have high sound-pressure-levels (>240 dB re 1 µPa @ 1 m). The long ping lengths and high duty cycle of LFA sonars increase their total energy outputs relative to the short pulse length and relatively low duty cycle of seismic airgun arrays. Both the LFA-sonar and airgun arrays have dominant energy at low frequencies, where long-range propagation is likely. Mid-frequency naval sonars (such as the SQS-53C) have shorter ping durations and more moderate duty cycles, and since they operate at mid-frequencies, propagation effects also limit their range. Commercial vessels are arguably the most ubiquitous anthropogenic sound source, with more than 90,000 vessels operating worldwide. The origin of these noise sources will be concentrated near major ports and along the most heavily traveled shipping lanes, although their low-frequencies allows these sounds to propagate over ocean-basin scales. The moored research sound source for the ATOC project is an equivalent source level to a supertanker, although it operates on a low duty cycle. Acoustic harassment devices have high source levels, whereas acoustic deterrent devices have more moderate source levels. Multibeam hull-mounted echo-sounders have high source levels, but their narrow beam widths and medium frequencies limit their range and the area that they ensonify.

An annual energy budget is one approach to comparing the contribution of each anthropogenic noise source (Hildebrand 2005). The approach taken is to consider the acoustic energy output at the source itself, rather than as the sum of many sources after propagation within the ocean, as would be experienced by a receiver at a particular location. The question considered is a simple one: what is the total energy output from each source type at the location of the source. All sources are assumed to be at a compact location, at range of 1 m, and the total annual energy output of each source type is estimated. Starting with the source pressure levels, the additional information needed includes the source directionality, duration, rate of usage, and total number of sources.

In the proposed annual energy budget the most energetic regularly operated sound sources are the seismic airgun arrays from 90 industry vessels operating for 80 days/year to produce 3.9E+13 Joules. Naval sonars for anti-submarine warfare operated on 300 vessels for 30 days/year produce 2.6E+13 Joules. The contribution from shipping comes mostly from the largest vessel classes, with 11000 supertankers, operating 300 days/year, to yield 3.7E+12 Joules. Lesser contributions are made by other vessel classes (e.g. merchant and fishing) and by navigation and research sonars. For comparison a small power plant of 100 Mwatts with an annual energy output of 3.2E+15 Joules, and at the low energy end, a symphony orchestra produces about 10 W of sound energy, and would emit 3.2E+08 Joules playing for a year.

Overall trends for anthropogenic noise in the ocean are poorly documented, both in terms of field measurements, and in terms of source usage. In order of importance, the anthropogenic sources most likely to have contributed to increased noise are: commercial shipping, offshore oil and gas exploration and drilling, and naval and other uses of sonar. Some data on long-term noise trends come from comparison of historical U.S. Navy acoustic array data (Wenz 1969) with modern recordings along the west coast of North America (McDonald et al. 2006). A low-frequency noise increase of 10-12 dB over 39 years was observed at a site off the southern California coast, suggesting an average noise increase rate of about 3 dB per decade. One explanation for a noise increase in this band is the growth in commercial shipping, in terms of both number of ships and gross tonnage. In the North Pacific, seismic operations are not thought to be a dominant anthropogenic noise source, whereas in the Atlantic they have been shown to make a significant contribution. Naval and other uses of sonar may have increased proportional to the number of vessels equipped with these systems. Since they are operated at mid- and high- frequencies, their contribution to the background noise budget may be limited to regional scales owing to their limited propagation.

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1.2 Overview on seismic survey activities in the Southern Ocean

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Abstract

The Southern Ocean is the body of water which encircles the Antarctic continent. It extends from 60°S latitude to the Antarctic coastline and encompasses 360° longitude. It covers an area of about 20 million km^2, which are about 56 times the size of Germany and slightly more than twice the size of the United States. It mainly includes the Amundsen Sea, Bellingshausen Sea, Wedell Sea, Ross Sea and parts of the Scotia Sea and Drake Passage. The Southern Ocean is rather deep with 4000 - 5000 m water depth over most of is extent and only limited parts of shallow water. Most parts of the continental shelves are ice-covered.

Based on the Antarctic Treaty System seismic survey activities in the Southern Ocean are confined to academic research. Due to the environmental conditions they only take place during the austral summer seasons. In order to allow a scientific exchange and provide an open access to all Antarctic multichannel seismic reflection data (MCS) for use in cooperative research projects the Antarctic Seismic Data Library System For Cooperative Research (SDLS) was created in April 1991 to function under the auspices of the Scientific Committee of Antarctic Research (SCAR). According to the regulations described in the SCAR Report No 9, January 2001, all digital MCS data has to be submitted to the SDLS within 4 years of collection, remain there under SDLS guidelines for 4 years and go to World Data Centres or equivalents for general dissemination 8 years after collection. Additionally, the navigation data of all MCS track lines should be made available via the SDLS almost immediately after the end of the cruises. Thus, the SDLS is not only a tool for scientific data exchange and access but is also a tool which provides an overview on all completed MCS survey activities, so that future track lines can be planned, duplication of lines can be avoided and acoustic impacts can be minimized.

After a recent update finished 30 June, 2006 the SDLS presently contains data from 121 MCS cruises collected by 15 nations between 1976/77 and 2005/06. The total length of all profiles amounts to 305'111 km. Among the 15 nations USSR/Russia were most active and collected 70'160 km of MCS lines during 24 surveys, followed by Germany with 52'975 km during 16 surveys, Japan with 48'980 km during 21 surveys, Australia with 30'479 km during 5 surveys, Italy with 28'090 km during 11 surveys, USA with 18'780 km during 11 surveys and Norway with 12'771 km during 6 surveys. The contributions of the other 8 nations are less than 10'000 km/nation. Poland, China and New Zealand range at the lower end with only 1 cruise of 1'100, 2'015 and 3'400 km MCS survey line length.

Enhanced seismic survey activities occurred during the seasons 1985/86 - 1987/88 with 11'235 - 19'104 profile km/season, from 1989/90 - 1991/92 with 16'623 - 22'281 profile km/season, from 1993/94 - 1996/97 with 10'114 - 14'411 profile km/season and from 2000/01 - 2001/02 with 19'826 - 21'223 profile km/season around the whole Antarctic Continent with a coastline of about 18'000 km length, which is about 30 times the distance between Hamburg and Munich and more than 4 times the distance between New York and San Francisco.

Assuming an average survey velocity of 5 kn these enhanced activities are equivalent to 51 - 85 survey days/season between 1985/86 - 1987/88, 75 - 100 survey days/season between 1989/90 - 1991/92, 46 - 65 survey days/season during 1993/94 - 1996/97 and to 90 - 96 survey days/season between 2000/01 - 2001/02 in the whole Southern Ocean.

A more detailed examination of the survey activities in five different areas surrounding the Antarctic Continent shows that the greatest portion of all MCS survey lines - 87'409 km totally - were collected around the Antarctic Peninsula and Marie Byrd Land, an area covering ~4.6 million km^2 (~13 times the size of Germany or about half the size of the United States). Assuming a survey velocity of 5 kn and 30 seasons between 1976/77 and 2005/06 this is equivalent to an average of 13.1 survey days/season and 2'914 profile km/season. The second most seismic activities occurred in the Wedell Sea and Queen Maud Land with an average of 10.4 survey days/season and 2'322 profile km/season in an area of ~5.4 million km^2 (~15 times the size of Germany and slightly more than half the size of the United States). In Wilkes Land (~1.9 million km^2), an average of 1'683 profile km was collected during 7.6 days/season. In the Ross Sea (~1.2 million km^2) the average profile length was 1'634 km and the average number of survey days/season 7.4. Lowest survey activities occurred in Prydz Bay and Enderby Land (~0.8 million km^2) with an average of 1'617 profile km/season collected during 7.3 days/season.

All of these MCS surveys were conducted as 2D seismic lines and had often the meaning of reconnaissance surveys. A comparison with marine seismic exploration surveys for example undertaken by the Norwegian Petroleum Department on the continental margins off Norway mainly as 3D- and to a lesser extent as 2D-surveys shows that between 1999 and 2005 the total length of survey lines varied between ~330'000 and ~750'000 km/year in an area which covers less than 2% of the area of the Antarctic Continent or the Southern Ocean.

1.3 Report on the IWC-Workshop "Review of the Potential Impacts of Seismic Surveys on Cetaceans". Pre-Meeting of the IWC Environmental Concerns Sub-Committee, 24-25 May, St. Kitts, West Indies

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Wolfgang Dinter (presenter)
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The abstract was not available at the editorial deadline.

2. Different seismic sound generators and their characteristics on acoustics

2.1 Physical Principles of Sound Propagation in the Marine Environment

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Abstract

The sound field that results from a particular source depends on the characteristics of that source and on the ocean environment. Near the source, the sound pressure level is determined primarily by the source itself. As distance from the source increases, environmental factors are increasingly important in defining the sound field.

During propagation, sound waves spread out and dissipate as they travel farther from their source. If sound waves do not interact with any object or changes within the ocean environment, they spread spherically as they propagate, resulting in a *20*log(range)* decrease in the sound pressure level. When sound waves encounter an object, they may scatter, bend, and reflect. Sound waves also bend if they travel through water with changing properties (*e.g.* varying sound velocity). High frequency sound is absorbed more than low frequency sound, and in general low frequency sound will attenuate less than high frequency sound. For example, a 100 Hz sound may be detectable after propagating hundreds of kilometers underwater, whereas a 100 kHz sound may be detectable only for a few kilometers.

The effect of oceanographic features on the propagation of sound is a topic of current research. Low-frequency sound propagation in shallow waters (*e.g*., continental shelf areas) is complicated by interaction with the seafloor and with oceanic fronts and internal waves, features which can focus sound. In deep-water settings, the ocean may act as a waveguide for sound, resulting in *10*log(range)* propagation. This waveguide is called the oceanic sound channel, and it allows sound to propagate over ocean basin scales. For instance, noise from ships at high latitudes is particularly efficient at propagating over long distances because in these regions the oceanic sound channel reaches the ocean surface.

2.2 Industrial Seismic Surveys - Sound Sources and Measured Received Levels in Australian Waters

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Abstract

Marine seismic exploration is carried out in order to locate potential reserves of oil and gas deep within the seabed. These surveys typically use sound sources comprising arrays of airguns, each of which produces a short, high amplitude sound pulse followed by a decaying periodic component due to oscillation of a gas bubble. The arrays are designed to produce a signal with maximum amplitude and particular, desirable characteristics in the downward direction, but inevitably also result in a significant amount of sound energy travelling in directions close to the horizontal that can propagate to long range. This horizontally propagating energy is of considerable concern because of its potential impact on marine animals.

This talk will provide an overview of the typical characteristics of the airgun arrays used in commercial seismic exploration, including the acoustic characteristics of airguns, typical array configurations, directionality patterns and source levels. The results of a large number of measurements of the sound levels produced by airgun surveys in Australian waters will also be presented.

2.3 Sound generators used in scientific seismic surveys - calibration and modelling

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Abstract

Academic research in the Southern Ocean comprises both high-resolution reflection seismic surveys to study - for instance - the depositional history of fine-scale sedimentary structures and lower-resolution, deep-penetrating reflection and refraction seismic surveys to study - for instance - large scale crustal structures. These studies are usually embedded in research programs focussing on topics like the geodynamic evolution and the plate tectonic, paleoceanographic and climatic history of the Southern Ocean. Single airguns or airgun arrays of small size and volume and single- and multi-channel streamers are usually used as sound sources and receivers for high-resolution reflection seismic surveys, whereas airguns and airgun arrays of larger size and volume and ocean-bottom-hydrophones and seismometers and single- and multi-channel streamers are usually applied for lower-resolution , deep penetrating reflection and refraction seismic surveys. To ensure that these research activities do not affect marine wildlife and particularly marine mammals in the Southern Ocean adversely knowledge of the sound pressure field of the seismic sources is essential. Therefore, as an example, a broadband marine seismic source calibration study conducted with R/V Polarstern at the Heggernes Acoustic Range, Herdlefjord, Norway in October 2003 is presented here. The objectives were (1) to determine the spatial distribution of the sound pressure levels emitted by the airguns and airgun arrays available at the Alfred-Wegener-Institute for Polar and Marine Research, Bremerhaven, Germany in October 2003, (2) to determine the frequency bandwidth, the spectral peak level and the amplitude decay at higher frequencies, and the cumulative and total energy of the different source signatures, (3) to determine the theoretical, back-projected nominal source levels at 1 m distance from far-field measurements assuming a spherical amplitude spreading, (4) to determine radii, within which according to the presently applied thresholds and the current scientific knowledge marine mammals might possibly experience behavioral or physiological disturbance or physical injury due to the received sound pressure levels.

Up to now thresholds defined by the National Marine Fisheries Service (NMFS), USA have often been used. According to these regulations received levels greater than 180 dB_{rms} re 1 µPa might possibly cause hearing effects like temporary threshold shifts (TTS), and received levels greater than 160 dB_{rms} re 1 µPa might possibly lead to behavioral disturbances like avoidance of the sound source for cetaceans. For underwater pinnipeds received levels are allowed to be 10 dB_{rms} higher. Furthermore, recent studies on mid-frequency cetaceans like bottlenose dolphins (Tursiops truncatus) and white whales (Delphinapterus leucas) have shown that in addition to the (rms-) sound pressure level the signal duration and energy plays an important role whether and to what extent TTS is induced. Therefore, a dual criterion which takes both the maximum peak pressure level and the total energy flux level (= sound exposure level (SEL)) into account is recommended as improved, science-based mitigative tool, and a 90% energy approach is recommended for

the derivation of the signal duration. During the 2nd meeting of the Marine Mammal Commission in 2004, the Noise Exposure Criteria Group introduced first levels for such a dual criterion which take the different characteristics of impulsive signals (e.g. seismic airguns) and quasi-monofrequency tones (e.g. sonars) into account, and defines that TTS is potentially induced if either a peak pressure of 224 dB re 1 µPa or a SEL of 183 dB re 1 $µPa^2s$ for impulsive signals or 195 dB re 1 $µPa^2s$ for quasi-monofrequency tones is exceeded. For underwater pinnipeds levels are defined to be 20 dB lower.

To give a complete overview, here radii are presented for both the rms-level and the dual peak pressure and SEL-based criterion, using the presently known thresholds. It is worth to mention that the 195 dB_{SEL} threshold for quasi-monofrequency tones is based on many consistent TTS measurements on bottlenose dolphins and white whales and is therefore rather well established, whereas the 224 dB_{0-pk} and the 183 dB_{SEL} threshold for impulsive signals presently relies on only one measured TTS induced in a white whale by a watergun signal and is therefore possibly subject to change in future, when additional data and/or new scientific knowledge is available.

To determine the spatial distribution of the sound pressure levels during the calibration survey each airgun (array) was shot along a line of 2 - 3 km length running between 2 hydrophone chains with receivers in 35, 100, 198 and 263 m depth. A GI-Gun (2.4 l), a G-Gun (8.5 l) and a Bolt PAR CT800 (32.8 l) were deployed as single sources, and 3 GI-Guns (7.4 l), 3 G-Guns (25.6 l) and 8 VLF-Guns (24 l) as arrays. The measurements are complemented by a modeling approach for an 8 G-Gun (68.2 l) and an 8 G-Gun+1 Bolt PAR CT800 array (100.1 l). The data analysis was based on the "SEG Standard for Specifying Marine Seismic Energy Sources" and includes a determination of the peak-to-peak, zero-to-peak and RMS-amplitudes, sound exposure levels and amplitude spectra as function of source-receiver distance.

The amplitude vs distance graphs, analyzed for the 4 hydrophone depths, show the typical directivity of marine seismic sources. Due the destructive interference of the direct wave and the ghost reflection, amplitudes almost vanish close to the sea surface and are highest in several hundred meters depth ("Lloyd mirror effect"). A comparison between the amplitudes recorded during approach and departure reveals a shadowing effect of Polarsterns's hull. Amplitudes recorded at the same source-receiver distance are lower during approach than during departure indicating that the ship's hull deflects sound propagation forward the ship. Mitigation radii derived from the amplitude vs distance graphs of the deepest hydrophone for the 180 dB_{rms} level vary between 200 - 600 m for the measured single airguns and between 300 - ~1300 m for the measured and modeled airgun arrays. Extrapolated source levels range from 224 - 239 dB_{0-pk} re 1 µPa @ 1 m for the single airguns and from 232 - ~250 dB_{0-pk} re 1 µPa @ 1 m for the airgun arrays. Spectral peak levels occur below 100 Hz, amount to 182 - 194 dB re 1 µPa/Hz @ 1 m and decrease by ~30 dB re 1 µPa/Hz within the 1 kHz range, and by ~50 - 60 dB re 1 µPa/Hz within the broadband range up to 96 kHz. A first modeling approach of source directivities based on the assumptions of deep water and a homogeneous water column shows slight differences between the amplitude decay curves of the single G-Gun signals recorded at the 2 deepest hydrophones and more pronounced discrepancies for the recordings at the 2 shallow hydrophones. One possible explanation for these discrepancies is a stratification of the water column. Further studies which replace the assumption of a homogenous water column by a depth-dependent sound velocity profile in the modeling approach are necessary here.

3. *Impacts on Whales*

3.1 Vocalisations of baleen whales and their reaction to seismic noise

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Abstract

Great whales produce a wide variety of sounds. The most obvious are male reproductive displays, or songs, consisting of long, intense, hierarchically organized and repeated patterns of notes. In 1971 Roger Payne and Doug Webb proposed that prior to the advent of modern shipping the largest of all earth's creatures, blue and fin whales, might have communicated across oceans. Over the last fifteen years, through access to the US Navy's Sound Surveillance System (SOSUS), there is now evidence of whale detections across ocean basins. The SOSUS acoustic telescope allows observations of singing whales over large spatial and temporal scales commensurate with their ecologies and ocean habitats. Songs of pelagic species (blue and fin whales) are intense, infrasonic (<20Hz), narrow band, simple, and stereotypic: features advantageous for ultra-long-range communication and navigation in the deep ocean. The sounds of coastal species (e.g., right and bowhead whales) are intense, broad-band, low-frequency (< 1000Hz), complex, and highly variable: features advantageous for short- to mid-range communication in shallow water. The actual ranges over which whales communicate are unknown, but a critical factor influencing these ranges is ocean ambient noise. Over the last half century ocean noise in many parts of the Northern Hemisphere has increased significantly, and there are habitats for some endangered species in which noise is probably at or above chronic levels. Seismic exploration injects high levels and large amounts of infrasonic and low-frequency noise into the ocean inadvertently but specifically into the communication frequency bands used by whales. The temporal (many tens of thousands of nmi2) and spatial (months) scales over which noise bi-product from a seismic operation occurs match the ecological scales of whale populations. Fin whales appear to avoid and depart from feeding areas of high seismic activity as well as reduce their singing rates. Large-scale data for other species such as blue and humpback whales are incomplete but suggest similar responses. Paradoxically, modern opportunities to finally perceive and understand the lives of the great whales are drowning in the rising tide of human-generated acoustic noise, which now compromises the whales' basic abilities to hear, communicate and perceive their environment.

3.2 Communication of toothed whales and their reaction to seismic noise

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Abstract

Most of the energy from seismic surveys is concentrated below 300 Hz, a frequency region where toothed whales have less sensitive hearing than baleen whales are thought to have. This has traditionally led regulators to discount the potential impact of seismic survey on toothed whales. However, over the past decade, there has been increasing information of energy above 1 kHz from air gun arrays used for seismic survey. While this is much lower than the energy below 300 Hz, the overall source level is so high, that airguns can represent a significant source of acoustic energy in the frequencies heard by toothed whales. One indication that odontocetes may react to seismic survey stems from observers on commercial seismic surveys. Stone (2003) tallied the distance of small dolphins and porpoises to the survey vessel comparing airgun off vs airgun on condition, and found these animals were significantly farther from the vessel when the airguns were on. This indicates an avoidance reaction. By contrast, sperm whales were sighted at closer ranges when the source was on, although this difference was not statistically significant. Recently an experiment was designed to test the effects of controlled exposures of airguns on avoidance and foraging behavior of 8 sperm whales tagged with a sound and behavior recording tag. The whale most closely approached remained at the surface during exposure; this suggests that the increase in close range sightings of sperm whales exposed to seismic signals reflects a surfacing reaction rather than horizontal approach. No obvious changes in foraging dives or direction-of-movement were observed during gradual ramp-up at distances of 7-13km, or full array exposures at 1-13km. However, some changes in foraging behavior were indicated during deep dives. Behavioural indices of foraging rate (echolocation buzzes produced during prey capture) and locomotion cost (from pitching movements generated by active swimming) of the 7 remaining exposed whales were compared to sham exposure and post-exposure control periods in 13 unexposed whales. Pitching movements were 6% lower during exposure ($P=0.014$) with all 7 whales reducing fluke strokes. Mean buzz rates were 19% lower during the exposure condition, but this difference was not statistically significant ($P=0.141$). The substantial change in mean buzz rate from this small sample motivated a Bayesian analysis, which determined that models of reduced buzz rate and pitching movement had roughly three times more posterior support than models of no effect. While these results are preliminary, they suggest disruption of foraging behavior at ranges to 10 km and exposures in the 130-160 dB re 1 µPa range, well below exposures currently regulated. The lack of avoidance behavior in sperm whales differs from baleen whales and smaller odontocetes, and provides no empirical justification for the assumption that sperm whales will move out of a danger zone during ramp up or approach.

4. *Impacts of seismic surveys on other marine biota*

4.1 Seals and Seismic

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Abstract

Most acoustic energy from seismic airguns is at low frequencies to which seals are significantly more sensitive than odontocetes. This, and the fact that being generally more at risk of predation than cetaceans they might be expected to be more cautious, may lead to an expectation that they would be amongst the most vulnerable of marine mammals to disturbance from airgun noise. However, directed research in this area is surprisingly sparse and, in some cases, contradictory.

Detailed observations of common and grey seals exposed to small airgun arrays revealed clear and dramatic behavioural responses. Free ranging seals fitted with a range of telemetry devices were monitored before during and after exposure to airgun blasts. Seals foraging in open water typically showed pronounced startle responses (dramatic reduction in heart rate) followed by a clear change in behaviour, with shorter erratic dives, rapid movement away from the noise source and a cessation of feeding. Exposures lasted for an hour, and after they stopped the seals either hauled out on land or resumed foraging. While these short-term observations suggest that seals may behave "appropriately", moving away from airguns and reducing the risk of sustaining hearing damage, they also raise concerns about the effects of long-term habitat exclusion and foraging disruption over longer periods of exposure.

Opportunistic observations of ringed seals made from a survey vessel during seismic surveys in shallow inshore waters off Alaska, indicated only partial avoidance from animals within 250m of the track line. Many factors may contribute to an explanation of this discrepancy including: habituation, very different habitat characteristics (shallow inshore water with ice cover), differences in observational method and inter-species differences.

Observations of responses to another source of loud impulsive noise, pile driving, may also suggest differing sensitivities between species and areas, but this work has not included detailed observations of behaviour at sea.

Recent research in controlled captive situations indicates that seals are at least as sensitive to auditory damage from exposure to intense noise as are cetaceans.

Although seals come ashore to breed and to haul out they can range hundreds or thousands of miles from their haulout sites. Thus seals may be encountered in any European shelf waters and in adjacent oceanic waters. All European seals are included on AnnexII of the EU Habitats Directive, requiring the designation of special areas of conservation, and the critically endangered monk seal is on Appendix IV, judged in need of protection (including from deliberate disturbance) in all areas.

In spite of their sensitivity and the protected status of some species, regulators have often either ignored seals or applied sound threshold levels for exclusion zones that are higher than for cetaceans, implying a lower acoustic sensitivity.

Seals may be particularly vulnerable to other oil-industry related activities. Wellhead removal and decommissioning activities are increasing as oilfields become exhausted. Explosives are typically used for this, putting seals, which seem to be attracted to these features, at risk.

Pinnipeds certainly present a challenge for real time mitigation. They are small and undemonstrative making them difficult to spot at sea. They are not consistently vocally active, so there is little potential for PAM to significantly increase detection probabilities.

Further work is required to reconcile and understand differences in behavioural sensitivity indicated by different studies, to understand whether long-term habitat exclusion or foraging disruption occurs and what the population consequences of this might be in order to develop and prove the efficacy of appropriate mitigation procedures.

4.2 Impacts of Air-Guns on Fish

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Abstract

The past several years have seen a substantial increase in concerns about the effects of human-generated sounds on fish. Sound sources that can potentially impact fish include shipping noise, sonar, pile driving, seismic air-guns, and numerous other sources. However, a careful review of the literature shows that very little is actually known about effects of human-generated sounds on fishes. This literature has been critically reviewed by Hastings and Popper.[1]

Much of the concern about human-generated sounds has focussed on short-duration (but often frequently repeated) high intensity impulsive sounds, such as produced by pile driving or seismic air-guns. However, it must not be overlooked that there is also growing concern about general increases in background noise that may come from increased shipping in a harbor or noise in an aquaculture facility or a marine aquarium.

No matter what the source of the human-generated sound, the range of effects extends from no effect to the immediate death of the impacted animal. In between effects may involve minor changes in behavior which are biologically insignificant to more significant changes in behavior (e.g., movement from feeding grounds). There may also be effects on physiology, such as increases in stress hormones. Or there may be effects on body structures such as damage to the swim bladder or rupture of blood vessels. Finally, there may be effects on hearing that can be temporary or permanent.

Seismic air-guns produce sounds within the hearing range of most fishes. Moreover, the levels of sounds produced by air-guns have the potential to not only affect hearing, but also other organ systems. However, little is actually known about air-gun effects on fishes. The few peer-reviewed experimental studies can be divided into three groups:
(a) several studies on effects on overall behavior and impact on fishing; (b) one study on the effects on the ear; and (c) one study on the effects on hearing.

Studies on behaviour examined whether there are differences on fishing success before and after a fishing site has been subject to a seismic survey. The results from a very limited set of studies on very few species suggests that there may be some change in catch success,[2] at least measured in certain ways, but it is clear that this work needs replication and extension

[1] Hastings, M. C. and Popper, A. N. (2005). Effects of sound on fish. California Department of Transportation Contract 43A0139 Task Order, 1. http://www4.trb.org/trb/crp.nsf/reference/boilerplate/Attachments/$file/EffectsOfSoundOnFish1-28-05(FINAL).pdf

[2] E.g., Engås, A., Løkkeborg, S., Ona, E., and Soldal, A. V. (1996). "ffects of seismic shooting on local abundance and catch rates of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*).Can. J. Fish. Aquat. Sci. 53, 2238-2249.

to other species. Only one study[3] actually observed the fish during exposure to a seismic device, and it is important that future studies actually “watch” the behavior of fish to determine how they react to sounds.

There has been one study on effects of seismic exposure on ear structure.[4] This study, on one species of caged fish, showed damage to the sensory hair cells of the inner ear, the cells responsible for sound detection. Significantly, the effect did not show up until days after exposure to the seismic source.

Finally, one study examined the effects of exposure to seismic air-guns on hearing in three species of fish.[5] This study showed a temporary loss of hearing in two species but not in a third. And, in the two species with hearing loss, hearing returned within 24 hours.

While these studies suggest that there may be some potential effect of seismic air-gun sounds on fishes, it is really premature to make any broad statements on this topic. Indeed, the three sets of experiments are very hard to compare since all were done in very different ways, with different sound sources, fish exposed to different sound levels, and with different sound durations. Moreover, and most importantly, all studies used different species and only a tiny minority of the more than 25,000 extant fish species have been examined. Thus, one must question whether these data can be extrapolated to species other than those directly studied. Indeed, interspecific differences in fish behavior, physiology, hearing capabilities, and anatomy are very great, and so results from one species may be very little help in understanding whether the same stimulus with have the same effect on another species

The conclusion one must reach at this time is that we know far too little about effects of seismic air-guns on fish. Additional studies need to be done to answer virtually all questions that can be asked. And these studies need to include different sound sources, different acoustic environments, and most importantly, different species. At the same time, as suggested for future studies of pile driving by Hastings and Popper (reference 1), it is impossible to study all species with all sound sources. nstead, there needs to be a set of studies that use carefully defined sets of stimuli and species that represent the diversity of fishes. Only with such studies will we be able to start to reach meaningful conclusions as to whether seismic air-guns have any effect on fish.

[3] Wardle, C. S., Carter, T. J., Urquhart, G. G., Johnstone, A. D. F., Ziolkowski, A. M., Hampson, G., and Mackie, D. (2001). Effects of seismic air guns on marine fish. Continental Shelf Res. 21, 1005-1027.

[4] McCauley, R. D., Fewtrell, J., and Popper. A. N. (2003). High intensity anthropogenic sound damages fish ears. J. Acoust. Soc. Am. 113, 638-642.

[5] Popper, A. N., Smith, M. E., Cott, P. A., Hanna, B. W., MacGillivray, A, O, Austin, M. E, Mann, D. A. (2005). Effects of exposure to seismic airgun use on hearing of three fish species. J. Acoust. Soc. Am.,117:3958-3971.

4.3 Severe injuries in the giant squid *Architeuthis dux* stranded after seismic explorations

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Abstract

There are spatial and temporal links between two strandings of giant squids (*Architetuhis dux*) and geophysical prospecting using air gun arrays in the Bay of Biscay (North-eastern Atlantic). Here we present evidence of acute tissue damage in stranded and surface floating giant squids, challenging the view that these giant squids do not suffer any kind of human caused mortality. The incidence of such cases during two research cruises in 2001 and 2003 during integrated geological and geophysical studies in the continental shelf of the Cantabric Sea indicate that acoustic factors could be important in organ and tissue lesions that accounted for the dead of these animals and may call for further environmental regulation of such activity. Two possible mechanisms to explain the effect of the acoustic pulses are suggested.

Giant squid's strandings

Forty two records of stranding and sightings of giant squids (*Architeuthis dux*) in Asturian coasts (North Spain) are registered since 1962[1, 2]. This signifies that an average of about one register per year was a normal situation. Moreover, 75 % of these registers were from live animals caught by trawlers or pair trawlers targeting blue whiting (*Micromesistius poutassou*), which is one of the main prey items of giant squids in this area. These catches were undertaken between 250 and 800 m depth, close to the submarine canyons present in this area (Fig. 1a). The natural rhythm of stranding and sightings was changed twice. Five giant squids stranded close to the site where an international project carried out by the vessels *Barracuda* and *Nina Hay 502* held between the end of September and the middle of October 2001. These vessels were prospecting for gas and oil using air guns arrays. Four giant squids were stranded or caught moribund floating at surface from 13 to 17 September 2003 close to the site where the first cruise for geophysical registers of the international project MARCONI was carried out on board the Spanish R/V *Hespérides*[3]. This cruise held from 30 August to 18 September 2003. The seismic equipment employed was also air guns arrays working at low frequency (<100 Hz) and 200 dB re 1µPa. There were 7 guns *Bolt* shooting every 40 s. The streamer was TELEDYNE 40508 with 96 channels and 2.400 m length of active section. The acoustics equipment was composed by a multibeam SIMRAD EM-12S-120 (13 kHz), a monobeam SIMRAD EA-500 (12 kHz) and bathythermographic echo sound SIPPICAN MK-12[4]. Figure 1b shows the area where the geophysical survey was performed.

The necropsies

We necropsied seven of these nine *A. dux*. Six were immature or maturing females and one a maturing male. Females' sizes ranged from 67 Kg and 127 cm mantle length (ML) to 140 Kg and 177 cm ML. The male was 66 kg and 122 cm ML.

One of these animals (an immature female of 140 kg and 153 cm ML; specimen 1) stranded dead in Colunga beach on 13 September 2003. This animal was caught very fresh and preserved in formalin 10% two hour after collecting it. Its mantle wall was 3.5 cm thick and showed severe injuries on tissues in a band of 43 cm width located in the central zone of the body (Fig. 2). The mantle epidermis was completely lost, which is common in stranded animals. The outer and the inner collagen tunics that sandwiched the mantle musculature were intact. These tunics are composed of crosses-fibre layers wrapping the body helically with a fibre angle of 27^{o}. The circular and radial muscle fibres were, however, smashed and cut into small pieces (Fig. 3). The injured zone affected a central layer of 2 cm thick. This zone showed an intact rhomboid reticulate of intermuscular fibres which angles are of 30^{o} to the long axis in longitudinal section[5]. All the small smashed muscle fibres were embedded in a liquid with high concentration of ammoniacal compounds from the broken vacuoles occurring within the mantle muscles[6]. This animal also showed the majority of the internal organs very injured (Fig. 4) and unrecognizable in many cases. An amorphous mass of tissues embedded in liquid spilled out by broken organs and coelomic cavities affected were observed within the mantle cavity. The components of the digestive tract showed long gaps in different regions, especially in the coecum, which digestive juices had been poured out into the mantle cavity; the digestive gland was found completely mangled and its content, a thick oily brown fluid, scattered over the mass of tissues; the stomach walls were also ripped. The outer layer of columnar epithelium of the two branchial hearts was ripped in different places, given the impression to have exploded. The gills were bruised showing several small blood vessels of its capillary network broken. The ovary was also bruised and the small oocytes spread out into the mantle cavity. No signs of vascular congestion or microvascular haemorrhages were observed within these or other vital organs. No gas bubbles formation was observed in tissues. No parasites were found in the carcase. In the vestibular system or statocysts[7] (macula-statolith-statoconia system, Fig. 5) [8], the statoliths (small structures made of aragonite with an organic matrix) were not found due to formalin dissolution effect.

The lesions found in the remainders five females do not were so severe than the ones found in the previous one. All they also showed a normal internal coloration as well as any sing of putrefaction. The two females examined after defrosted showed some gill capillaries broken. The analysis for heavy metals in tissues of several organs in frozen samples showed very low levels of contamination.

We had the opportunity to examine a male which was caught dying and immediately frozen at -20^{o}C after capture. We necropsied this animal after defrosted at room temperature. It showed an excellent state of health and all the internal organs except the gills in perfect condition. The right gill was practically destroyed whilst the right gill was bruised showing several small blood vessels of its capillary network broken. No sings of vascular congestion or microvascular haemorrhages, neither intravascular bubbles were observed. No parasites were found, and no pathogenic bacteria were isolated from this carcase. The statoliths (approximately 2 mm length) were found detached from their respective maculae.

Searching for explanations

Previous works

Only one paper on the lethal effects of seismic shots on squid was found [9, 10]. They report short term tolerance of sound levels to 260 dB re 1 µPa by one species but lethal effects at levels of 246-252 dB re 1 µPa for another.

We have only two studies of squid reaction to airgun noise. There were found alarm responses at 156-161 dB re 1 µPa. rms. and strong startle response at 174 dB re 1 µPa. rms involving ink ejection and rapid swimming in the squid *Sepioteuthis australis* maintained in cages and exposed to airguns. Cephalopods and particularly squids are extremely important components of the food chain for many higher order predators, and sustain dedicated fisheries in some parts of the world. The responses seen in the cages suggest behavioural changes and avoidance to an operating air-gun would occur at some range[11]. There were not changes in squid (*Illex argentinus*) catch for trawling in an area exposed to < 149 dB re 1 µPa. The observed alarm response suggest that squid would likely move outside the lethal range of a sound source. Any possible effects on squid mortality produced by extra swimming caused by the alarm response are unknown[12].

Studies of seismic surveys on other invertebrates have been summarised and the main conclusions are: i) most of the effects have investigated mortality and physiological changes when organisms are near airguns; ii) the field studies are scarce; iii) limited physiological studies suggest that most effects on invertebrates without gas-filled cavities are likely to be small to be measurable in the field; iv) scallop shells were damage by airguns 2 m away, but other species showed no effects within 0.5 m of airgun; and v) seismic surveys cause very small effects on rock lobster CPUE between 1978 and 2004 in western Victoria (Australia) [13].

Two hypotheses

The sexual stage of the stranded giant squids allows firmly strengthening that dead was not due to post reproductive mortality. There were no signs showing natural mortality causes of the decease. On the contrary, the observed lesions as well as the concomitance of both significant increase of stranding and presence of vessels using air guns arrays suggest lethal or sublethal effects of the shock acoustic waves.

No signs of vascular congestion or microvascular haemorrhages were observed in the necropsied squids, as was found in *Ziphius cavirostris*, *Messoplodon densirostris* and *M. europaeus* exposed to midfrequency sonar signals[14]. This could be due to the relative low blood volume (ca 5% of body weight) and to the difficulty for haemorrhages observation in animals which blood is cell-free[5], its respiratory pigment is haemocyanin and the colour of the blood is white-bluish. The small blood vessels broken observed in the capillary network of the gills could have been produced by seismic waves and/or other causes linked to stranding.

A second lethal effect of the shock waves involves the activation of supersaturated gas in marine mammal's blood and their cells to form small bubbles which can provoke severe lesions in different vital organs[14, 15]. The bubble effect is present in deep-diving airbreathing animals that will have the highest levels of supersaturated gasses in their blood and cells[16].

There were severe injuries in the mantle and viscera of one specimen which were enough to cause its death. Although squid have not compressible structures with gas-filled cavities, *Architeuthis* accumulate substances derived of ammonium as a result of their proteic metabolism –in vacuoles embedded in the muscle of the mantle and the arms- which allow them a floating system energetically favourable. These vacuoles are not present in the inner and outer collagen layers of the mantle. It seems plausible that the lethal lesions observed in this region are due to differential impact produced by the seismic surveys in tissues of different chemical composition and tisular structure (hypothesis of direct effect). Since *A. dux* inhabits water depths ranging from 250 to 1200 m[17] a contact with the array (about 20 m depth) is not plausible at least the animal is almost dead.

It was not established evidence of damage to the hearing system (macula-otolith) of exposed fishes in the form of ablated or damaged hair-cells, although an exposure regime required producing this damage, and it is believed such damage would require exposure to high level air-gun signals at short range from the source. It has been suggested that: i) above an air-gun level threshold of around 171 dB re 1 µPa mean squared pressure a fish macula-otolith system begins to show a rapid increase in absolute displacement parameters, suggesting that associated behavioural response and susceptibility to mechanical damage will increase accordingly; ii) smaller otolith systems may be at less mechanical risk from air-gun exposure than larger ones; and iii) the otolith system responded primarily to air-gun energy < 150 Hz, which encompassed the frequency of maximum energy of the input air-gun signals[11].

The presence of statoliths detached in the hearing-equilibrium system of the male examined, which was not previously observed in freezed and thawed animals examined, allows us to hypothesize an explanatory mechanism of the death and posterior stranding of these giant squids (hypothesis of indirect effect). That sublethal lesion could have caused the animals disoriented as it swims and important disturbs with brain information about rotational acceleration which enable they to regulate the position of the head, funnel and especially eyes[18]. Besides disorientation, acoustic waves could also have produced daze because cephalopods are quite sensitive to low-frequency vibrations[18]. Disoriented and daze, these moderately active, buoyant cephalopods[18] could have floated towards the surface, going from deep cold waters to warmer and shallower waters. The presence of an excess of a fourfold decrease in O_2 affinity when temperature is increased from 6.4 to 15^{o} C observed in one live giant squid caught off Radöy near Bergen, Norway, strongly suggests that giant squids may suffocate from arterial desaturation when increased ambient temperature are experienced [19].

Final recommendations

Further investigation is needed into the physical, physiological and behavioural effects on cephalopods exposed to acoustic waves both in cages and in the field and the relation of these effects to tissues and organs lesions and to strandings. These multidisciplinary researches should be done with the aim to compare stranded cephalopods suspected of having been exposed to sound with results from experimentally exposed and unexposed controls.

Necropsies should aim to try to: i) found whether or not gas-bubble lesions can develop in cephalopods as well as in marine mammals, and ii) include micro-anatomical and histological signs of the lesions caused by the impact of noise, in particular if created by airguns.

In a wider conservation sense, our findings need to be taken into account in considering the regulation and limitation of the adverse impact of anthropogenic acoustic waves on cephalopods. On the other hand, our findings with giant squids could be only the tip of one iceberg indicating that other species, some of them of commercial interest in Asturian fishing grounds, could be also affected.

Finally, and while sufficient evidences on the impact of a ban of marine acoustic technology was obtained for applications using high energy and low frequency sources mitigation strategies involving survey design, timing, ramping of source levels and shut down zones, as recommended[10], should be used.

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Figures

Figure 1. Maps showing the Asturian waters where *Architeuthis* specimens were collected (a) and the area where the geophysical survey MARCONI was performed (b).

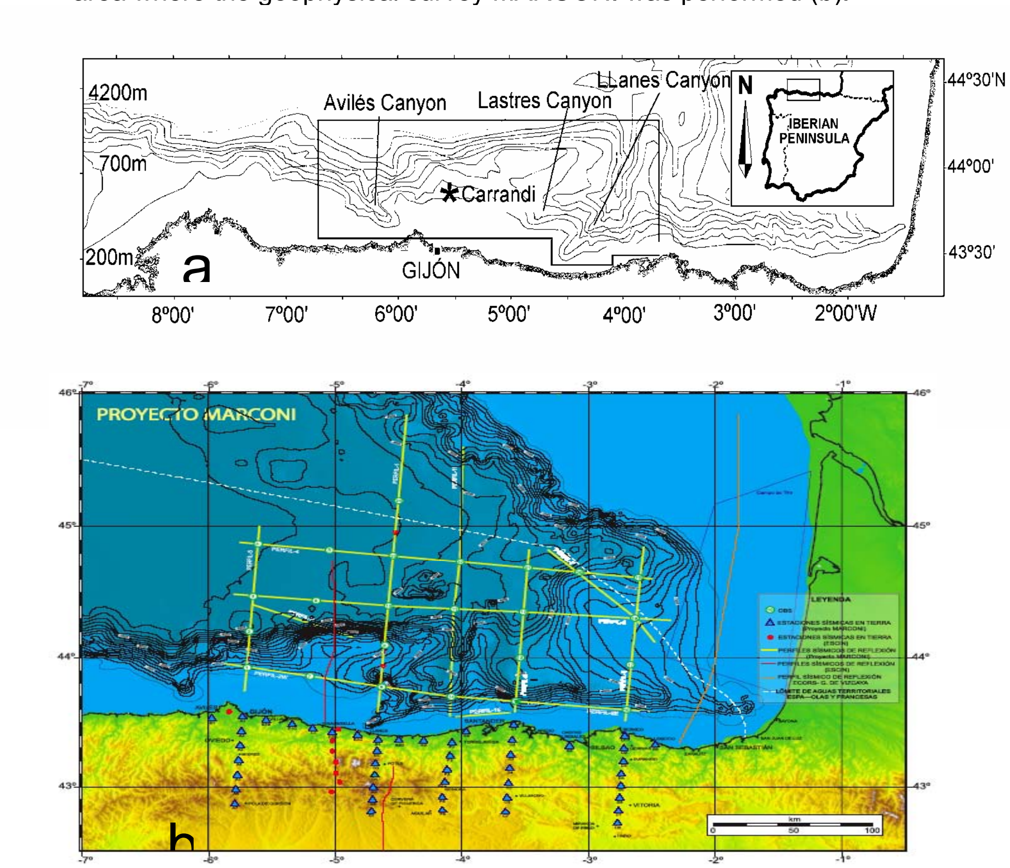


Figure 2. Specimens of *Architetuhis dux* necropsied on 23 September 2003

Figure 3. Mantle of the specimen nº 1. a) General view of the mantle cavity showing the injured zone; b) Detail of the injury.

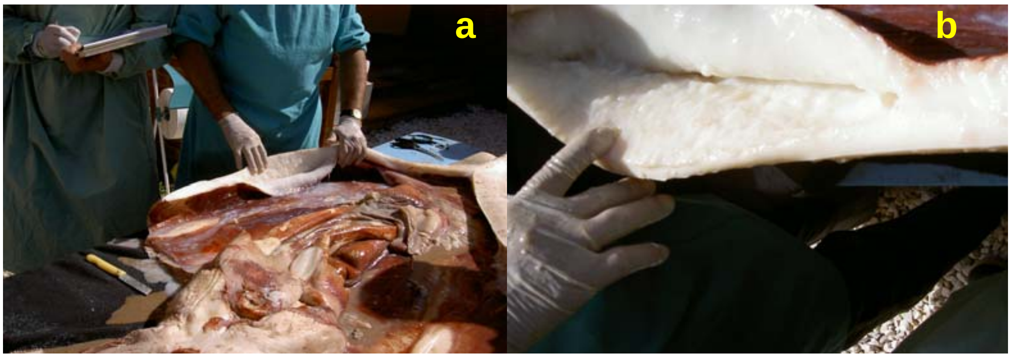
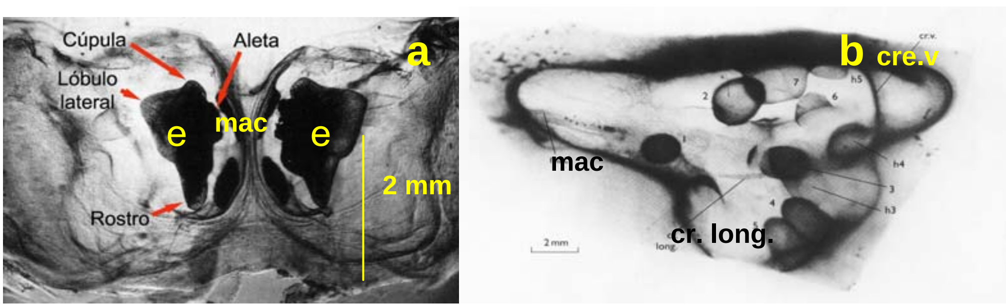


Figure 4. Mantle cavity of specimen 1 showing some internal organs bristled.

Figure 5. Hearing-equilibrium system of *Architeuthis*[8]. The macula (mac)-statolith (es) system is quite large but narrow due to the length of the macula. The cristae (cr. long.)-cupula (cr.v.) system is formed by seven protuberant crests (1-7) and five cavities or hamulus (h1-h5). The most hearing sensitive frequencies are between 10 and 200 Hz. Japanese squid boats use a sound at 600 Hz to attract some squid[18]



5. *Risk Analysis for airguns/airgun-arrays used for academic purposes*

5.1 Risk analysis – how to structure risk assessment of acoustic sources

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Abstract

The assessment of the contingent risk of specific sound sources for marine mammals comprises a) the risk analysis (in terms of our current scientific and technical knowledge) and a subsequent b) risk evaluation (in terms of ethical standards and in comparison other risks). The risk analysis may be performed in a sequence of distinct steps:

- hazard identification (incl. determination of critical thresholds)
- emission analysis
- response analysis

The talk applies this concept to the situation of a seismic research cruise within the Antarctic Treaty area, proposing hazards, thresholds and scenarios that should be analyzed and employed in this context.

6. International Measures of Mitigation (under discussion, recommended, or in force)

6.1 Towards Effective Cetacean Protection from Seismic Surveys

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WDCS and NOISE POLLUTION

WDCS is the global voice for the protection of whales, dolphins and their environment. Our mission statement requires that as an organisation we consider both the welfare of individual cetaceans and the conservation of populations and species.

We will begin this presentation by introducing conservation and welfare of species in relation to noise impacts. We will continue by discussing the mitigation options available on board seismic survey vessels in various parts of the world and go on to discuss the broader management and mitigation measures that can provide wider and longer-term protection to cetaceans. Some countries that have implemented mitigation guidelines as well as wider regional protection mechanisms and these will briefly be discussed. Throughout the presentation we will draw on some recommendations made at the recent International Whaling Commission Scientific Committee (IWC SC) Seismic Workshop, held in St. Kitts in May 2006.

CONSERVATION of CETACEANS

To begin with, much discussion relating to the issue of marine noise is focused around the conservation of populations of cetaceans. We suspect that this is led, at least in part, by the US regulatory system which manages 'takes' in relation to populations of animals as well as the prominent role of the US in the issue of noise pollution. It is important to manage the marine environment with the conservation of populations in mind, and especially in areas of critical habitat, where broader protection mechanisms are required. However, appropriate conservation outcomes can not be considered in isolation to the welfare of individual animals. Indeed, in the UK, the Joint Nature Conservation Committee (JNCC), the statutory nature conservation agency who introduced seismic guidelines as early as 1995, focused the protection of individual animals from the source of the noise, within a small radius around the vessel.

There are a number of reasons why it may not be appropriate for protection mechanisms in Europe to follow the US process. In addition to important ethical reasons, there are less funds available for the wide-scale baseline survey work that leads to reliable population estimates for cetacean species within European waters. Without a reasonable understanding of the status and distribution of our populations, how can we focus protection this way?

Additionally, without the sophisticated suite of environmental legislation that is well-developed and tested in the US, we suggest that such a task is impossible. Each individual has a vital role to play within its population. It makes practical sense to monitor for impacts to individuals and we believe that this is the intention of on-board mitigation of seismic surveying within Europe. On-board monitoring is currently conducted to prevent injury and in some cases monitor behavioural change of individuals.

IWC SEISMIC WORKSHOP in ST. KITTS, MAY 2006

The International Whaling Commission (IWC) maintained it's interest and primacy in the issue of noise pollution by considering seismic surveying at this years' meeting in St. Kitts. Although discussions were often focused on industry both industry and research vessels were considered. The Scientific Committee of the IWC, in which WDCS participated, endorsed all of the recommendations that came out of the 2006 IWC Seismic Workshop.

Its recommendations were broadly based on two areas that we will discuss in turn:

- ON BOARD SEISMIC MITIGATION AND MONITORING
- BROADER MEASURES FOR CETACEAN PROTECTION

MITIGATION and MONITORING

In particular, the IWC Scientific Committee ***recommends*** *that managers:*

- carefully review the goals of specific monitoring and mitigation measures
- evaluate whether current data are available to decide whether their meet their goals, and
- modify procedures or conduct new research to ensure that mitigation measures represent current best practice

The IWC SC also provided a set of ***recommendations for member governments*** *permitting seismic surveys, i.e. that they should:*

- Implement monitoring programs, as defined in the IWC report
- Develop and/or evaluate nationally relevant mitigation procedures
- Identify and facilitate research, monitoring and mitigation procedures that address the recommendations detailed in the report

The IWC Seismic Workshop demonstrated that cetacean research techniques used to investigate the impacts of noise are increasingly sophisticated, providing important information about the individuals' behaviour once it is out of sight below the water. Such devices can also provide valuable information about the received level of the seismic source of concern. The results are fascinating, as we have witnessed at this meeting.

Considerable time was spent discussing some of these observable impacts at the meeting of the IWC Seismic Workshop. Whilst we do not have time to go into the detail of those discussions here, the following recommendations that came from the meeting, go someway to convey the areas where more attention needs to be paid regarding the current status of mitigation on seismic surveys.

Some recommendations on MITIGATION and MONITORING from the IWC SC

The IWC Scientific Committee ***recommended*** *that horizontal energy output of airgun arrays be measured and modelled and that there be a reduction of energy in frequencies not useful.*

The group ***recommended*** *that redily available and appropriate sound propagation models for predicting sound exposure levels, although more complicated, should be employed and validated with empirical data, where available.*

Scientists and others have been calling for research into the effectiveness of on board mitigation measures for many years now. To emphasise this, *the IWC SC* ***recommended*** *that research be conducted to validate and quantify the effectiveness of detection monitoring methods, singly or in various combinations.*

Many other recommendations were made.

There is an urgent need to strengthen and standardise mitigation measures, and, critically, to investigate their effectiveness. We should work towards **regional guidelines** and **coverage throughout the world**, wherever surveys take place. The following points are recommended for incorporation into minimal mitigation procedures and have been extracted from Weir et al. (2006), where each bullet is documented in more detail. This paper is available at this meeting.

- Marine mammal mitigation **guidelines should be adopted by *all* oil and gas companies**
- **MMOs** must be qualified, dedicated and experienced
- Seismic **PAM** towed array technology should be further developed
- **Alternative seismic technology** should be developed
- Mitigation measures should apply to ***all marine mammal species*** (and turtles)
- Every seismic operator should implement a ***soft start procedure*** for every use of airguns.
- The use of the ***lowest practicable airgun volume*** should be defined and enforced.
- There should be a scientific basis for the ***exclusion zone***
- There should be a dedicated ***pre-shoot watch*** of 30 min or 60 min for deep-diving species
- There should be a ***delay to commencement of soft start*** for all marine mammal species (and marine turtles) observed within the EZ. Soft start may not begin until 30 min after the animals depart the EZ or 30 min after they are last seen
- There should be a ***shut-down*** of the airguns whenever a marine mammal (or marine turtle) is seen to enter the EZ. Following a shut-down, a full soft start is mandatory.
- Extra mitigation measures should be applied in deep water areas for ***sperm and beaked whales*** seen diving on the vessel trackline, soft start delays and shut-down procedures are applied to animals seen diving within 2 km ahead of the source, even if outside of the EZ at the time of last visual confirmation
- Ideally, airgun use should be ***prohibited at night***
- Airgun use should be restricted during ***adverse weather conditions*** (Beaufort sea state ≥ 4, swell ≥ 3 m, thick fog)
- Disturbance from ***other vessels*** associated with the seismic operation (e.g. guard vessels, supply boats, work boats, undershoot vessels etc) should be minimised

- MMOs should ***report directly to the regulating body*** throughout and on completion of each survey to ensure that reports are received without other involvement. Standardised reporting should also be a requirement

It is becoming increasingly clear in many parts of the world that protection of cetaceans can not be assured by such on board mitigation measures alone. This is illustrated by the recommendations from the Seismic Workshop of the IWC SC this year. Significantly, the received level at the animal can be just as high at 12 km as at a range of 2 km from the seismic array (Madsen *et al*. 2006). Indeed, higher received levels have been recorded at distance than closer to the source. Given that it is not realistic to limit mitigation of potential impacts to within an observable radius of the sound source, wider protection remains an important consideration as a management option. Protection of cetaceans for noise impacts therefore needs to incorporate wider and longer term options. These are to be discussed in the remainder of this presentation.

BROADER MEASURES for CETACEAN PROTECTION

Following thought provoking presentations and discussions, the IWC Seismic Workshop investigated options beyond those mitigation measures that are offered on-board the seismic survey vessel itself. Many cetacean species are wide ranging, and solutions to noise pollution issues will only begin to be mastered if we consider the problems on the same scales, i.e. both regionally and globally.

Some of the broad recommendations from the IWC SC included the following measures:

1. The future of the seismic industry
2. Acoustic exposure and stranding events
3. Long term effects
4. Critical species and habitats

1. The future of the seismic industry

*The Committee **recommends** that relevant governments should characterise future (i.e. a 5 – 10 year period) industry exploration plans in a regional or national context. This information will allow the IWC Scientific Committee to provide the best scientific guidance on cetacean species of concern within these regions of operations.*

*With respect to data on operations, the Committee **recommends** that collection of data from seismic surveys should be standardised, transparent and ideally mandatory throughout the industry. World wide datasets should be developed and made available to assess the global extent of both industry and academic seismic surveys.*

*The IWC SC group **strongly recommends** that baseline whale population and ecosystem data be collected before any exploration and field development has started. Pre-exposure data need to be assembled with a long term focus.*

*The group **recommended** additional research into other alternate signal sources or techniques, such as marine vibroseis and horizontal beam patterns.*

It is clear that progress can not be made on these important areas of concern without involvement and the commitment of the seismic industry itself. Working towards a progressive system where data is available early in the planning stages of oil and gas

development, and possibly even before exploration enters a region, will enable specialists like those within the IWC Scientific Committee to provide information about patterns and movements of populations of animals. Holistic integrated science should be incorporated into collaborative decision-making at an early stage in the development of industry plans.
This should, if implemented appropriately, aid integrated and adaptive management, if based on a set of pre-determined and clear environmental objectives that have the aim to minimise disruption to critical habitats and important life functions.

This leads us onto the next bullet point for discussion.

2. Acoustic exposure and stranding events

*The Committee **recommended** that future and retrospective analysis of the potential role of acoustic exposure in marine mammal stranding events should be investigated, using all available scientific tools, and should consider all potential contributing factors when discriminating between correlation and causation.*

Valuable data can be obtained from strandings and non-strandings. Information collected from dead stranded animals can provide us with data that can often prove the first indication of a wider impact. We can also learn a considerable amount from historic strandings data and efforts should be made to collate such information from all available sources.

Whilst necropsy investigations in acoustic events are at an early stage of development, introduction of an international protocol will greatly aid the collation of standardised data to improve knowledge. An acoustic stranding protocol (Geraci and Lounsbury, 2005) that has been developed by experienced veterinarians and pathologists would seem to be an appropriate starting point.

3. Long-term effects

*The Committee **strongly recommended** well-planned and properly conducted long-term monitoring studies with appropriate control populations for measuring effects at the population level.*

*The group **agreed** that long-term studies could yield important insights into population changes that might not be apparent from monitoring of short-term responses.*

Our understanding of how about short-term responses relates to long-term impacts are limited. New studies conducted on the whale watching industry provide us with good examples of this. In particular, Bejder *et al* (in press) showed that in the absence of long term studies, data could be misinterpreted as being less significant than long-term data should that they were. What was initially interpreted as an impact not having a detrimental effect, turned out to be a long-term decline in the population. This brings into question the traditional premise that short-term behavioural responses are sufficient indicators of impacts of anthropogenic disturbance (Bejder *et al.* in press).

4. Critical species and habitats

The group **agreed** that spatial and temporal scales need to be considered when designing monitoring programs.

Case studies were presented at the IWC Workshop on three cetacean species: Western grey whales, bowhead whales and sperm whales. All of these species are subject to ongoing seismic surveying and other activities related to oil and gas development in areas that are significant for important life functions.

All developed national seismic guidelines recognise sensitive areas for marine mammals, but there is little rigorous definition of these areas and how they apply to seismic survey applications. Both Brazil (reported in Environmental Licensing Guide (IBAMA, 2005)) and Australia (Dolman, *in press*) have allocated defined prohibited areas for seismic surveys due to marine fauna. Whilst the Great Australian Bight MMPZ was set up in a precautionary manner solely for the protection of the vulnerable species that had been identified within it, the Abrolhos Bank moratorium in Brazil was set in place in response to unusual stranding mortality that led to a high level of domestic and international concern about seismic activities in this region.

Avoidance of seismic surveys in sensitive habitat is the most effective and straightforward mitigation measure that can be applied to protect marine mammals and more regions should investigate this option.

Surveys should be planned so that entire habitats or migration paths are not blocked. Use of airguns should completely prohibited within and adjacent to key habitats during particular seasons or on a year-round basis so that damaging or disturbing noise levels are not created.

CONCLUSION

In conclusion, whilst on-board mitigation measures remain the primary method of protecting cetaceans from noise pollution, there is an urgent need to strengthen and standardise these, and, critically, to investigate their effectiveness. However the ad hoc mitigation measures currently in place do not reflect the escalating international concern regarding the impacts of noise pollution and we should work towards regional guidelines and coverage throughout the world, wherever surveys take place.

Although precautionary on-board mitigation measures are critically important, their practical limitations are now widely recognised. We therefore emphasise the need for broader measures for cetacean protection. Those recommendations made by the IWC Scientific Committee following the Seismic Workshop in May 2006 are critical to achieve this aim. These broader measures require a longer term commitment to the issue. Only with access to future seismic survey plans, funding for long term cetacean baseline and monitoring programs, determination of the location and then the protection of critical habitats, as well as pursuing appropriately focused stranding research, will we get to grips with this challenging issue.

We believe that the time is right for Germany to develop it's policy to be strong, forward thinking and to include ongoing discussions.

Most importantly, what we, and the whales need, is effective action!

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6.2 Mitigating the Impacts of Airgun Surveys: Current Policy and Best Practice

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Under international law a state maintains exclusive rights over its continental shelf lands and may explore or exploit them as it sees fit. But with those rights come responsibilities. The 1982 Law of the Sea Convention (21 I.L.M. 1245), the leading international instrument for the governance of the oceans, imposes a general duty on all states to conserve the marine environment within their jurisdiction (Art. 192) as well as specific duties "to prevent, reduce, and control pollution of the marine environment from any source" (Art. 194(1)) and to take special measures for the preservation of rare or fragile ecosystems, particularly those that host imperiled species (Art. 194(5)). In practice, of course, states differ broadly in how they discharge these responsibilities, and there exists no universal set of guidelines or regulations for the conduct of airgun surveys. This presentation will review and assess some of the mitigation measures for seismic surveys that are currently applied under domestic law.

Regulatory Gaps

As we have heard, the noise from seismic exploration contributes significantly to the ocean noise budget. At least 25 industry crews on average are shooting trackline somewhere in the world on any given day of the year (Jasny et al. 2005).[6] While the northern Gulf of Mexico, within the U.S. Exclusive Economic Zone, is the most intensely surveyed body of water in the world, exploration is occurring in virtually every major coastal region. Brazil has seen extensive survey work over the last decade, as have China and India; together the three countries account for more than 20 percent of all the offshore seismic work conducted between 2002 and Jan. 2005 (Jasny et al. 2005). The west coast of Africa is another site of major interest, and off the west coast of Europe the North Sea remains a mainstay of global exploration and production. New areas in various corners of the world are being opened to exploration and development.

What protection coastal areas receive, whether through mitigation or moratoria, depends largely on domestic policy. Of the top fifteen jurisdictions—a group that represented roughly 75 percent of reported crew counts between 2002 and Jan. 2005 (Jasny et al. 2005)—only the United States, Brazil, the United Kingdom/North Sea, Australia, and Canada routinely require some form of mitigation as a condition of conducting offshore surveys. Fortunately, the United States and Brazil were among the leading jurisdictions for offshore exploration during that period, and together the five countries were responsible for more than 30 percent of global activity (Jasny et al. 2005). But to our knowledge mitigation is not routinely required

[6] The analysis of survey work presented in this section is based on data obtained by NRDC from IHS Energy, which tallies crew counts for its publication *Worldwide Geophysical News* (Jasny et al. 2005). These data were collected through voluntary reporting and so are likely to underestimate the total amount of activity taking place around the world; in addition, certain inconsistencies in the reporting of locations somewhat limit their use (Jopling et al. 2006). While valuable, they nonetheless suggest the need for a standardized, mandatory reporting system for industrial seismic surveys (Jopling et al. 2006).

in the jurisdictions that made up the remaining 40-45 percent: China, India, Mexico, West Africa (including Nigeria and Equatorial Guinea), Indonesia, Malaysia, Russia, and Iran.

It is reasonable to conclude, on the basis of this analysis, that attention should focus on the leading non-regulators, so that those states with the greatest offshore activity all come through with mitigation plans. Simply adding China, India, Mexico, and West Africa to the mitigation list would cover almost an additional 30 percent of surveys worldwide (assuming 2002 to 2005 data). It remains an open question, however, whether the jurisdictions with themost offshore activity present the greatest environmental risk. Areas that include critically important habitat, such as the Western gray whale feeding grounds in the Sea of Okhotsk, make a strong claim to priority regardless of which jurisdiction they're found in. Just as important, proceeding on a state-by-state basis may not in the end be practicable. Obstacles in some of the leading unregulated jurisdictions include the absence of appropriate legal frameworks and enforcement mechanisms, the lack of technical capacity, and acute financial need. For some areas, states, and parts of the world, the most effective approach to mitigation may be regional or multinational.

Regional bodies provide one possible framework for action, or at least for the coordination of action among states. For example, the members of ACCOBAMS (Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area), in a resolution on ocean noise, have charged their Scientific Committee with producing "a common set of guidelines" for activities with the potential to harm cetaceans (ACCOBAMS 2004). How those guidelines will be implemented or enforced is not clear. But because regional instruments like ACCOBAMS allow for cooperation among nations at manageable and environmentally meaningful scales, some commentators have suggested that they are likely to provide the most progress on noise in the short term, regardless of their legal enforceability (*e.g.*, Scott 2004). In any case, it is increasingly recognized for reasons of economy, capacity, and jurisdictional clarity that some degree of international action is required.

Current and Best Practice

As with other sources of ocean noise, the practice of mitigation even in those countries that engage in it most regularly is still evolving. Broad categories of mitigation have been identified, but only some techniques have been implemented and others—unfortunately, some of the most important—remain highly controverted or under development. In addition, the universe of mitigation has been somewhat constrained by limitations inherent in the regulatory process as it unfolds in most states: the activity-by-activity review conducted in most jurisdictions, while important, tends to preclude consideration of such methods as ocean zoning, which depend on regional-level planning for their management.

In general, existing measures tend to fall into three categories: (1) geographic restrictions, (2) operational procedures, and (3) engineering and mechanical modifications.

Geographic restrictions. As the International Whaling Commission's reports on noise make clear, geographic restrictions on surveys are imperative, especially for the breeding and foraging grounds of the great whales, many of which remain endangered or vulnerable after centuries of whaling (IWC 2004, 2006). Yet geographic mitigation remains a grossly underutilized measure. To our knowledge, the only states that have categorically excluded waters from exploration are Brazil, which has created exclusion zones along many parts of its coast for the protection of humpback whales, southern right whales, sea turtles, and other species (IBAMA 2005); and Australia, which has put certain waters in the Great Australian Bight off-limits throughout the year, for the protection of southern right whales and fur seals (Australian Director of National Parks 2005). Research on population distribution and abundance and the development of predictive models are critical to expanding the use of geographical restrictions; so is higher-level planning, since individual surveys or even small groups of surveys may provide too narrow a field, in some cases, for designating exclusion areas. (It is worth noting that Brazil set forth its exclusions in the course of a broader leasing.) For some states currently without strong regulatory regimes, it may be possible to reach *ad hoc* arrangements with industry, such as has at least been contemplated for the Gabonese coast and its seasonal breeding grounds for humpback whales; but this is no substitute for oversight by a state or regional authority.

Regional agreements may be among the best vehicles for inscribing sound into the management of coastal habitat. The OSPAR Convention, which protects the environment of the northeast Atlantic, has already identified noise as a potentially dangerous form of human disturbance that may need to be regulated within the region's marine protected areas (OSPAR Commission 2003). Also of note are more far-reaching instruments such as the Convention on Biological Diversity, whose members are attempting to coordinate management of protected areas on the national, regional, and global levels (CBD 2004). Several commentators have embraced such approaches as allowing states the flexibility to focus on areas and animals most harmed by undersea noise (*e.g.*, Johnson 2004).

Operational procedures: the case of safety zones. By comparison with geographic restrictions, the "safety zone" is a mature measure, meaning that it is widely accepted among regulator states; but the details of the procedure (what distances are required for shut-down, what forms of monitoring are required) are debated and in need of technical improvement. Throughout the UK (JNCC 2004), and in the heavily surveyed Gulf of Mexico (MMS 2004), the safety zone established by management authorities is a plainly inadequate 500 meters, which in many circumstances would not correspond even to the 180-decibel isopleth; by contrast, Australia's safety zone, the largest radius-based zone that has yet been prescribed, runs to 3000 meters (Australia Department of Environment and Heritage 2001). An alternative used by some jurisdictions—including California (HESS 1999) and the U.S. Arctic (MMS 2006)—is the isopleth-based safety zone, which pegs the size of the exclusion area to propagation distances. Provided that operators use conservative models and regularly verify their distances in the field, isopleth-based zones could effectively account for differences among sources and environments (Weir et al. 2006); if done well, they could also provide needed incentives to operators for reducing their source levels. The largest isopleth-based zone that has yet been devised appears to be the 120-decibel bowhead whale exclusion area recently set by the U.S. in the northern Arctic (MMS 2006); but limitations in the monitoring scheme, which requires aerial surveillance before but not during the survey itself, raise questions about whether an outright geographic exclusion was not more appropriate.

Indeed, the methods that operators use to monitor their safety zones are a major source of controversy. Regulators have reached different conclusions about the number of ship-based observers to demand, the training and experience required by those observers, the need to impose restrictions at night and during other times when visibility is low, and the use of additional monitoring techniques, such as aerial surveillance and passive acoustic monitoring (*e.g.*, Weir et al. 2006). One of the most voluble debates of the last few years concerns the use of passive acoustic monitoring, or PAM. While, in general, everyone agrees that PAM is a promising method, operators have argued that the technology is not yet ripe and, at present, only the U.K. regularly requires it, to detect cryptic species such as sperm whales off the northwest coast of Britain (JNCC 2004; Tasker pers. comm.). The United States, at this stage, merely encourages it, providing mild incentives for its use (MMS 2004, 2006).

Engineering and mechanical modifications. Source-based mitigation, whether to reduce power levels or to alter harmful acoustic characteristics, is being considered for a number of major sources of noise, including military sonar and commercial ships (Lok 2004, Southall 2005). Seismic surveys have sparked discussion along these lines as well, and in some jurisdictions a few requirements have even been set. Overall, though, progress seems to be limited, at least to the public eye. To our knowledge, the only real gain that has been achieved is in airgun orientation: off Sakhalin Island and in the northern Arctic (MMS 2006), some operators configure their airguns to ensure that the energy is directed maximally downward, minimizing the horizontal propagation of sound.

The U.K. guidelines give the nod to another important requirement. They mandate that industry work to suppress or baffle the higher-frequency noise from their guns (JNCC 2004)—noise that is completely superfluous from the company's point of view, but still constitutes a significant part of the pulse (*e.g.*, Goold and Coates 2006). Yet the requirement is not strongly enforced and to our knowledge, industry has never placed a suppressor on a working airgun. A number of other technologies, such as mechanical vibrators, have been proposed (*e.g.*, Deffenbaugh 2002), but the extent to which industry has made progress along these lines is not clear. To spark further development, we recommend holding an international design and engineering workshop analogous to the one planned for the shipping industry (Southall 2005); and adding incentives (such as conservative safety zone requirements) or technology-forcing measures to regulatory guidelines.

Other mitigation measures. Other measures that have been proposed or implemented in some jurisdictions include "ramp-up" (or "soft start"), source-level reductions, and data-sharing. Some of these measures will be reviewed during the presentation in Dessau.

Conclusion

The past five years have seen a tremendous increase in awareness of ocean noise pollution as an issue that must be addressed both domestically and multilaterally. In general, more coordination is needed to understand the adverse impacts of man-made noise, including noise from seismic exploration, and more research is needed on ways to reduce those impacts. Improving safety zones and monitoring techniques is important, but the need to boost mitigation that does not depend on detection is also critical, and has been expressed not only in policy circles but also in two recent U.S. court decisions on military sonar (NRDC v. Evans; NRDC v. Winter). Strengthening domestic protections for marine mammals and endangered species, establishing best practice guidelines, regulating for noise within marine protected areas, and helping to improve control technology are among the steps that should be taken; more specific recommendations will be made during the presentation in Dessau. The means exist to achieve better protection for marine life, and with each passing year the reasons for doing so are becoming more and more clear.

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7. *Detection of Whales before and during use of airguns*

7.1 MAPS: Marine Mammal Automated Perimeter Surveillance – experiences and improvements

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Abstract

MAPS focuses on research to study, implement and inter-compare detection techniques of marine mammals – with focus on whales - from RV Polarstern. Four techniques are currently being examined:

- quasi-opportunistic, visual sightings
- use of an multi-sensor, visual and infra-red based, automated camera system
- passive acoustic recordings
- active whale sonar.

First results suggest that all methods are capable of detecting whales, but that each method has its particular strengths and weaknesses which are discussed and evaluated.

7.2 (a) Acoustic Detection – Basics, Experiences and Perspectives

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Acoustics is the method of choice to detect underwater objects and has been known for a long time. Leonardo da Vinci is often mentioned as having proposed that distant ships can be detected by listening to the underwater sounds they radiate into the water. Passive and active sonar systems are the human approaches to implement underwater acoustical concepts. All experiences and perspectives of acoustic detection are directly linked with the sonar equation, a set of basic principles that govern the design and use of these sonar systems. Starting from the sonar equation, this paper discusses some general concepts that control the performance of most sonar systems and their pros and cons. The paper addresses passive and active sonar, the use of single hydrophones and line arrays, and describes the effort required to obtain satisfactory results for acoustic detection of marine mammals.

Introduction

Underwater acoustics has not only been a key innovation that allowed certain land mammals to return to the sea and to become marine mammals a long time ago: it also enables the human species at present day to understand more about life in the sea. Knowing where and how marine mammals live is essential if one wishes to avoid or mitigate negative impact on anthropogenic activity. Visual techniques for the detection of submerged life forms are limited to short ranges, and are constrained by the presence of light. Light and other electromagnetic waves attenuate extremely rapidly, which limits their range and usefulness. Acoustic waves are currently the only practical way to transmit information under water over long distances. Active sonar, where sound is emitted to detect underwater objects, is the human equivalent to echolocation by cetaceans. As with echolocation, the use of active sonar is limited to relatively short detection ranges. Passive sonar listens to whale vocalizations and can be used over much larger distances, but its success depends on a variety of conditions, in particular, on the probability that the whale vocalization can be intercepted by the sonar system.

Sonar Equation

The sonar equation is a standardized and straightforward tool used to assess if sound will be received with sufficient signal-to-noise ratio to allow detection and classification.

The sonar equation integrates source and environmental parameters in terms of decibels (dB) in simple equations and assumes that detection can occur if the received signal-to-noise ratio *SNR* exceeds a reception threshold *DT* (Fig 1), i.e.:

$$SNR > DT \quad (1)$$

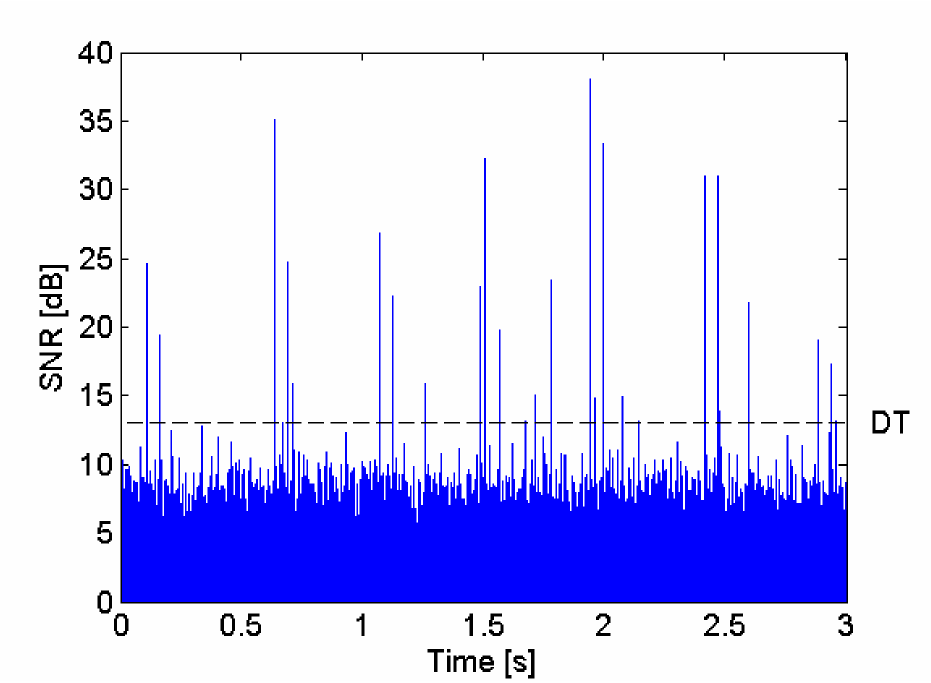

Figure 1: Signal-to-noise ratio (SNR) at the receiver output together with a detection threshold DT = 13 dB.

The signal-to-noise ratio *SNR* in dB is the difference between the received signal level RL and the background (ambient) noise level NL at the receiver output

$$SNR = RL - NL \qquad (2)$$

The threshold *DT* in dB is for Rayleigh distributed ambient noise related to the probability of false alarm P_{FA} and is for a linear receiver given by

$$DT = 10\log[-2\ln(P_{FA})] \qquad (3)$$

The ambient noise level *NL* is the received noise in the absence of any signal quantified in the same manner as the signal of interest. Ambient noise has very distinct physical and biological origin (e.g.: seismic and volcanic activity, shipping, surface agitation, marine life, etc.)

The received noise level *NL* is conveniently measured at the receiver output and may be computed by

$$NL = NL0 + 10\log(B) - AG - PG \qquad (4)$$

where *NL0* is the noise power spectral density [dB//1µPa^2/Hz], B is the receiver bandwidth [Hz], *AG* is the receiving array gain in dB, and *PG* is the signal processing gain in dB.

The received level *RL* depends on the source level *SL* [dB//1µPa @ 1m] which, for directional sound sources, is a function of the aspect and the transmission loss TL between source and receiver, and is for a listening system (passive sonar)

$$RL = SL(\vartheta) - TL(R) \qquad (5)$$

where ϑ describes the aspect and *R* is the distance between source and receiver [m].

For sound sources that radiate equally in all directions (omni-directional sources) *SL* is independent of ϑ, while for most echolocating cetaceans *SL* varies rapidly with the aspect (or off-axis angle ϑ) having a maximum on the axis of the sound beam.

The transmission loss *TL* can in simple cases be considered as composed of a geometric loss and frequency dependent absorption

$$TL(R) = 20\log(R) + \alpha_f R \quad (6)$$

Where α_f is the frequency dependent absorption coefficient [dB/m].

For a noise limited active sonar system, the received level Eq. 5 is replaced by

$$RL = SL_A - 2TL(R) + TS \quad (7)$$

where SL_A is the source level of the active sonar system, *R* is the distance between the sonar and the target, and *TS* is the target strength in dB @ 1m. The target strength is the signal gain in a given direction of the reflecting target. Eq. 7 is valid for mono-static active sonar where the sound source and the receiver are collocated on the same platform.

To calculate the maximum detection range of a sonar system, a modification of the sonar equation is used, where the range dependent transmission loss is brought on one side of the equation.

Passive sonar

$$TL(R_{\max}) = SL(\vartheta) - NL0 - 10\log(B) + AG + PG - DT \quad (8)$$

Active sonar (noise limited)

$$2TL(R_{\max}) = SL + TS - NL0 - 10\log(B) + AG + PG - DT \quad (9)$$

The two equations 8 and 9 show that the detection range increases with decreasing processing bandwidth *B* (narrowband is better than broadband processing), and increases with array and processing gain.

For coherent processing, where signal features are known (replica correlation), the maximum processing gain *PG* may be expressed as:

$$PG = 10\log(BT) \quad (10)$$

where T is the duration of the signal in s.

Inserting Eq. 10 in Eq. 8 and 9, it can be seen that for coherent processing, the maximum allowed transmission loss and therefore the detection range, is independent of bandwidth *B* and increases with the duration *T* of the signal.

For the following analysis it may be useful to present a rule of thumb expression for the frequency dependence of the spectral noise level NL0 and the absorption coefficient α_f.

To describe the spectral noise level between 1 and 100 kHz, sonar performance evaluation traditionally uses the Knudsen model which for a reasonable sea state SS = 2 becomes

$$NL0 = 61.5 - 17\log(f_{kHz}). \quad (11)$$

The absorption coefficient between 1 and 100 kHz may be approximated by the Francois-Garrison formula (Salinity 38 p.s.u., depth of zero, and 20 deg C)

$$\alpha_f = \frac{0.27 f_{kHz}^2}{2.7 + f_{kHz}^2} + \frac{106 f_{kHz}^2}{17400 + f_{kHz}^2} + 2.2 \cdot 10^{-4} f_{kHz}^2. \quad (12)$$

Implementations of passive sonar

Two typical passive sonar configurations (single hydrophone and array of hydrophones) are discussed below, for the detection of two echolocating cetaceans (sperm whale and Cuvier's beaked whale), where the following parameters are assumed for the sonar equation:

Sperm whale:

SL = 210 dB//1µPa @ 1m, (omni directional component)

NL0 = 41.5 dB//1µPa^2/Hz (15 kHz, sea state 2, deep water, after Eq. 11)

α_f = 1.7 dB/km(at 15 kHz, after Eq. 12)

T = 0.1 ms

B = 10 kHz

Cuviers's beaked whale:

SL = 210 dB//1µPa @ 1m, (directional)

NL0 = 34.3 dB//1µPa^2/Hz (40 kHz, sea state 2, deep water, after Eq. 11)

α_f = 9.5 dB/km (at 40 kHz, after Eq. 12)

T = 0.2 ms

B = 20 kHz

Assuming a coherent processor, that is, Eq. 10 applies for the processing gain and assuming also a modest probability of false alarm of P_{FA}= 1e-4, then the detection threshold becomes 13 dB. The probability of false alarm is modest as it simply says that in absence of any signal, there is a false detection every 1 or 2 seconds, as the average time between consecutive false alarms is about T/ P_{FA}.

Single omni-directional hydrophone

For an omni-directional hydrophone (Fig 2) the array gain is zero AG = 0 and we get for passive sonar systems (Eq. 8) the following equations.

Sperm whale:

$$TL(R_{max}) = 210 - 41.5 - 40 + 0 + 0 - 13 = 115.5 \text{ dB}$$

Cuvier's beaked whale:

$$TL(R_{max}) = 210 - 34.3 - 43 + 0 + 6 - 13 = 125.7 \text{ dB}$$

The maximum detection ranges may be obtained by solving Eq. 6 and result to

Sperm whale:

Rmax = 17.9 km

Cuvier's beaked whale:

Rmax = 5.4 km (assuming the whale points towards the hydrophone)

The maximum detection range of Cuvier's beaked whale is only a third of that of the sperm whale and is a consequence of higher absorption of the sound at 40 kHz compared to 15 kHz of a sperm whale click.

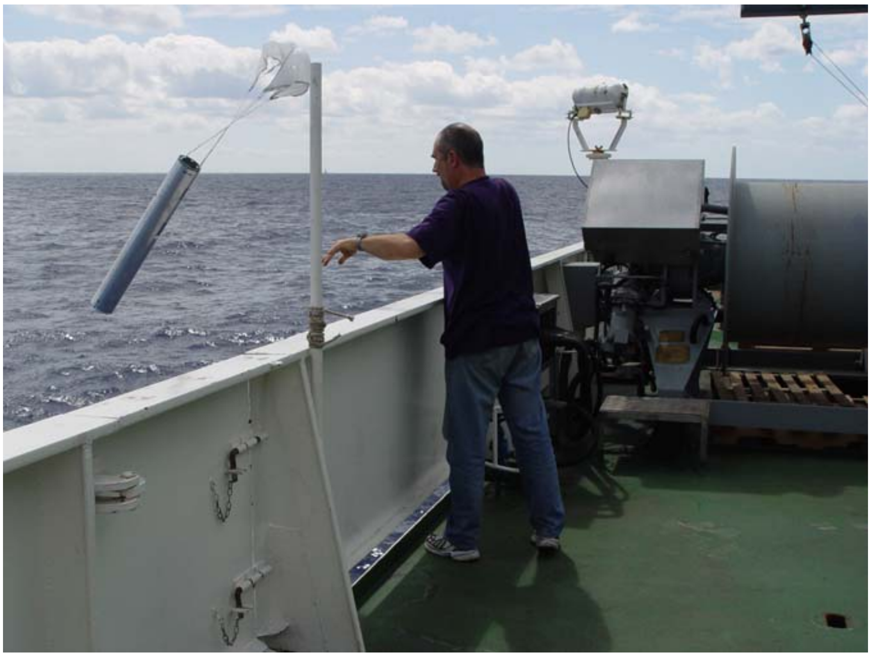

Figure 2: Sonobuoy as example for an easy deployable single hydrophone.

Array of hydrophones

Since a single hydrophone has an array gain of zero dB, an array of omni-directional hydrophones (fig 3) may be used to increase the array gain and to improve the detection range. Assuming for simplicity that the receiver used has a linear array of N = 100 hydrophones, then the array gain may reach up to AG = 10log(N) = 20 dB under certain constraints.

The maximum detection ranges for the two species then increase with an array gain AG = 20 dB to

Sperm whale:

Rmax = 27.5 km

Cuvier's beaked whale:

Rmax = 7.2 km (assuming the whale points towards the hydrophone)

From an array of 100 hydrophones, the maximum detection range for sperm whale clicks increases by 56%, although for beaked whale clicks the improvement is only 33%. This smaller increase is again due to the higher attenuation of beaked whale sounds.

Figure 3: Deployment of a 128 element towed array from NRV Alliance.

The use of multiple hydrophones may increase the maximum detection range as noise suppression is achieved by coherently combining the received sound that arrives from a given direction. This process, called beamforming, reduces the noise in the selected direction and has to be repeated for different directions. The number of different (independent) directions is proportional to the length of the line array and for a given array length (aperture) the minimum number of hydrophones is estimated by dividing the array length by half the wavelength of the highest frequency of interest.

For frequencies up to 15 kHz, a 100 hydrophone array will be nearly 5 m long. For a maximum frequency of 40 kHz, a 100 element array would be 1.9 m long.

This improvement in detection range however, comes with increased processing requirements. As a general rule, if the direction of the sound source is unknown, as many beams should be formed from a linear array as there are hydrophones. The amount of processing required to form all beams grows linearly with the sampling frequency and quadratically with the number of hydrophones. As example, the NURC 128 element towed line array (Fig 3) used for sperm whale detection and tracking required a specially designed beamformer capable of 128*128*32000*8 = 4.2 10^9 multiplication and additions per second.

Direction finding

As seen in the previous section, arrays may be useful in increasing detection range by reducing the background noise that could interfere with the detection process. This is achieved by beamforming, where the isotropic noise space is divided into smaller sections or beams, reducing the noise from unwanted directions. By virtue of its construction, a beamformer also gives the direction of the wanted signal, whereby the angular resolution is determined by the length of the array. The minimum width of the main lobe is for a linear array about 50°λ/L, where λ is the wavelength of the signal, and L is the length of the array. The longer the array and the higher the frequency, the narrower will be the beams that may be formed.

A beamformer is a spatial filter that suppresses the unwanted noise and gives the direction of the sound source. If the detection range of a single hydrophone is sufficient, one may obtain the direction of a sound source without a costly linear array and beamformer combination by using two hydrophones. The technique used is generally referred to as crosscorrelation. This technique uses the fact that a signal from a certain direction β will arrive at the two hydrophones at different times (Fig 4), say t_1 and t_2, and estimates of the arrival direction of the sound relative to hydrophone axis are obtained by solving the following equation:

$$\cos\beta = \frac{c(t_2 - t_1)}{L} \qquad (13)$$

whereby c=1500 m/s is the sound speed and L is the separation of the two hydrophones in m. This technique works only if the signal structure is detailed enough (e.g. very short pulses, or highly variable) to estimate different arrival times of the same signal at the two hydrophones, while whistles and other long tonal signals generate less precise directions.

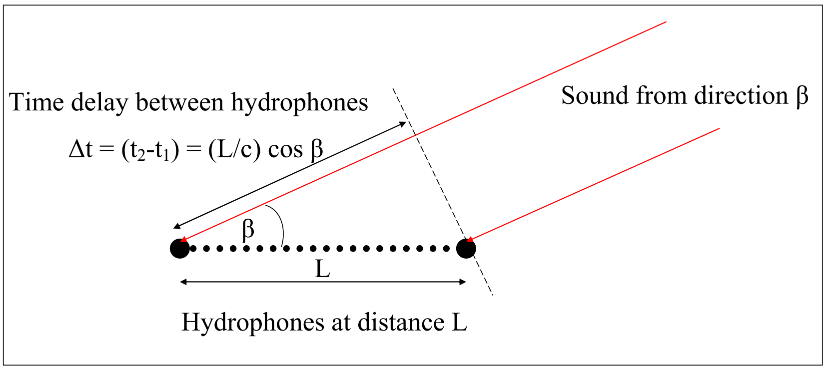

Figure 4: Direction finding with two hydrophones.

Probability of detection

The sonar equation discussed above gives only the maximum detection range but says nothing about the success of a passive sonar system. To be successful, a list of conditions must be met, not all of which are dependent on the implementation of the passive sonar system.

First of all, a sound source (e.g.: echolocating cetacean) must be present, where presence should mean within the maximum detection range. For some applications this presence is known (e.g.: tracking of a previously detected animal), but most interesting applications ignore if animals are present and use passive sonar to detect animals.

Assuming that echolocating whales are within maximum detection range, these whales must emit sound to be heard, but echolocating whales tend only to be acoustically active while foraging, if we ignore intra-species communication that are usually much weaker than echolocation sounds. The temporal uncertainty about the clicking of foraging whales may easily be overcome by sufficiently long listening time. If the listening time is longer than the time whales are on the average quiet, then the possibility of hearing them increases.

Given the scenario that we have a whale within the maximum detection range and that the listening time is long enough to cover the whale vocalizations, then the echolocation sound may only be heard if the sound from the whale is directed to the passive sonar. Here the directionality of whale sound comes into play. Echolocation sounds are in general very directive, that is, they are emitted by the whale mostly in forward direction. One notable exception to this rule is the sperm whale which emits multi-pulsed clicks, where the first pulse of each click is nearly omnidirectional (used in our examples) but where also a very narrow forward oriented echolocation pulse exists (not used here).

The narrowness of an echolocation click is usually described by the directivity index DI, which describes roughly, on a dB scale, how much smaller the sound beam is compared to the surface area of a sphere that is placed around the sound source. Omni-directional sound goes in all directions, covers all surface area of the sphere, and has therefore a DI of zero dB. Typical DI values of echolocation clicks are between 20 to 30 dB. A Cuvier's beaked whale (Ziphius) echolocation click has a typical DI of 28 dB and covers consequently only 0.16% of the surface area of a sphere around the whale. This has dramatic consequences on the success of intercepting (and therefore detecting) a Ziphius click. Assuming that the whale may orient its click in any direction, the probability is only 0.16% that the click may be intercepted (that is, the click is oriented towards the passive sonar). An omni-directional pulse of a sperm whale within detection range will be intercepted with 100% success.

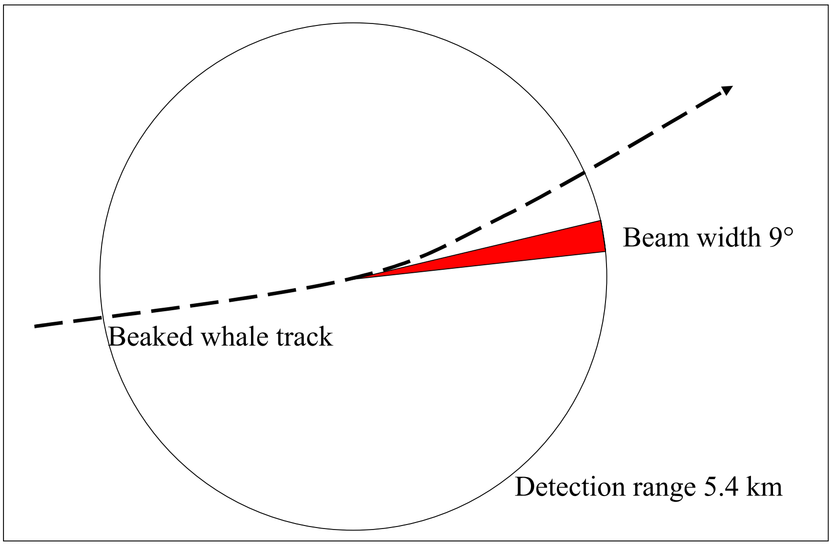

Figure 5: Detection of a single beaked whale echolocation click. The circle describes the maximum detection range and the red section indicates the area where this particular click may be detected.

While the probability of intercept detection of a single narrow echolocation click is very, very small, the detection of an echolocating whale is nevertheless feasible. This is simply due to the fact that most echolocating whales do not emit only a single click while foraging, but thousands of them. In addition as they search for food, they will illuminate most of the water volume around them, that is, they will tend to emit clicks in all possible directions. This foraging behaviour allows a passive sonar system to intercept sufficient clicks to enable a decision on the presence of these whales. The longer the listening operation, the more likely echolocation clicks will be intercepted.

Active Sonar

Passive detection of echolocating whales is feasible, but may require long listening times, which may not be possible for short term operations. In particular, the *conditio sine qua non* that a whale must emit sound to be detected by passive sonar calls for alternatives. The obvious alternative is active sonar. Here sound is emitted by the sonar and echoes from whales are intercepted similar to passive sonar.

The advantage of active sonar is that the sonar operator has the choice of most parameters of the sonar equation (Eq. 9) except TS, the target strength (relative amount of sound reflected back to the receiver). The target strength depends heavily on the reflectivity of the ensonified object, the more the object is acoustically transparent the less the target strength will be. Typically air volumes and bones are better sound reflectors than muscles or fat. The target strength depends also to a certain extent on the ratio of object size to wavelength, whereby short wavelength and large object size increase the target strength.
Considering that air volume is under water one of the best sound reflector and taking into account that air volume compresses as a function of the hydrostatic pressure according to

$$V(z) = \frac{V(0)}{1 + 0.1z}, \tag{14}$$

where the depth z is measured in m, then it appears intuitive to assume that whales are best detected by active sonar when they are close to the surface.

To get an idea of the target strength, let us consider an ideal sphere of air with volume V [L] then the target strength for frequencies much higher than the resonance frequency is given by

$$TS_{sphere} \approx -30 + 6.7\log(V). \tag{15}$$

As example, taking a lung volume of about 600 L for a 23 ton sperm whale and 60 L for a 2.3 ton Ziphius, at a dive depth of 10 m, the following target strength values are:

Sperm whale

TS = -13 dB

Cuvier’s beaked whale

TS = -20 dB

These values are based on simplistic assumptions and should be taken with care. Target strength in general is highly variable and strongly dependent on incident angle and the presence of special features like corners, and variations of over 20 dB are not uncommon.

As the quantities for spectral noise level (Eq. 11) and absorption coefficient (Eq. 12) are frequency dependent, an analysis of the performance of a sonar system for frequencies varying between 1 and 40 kHz is presented here, using the case of detecting Cuvier’s beaked whale as an example.

From the sonar equations previously presented (Eq. 9 with 10), we know that the detection range also depends on the length of the signals. While biological echolocation clicks are in the order of 1 ms or shorter, typical active sonar signals are 0.1 s or longer. To cover both extremes, let us assume the signal length to vary from 0.1 ms to 1 s.

Finally, we will assume an active sonar source level of SL_A= 220 dB//1µPa @ 1m and will consider only the detection of Ziphius (TS = –20 dB), assuming that the target strength is constant for the selected range of frequencies.

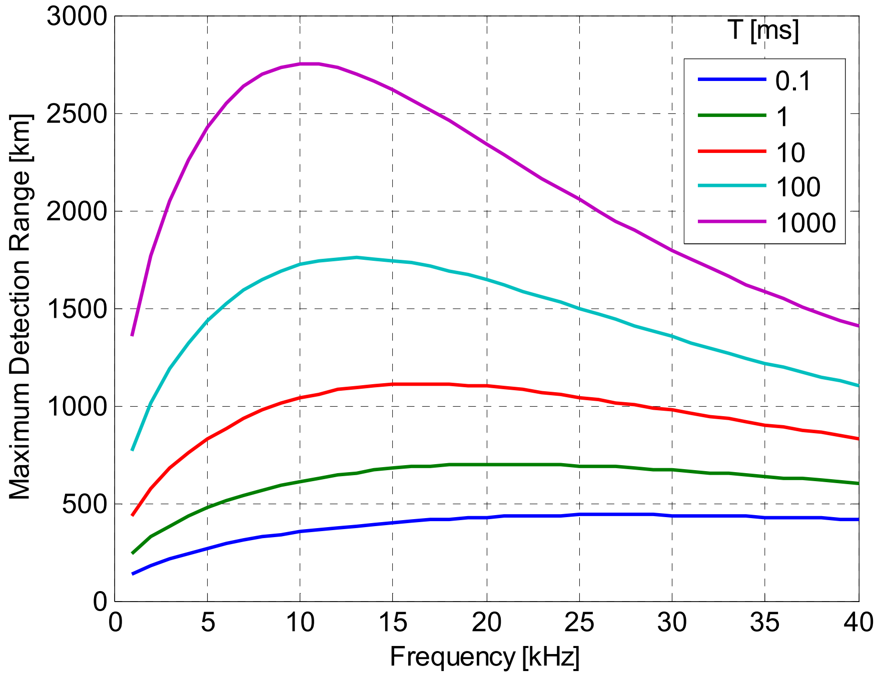

Figure 6: Maximum active sonar range as function of frequency and for different sonar pulse length T.

The maximum active sonar detection range is estimated using Eq. 9 and 6 and shown in Figure 6. As expected the detection range increases with the pulse length T and for a 1 s pulse may reach 2.75 km. Fig. 6 also shows that there is always an optimal frequency, which is less pronounced for shorter than for longer sonar pulses, decreasing slowly from about 27.5 kHz for T = 0.1 ms to 11 kHz for T = 1 s.

Active sonar is sometimes considered undesirable as the acoustic burden for the whale may increase over acceptable limits. The sound level received by the whale varies for a constant active sonar source level as a function of detection range and is estimated according to

$$RL_{\min} = SL_A - TL(R_{\max}) . \qquad (16)$$

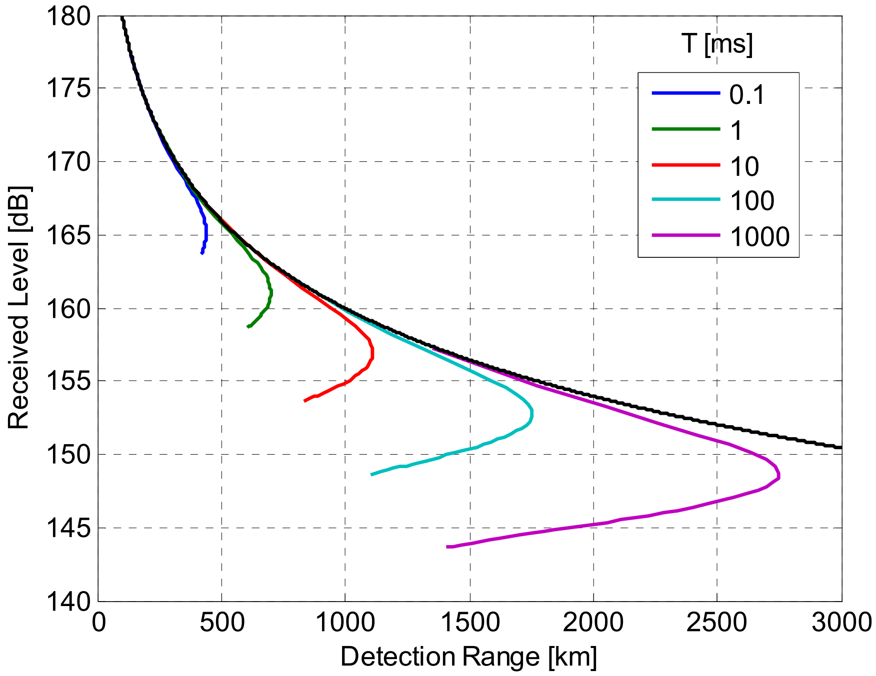

Figure 7: Received level RL_{min} as function of detection range for varying sonar pulse durations. The black line corresponds to the geometric spreading loss and delimits the low frequency side of the detection ranges.

As seen from Fig. 7 and as expected, the minimum received sound level at the whale depends on the maximum detection range, which itself varies with the sonar pulse length (colored lines in Fig. 7) but is always below the geometric spreading loss (black line in Fig. 7). Another way to interpret Fig. 7 is to say that increasing the duration of the sonar pulses will increase the detection range allowing at the same time the sound pressure level at the whale to decrease.

The values for RL_{min} are the minimum levels received by the whale during a positive detection. That is, if we assume that the above designed active sonar will detect a Ziphius, then the received level will be always on the left side of the curves given in Fig 7 as the actual range of a detected whale will be always below the ranges shown if Fig. 6.

To estimate the minimum range active sonar that can be used, let's define a maximum received level RL_{max} of say 180 dB and obtain as the minimum allowed sonar range R_{min} = 0.1 km nearly independent of frequency. For all distances greater than 100 m the sound pressure level at the whale will be therefore less than 180 dB.

Summary

Passive sonar is the method of choice to detect diving echolocating whales and dolphins. Echolocation sounds of whales and dolphins are known to be very powerful and therefore suitable for detection by passive sonar. However these sounds are also very narrow and therefore difficult to intercept. Fortunately echolocation signals are used in searching for prey and are emitted in all directions, therefore increasing significantly the probability of intercept. As such, if passive sonar is used for a sufficiently long time, echolocating whales and dolphins may be detected with high probability.

Active sonar is so far the only practical method used to detect silent submerged whales and dolphins. It gives the user the greatest flexibility in design and operation. While this paper's evaluation of active sonar is based on some simple assumptions (e.g. target strength, limitation to shallow dive depth), it nevertheless demonstrates that whale detection by active sonar is feasible, but in general limited to shorter ranges than achievable by passive sonar. Practical design considerations of whale finder sonar will require a more realistic estimation of the expected target strength of whales and dolphins.

Both methods, active and passive sonar, are valid and complimentary choices for the detection of submerged acoustically active marine life. Both should be considered for use in detecting marine mammals so as to avoid or to mitigate the risk of acoustic sound on marine life.

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7.2 (b) Acoustic detection and surveillance – experiences and improvements

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Abstract

Surveys for marine mammals initially relied exclusively on visual observations. As survey techniques have been refined, research has focused on detection probability as a function of range. These studies have shown that probabilities of detecting some marine mammals, particularly deep diving toothed whales, can be quite low. At the same time, our ability to record the sounds of marine mammals, and our understanding of marine mammal bioacoustics has increased dramatically. Initial studies comparing visual to acoustic detections showed that acoustic monitoring can provide an order of magnitude or more increase in detections, often for less cost. While the process of visual monitoring is complex and affected by subjective factors for each observer, automated detectors and classifiers of marine mammal sounds are starting to come on line, with quantifiable receiver operating characteristics. Countering the advantages of acoustic monitoring, marine mammals must surface regularly to breathe, but do not have to vocalize regularly. A critical parameter for estimating the probability of detecting a marine mammal vocalization involves the distribution of intervals between vocalizations, which is likely to vary diurnally, by season, and age and sex class of the individual animal. Acoustic recording tags are a useful tool for estimating this parameter, and data are presented for right and beaked whales. Once one knows the source level and directivity of a call, along with environmental parameters important for acoustic propagation, there are well developed models for predicting probability of detection and of false alarm. Most visual surveys require shipboard or aerial platforms which are expensive. Where monitoring is required as part of a mitigation strategy, critical parameters include the range of mitigation required, species involved, and the required probability of detection. In most settings a combination of monitoring methods will perform significantly better than visual alone, but much more research is required to define the actual effectiveness of different monitoring regimes at sea. If mitigation is required for a vessel-based activity, initial methods have been based on the vessel itself. Where vessel-based monitoring is insufficient, off-board systems such as autonomous vehicles, bottom recorders, and buoys can provide cost effective modes for increasing the effectiveness of passive acoustic monitoring for marine mammals.

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- marine mammals and anthropogenic noise
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- Program leader for Southern Ocean and Noise campaigns
- Participation in a number of international and regional policy and scientific meetings, including IWC, ATCM, OSPAR and CCAMLR
- Liaison with Governments and members of Parliament
- Development and maintenance of effective collaborations with relevant stakeholders

- Membership of a number of committee's, including the US Federal Advisory Committee on Acoustic Impacts, National Strandings Establishment Committee and the Australian Seismic Steering Committee
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Big Island, Hawaii	Odontocete Acoustic Study, Survey Leader	July 2006
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Inner Hebrides, Scotland	Small Vessel Basking Shark Research	September 2005
Ross Sea, Antarctic: ANSLOPE3	Mammal Observer Team Leader, Marine Voyage	Oct 2004 – Dec 2004
Antarctic & sub-Antarctic	Cetacean & Sea-Ice Observer & Acoustics	Feb 2004 – March 2004
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Cardigan Bay, Wales	Project Co-ordinator, odontocetes	July 1999 – August 2000

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- **Dolman**, S. J., Swift, R., Asmus, K. and Thiele, D. 2005. Preliminary analysis of passive acoustic recordings made in the Ross Sea during ANSLOPE III in 2004. SC/57/E10. Presented to the IWC Scientific Committee.

- **Dolman**, S. J. The Southern Ocean. Spring 2005. A WDCS Australasia Report.
- Thiele, D., Asmus, K., **Dolman**, S. J., Falkenberg, C. D., Glasgow, D., Hodda, P., McDonald, M., McKay, S., Oleson, E., Sirovic, A., Souter, A., Moore, S. and Hildebrand, J. 2004. International Whaling Commission – Southern Ocean GLOBEC/CCAMLR collaboration. SC/56/E24. Presented to the IWC Scientific Committee.
- **Dolman**, S. J. and Simmonds, M. P. 2004. A note on some recent developments in the field of marine noise pollution, including Controlled Exposure Experiments. SC/56/E18. Presented to the IWC Scientific Committee.
- Asmus, K. and **Dolman**, S. J. 2004.Cetaceans, Sea Ice & Wildlife Diversity Cruise Report: Anslope 3 NBP 0408, RVIB Nathaniel B. Palmer.
- Simmonds, M. P., **Dolman**, S. J. and Weilgart, L. 2003. Oceans of Noise. A WDCS Science Report. 169 pages.
- **Dolman**, S. J. and Simmonds, M. P. 2003. Update on the impacts of acoustic pollution: with particular regard to research developments. SC/55/E5. Presented to the IWC Scientific Committee.
- **Dolman**, S. J., Simmonds, M. P. and S. Keith. 2003. Marine wind farms and cetaceans. SC/55/E4. Presented to the IWC Scientific Committee.
- **Dolman**, S. J., Parsons, E. C. M. and Simmonds, M. P. 2002. Noise sources in the cetacean environment. SC/54/E7. Presented to the IWC Scientific Committee.
- Simmonds, M. P., Perry, C. and **Dolman**, S. J. 2000. Reporting the 'State of the Cetacean Environment': ideas and examples. SC/52/E12. Presented to the IWC Scientific Committee.
- Simmonds, M. P., Hanly, K. and **Dolman**, S. J. 2000. Toxic equivalency and cetaceans: a note on the threat posed by environmental pollutants. SC/52/E13. Presented to the IWC Scientific Committee.
- Simmonds, M. P. and **Dolman**, S. J. 1999. A note on the vulnerability of cetaceans to acoustic disturbance. SC/51/E15. Presented to the IWC Scientific Committee.
- Simmonds, M. P., **Dolman**, S. J. and Perry, C. 1999. Recent important developments in the cetacean environment. SC/51/E14. Presented to the IWC Scientific Committee.
- **Dolman**, S. J. and Simmonds, M. P. 1998. The threat posed by noise to cetaceans: preliminary considerations with particular reference to anti-predator devices. SC/50/E8. Presented to the IWC Scientific Committee.

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Alec graduated from the Royal Melbourne Institute of Technology in Melbourne, Australia, with a Bachelors degree in Applied Physics in 1979. After that he spent five years in the UK, mainly at the University of Bath where he worked on the development of an early interferometric sidescan sonar.

He returned to Australia in 1984 to take up a position at the Centre for Marine Science and Technology at what later became Curtin University of Technology in Perth, Western Australia. He has been there ever since, apart from a four year stint with a private company in Melbourne in the late '80s.

His work at CMST has focussed on underwater acoustics, with a wide variety of projects spanning the frequency range 0.1 Hz to 300 kHz. These have included developing acoustic based marine instrumentation such as acoustic navigation systems, upward looking sonars, and submersible long term recording systems, and carrying out numerical modelling of acoustic sources and acoustic propagation in a wide range of scenarios.

In 2004 he completed his PhD on the topic of using a towed array of hydrophones to localise and quantify sources of underwater sound on the tow-vessel.

He now divides his time between research and teaching undergraduate and masters level courses in Physics and Marine Acoustics.

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As a field biologist have a great deal of experience of conducting field studies of live marine mammals at sea, in particular pioneering the use of small independent vessels as research platforms and using passive acoustic techniques to detect marine mammals, assess populations and study behaviour. I have also gained practical experience of working to understand and mitigate the effects of underwater noise.

I aim to use this expertise, and these powerful, cost-effective techniques and skills to find practical solutions to many of the problems that marine mammals encounter in the modern world by conducting focused, high quality, applied scientific research.

QUALIFICATIONS:

1987 Ph.D. University of Cambridge, Social behaviour and ecology of sperm whales.
1980 B.A. University of Cambridge. Zoology, Class II[1].

CURRENT EMPLOYER:

University of Saint Andrews, Sea Mammal Research Unit
Ecologic UK, Consultancy.

PRINCIPAL DISCIPLINE:

Marine mammal behavioural research combined with consultancy and mitigation

MAJOR RESEARCH INTERESTS

I aim to combine various academic interests in marine mammal biology and behaviour, particularly in their acoustics, with practical conservation research, consultancy and mitigation activities.

Sperm whale acoustics, demography and social behaviour.
Research on the effects of noise on marine mammals including sperm whales, porpoise and seals.
Prediction of the offshore distribution of marine mammals based on topographic and oceanographic parameters.
Development and utilisation of passive acoustic methods for detecting, measuring and counting cetaceans.
Development of methodology and equipment for mitigating the effects of powerful anthropogenic noise on marine mammals –and provision of consultancy and mitigation services.

MEMBERSHIP OF RELEVANT NATIONAL/INTERNATIONAL COMMITTEES

ACOBAMS and ICES working groups on Underwater Noise

2004-2005 Member IACMST working group on Underwater Sound and Marine Life.

2002-3. Member of the US National Research Council's Ocean Studies Board Committee on Ambient Noise and Marine Mammals

2000 – present. Member IUCN Cetacean Specialist Group, Member IWC Scientific Committee

2000-02 Member UKOOA advisory group on the effects of noise on marine mammals

PROJECT MANAGEMENT EXPERIENCE

2003-05 Prediction of marine mammal aggregation by reference to oceanographic observables in the seas to the north and west of the Hebrides. Cetacean surveys, seal satellite tagging.

2002 –05 Principal investigator on investigations of the effects of seismic surveys on sperm whales in the Gulf of Mexico for Minerals Management Service.

2003-2005 PAMGUARD Development of opens source passive acoustic monitoring software, in conjunction with Herriot Watt University. Funded by the Industry Research Funding Coalition.

1996-2000 Development of automated cetacean monitoring systems for seismic survey mitigation, with BRDL.

1987-2000 initiated and project managed ~12 offshore marine mammal research projects mostly utilising a dedicated 46' motor sailing research vessel. Projects in UK, Azores, Madeira, Canaries, Mediterranean, Caribbean, Mexico, US East Coast, New Zealand.

INTERNATIONAL CONSULTANCY

Consultancies to NOAA Fisheries, USA. on sperm whale field research techniques (2000,01), harbour porpoise acoustic surveying methods (1999,2000,2003)

CURRENT RESEARCH FUNDING

SWSS Sperm whale project (jointly with TAMUG) ~$300K
PAMGUARD IRFC, (jointly with HWU) ~

PUBLICATION RECORD

~50 papers, book chapters and books

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Biodiversity and Marine Ecology
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- **Personal details:** Born in Madrid, 28.02.1947; Nationality: Spanish; DNI: 1794500. Address: c/ Levante nº 1, 7º B, 36208 Vigo (Spain). Phone: 986 251211. Married. Two sons.

- **Present work situation:** Research professor of the Spanish Council of Scientific Research or Consejo Superior de Investigaciones Científicas (CSIC). Head of the Marine Ecology a Resources Department and the Marine Ecology and Biodiversity Research Group (ECOBIOMAR) at the Marine Research Institute or Instituto de Investigaciones Marinas, (IIM).

- **Educational qualifications**: Degree on Biological Sciences by the University of Barcelona (1969); Ph D. degree on Biological Sciences. University of Barcelona (1977). Cum laude.

- **Fields of scientific specialisation:** Marine Biology and Ecology; Biodiversity; Population Dynamics; Biological Conservation; Fisheries Biology; Marine Resources; Biological Oceanography.

- **Previous work experience of a scientific-professional nature:** Technical Director of the Viaro High School. Barcelona. 1969-1973. Fellowship of the Development Plans. Presidency of the Spanish Government. Fisheries Research Institute (IIP- CSIC-Barcelona). 1974-1975**.** Contracted by Presidency of Government as Graduate Trained (IIP- CSIC Barcelona & Vigo). 1975-1981. Tenure Scientist of the CSIC. (IIM- CSIC-Vigo). 1981-1987**.** Head of the Marine Biology Research Group (IIM-CSIC-Vigo), 1979-88**.** Executive Secretary of the National Marine Sciences Centre (CENCIMAR, CSIC). 1981-84.CENCIMAR included five Spanish Marine Institutes: Barcelona, Blanes, Castellón, Cádiz and Vigo. President of CENCIMAR. 1984-87**.** Deputy Director (IIM-CSIC-Vigo). 1990-1994**.** Research Scientist of the CSIC.1987- 2002**.** Head of the Eco-physiology of Cephalopods Research Group (IIM-CSIC-Vigo).1989-1998**.** Research Professor CSIC. 29.07.2002

- **Seven research stays (more than 3 months) in foreign centres of France, USA, U.K. and Japan.**

- **Publications:** Books: 6; Book's chapters: 10; Papers in scientific journals (no SCI): 52. Papers in SCI journals: 99. According to the ISI web of Knowledge and for the period December 1995 to March 2006 the number of citations was 774, the number of cited papers 80, and the citations per paper 9.68.

- **Other merits or supporting comments you wish to put on record: i)** Leadership and/or participation in 26 national and **international research projects**. **ii)** Supervisor of 18 **Ph.D. and 5 Master Theses** on Biological Sciences**. iii)** Communications presented in National and International Congresses, Symposia and Workshops: 134. **iv) Relevant Research Contracts** with the Industry, Administrations and Agencies: 38; **v) Teaching experience**: Marine Research Institute. 1978 and 1979. Population Dynamics of Marine Exploited Resources. Postdoctoral Course to Cuban and Mexican students. CAICYT. First Course to Graduate Technicians in Aquaculture. Mariñán (La Coruña).1984. Faculty of Sciences; University of Vigo. 1990. Coordinator of the summer course to postgraduate students on "Marine Resources: present situation and perspectives". Faculty of Biological Sciences. University of Santiago de Compostela at Noia 1990. Summer course on "The Biological Conservation of Marine Galician Malacological Resources". Faculty of Biological Sciences. University of Santiago de Compostela at Noia. 1992. Summer course on "The Biological Conservation of Marine Galician Resources". Faculty of Sciences. University of Vigo. 1993 Summer Course: "Sanity and submarine world". Faculty of Sciences, University of Santiago de Compostela (1994-1996). Subject: "Biodiversity and Ecology of Cephalopods". Course for obtaining Ph.D. degree on Marine Biology and Aquaculture. Faculty of Sciences, University of Vigo, Spain (1997-2002). Subjects: "Exploitation of Marine Renewable Resources" and "Cephalopod Ecology". Courses for obtaining Ph.D. degree on Marine Biology and Aquaculture. University of Arturo Prat (Chile). Subjects: "Fishery Biology" and "Biodiversity and Ecology of Cephalopods". Postdoctoral Courses. 1988 and 1991. Institut National Scientifique et Technique d'Océanographie et de la Pêche. Túnez. Subject: "Cephalopod Population Dynamics". Postdoctoral Course. 1994. University of Chile. Santiago de Chile. "Advances and perspectives of the Marine Research in Cephalopods". Course for obtaining Ph.D. degree on Marine Biology. 2000. "Oceans, Fisheries and Environment". Instituto de Ecología y Mercado de la Fundación para el Análisis y Estudio de Temas Sociales. Madrid. 2002. International Master on Economy and Management of the Fishery Activity. Barcelona. 2005-2006. **vi) Editorial tasks**: Editor of 4 volumes of proceedings of International Malacological Congresses. Member of the Fauna Ibérica Editorial Board (National Museum of Natural History-CSIC). 1989-2006; 25 volumes published until present. Editor of publications of the Spanish Malacological Society (SEM). Iberus (8 volumes) and SEM Newsletter, 1996-2000. Member of the Editorial Boar of Fisheries Research; Frente Marítimo, Iberus and Scientia Marina. **vii) Scientific Divulgation**: Articles in specialized journals: 32; Book reviews: 4; Videos: 3 (Iberian Fauna project (CSIC) and Kraken project (Transglobe Films); Museum Exhibitions: 2; Numerous Press releases in local (La Voz de Galicia; El Comercio de Asturias, Faro de Vigo, etc.), national (El País, El Mundo, La Razón, ABC, etc) and International newspapers(New York Times), also in scientific divulgation media (National Geographic, ICES Newsletter, Noticiario de la SEM, etc.); Interviews in Local, national and international radios (SER, Onda Cero, COPE, BBC, etc) and TV (TVE 2). The press, radio and TV impact of Kraken project was valuated in 2 millions € by a Spanish purchasing company**. viii) Oceanographic cruises**: 14. Mediterranean Sea: 3; Atlantic Ocean: 10; North-eastern Pacific Ocean: 1; Scientific Chief in 7**. ix)** Scientific reports which does not give publications: 12. **x) Invited Lectures**: 39 (Spain, United Kingdom, Portugal, France, Greece, USA, Cuba, Chile, Argentina, Tunisia and Morocco). **xi) Congresses, Seminars and Workshop organizer**: International Workshop on Ageing in Cephalopods. IIM (CSIC). 1993. International Workshop on Rearing and Ageing Methods in Cephalopods.1994.First International Symposium on Scientific and Technological aspects of the Cephalopod. Investigaciones de Tecnología Pesquera y de Alimentos Regionales, Mar del Plata, Argentina. 1995. Twelfth International Malacological Congress. Vigo, 3-9 septiembre de 1995. Assistants: 512 scientists from 52 countries. Functional Morphology of Cephalopods Symposium under the umbrella of CIAC. 1995.

Second International Symposium on Scientific and Technological aspects of the Cephalopod. Instituto del Frío (CSIC), Madrid. 1996. Cephalopod Advisory International Council Symposium 2009. **xii) Committees, national and international representations**: Spanish represent in ICSEAF, CECAF and NAFO scientific meetings (1973-79). Member of the combined Committee between the Spanish Institute of Oceanography (IEO) and the CSIC (1984-1989). Founder of the CIAC and member of the Executive Committee (1984-2006). Scientific consultant of the University Arturo Prat (Chile). 1987-1991. Member of the Spanish Malacological Society and member of the Executive Committee (1996-2000). President of UNITAS MALACOLOGICA (1993-1995). Scientific consultant of the Ministry of Fisheries and Aquiculture of the Galician Government (1994-1998). CSIC representing in the Environmental Ministry of the Galician Government (1998-1999). Member of the Working Group for the catalogue of marine species. Ministry of Environment, Madrid. (1999-2001). Coordinator of the Cooperative Agreement between the CSIC, the NGO CEMMA and Environmental Ministry of the Galician Government for the study, assistance and protection of the marine mammals and their habitats in the Galician waters (1999-2002). Member of the Scientific Committee of the third Latin-American Congress of Malacology (2004). Member of the International juries of Ph. D. European Thesis in the Universities of Rabat (1988), Porto (1995), Las Palmas (1995); Algarve (1995), Rennes (1996); Algarve (2000) and Caen (2005). Scientific consultant of the Working Group on Catalogued Marine Species. Ministry of Environment, Madrid. (1999-2001). Advisory member of the Committee of the European Communities. Directorate-General for Science, Research and Development, Brussels. 1999-2001. Scientific consultant of the Kraken project: in search of the giant squid. Transglobe Films and Explora (2000-06). Member of the Panel of experts for designing Marine Protected Areas in the Iberian Peninsula. WWW-Adena. Member of the scientific committee for projects evaluation of the National Grating Agency for Evaluation and Prospective (ANEP). 2000-present. Member of the scientific committee for projects evaluation of the CICYT (Granting Agency of the Ministry of Education and Science).National Research Plant, subprogram MAR I+D+I. 2000-present. Xiii) Reviewer of 24 SCI Journals. **xiii) Awards**: 1982. Annual awards to the scientific research. Excma. Diputación de Pontevedra. 1984. Annual awards to the scientific research. Excma. Diputación de Pontevedra. 1995. Insignia Distintiva. Consejo Superior de Investigaciones Científicas. 2006. “Vigueses distinguidos” by the Vigo Council to all the members of the IIM.

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EDUCATION:	B.S., UCSD, Physics and Electrical Engineering, 1978 Ph.D., Stanford, Applied Physics, 1983 Thesis Advisor: Calvin F. Quate (Stanford University) Post Doctoral Advisor: Fred N. Spiess (Scripps Inst. Oceanography)
PROFESSIONAL EXPERIENCE:	Marine Mammal Commission, Board Scientific Advisor 2003-present Member, MMC Subcommittee on Sound and Marine Mammals Professor of Oceanography, Scripps Institution of Oceanography, University of California, San Diego 1995-present Scripps Institution of Oceanography Faculty Chair 2002-2003 Member, SIO Applied Ocean Sciences Curricular Group Member, SIO Biological Oceanography Curricular Group Adjunct Professor, Department Electrical and Computer Engineering, University of California, San Diego 1991-present Associate Professor of Oceanography, Scripps Inst. of Oceanography University of California, San Diego 1991-95 Assistant Professor of Oceanography, Scripps Inst. of Oceanography University of California, San Diego 1987-91 Assistant Research Geophysicist, Scripps Inst. of Oceanography University of California, San Diego 1983-87
PROFESSIONAL SOCIETIES:	Acoustical Society of America, American Geophysical Union, Society for Marine Mammalogy, Society for Exploration Geophysics

RESEARCH INTERESTS: Marine mammal population census with acoustics; ambient noise impacts on marine mammals; field studies in the Southern Ocean, the southern California Bight, the Bering Sea, the Beaufort Sea, Gulf of Alaska, Gulf of California, Hawaii

SELECTED RECENT PUBLICATIONS:

McDonald, M. A., J. A. Hildebrand, and S. C. Webb (1995). Blue and fin whales observed on a seafloor array in the Northeast Pacific. J. Acoust. Soc. Am. 98(2): 712-721.

McDonald, M. A., J.Calambokidis, A. M. Teranishi and J. A. Hildebrand (2001). The acoustic calls of blue whales off California with gender data. J. Acoust. Soc. Am 109 (4): 1728-1735.

Oleson, E., J. Barlow, J. Gordon, S. Rankin and J. A. Hildebrand (2003). Low Frequency Calls Of Bryde's Whales. Marine Mammal Science 19(2): 407-419.

Swartz, S. L., T. Cole, M.A. McDonald, J.A. Hildebrand, E.M. Oleson, A. and P. J. C. Martinez, J. Barlow, and M.L. Jones. (2003). Acoustic and visual survey of humpback whale (Megaptera novaeangliae) distribution in the eastern and southeastern Caribbean Sea. Caribbean Journal of Science 39(2): 195-208.

Wiggins, S. M., McDonald, M. A., Munger, L. M., Moore, S. E., and J. A. Hildebrand (2004). Waveguide propagation allows range estimates for North Pacific right whales in the Bering Sea. Canadian Acoustics 32(2): 146-154.

Burtenshaw, J. C., E. M. Oleson, J. A. Hildebrand, M. A. McDonald, R. K. Andrew, B. M. Howe, and J. A. Mercer. (2004). Acoustic and Satellite Remote Sensing of Blue Whale Seasonality and Habitat in the Northeast Pacific. Deep Sea Research II 51:967-986.

Sirovic, A., J. A. Hildebrand, S. M. Wiggins, M. A. McDonald, S. E. Moore, and D. Thiele. (2004) Seasonality of blue and fin whale calls and the influence of sea ice in the Western Antarctic Peninsula. Deep Sea Research II, 51: 2327-2344.

McDonald, M. A., J. A. Hildebrand, S. M. Wiggins, D. Thiele, D. Glasgow, S. E. Moore. (2005) Sei whale sounds recorded in the Antarctic J. Acoust. Soc. Am., 118:3941-3945.

Wiggins, S. M., E. M. Oleson, M. A. McDonald, and J. A. Hildebrand. (2005) Blue Whale (*Balaenoptera musculus*) Diel Call Patterns offshore of Southern California Aquatic Mammals 31(2): 161-168.

Hildebrand, J. A. (2005) "Impacts of Anthropogenic Sound" in J.E. Reynolds et al. (eds), *Marine Mammal Research: Conservation beyond Crisis*. The Johns Hopkins University Press, Baltimore, Maryland..

Moore, S. E.; Stafford, K. M.; Mellinger, D. K.; and J. A. Hildebrand. (2006) Listening for Large Whales in the Offshore Waters of Alaska. BioScience 56(1):49-55.

Goldbogen, J.A.; Calambokidis, J; Shadwick, R E; Oleson, E M; McDonald, M A; and J A Hildebrand. (2006) Kinematics of foraging dives and lunge-feeding in fin whale, Journal of Experimental Biology 209, 1231-1244.

McDonald, M. A., J. A. Hildebrand and S. M. Wiggins. (2006) Increases in deep ocean ambient noise west of San Nicolas Island, California, J. Acoust. Soc. Am., 120 (2), 1-8.

Michael Jasny
Senior Policy Analyst
Natural Resources Defense Council (NRDC)
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Michael Jasny joined the staff of the Natural Resources Defense Council's (NRDC) Los Angeles office in 2001. Michael holds a bachelor's degree at Yale College and earned his law degree at Harvard Law School, where he served on the editorial board of the *Harvard Human Rights Journal*. Following law school, he worked with a White House commission charged with investigating the government's history of radiation experimentation on humans during the Cold War. He also served as a consultant for NRDC on a variety of issues affecting southern California.

Michael is a Senior Policy Analyst, specializing in the protection of marine mammals and their habitat. As a national expert on ocean noise pollution, he regularly speaks to industrial, regulatory, and other groups on the issue. He has played a central role in NRDC's ongoing campaign against the proliferation of intense active sonar in the oceans, and is working through litigation, legislative outreach, and public discussion to improve regulation of this emergent global problem. Aside from his work on ocean noise, Michael is increasingly focused on conserving vulnerable species and populations and on protecting marine mammals from the effects of toxic pollution and climate change.

Michael is the author of several NRDC reports including *Sounding the Depths: Supertankers, Sonar, and the Rise of Undersea Noise* (1999), which was the first comprehensive study by an NGO of the ocean noise issue, and a 2005 follow-up report, which has helped advance policy discussion in this field. He is also co-author and editor of *Drawdown* (2000), a report on groundwater depletion on the Hopi and Navajo reservations in northeastern Arizona that was featured in a major *Time* magazine story on the controversy.

Michael lives in Vancouver, British Columbia, with his wife and son.

The Natural Resources Defense Council is a national, non-profit organization of scientists, lawyers and environmental specialists dedicated to protecting public health and the environment. Founded in 1970, NRDC has more than 600,000 members nationwide, served from offices in New York, Washington, Los Angeles and San Francisco. More information is available through NRDC's Web site at *www.nrdc.org*.

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Dr. Hans Heinrich Lindemann was born on 10 April 1955 in Bielefeld, Germany. From 1973 until 1980 he studied jurisprudence, with the emphasis on public administration, at Bielefeld University. His studies also included a training course at the European Commission in Brussels.

Following his university education, he was scientific adviser at the Max Planck Institute for Comparative Public Law and International Law in Heidelberg for four years, focussing on comparative law. After he had obtained a doctorate in jurisprudence at the University of Bielefeld (topic: General legal principles and European public service) he was employed by the city of Bielefeld as a legal specialist in environmental law.

In 1991, he was employed as Head of Section on jurisdictional environmental questions at the Federal Environment Agency in Berlin. Since 2003, he is Head of the Department of instruments for environmental protection.

Professor Arthur N. Popper
University of Maryland
Department of Biology
Interim Associate Dean, College of Chemical and Life Sciences
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Arthur Popper is a neuroscientist whose research interest lies with the structure, function, and evolution of the auditory system. While much of the research in his laboratory has focused on basic mechanisms of hearing, and especially that of fishes and other marine vertebrates, recent work in Popper's lab has extended to include investigations of the effects of human-generated (anthropogenic) sound on marine animals. Current research projects in the Popper laboratory (www.life.umd.edu/biology/popperlab) include studies of the structure of the auditory system of deep-sea fishes, evolution of hearing mechanisms in primitive fishes, and development and regeneration of sensory hair cells in the ear.

In more applied areas, Popper's lab is investigating effects of small increases in background sounds on fish hearing and physiology, effects of very high intensity sonar on fish, and studies of pile driving on fish physiology. These studies include investigations of the effects of seismic air-guns on the ears of fish in one study, and on hearing the ear structure in another. Current investigations include the effects of low and mid-frequency sonars on fish hearing and the effects of pile driving sound on fish hearing and survival.

Popper received his doctorate in Biology (Animal Behavior) from the City University of New York. He then joined the faculty of the Department of Zoology at the University of Hawaii and then joined the Department of Anatomy and Cell Biology at the Georgetown University School of Medicine. In 1987 he became professor and chair of Zoology (now Biology) at the University of Maryland, College Park, MD. After 10 years as chair he assumed the directorship of the Neuroscience and Cognitive Science Program at the University of Maryland. This was followed by his becoming chair of the University Senate, the main governing body for faculty, staff, and students at the University. He is currently co-director of the Center for Comparative and Evolutionary Biology of Hearing at UMD as well as interim associate dean of the College of Chemical and Life Sciences.

Dr. Popper chaired the 2000 panel of the National Research Council on effects of sound on marine mammals, and served on several other NRC committees in the same area. He currently co-chairs the S3 Standards Working Group of the Acoustical Society of America on "Effects of noise on fish and marine mammals." He also consults with state and federal organizations and with industry in the U.S. and abroad on effects of noise on marine animals and on effects of highway noise on birds.

Popper is author of well over 150 scientific papers, including recent peer-reviewed publications on effect of noise on marine animals. He is also co-editor of the Springer Handbook of Auditory Research (SHAR), a series of books (28 current, 12 more in various stages of production) on all aspects of hearing. SHAR has become the definitive work on the hearing sciences.

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Senior Scientist (with tenure)
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EDUCATION
A.B., *summa cum laude* in Biology, Harvard College, l976.
Ph.D., in Animal Behavior, Rockefeller University, 1982, Donald R. Griffin, advisor.

EMPLOYMENT

1971-1972:	Research Assistant	Alza Co
1974-1975:	Research Associate	New York Zoological Society
1976:	Staff Biologist	Oregon Public Utilities Commission
1977-1981:	Research Associate	New York Zoological Society
1977-1982:	Graduate Fellow	Rockefeller University
1982-1983:	Postdoctoral Scholar	Woods Hole Oceanographic Institution
1983-1985:	Guest Investigator	Woods Hole Oceanographic Institution
1985-1989:	Assistant Scientist	Woods Hole Oceanographic Institution
1989-1999:	Associate Scientist	Woods Hole Oceanographic Institution
1994-1995:	Fellow	Center for Advanced Study in the
1999-:	Senior Scientist	Woods Hole Oceanographic Institution
2001-	Walter A. and Hope Noyes Chair in Oceanography	Woods Hole Oceanographic Institution
2001-2002	Visiting Scientist	Saclant Undersea Research Centre, La Spezia Italy

MEMBERSHIPS
Federal Advisory Committee on Acoustic Impacts on Marine Mammals, US Marine Mammal Commission (2004-2005)
Committee on Characterizing Biologically Significant Marine Mammal Behavior. Ocean Studies Board, National Research Council (2003-2004)
Committee to Review Results of ATOC's Marine Mammal Research Program. Ocean Studies Board, National Research Council (1996-2000)
Committee on Low Frequency Sound and Marine Mammals, Ocean Studies Board, National Research Council (1992-1994)
Advisory Board for Marine Mammal Research Program, ATOC.
Trustee, Center for Coastal Studies (1996-1999)
Member, Scientific Advisory Board, New England Aquarium (1992-1996)
Member; Acoustical Society of America, Animal Behavior Society; A.A.A.S., Sigma Xi
Charter Member, Society for Marine Mammalogy
Associate, Behavioral and Brain Sciences.
Fellow, Center for Climate and Ocean Research (CICOR)
Fellow, Acoustical Society of America
Member, Committee of Scientific Advisors on Marine Mammals,
Marine Mammal Commission 2000-2003
Associate Editor, Marine Mammal Science, Encyclopedia of Ocean Sciences,
IEEE Journal of Oceanic Engineering
Adjunct Scientist, Mote Marine Aquarium
Adjunct Professor, Department of Oceanography, University of Rhode Island

RESEARCH INTERESTS

- Social behavior and acoustic communication in cetaceans.
- Vocal learning and mimicry in the natural communication systems of cetaceans.
- Individually distinctive signature signals, vocal learning, and mimicry in the bottlenose dolphin and the sperm whale.
- Acoustic structure and social functions of the songs of baleen whales.
- Responses of cetaceans to manmade noise.
- Playback to cetaceans of their own and conspecific vocalizations.
- Development of methods to identify which cetacean produces a sound within a social group.

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