ESOMM-2011
4th International Conference on the Effects of
Sound in the Ocean on Marine Mammals

Amsterdam, The Netherlands,
5-9 September 2011

Photo back cover:
Leigh Hickmott (Open Ocean Consulting)

Conference organizers:
Frans-Peter Lam (TNO)
René Dekeling (NL Defence Materiel Organisation)
Marije Siemensma (Marine Science & Communication)

Contents

1 Introduction

Fifteen years ago, several months after the stranding in Kyparissiakos Gulf, researchers found an earlier warning to mariners (released by the Hellenic Navy Hydrographic Service) and their finding indicated that a stranding of marine mammals could be caused by use of active sonar systems. Soon it became apparent that NATO navies were facing a new challenge: for navies underwater detection is an essential capability and for this underwater detection they are dependent on active sonar systems. At the same time the use of these systems was questioned and we were even challenged to stop using these systems. Navies had to demonstrate that use of these systems could be done in a responsible way with an acceptable impact on the environment.

Fifteen years later, navies realize that the protection of marine life by the responsible use of sonar is part of everyday routine. And while sonar maybe is no longer seen as the exclusive cause of acoustic risk to the environment, both regulators and non-governmental parties still expect navies to invest in expanding the knowledge. Research over the last fifteen years has provided us with a growing fundamental understanding of how military sonar systems may affect marine life. The dramatic and explicit stranding events that initiated concern on military sonar systems have not happened frequently over the last decade. But our improved understanding shows us that marine life may be affected by more complex and subtle impacts like behavioral responses and masking that may influence populations and eco-systems.
The requirement to quantify impact and to show efficacy of mitigation action will stay; but quantifying complex and often subtle impacts is a slow and costly process and where government research budgets are under pressure, we must be able to show that research is cost-effective and investments are justified.

The focus of this conference is on quantifying and mitigating the effects of naval sonar on marine life, but this meeting will also bring scientists from other fields, professionals working on environmental policy and representatives of offshore industry to Amsterdam. We will learn what the state of the art of science is, but we will also be able to assess progress made in expanding knowledge in this field over the last years, and whether we are progressing enough and in the right direction. We shall address

technological and societal developments that determine the future requirements for sound producers. That way, we can determine priorities, and plan cost-effective research, both for the short term as for comprehensive research strategies for the longer term. We hope that all visitors will contribute actively this week- because in the end, it is not the organizers, but the participants that decide on the success of the conference.

René Dekeling
Frans-Peter Lam

2 Conference Programme

Monday 5 September

- *registration and coffee – 08:00*
- welcome by organizers – 09:30
- opening of conference by Commander of the Royal Netherlands Navy, Vice Admiral Mathieu J.M. Borsboom
  trends in active sonar
- *coffee break*
- overview of regulations and science status – different authors
- *lunch break*
- scientific highlights – different authors
- *coffee break*
- scientific highlights and industry background – different authors
- *reception at naval base – 17:30 – 19:00*

Tuesday 6 September

- *coffee – 08:00*
- Behavioural Response Study/
  Controlled Exposure Experiment-fieldwork session – 08:30
- *coffee break*
- BRS/CEE-fieldwork session (cont'd)
- *lunch break*
- BRS/CEE-fieldwork session (cont'd)
- Detection Classification Localization session
- *coffee break*
- DCL session (cont'd)
- *Closure - 17:00*

Wednesday 7 September

- *coffee – 08:00*
- Hearing and physiology session – 08:30
- *coffee break*
- Hearing and physiology session (cont'd)
- *lunch break*
- combined seismic / mitigation / policy session
- *coffee break; mitigation software demos 15:30 – 17:00*
- *boat tour and conference dinner – 18:00 – 22:00*

Thursday 8 September

- *coffee – 08:00*
- combined other / related / emerging topics session – 08:30
- *coffee break*
- combined other / related / emerging topics session (cont'd)
- *lunch break*
- Population Consequences of Acoustic Disturbance session
- *coffee break*
- PCAD session (cont'd)
- closing of plenary programme of ESOMM-2011 – 16:00
- *transfer by bus to The Hague / Scheveningen (optional) – 16:30*

Friday 9 September

- Project meetings at TNO in The Hague - All day
  (people involved should have been informed)

Poster programme

- Posters are on display from Monday to Thursday during all breaks of the plenary programme.

Please note that all timings in this programme can be subject to last minute changes. A detailed and final programme, containing all individual presentations and posters will be advertised on the website: http://esomm.msandc.nl a week in advance and will be provided as a hard copy at the start of the conference.

3 Abstracts (talks) – in alphabetical order

The environmental cost of marine sound sources

Ainslie, M.A. (1), Dekeling, R.P.A. (2, 3)

Cumulative acoustic exposure is used as an indicator for the risk of negative impact to animals as a consequence of exposure to underwater sound. The free-field energy of a single source, defined as the total acoustic energy that would exist in the source's free field, is shown to be closely related to the total cumulative exposure added over a population of animals. On this basis, the free-field energy of an underwater sound source, referred to as its "energy cost", is proposed as an indicator of its environmental risk. For otherwise the same conditions, the environmental cost so defined of a multi-beam echo sounder (frequency 100 kHz) is about 40 000 times less than that of a search sonar (1 kHz) of the same source level. In turn, the cost of the same sonar is about 300 times less than that of a pile driver of the same energy source level, implying that source level (or energy source level) alone is a poor indicator of environmental risk. The main reason for this is that source level takes no account either of the amount of space occupied by the sound once in the water, or of the time required for the sound to dissipate. The free-field source energy, which includes the effects of source directivity and decay time, is a better indicator of the environmental cost of a marine sound source, and may be used to identify those sources in greatest need of risk mitigation.

An earlier version of this abstract was published in the Proceedings of the Fourth "Underwater Acoustic Measurements: Technologies and Results", held in Kos (Greece), 20-24 June 2011.
http://www.uam-conferences.org/]

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Live monitoring of noise and acoustics events: integrated solutions for a sustainable development of the offshore industry

Michel André (1), Mike van der Schaar1, Serge Zaugg (1), Ludwig Houégnigan (1), Antonio M. Sánchez (1), Joan V. Castell (1)

The next decades will see increasing levels of offshore industrial development that will lead to increased amounts of noise pollution in the oceans. Amongst these developments, oil and gas prospection, navy exercises as well as offshore windmills are already playing a leading role in introducing considerable amount of noise in an increasing number of areas. These sounds can have physical, physiological and behavioural effects on the marine fauna in the area of action: mammals, reptiles, fish and invertebrates can be affected at various levels depending on the distance to the sound source. The problem faced by the industry, and more generally by the society, is that many economically important activities at sea are at risk because of a lack of information about the effects of anthropogenic sound on marine mammals and especially a lack of available tools to mitigate these effects. The challenge here is to implement technological developments that combine the interests of the industry and the good environmental status of the oceans. Based on the existing technology successfully implemented at underwater observatories worldwide (European Sea-floor Observatories Network of Excellence, ESONET, European Member States; ANTARES, France; NEPTUNE, Canada; Kushiro, Japan) by the Laboratory of Applied Bioacoustics of the Technical University of Catalonia (LIDO, Listen to the Deep-Ocean Environment, http://listentothedeep.com), a real-time passive acoustic monitoring solution is available to mitigate the potential effects of noise associated to the offshore industry.
The LIDO acoustic detection, classification and localization (DCL) system can be integrated in a series of expandable radio-linked autonomous buoys that are timely deployed in areas of action. In that case, the DCL is performed at buoy level. A mesh network allows buoy-to-buoy communication and an alert service provides the ship/offshore platform with the DCL analysis: the real-time continuous monitoring of cetacean presence. The advantages are relevant:

-The LIDO DCL is automated and performed no matter sea state or light conditions
-No expertise is needed onboard the survey vessels/offshore platforms since the alert service informs on the identification and position of cetacean species that is displayed on a user-friendly interface

-The real-time continuous monitoring of cetaceans allows determining areas of exclusion depending on the sound source and the species involved.
-The decision-taking regarding the management of the offshore activity in presence of cetaceans falls under scientifically contrasted, objective and standardised procedures that ensure the sustainable development of the activity.
-The LIDO DCL is supported by virtually any hardware, e.g. towed arrays, gliders, AUV, ROV, radio-linked autonomous buoys, cabled observatories.

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Behavioral responses of long-finned pilot whales (*Globicephala melas*) to sonar exposure

Antunes (1) R., Alves (1), A., Lam (2) F. P. A., Kvadsheim (3) P., Miller (1) P.J.O.

To augment our knowledge on the impact of military sonar in cetaceans, we assessed the behavioural responses of 6 long-finned pilot whales during 15 (30-60 minute, 1-2kHz or 6-7kHz FM sweeps) sonar exposures and 4 control silent passes, conducted in Norway in 2008 /2009 (3S). Additional baseline data was collected in 2010. Whales were instrumented with archival tags (DTAGs) and tracked from an observation vessel approximately every 2 min. Changes in behaviour potentially caused by sonar exposure were identified by inspection of the data records (direction/speed of horizontal movement, diving and social-sounds). Apparent horizontal avoidance was observed in 3 of 8 1-2kHz exposures and 2 of 7 6-7kHz exposures. Multivariate breakpoint analysis based on Mahalanobis distance was conducted in parallel to identity behavioural changes unlikely to have been observed during baseline using a randomization procedure. Baseline and pre-exposure data indicated that whales made bouts of benthic deep dives with production of echolocation clicks and buzzes. In 2 exposures to 1-2kHz signals, whales switched from deep-diving to shallow-diving in association with horizontal avoidance and increased production of social-sounds. In both cases foraging was resumed later. In contrast dive state was unaltered during the remaining 1-2kHz exposure where foraging was observed. Foraging was not interrupted during 6-7kHz exposures where it was observed and actually commenced during one 6-7kHz exposure. Our results indicate that exposure to sonar in the 1-2kHz band has the potential to disrupt feeding of long-finned pilot whales in the short-term but found no indications of longer term effects.

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Trends in active sonar

S.P. Beerens

Sound, a manifestation of acoustic waves, is the best propagating wave field in the ocean and therefore the best means of transporting information. For many ages marine mammals have been using sound for communication, navigation and echo-location. Only recently, also man discovered the benefits of sound as information carrier in the ocean. From the beginning of the previous century sonar was developed; both passive sonar (listen only) and active sonar (in which echoes of transmitted signals are registered). Nowadays, active sonar is used in many civil and military applications.
An important design criterion is the sonar frequency. Sonar frequencies, like marine mammal vocalizations, cover the whole acoustic spectrum; ranging from infra-sonic in seismic exploration, to audible frequencies for naval sonar, to ultra-sonic frequencies for imaging. Generally low frequencies propagate better, but at high frequencies more bandwidth is available and higher resolution can be achieved.
A trend in active sonar is the development of systems with higher bandwidth via new transducer technology and associated wideband signal processing. This means that more resolution becomes available, or that the same resolution can be achieved at lower frequencies. The lowering of frequency to achieve longer detection ranges is another trend. Further increase of source levels is not likely due to physical limitations and reduced added-value.
Note that active sonar is based on the transmission of sounds and thus induces a pollution of the ocean environment with a possible disturbance of its original habitants. Modern sonar design should take this aspect into account to balance with other design criteria. Furthermore, active sonar users should take mitigation measures to minimize the risk. In the Royal Netherlands Navy the use of a risk mitigation is obligatory before active sonar use.

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Theoretical assessment of ramp-up efficacy on marine mammals

A.M. von Benda-Beckmann (1), M.A. Ainslie (1), P.A. Wensveen (3),
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Ramp-up (or soft-start) schemes are widely used to mitigate the impact of sonar sound on marine mammals, motivated by the so-called "precautionary principle". So far, no studies exists which document that ramp-up is effective at reducing the risk of impact on marine mammals. Although individual animals are given the opportunity to swim away from the sound source, their exposure or that on other animals might be increased because they may swim too slowly or respond too late to get out of harm's way.

A theoretical framework is proposed that calculates the risk of hearing impairment in marine mammals under different ramp up schemes. It is applied to a scenario in which a population of killer whales is exposed by a moving sonar source. The model includes a behavioural avoidance response model of killer whales that is based on observed response reactions to sonar during the 3S controlled exposure experiments.
By simulating a wide range of ramp-up schemes, we determined a ramp-up scheme that minimizes the risk of direct physical injury on a population of killer whales.

Results from this study show that a ramp-up scheme decreases the risk of hearing injury to killer whales by a factor of 5 to 10, while the risk of disturbing the population is not significantly increased. The main parameter that determines the efficacy of ramp-up schemes is its duration. It is found that, contrary to wide-held belief, long ramp-up times are not always beneficial.

The same method is applicable to other types of anthropogenic activities for which ramp-up schemes are used as a mitigation strategy, such as seismic exploration.

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An International Quiet Ocean Experiment

Ian Boyd, Ed Urban, George Frisk, Peter Tyack, Jesse Ausubel, Sophie Seeyave, Doug Cato, Brandon Southall, Michael Weise, Rex Andrew, Tomonari Akamatsu, René Dekeling, Christine Erbe, David Farmer, Roger Gentry, Tom Gross, Anthony Hawkins, Fenghua Li, Kathy Metcalf, James Miller, Dave Moretti, Cristian Rodrigo, Tomio Shinke

The effect of noise on marine life is one of the big unknowns of current marine science. There is considerable evidence that the human contribution to ocean noise has increased during the past few decades; human noise has become the dominant component of marine noise in some regions and noise is directly correlated with the increasing industrialization of the ocean. Sound is an important factor in the lives of many marine organisms and increasing theory and observations suggest that human noise could be approaching levels at which negative effects on marine life may be occurring. Some species show symptoms of effects of sound. Although some of these effects are acute and rare in occurrence, chronic sub-lethal effects may be much more prevalent, but are much more difficult to measure. We need to identify the thresholds of such effects for different species and be in a position to predict how increasing anthropogenic sound will increase the effects. To achieve this, an International Quiet Ocean Experiment (IQOE) is being developed, with the objective of coordinating among the international research community to both quantify the ocean soundscape and examine the functional relationship between sound and the viability of key marine organisms.

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Behavioral Response of Australian Humpback Whales to Seismic Surveys

Douglas H. Cato (1,2), Michael J. Noad (3), Rebecca A. Dunlop (3), Robert D. McCauley (4)Nicholas J. Gales Chandra P. Salgado Kent (4), David Paton (7) Hendrik Kniest (6) John Noad (3)

The first of four major experiments in project BRAHSS (Behavioural Response of Australian Humpback whales to Seismic Surveys) was conducted on the east coast of Australia in September, October 2010. The project aims to understand how humpback whales respond to seismic surveys and to provide the information that will allow these surveys to be conducted efficiently with minimal impact on whales. It also aims to determine how the whales react to ramp-up or soft start, and to assess how effective this is in mitigation. The 2010 experiment used a single air gun. Four air guns will be used in the next two experiments and a full seismic array in the final experiment in 2013. During the 2010 experiment, behavior and tracks of whales were recorded by four theodolite stations on elevated coastal positions and DTAGs used on some whales. Vocalizing whales were tracked with a wide base line hydrophone array. A further four acoustic recorders were used to measure propagation loss and to characterize the sound field throughout the area. A wide range of variables likely to affect whale response was measured. [Sponsored by JIP E&P Sound & Marine Life and Bureau of Ocean Energy Management, Regulation and Enforcement].

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A Bioenergetics Approach to Understanding the Population Consequences of Acoustic Disturbance: Elephant seals as a Model System

D.P. Costa (1), L Schwarz (1), R. S. Schick (2), L. F. New (3), L. Thomas (3), M. A. Hindell (4), C. McMahon (4), P. W. Robinson (1), S. E. Simmons (1), J. Harwood (3), and J. S. Clark (2)

A major hurdle with marine mammal conservation and management is to know if and when measurable short term responses result in biologically meaningful changes in populations. Using natural and manipulative experiments we are using northern elephant seals to parameterize the transfer functions developed in the conceptual model developed by the NRC Committee on the population consequences of acoustic disturbance or PCAD. Within marine mammals there are two fundamental life history patterns comprised of capital and income breeders. We are developing a bioenergetics approach to parameterize the transfer functions developed in the PCAD model. Such an approach can identify species and or particular life history characteristics that are likely to be sensitive or resilient to acoustic disturbance. Our effort is using elephant seals as a model of a capital breeder that will held us understand 1) how constrained capital breeders are in their ability to accommodate to short terms changes in their foraging behaviour and or success, 2) the coupling between short term changes in foraging behaviour to reproductive success and adult survival. 3) the linkage between foraging behaviour and reproductive success and adult survival vary relative to environmental perturbations.

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Consistent reactions of sperm whales and long-finned pilot whales to playback of killer whale sounds

Curé Charlotte (1), Antunes Ricardo (1), Alves Ana-Catarina (1),
Visser Fleur (2), Kvadsheim Petter-Helgevold (3) and Miller Patrick (1)

This study is part of the 3S project investigating how naval sonar affects cetaceans and aims to assess whether reactions to sonar sounds are similar to reactions to predators presence. Disturbance stimuli should be analogous to predation risk as they both create similar trade-offs between avoiding perceived risk or continuing fitness-enhancing activities such as feeding, parental care, or mating displays. We test here the hypothesis that cetaceans' behaviour is altered by detection of their predator's (the killer whale, Orcinus orca) vocalizations. We performed underwater killer whale playbacks in Norwegian waters with 5 sperm whales (Physeter macrocephalus) encountered off Andenes and 5 long-finned pilot whales (Globicephala melas) encountered inside the Vestfjord basin and we assessed the behavioural responses of the targeted animals. Behavioural data were collected using D-TAGs that were attached to the tested animals prior to sound playback exposure. To assess whether of killer whale playbacks induced behavioural changes in both studied species, we compared behavioural data collected before sound exposure to those collected during sound exposure. Our most striking results showed that in sperm whales, killer whale sounds elicited an interruption in the descent phase of diving and a return to the surface (4/5 experiments). For pilot whales, killer whale vocalizations strongly attracted animals which diverted their course towards the speaker (4/5 experiments) and induced a decrease in inter-group spacing. These clear and consistent reactions to killer whale playbacks contrast with the high variability of results with sonar exposures.

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Behavioral responses of herring to naval sonars

Lise Doksæter (1), Petter H. Kvadsheim (2), Olav Rune Godø (1),
Frans-Peter Lam (3), Patrick J.O. Miller (4)

Herring is one of the most important prey species for cetaceans in Norwegian waters and, with their good hearing capability, can detect the frequencies most commonly used by naval sonars. Negative impacts of sonar transmission on herring could thus potentially affect prey availability for cetaceans as well as the commercial fishery. Throughout a four year period (2006-2010) we have conducted extensive studies of herring behavioural responses to naval sonars (1-7 kHz) both in field (3S) and captivity (LOWFREQ). Field experiments have been conducted during overwintering, representing the densest yearly distribution regime as well as being period of the year when herring are known to be most responsive, and during the summer feeding migration when the herring are in the lowest annual energetic condition, thus making them highly vulnerable to stressors such as noise disturbance. In addition, captive experiments have been conducted in all seasons of the year. In all experiments, both in field and captivity, the herring did not show any behavioral responses to the frequencies and exposure levels tested [1-7 kHz, with RL up to176 dB (re 1µPa), and SEL up to 181 (re 1µPa2 s)]. In contrast, sounds from feeding killer whales and boat engine noise induced typical avoidance responses in the form of rapid diving by the herring, demonstrating the herring`s ability to perform avoidance reactions as well as our methodology to be able to detect such a reaction. The lack of responses to sonar exposures at the high levels tested indicate that operational sonar use is unlikely to pose a threat to herring populations or negatively affect herring consumers.

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Auditory weighting functions and acoustic damage risk criteria for marine mammals

James J. Finneran (1) Carolyn E. Schlundt (2)

The variation in susceptibility to noise as a function of frequency is handled by "weighting" sound exposures to emphasize frequencies where susceptibility to noise is highest. This technique allows the use of single, weighted numeric values for acoustic damage-risk criteria, regardless of the sound frequency. Human auditory weighting functions were derived from equal loudness contours obtained from subjective loudness level comparisons. Loudness comparisons in human listeners are straightforward; however, it is difficult to convey the concepts of loudness matching or loudness comparison to non-verbal animals. For this reason, there have been no direct measurements of loudness level or equal loudness contours in a non-verbal animal, and auditory weighting functions in marine mammals have been estimated from known or suspected auditory sensitivity or bandwidth. Recently, a bottlenose dolphin was trained to perform a loudness comparison test, and psychometric functions describing the loudness relationship between a tone at a particular frequency and level and that of a reference tone were constructed and used to derive equal loudness contours and auditory weighting functions. This talk reviews auditory weighting functions in the context of recent high-frequency dolphin temporary threshold shift (TTS) data. The manner in which the dolphin subjective loudness comparisons were performed and the equal loudness level contours constructed will be discussed, and the resulting weighting functions compared to the dolphin TTS data. Finally, some alternate approaches to estimating equal loudness contours and weighting functions will be explored.

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From experimental data to a scale of sound-induced effects expressed in terms of perceived levels

Gannier, Alexandre (1), Mifsud, Laurent (2)

There are numerous examples of sound-induced effects recorded for cetaceans, either in controlled situations, or opportunistically. These effects cover almost all major families/super families and include either behavioural effects or auditory threshold shifts. Broad or narrow band continuous sounds, as well as pulses, have been documented to cause effects ranging from slight behavioral change, to activity disruption, avoidance, and threshold shift, either short or long term. An analysis of the available literature allows to express this sound-induced effects as a function of perceived levels, and perceived doses when sound duration is taken into account. We proposed a scale of sound-induced effects based on perceived levels, in order to be able to predict various classes of disturbance with a reasonable precision (aiming to +/- 10 dB). Our scale ranges from 60 dB perceived level for a behavioural change, to 75 dB for initial evasion effects, 100 dB perceived dose for initial TTS, and 115 dB for strong and persistent TTS. The scale was implemented for different cetacean families, and is presented here for the "oceanic delphinid" class. Although our proposal is approximate, it already enables effect predictions and could be further tested and refined, with the onset of new experimental results. Whenever coupled with source and propagation properties and a particular cetacean biotope, the scale allows to predict potential impacts. A mitigation protocole can be designed and implemented, accounting for the safety policy in place.

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Ocean Basin Scale Low Frequency Communication Masking Potential from a Seismic Survey

Jason Gedamke (1), Rob McCauley (2)

A seismic survey operating off the Australian continental shelf was recorded on 3 autonomous long term instruments deployed between Tasmania and Antarctica. The instruments were located ~450, ~1500, and ~2800km from the survey site. Recordings from a five day period were separated into those with and without airgun activity for acoustic analysis. Sound levels across a 20-50 Hz bandwidth were calculated to assess increases in noise in Antarctic blue and fin whale song frequency bands. Levels from 1s samples were compared between the seismic and non-seismic datasets to determine the percentage of time and degree to which sound levels increased due to airgun signals. During seismic operations, a distinct shift in the distribution of sound pressure levels in the 1s samples occurred suggesting even during 'quiet' periods between shots, sound levels remained slightly elevated. Averaged overall, including periods during and between individual shots, sound levels increased by 4.5 dB re 1µPa, 3.5 dB, and 3.0 dB at the nearest to furthest instruments, respectively. Accounting for temporal variation of the seismic signals shows that the background noise increases during seismic periods reduce potential communication area to <45% of the area available with mean non-seismic background levels, for over 50% of the time at all instruments. Communication area was further reduced to <20% of 'normal background' area, for 32%, 22%, and 14% of the time moving from north to south. These results demonstrate the potential ocean basin scale reduction of communication space resulting from the operation of a distant seismic survey.

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The Joint Industry Program; its History and an Update

Roger l. Gentry (1) and John a. Campbell (2)

The JIP is a temporary association involving 10 oil and gas-producing companies. It funds original research on the output, effects, and mitigation of industry sound sources (emphasis on seismic airguns) as they relate to marine life. The program's goals are to improve industry risk assessments, reduce regulatory uncertainty, and contribute to the scientific literature on the effects of acoustic sources on marine mammals and fish. The program uses procedures for soliciting, reviewing, and selecting proposals modeled after those of the U.S. Office of Naval Research. The JIP started in 2006 and is halfway through its second three-year funding phase. Sixty three projects have been started to date (~$25M spent); 10 are still active. JIP projects cover 10 of the 15 topics listed for this workshop. Final reports of the completed projects are available on the JIP website (www.soundandmarinelife.org), and in the open literature. This talk will discuss the breadth of the program, its major contributions to date, and the projects that are still under way. The funding of new projects in 2011 has been curtailed due to the present high cost, and future unknown costs, of a study on the effects of airguns on humpback whales in Australia, funded jointly with BOEMRE. The few small projects that may be started in 2011 will also be discussed.

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The Current U.S. Navy Approach to Environmental Effects of Underwater Sound

Robert C. Gisiner

The U.S. Navy currently conducts all acoustic activities on its test and training ranges under Marine Mammal Protection Act permits issued by the regulatory agency, National Marine Fisheries Service (NMFS), which is also an official cooperating agency partner in the Navy's risk assessment, monitoring and risk mitigation program. The types and levels of activity at each site are reviewed annually by the US Navy and NMFS, along with all recent marine mammal survey, monitoring and research data.
This information is used to shape the subsequent year's plan of naval training activities, environmental monitoring, and research. This process is typical of the Adaptive Management processes applied in fisheries management and many other environmental resource management practices today. The Navy's Integrated Comprehensive Monitoring Program (ICMP) will be reviewed and the various steps of interagency communication, public outreach, and internal planning and documentation will be described. The ICMP process meets the adaptive management goals of monitoring the ongoing health of the environment in which the Navy operates, and managing naval training and exercise activities to minimize environmental risk without loss of national security mission readiness.

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Conceptual, mathematical and statistical frameworks for evaluating the effects of sound on marine mammal populations

John Harwood (1), James S. Clark (2), Daniel P. Costa (3), Len Thomas (1), Peter Tyack (4)

Concern about the harmful effects of anthropogenic sounds on marine mammals originally focussed on their potential physiological impacts. More recently, concern has grown about the effects of sound on behavior - largely because this can affect a much higher proportion of a local population.
In 2005 a National Research Council Committee on Potential Effects of Ambient Noise in the Ocean on Marine Mammals developed what it called "a conceptual model that will relate behavioural responses caused by anthropogenic sound to biologically significant, population-level consequences." In the last two years a US Office of Naval Research (ONR) working group has attempted to formalise this conceptual model into a set of nested, stochastic spatio-temporal mathematical models that can be fitted to observational data from marine mammal populations.

The ONR working group has focused on a number of case studies where there are good data on the effects of changes in behaviour on individual marine mammal energy budgets, and on the potential effects of changes in these energy budget on vital rates. In this presentation, we will provide a general introduction to the mathematical and statistical approaches the group has used to construct and fit mechanistic models of individual animal behaviour for these case studies. Outputs from these models, such as the estimated distribution of calf/pup survival as a function of different levels of disturbance, are then used as inputs for simulation-based studies of the effects of changes in vital rates on population outcomes, such as growth rate.

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Controlled exposure study of bottlenose dolphins and California sea lions to simulated mid-frequency sonar signals

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The United States Navy is required to predict the impact of its major acoustic activities on marine mammals. Currently, behavioral impacts are estimated through a dose response function, which predicts harassment as a function of received sound pressure level. However, data suitable for defining the form of the function are scarce. Thirty dolphins and 15 sea lions from the U.S. Navy Marine Mammal Program participated in a controlled exposure study to determine the magnitude and occurrence of behavioral reactions associated with exposure to a sonar-like signal (~3250-3450 Hz). Animals were trained to swim across an open-water pen, touch a paddle, and return to the starting point. Ten trials were performed as a baseline followed by ten trials during which sound exposure occurred at the midpoint of the pen. Received sound pressure levels ranged from 115-185 dB re 1 μPa (RMS), but remained constant for each individual. An *a priori* severity scoring of anticipated behavioral responses was made by 14 anonymous scientists. "Blind" observers then scored reactions from session videotapes with the transmission audio removed to prevent distinguishing between control and experimental sessions. Blood samples were collected from dolphins one week before, immediately following, and one week after the exposure for stress hormone analysis. A subset of the dolphins wore heart rate monitors and acoustic dosimeters. The study provides a unique data set demonstrating the direct relationship between received level and behavioral response under a controlled situation. It demonstrates that profound behavioral responses can occur without overt physiological indicators of stress.

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Audibility and effect on behaviour of naval related sounds

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Anthropogenic sounds may be detrimental for harbour porpoises, as sound is a very important parameter in their ecology. Naval activities often produce underwater sounds. The first step in estimating the impact of a sound is to determine the distance up to which the sounds can be heard by a species, and the distance at which behavioural effects start to occur. Therefore, SEAMARCO was commissioned by the Netherlands Ministry of Defence to study the hearing sensitivity and effect on behaviour of a harbour porpoise for defence-related sounds. A psychophysical technique was used to determine 50% hearing thresholds for ship-mounted LFAS (1-2 kHz) and MFAS (6-7 kHz) up-sweeps and down-sweeps, for 5 helicopter 'dipping' sonar sweeps (HELRAS, 1.43-1.33 kHz down-sweeps and CW), and for an impulsive sound (mimicking a detonation sound). All studies were conducted with the same porpoise and so are comparable. The LFAS and MFAS hearing study showed that the presence of harmonics can greatly influence the detectability of sounds. This is because the hearing sensitivity of the porpoise increases sharply with increasing frequency in the frequency range of the fundamental frequency and harmonics. The frequency band of the HELRAS signals is so narrow, and the harmonics are so weak, that hearing thresholds for them can be predicted from the tonal audiogram. The hearing threshold for the detonation sound was much higher than would have been predicted from the tonal audiogram. The LFAS and MFAS behavioural study showed that harmonics can strongly influence the 50% startle response level. In peace time, sonar systems should produce sounds with weak or no harmonics, to reduce the sounds' impact on porpoises. The HELRAS down-sweep without harmonics had to be transmitted at a much higher level than the other signals before the 50% startle response level was reached. In peace time, this signal should be used to reduce impact on porpoises. In studies with higher duty cycles of ship-mounted LFAS and MFAS up-sweeps and down-sweeps, and 4 helicopter 'dipping' sonar sweeps, the effects of harmonics and of up- versus down-sweeps was learned. All studies were conducted with the same porpoise, and so are comparable.

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Hearing Risks in Underwater Ears: What the Incidence of Hearing Impairment in Wild Animals May Tell Us about Potential Impacts

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Although there are lightless ocean regions, none are soundless. Consequently, accurate acoustic percepts are critical for survival. Increasing human activities raises concerns for anthropogenic noise impacting species within our "acoustic reach". However, species and individuals vary substantially in their hearing abilities and therefore in susceptibility to noise impacts. Thus, there is no single “sound byte” that is universally, equally hazardous. To address these issues we must understand several critical interactions: how anthropogenic sounds compare with the hearing sensitivities of mobile individuals with varying acuity in multiple species in a range of soundscapes.

There has been substantial work on noise impacts in captive marine mammals and fishes. From these, we know some injury response mechanisms in fish basilar papillae and marine mammal cochleae are similar to those in land mammals. Noise induced hearing loss (NIHL) results from overstimulation of stereocilia and may be recoverable (TTS) or, if prolonged or intense, permanent (PTS), but the onset of TTS and PTS varies widely by individual, partly based on “ear health”, a critical factor in noise susceptibility. Thus, the distribution and range of ear conditions in the population affects the probable population level impact of any sound source. Current data demonstrate that marine species, like humans, sustain multiple conditions which in can diminish or exacerbate potential noise impacts. For a realistic risk analysis, it is important to consider population hearing variations rather than presuming uniformly optimal hearing across all individuals.

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Sonar exposure experiments on cetaceans in Norwegian waters - overview of the 3S-experiments

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The 3S-consortium, consisting of the four main partners FFI, TNO, WHOI and SMRU and several associate partners, has been conducting exposure experiments to study behavioral responses of cetaceans to naval sonar since 2006. The initial target species studied in the Norwegian Sea were killer whales, long-finned pilot whales and sperm whales. A total of 50 DTAGs were deployed and 14 dose escalation experiments have been conducted on these species. Our experimental design includes the use of an operational sonar source (SOCRATES) approaching the animal while transmitting 1-2 kHz, 6-7 kHz or no signals. In addition we conducted playbacks of killer whale sounds and collected baseline data from the same species in the same area. Data collection included measurements of acoustic dose, social behavior, horizontal movements, dive behavior and vocal behavior using a combination of archival tags (DTAGs) and observations from a second vessel. In 2011 the 3S-group initiated a new set of experiments on northern bottlenose whales, humpback whales and minke whales in the Barents Sea. The first trial was conducted in June 2011. The dose escalation design was kept mostly unchanged, but in addition we also conducted experiments to investigate the effectiveness of ramp up in mitigating risk to marine mammals.
The presentation will give an overview of the 3S-project as an introduction to several presentations on specific data analysis.

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Changes in dive behaviour and risk of bubble formation in deep-, intermediate and shallow diving toothed whales during exposure to naval sonar.

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It has been suggested that increased N_2 tension, and thereby an increased risk of tissue N_2 gas bubble formation, could occur if the sonar affects the dive behaviour or the physiological responses during diving, and that this represent a causal link between the use of naval sonar and whale strandings. To test this hypothesis, we used a combination of analysis of dive behaviour and a previously published mathematical model to estimate blood and tissue N_2 tension from dive records of sperm-, killer-, pilot-, Blainville's beaked- and Cuvier's beaked whales before, during and after exposure to Low (LFAS 1-2 kHz) and Mid (MFAS 2-7 kHz) frequency active sonar signals (3S and BRS data). Our objective was to determine if 1) natural species differences in dive behaviour affect risk, i.e. end-dive tissue and blood N_2 levels, or if sonar induced changes in 2) dive behaviour- or 3) hypothetical variation in the dive response are plausible risk factors. Contrary to previous modeling studies, our results suggest that deep dives generally appear to constitute a higher risk than shallow dives in the pre-exposure period. Sonar caused some changes in dive behaviour, but this did not lead to any consistent changes in end-dive blood or tissue N_2 levels. A hypothetical removal of the dive response during sonar exposure, caused a much greater variation in end-dive N_2 levels than did the behavioural response for all species at all dive depths. We conclude that behavioural and physiological adjustments appear to have the potential to alter the blood and tissue end-dive N_2 tension to potentially harmful levels which could cause formation of *in vivo* bubbles, but the actually observed behavioural responses of cetaceans to sonar do not imply increased risk. However, the results suggest that physiological changes during diving in large whales require further consideration.

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Recent developments of detection-classification-localization (DCL) technology; how far can we get exploiting passive acoustics?

Lam, Frans-Peter, Sander von Benda-Beckmann, Sander van IJsselmuide, Mark van Spellen

In 2004 the TNO *Delphinus system* for marine mammal detection was first tested at sea. By modifications on a nearly yearly basis, both on the hardware and the software, the system has matured and further tested in different environments and for different applications. At present, more seems feasible than expected beforehand, and also theoretical understanding of performance is now better understood by modeling verified by measurements. Potential applications are explored both for experimental (BRS) support, as well as for mitigation purposes, stand alone or integrated in operational systems. In this paper we will briefly present an overview of the background of the system and show latest improvements of the system. Left-right ambiguity is attempted to be resolved at high frequencies, and dedicated localization results will be illustrated, together with initial observations of Northern Bottlenose whales (*hyperoodon ampullatus*) of the latest 3S-11 BRS trial (June 2011) in the Norwegian Sea.

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An environmental NGO view on underwater noise

Eelco Leemans, Monique van de Water

Stichting De Noordzee / The North Sea Foundation is the nature and environmental organization dedicated to the sustainable use of the North Sea. Shipping, fisheries, spatial planning and nature conservation are our key areas of focus. As an expert advocate, the majority of our work is happening behind the scenes. We expose problems, lobby at national and international (EU, UN) level, seek out a dialogue with policymakers and those using the sea such as fishermen and windfarm builders, and propose realistic solutions.

From a biological viewpoint the North Sea is a very rich ecosystem. Apart from more than 200 fish species, the North Sea also hosts several marine mammals: seals, dolphins, porpoises and whales. The North Sea is also one of the busiest sea areas in the world, with human activities growing year by year.

When it comes to underwater noise, An inventory by TNO shows that the most pressing issues in the North Sea are pile driving for wind parks, shipping and seismic surveys. Apart from these activities, detonating WW2 explosives is also a cause for concern.

The North Sea Foundation, as a science-based organization, cooperates with ministries, experts (TNO) and users of the sea, to find solution based on consensus. We organize workshops to discuss issues in an open dialogue, often resulting in a set of agreements among stakeholders. Our latest activities is the installment of a think tank with Dutch noise experts. This Group will expand on the possibilities to regulate underwater noise in the North Sea.

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Passive acoustic detection and visual sightings of Cetaceans west off Portugal and in the Azores Front area

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This paper presents results of two sea trials in 2010 an 2011, conducted to assess the habitat use of Cetaceans in these areas and to test and evaluate the use of passive acoustic monitoring systems.
The first trial in 2010 was coordinated by the NATO Undersea Research Centre (NURC) in the area west off Portugal to investigate the habitat use of marine mammals, with the primary focus on beaked whales. Our goal in this joint research program was to test and evaluate a passive analysis software sonar (PASS) including a special tool for marine mammal acoustic detection (MMAD). The PASS system was connected to a towed array operated by CIBRA, University of Pavia and to an array operated by NURC. Automatic PASS detections were compared to those registered manually by experienced CIBRA operators. In total 14 species were sighted visually (10 identified and 4 undetermined), 9 species were identified acoustically by operators. Results of the PASS classifiers showed an accuracy of more than 90 % for delphinid species, but 25 % for sperm whales and a high amount of false alarms for beaked whales. Beaked whale detections were overlaid by dolphin clicks when these occurred at the same time.
During a second trial in 2011, conducted by WTD 71 in the area of the Azores Front, a new towed hydrophone array for passive acoustic monitoring was used. Here we present preliminary results of this line-transect cetacean survey, including acoustic detections and visual sightings along the Azores current system.

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Ecosystem monitoring: providing the proper context for interpreting behavioral responses of marine mammals

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Understanding behavioural response of marine mammals to environmental change such as sound produced by Naval activities requires comprehensive monitoring of the marine ecosystem. Incorporation of acoustic systems into ocean moorings and observatories provides important data to more fully interpret ecosystem responses to environmental perturbations. A passive acoustic recorder and three-frequency echosounder were integrated into a biophysical mooring on the eastern Bering Sea shelf. A temporary, mid-winter retreat of seasonal ice was detected from hydrographic data for a two week period in March 2009. Passive acoustic data provided a simultaneous time series of marine mammal vocalizations and changing soundscapes (sound levels and spectral shapes) related to surface ice conditions. Acoustic backscatter recorded by the echosounders provided information on relative prey abundance before, during and after the retreat. During the retreat there was a marked decrease in detected vocalizations from ice seals and an increase in vocalizations detected from bowhead whales and walrus. Thus, the combination of information obtained from the biophysical mooring sensors and acoustic monitoring systems provided otherwise unavailable information on how the ice retreat changed the habitat utilization of the biological components of the ecosystem. This more complete description of animal response in a rapidly changing ecosystem demonstrates the utility of acoustic monitoring systems to develop and support various theories predicting changes in marine mammal behaviour and distribution in relation to ecosystem dynamics. In turn, this provides an overall context into which additional stimuli, such as Naval acoustic activity or other anthropogenic noise sources might affect the biological ecosystem.

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Developing dose-response relationships for the onset of avoidance of sonar by free-ranging killer whales (*Orcinus orca*)

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Assessment of the potential environmental impact of sonar activities is hindered by a lack of dose-response studies needed to enable prediction of the acoustic thresholds at which free-ranging whales react to sonars. To test what received levels of sonar trigger avoidance reactions in killer whales, we conducted 8 experimental exposures with 4 groups tagged with Dtags. Each group was tracked during gradually-increasing exposures to 1-2 kHz or 6-7 kHz sonar signals. Killer whales increased speed and changed travel direction to avoid the sonar source during 6 of the 8 exposures. Cessation of feeding was associated with avoidance in two groups, and we observed separation of a dependent calf from its group during an exposure within a narrow fjord. Response thresholds from 94 to 164 dB re 1 μPa received sound pressure level were fit to a logistic dose-response function, which gave a predicted 50% response at 134 dB using all 8 exposures, or 128 dB using the first exposure for each group. Based upon published hearing thresholds of killer whales, the sensation level of a 6-7 kHz sonar signal would be 30 dB higher than that of a 1-2 kHz sonar signal at the same sound pressure level, but there was little indication that responsiveness depended upon sonar frequency. Our results suggest that exposure to sonar can lead to biologically relevant avoidance responses, but that received sensation level may provide only a weak predictor of the onset of avoidance. These data will be incorporated into a newly-developed Bayesian dose-response analysis framework that seeks to infer population-level dose-response curves, accounting for individual random effects, measurement uncertainty, and fixed effects of prior exposure and sonar frequency.

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The severity of behavioural changes observed during experimental exposures to sonar

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The 3S project seeks to describe and quantify the effects of sonar on wild cetaceans using controlled exposure experiments. In 2006-2009, 14 experiments were conducted with killer (N=4), longfinned pilot (N=6) and sperm (N=4) whales including 13 6-7 kHz upsweep sonar, 13 1-2 kHz upsweep, 5 1-2 kHz down-sweep exposures, 9 silent vessel controls, and 8 playbacks of killer whale sounds. We conducted experiments using operationally relevant source levels and a towable source that approached the subject following a ramp-up, resulting in gradual escalation of the sonar received level which was measured from Dtags and hydrophones towed from the observation vessel. Observations of whale behaviour were made using Dtags attached to one or more individuals in the target group, position tracking, and observations of group-level and surface behaviour. Detailed analysis of this rich dataset compiled into a technical report indicated a range of behavioural changes that we consider to be putative or possible effects of the sonar. Two panels independently scored the severity of behavioural changes observed during each sonar and control exposures, using the 0-9 point severity scale of Southall et al. (2007), and the two panels then reached a consensus. We found changes to diving, vocal, and movement behaviour, the most severe including calf separation, cessation of feeding and resting, and sustained avoidance of the source. This descriptive approach is helpful to define the most severe behavioural changes that occurred during our experiments, to identify and describe the diversity of potential responses to sonar, and to form specific hypothesis for further statistical analyses.

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Estimating the effect of Mid-Frequency Active (MFA) sonar on U.S. Navy ranges

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The U.S. operates multiple undersea ranges including the Atlantic Undersea Test and Evaluation Center (AUTEC) in the Bahamas, the Southern California Offshore Range (SCORE), and the Pacific Missile Range Facility off Kauai. Each provides a large field of hydrophones that are being used to develop passive acoustic tools to monitor cetaceans, including beaked whales, in the presence of mid-frequency active (MFA) sonar. Routinely, Blainville's beaked whales (*Mesoplodon densirostris, Md*) are detected at AUTEC and Cuviers's beaked whales (*Ziphius cavirostris, Zc*) are detected at SCORE, despite frequent use of sonar. A review of this research will be provided, including the broad-scale reaction of Blainville's beaked whales to MFA sonar, the results of passive acoustic density estimates for *Md* at AUTEC and *Zc* at SCORE, and the proposed Population Consequences of Acoustic Disturbance (PCAD) model for *Md* at AUTEC. These studies indicate beaked whales react to sonar at relatively low exposure levels (<140 dBreμPa@1m) which presents a distinct challenge to environmental regulators. At the same time, the movement of animals off the ranges suggests an avoidance behavior that would result in a low probability of a Temporary or Permanent Threshold Shift (TTS/PTS) in hearing; measures that are often used to determine the receive level of sonar that causes damage to animals. It is hoped that the combination of tools under development will provide a means of characterizing this avoidance behavior and allow cost effective long-term monitoring, while gaining insight into the effect of repeated sonar exposure on the health of the population.

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Modelling the effects of acoustic disturbance on beaked whale populations

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What appears to be a population of Blainville's beaked whales (*Mesoplodon densirostris, Md*) has been documented on the Atlantic Undersea Test and Evaluation Center (AUTEC) despite the frequent use of mid-frequency active (MFA) sonar. Passive acoustic monitoring around multi-ship MFA sonar operations strongly suggests these animals avoid sonar and move off the instrumented range during exercises. The effect of this displacement from what are presumed to be foraging grounds, based on the animals' persistent presence and measured dive behaviour, is unknown.
An energetics–based population model, following recommendations by the Office of Naval Research sponsored Population Consequences of Acoustic Disturbance (PCAD) working group, is being implemented to estimate the effect of such exercises on the health of the population. The model focuses on the relationship of prolonged displacement to female survival and reproduction. Tag data indicate vocalizations and therefore foraging are restricted to deep dives. Therefore, these dives can be used a proxy for caloric intake. Since the animals metronomically dive at a known rate, disruption of diving can be used to predict the total energy gain or loss over the period of disruption. The model combines the estimated of change in energy stores with published estimates for *Md* metabolic rate to predict the total energetic cost to adult females over a year, and relates it reproduction and survival within the population.

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Audiogram of a young male stranded Blainville's beaked whale (*Mesoplodon densirostris*) measured using auditory evoked potentials

Paul E. Nachtigall and Aude F. Pacini

The first association between sonar and stranded cetaceans was made between sonar and beaked whales. These cryptic species have not been kept in captivity and good measures of their hearing are rare. A young male Blainville's beaked whale stranded on Maui, Hawaii and was taken in for rehabilitation in a quiet tank. Measures of its hearing were conducted using and auditory evoked potential procedure. Thresholds to a total of 11 sinusoidally amplitude modulated tones were tested ranging from 5.6 to 160 kHz. The audiogram data indicated that the region of best hearing was found between 40 and 50 kHz with thresholds below 50 dB. This frequency range partially overlaps with the frequency modulated upsweep Blainville's beaked whales have been reported to use during echolocation. Concern for Blainville's beaked whales has been expressed in association with midfrequency sonars. The threshold for this whale at 5.6 kHz was 79.2 dB Cetaceans exposed to sonars are extremely unlikely to be effected by sound that they cannot hear. Audiograms provide quantitative measures of the level at which animals just begin to hear. Within limits, the level of sound from its source or origin can be predicted. If navy exercise planners had the auditory thresholds of all of the species found in the area of the exercise, they could predict minimum safe ranges for sound exposure for marine mammals.

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Do cetaceans change their hearing in response to signaled loud sound?

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Odontocete echolocation requires that animals produce short loud clicks that frequently exceed 200 dB that are followed immediately by echoes that are substantially quieter. The essential information for prey detection, discrimination and tracking is found in the echoes. We have been examining the hearing of both the outgoing clicks and the returning echoes of actively echolocating odontocetes using evoked auditory potential techniques.
In order to protect itself from the loud outgoing sound while still maximizing the hearing of the acoustic echo return, odontocete echolocators appear to have developed both passive and active control of their hearing. Passive control has been demonstrated by comparing hearing of their own outgoing signals to the same level signals presented to them from the outside. Clicks produced by the animal itself are heard about 40 dB down. Active control has been demonstrated by a comparison of hearing outgoing clicks during target present and target absent trials. During target absent trials, when searching for targets, clicks (and overall hearing) is 20 dB better than during target present trials. The critical question currently under examination is whether or not this hearing control is limited to echolocation. Does the animal have an active control of the hearing of loud impulsive sounds presented from the outside? If the animal is warned that a loud sound is about to arrive, does it possess a mechanism of self-mitigation that will allow the animal to control its own hearing and reduce the level of the incoming sound?

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Behavioral response of short-finned pilot whales to a scientific echosounder

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Studies of the forging ecology of marine mammals require observations of the prey field, which are typically obtained using scientific echosounders. It is not known, however, whether the signals produced by these echosounders influence the behaviour of marine mammals. This is particularly important for deep-diving odontocetes, which may forage at depths of more than 1000m, on relatively small prey. Quantitative descriptions of the biomass and distribution of such prey require considerable source levels. To address this question, therefore, we conducted a controlled field experiment to examine the response of short-finned pilot whales (*Globicephala macrorhynchus*) to signals produced by a SIMRAD EK-60 scientific echosounder system. We placed Digital Acoustic Tags (DTags) on 11 pilot whales off Cape Hatteras, North Carolina during May and June 2011 and conducted synoptic focal follows of the tagged whales and their groups using focal-animal sampling techniques. The experimental protocol consisted of one hour of pre-exposure conditions, followed by an hour of control or experimental conditions (in a randomized order) and then an hour of post-exposure monitoring; the observers conducting the focal sampling were blind to the experimental condition. During the experimental period, a research vessel approached the focal group with the EK-60 system producing pings at 38kHz every 2s at 2kW. We obtained biopsy samples from the tagged animals at the end of the post-exposure period to determine their sex. We are currently analyzing these data to determine how the whales respond to the sounds of the EK-60 system by examining vocalization rate and three-dimensional orientation of the tagged whales from the DTag records, together with observations of group cohesion and behaviour from the focal follows.

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Acoustic detection of beaked whales. Comparison of different equipments and techniques.

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Beaked whales are known to mass strand as result of naval sonar exercises and the ability to mitigate such negative effects is of increasing importance world-wide.
Expanding knowledge about their presence, distribution and density is of primary importance for both the planning and the execution of naval exercises, as well as other activities that may have an impact on them. Passive Acoustic Monitoring (PAM) techniques have been successfully employed to detect and track diving Cuvier's beaked whales as well as to assess their distribution and density over wide areas. We present and compare results obtained with different sensors, including wideband towed arrays operated by either oceanographic ships and sailing boats, towed sensors in 3D configuration wideband sonobuoys, and sea bottom sensors. Software solutions to make easier for the PAM operator to detect and track the animals are also presented and discussed considering real-world constraints. DSP techniques for Detection Classification and Localization (DCL) are also discussed.

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Vessel noise affects beaked whale behaviour: results of an acoustic response study

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Increasing evidence suggests that some beaked whale species are particularly susceptible to the detrimental effects of anthropogenic noise. Most studies so far have concentrated on the potential impact of military sonar, but other forms of acoustic disturbance (e.g. shipping noise) have been shown to disrupt behavior. A series of Ship Noise Evaluation Trials (SNETs), involving the exposure of target whale groups to intense vessel-generated noise, were carried out to test whether and how these exposures influenced the foraging behavior of Blainville's beaked whales (*Mesoplodon densirostris*) in the Tongue Of The Ocean (Bahamas). A military array of bottom-mounted hydrophones allowed tracking of the vocalizations of the groups. The archived acoustic data were used to compute metrics of the echolocation-based foraging behavior for 16 targeted groups, 10 groups further away on the range during the SNETs, and 26 non-exposed groups. Gaussian and Poisson Generalized Linear Models were used to assess the effect of the SNETs. While the duration of the foraging bouts was not affected by the exposure, the number of changes of the center hydrophone over which the whales were located decreased the closer the whales were to the sound source. A significant difference in this metric was also found between non-exposed groups and groups that were exposed to the noise at any distance. Our results suggest that broadband ship noise causes a subtle but significant disruption of beaked whale behavior, with potential energetic costs, at up to 27 kilometers away from the source.

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Designing and operating the 'whale friendly', submarine unfriendly sonar

John Polglaze

Navies need to conduct ASW sonar operations in a manner which not only recognises and addresses potential risks to sensitive marine fauna, yet which also strikes the correct balance with the need to develop and maintain essential warfighting skills. If not properly managed, the imposition of marine mammal risk mitigation measures can impede naval training and the development of critical personnel competencies, as well as equipment tests and trials. Conversely, the standard operating modes of many existing sonar systems result in unnecessary and otherwise avoidable acoustic exposure to marine fauna, and can restrict the risk mitigation options available to navies.

An enlightened approach to the design of ship sonar systems, and their methods of employment, can result in a diminution of risk to sensitive marine fauna, without tangible detriment to the operation of those systems. Furthermore, in some circumstances operating features intended to limit marine fauna exposure can simultaneously generate enhanced tactical effectiveness and utility.

The author has been involved with the conceptual development of this nascent next generation of sonars, and has undertaken environmental risk assessments of the operation of systems developed within this new paradigm. The presentation will provide information on key design features and operating characteristics of the conceptual 'whale friendly' sonar, and provide illumination on how these features may be adopted at least without detriment to operational effectiveness, if not the enhancement of capability. The presentation will also relate other common aspects of sonar design and operation which can unnecessarily expose marine fauna to potential risk.

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The legal and policy regimes that govern the impact of naval sonar on the marine environment – some current trends of note

Roland J Rogers

This conference paper seeks to provide the attendees at the 2011 ESOMM with a review of some of the noteworthy trends in state, regional and international policy and law pertinent to the future management of the impact of naval active sonar on the marine environment. The review will be based on the support provided by the author to the United Kingdom Royal Navy's Sonar 2117 capability and thus the perspective given will be a UK Royal Navy one.

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The relationship between foraging, disturbances to foraging, and vital rates in elephant seals

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Elephant seals are capital breeders that go on extended foraging trips at sea to build lipid reserves before returning to land to molt or breed. Disturbances that limit the seal's ability to forage can reduce their lipid stores. In the case of females, this will lower their pup's weaning mass and thus its survival. If a sufficient number of females are impacted by disturbance this could lead to changes at the level of the population.
We built a state-space model describing elephant seal behaviour while at sea in relation to a range of environmental covariates, and fit the model to data collected from satellite tags using computer-intensive methods. Outputs from the model included daily estimates of change in lipid mass and parameters governing the interaction with environmental covariates, which were then used to simulate the possible effects of disturbance on the population as a whole by excluding females from preferred feeding grounds. This resulted in increased movement and decreased energy intake.
The duration of the disturbance, combined with the proportion of the population exposed to its effects, determined the impact of the disturbance on the vital rate of concern. Large changes in maternal lipid mass were needed to reduce pup weaning mass to any extent, so pup survival did not change greatly, but the effect of these changes accumulates over time. This has conservation implications, because widespread, minor disturbances could significantly affect the species' abundance.

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Biological and Behavioral Response Studies (BRS) of Marine Mammals in southern California (SOCAL-10)

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SOCAL-10 was a scientific research project conducted in Aug-Sept 2010 in important biological areas near southern California. The overall objective was to provide a better basic understanding of marine mammal behavior, while providing direct scientific information for the Navy and regulatory agencies to estimate risk and minimize the impact of human sounds, particularly military sonar. SOCAL-10 was the first in a five-year dedicated effort to study a variety of marine mammal species in areas around the southern California coast and Channel Islands. SOCAL-10 involved an interdisciplinary collaboration of experts in marine mammal biology, behavior, and communication, as well as underwater acousticians and specialized field researchers. During a preliminary scouting phase and two research legs on different research vessels, SOCAL-10 observed, photographed, and/or tracked in detail, individuals of 21 different marine mammal species. Sixty-three tags (of six different varieties) were successfully secured on 44 individual animals of nine different marine mammal species. Scientists also conducted 28 controlled sound exposure experiments. Animals were monitored with suction cup acoustic sensors, listening devices and visual observers. Sounds were played to the animals under specific protocols and protective measures and changes in behavior were measured. Preliminary results indicate variable responses, depending on species, type of sound, and behavioral state during the experiments. Some observations in certain conditions suggest avoidance responses, while in other cases subjects seemed to not respond, at least overtly.

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Progress with developing indicators of underwater noise for the EU's Marine Strategy Framework Directive

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The EU's Marine Strategy Framework Directive aims to improve the condition of all of Europe's seas and ensure that human usage of the seas is sustainable. The Directive will work by requiring EU Member States to set a series of objectives for eleven Descriptors of Environmental Status. One of the descriptors concerns underwater noise: "*Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment*." The European Commission has decided that two types of underwater sound will be addressed initially by indicators of the descriptor – high amplitude (loud), low and mid frequency impulsive sounds and ambient sound within the frequency bands dominated by shipping.

Two international groups of experts have addressed the issues underlying the ambitions of the Directive in order to provide practical ways forward. In doing so, some of the greatest challenges have been due insufficient knowledge of the full effects of sound on marine life. This work provides a good example of the results of legal requirements meeting the uncertainties of biological science and the complexities of physical science.

The paper will describe the processes outlined above and outline possible future outcomes and research needs.

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LATTE: Modeling the Behavior of Beaked Whales in Response to Medium Frequency Active Sonar

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We describe an ongoing project that aims to improve our understanding of the response of beaked whales to medium frequency active sonar by jointly modeling tagging and passive acoustic data from the US Navy's AUTEC testing range in Tongue of the Ocean, Bahamas.

We are developing a detailed, mechanistic model of the diving and acoustic behavior of Blaineville's beaked whale at AUTEC, and how this behavior changes in response to active sonar. The model will then be parameterized within a Bayesian statistical framework using information from four sources:

- published information from previous studies, including from other related species where necessary (for example for when describing the synchronous diving of individuals within a group);
- individual-level data collected using digital acoustic tags (DTags) affixed to whales under both non-exposure and exposure conditions at AUTEC over a time scale of hours;
- individual-level data collected using satellite tags affixed to whales at AUTEC before navy exercises and remaining on the whales during and after the exercise (although very limited data are currently available);
- population-level data on spatio-temporal patterns of echolocation clicks collected on the fixed bottom-mounted hydrophone array at AUTEC.

By combining information from all four sources, we anticipate being able to make more powerful inferences than can be gained from any one alone.

We describe exploratory analysis we have undertaken on the passive acoustic data, aimed at quantifying changes in the location of diving groups of whales coincident with active sonar from individual vessels.

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DECAF (Density Estimation for Cetaceans from passive Acoustic Fixed sensors) and beyond

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Passive acoustic monitoring is often used to obtain indices of relative abundance, such as number of detections per unit time. However, for many applications, the quantity we really want to estimate is absolute population abundance (i.e., the number of animals in the population) or density (number of animals per unit area). We give an overview of a completed 3 year, multi-agency project (DECAF) to develop and implement methods for estimating the spatial population density of cetaceans based on detecting the sounds they make on fixed sensors. We describe the range of methods developed, and how they were applied to estimate density of beaked and sperm whales at Tongue of the Ocean, Bahamas, and minke whales in Hawiian waters. Methods developed during this project have also been used to estimate the population size of North pacific right whales in the Bearing Sea. We discuss ongoing efforts to develop inexpensive methods for density estimation, based on fixed sensors capable of detecting the range to detected vocalizations (the "Cheap DECAF project"). Lastly, we introduce an ambitious ongoing project to estimate the density of harbor porpoise in the Baltic Sea, based on a set of over 300 autonomous detectors (C-PODs) deployed at a random grid of points for two years (the "SAMBAH" project). Passive acoustic density estimation is a fast-developing area with enormous potential. Nevertheless, the reliability of estimates is currently constrained by our knowledge about many species' acoustic biology, such as what proportion of the population make a given vocalization, and the average vocalization rate.

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Studying the behavioral responses of cetaceans to controlled exposures of sonar sound.

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Concerns raised about effects of anthropogenic sound on marine mammals have stimulated development of experimental studies of behavioral responses of cetaceans to anthropogenic and control sounds. The first such studies involved effects of petroleum industry activities, but the association of atypical mass stranding of beaked whales during naval sonar exercises has led to the development of new methods to conduct field experiments on these difficult-to-study species. An important area for current development involves developing theory and methods to evaluate the biological significance of behavioral and physiological responses to repeated sound exposure on both individuals and populations. However, the risk of most concern for beaked whales remains acute risk of stranding. I will describe the first sonar CEE to a Cuvier's beaked whale to provide an example of this kind of experiment. A Cuvier's beaked whale (*Ziphius cavirostris*) was tagged with an acoustic recording tag (WHOI DTag) on 29 Sept 2010 on a naval underwater range off southern California (SOCAL10 study).
The tag recorded animal movement data for 18.3 hours and acoustic data for
14.3 hours. Playback of simulated mid-frequency sonar pings commenced during the second deep foraging dive after tagging. The source level started at 160dB re 1μPa@1m, and increased by 3dB per ping up to 209dB. Received levels (RLs) recorded on the whale ranged from 84-138dB re 1 μPa rms. When the RL reached ~100dB, the whale stopped echolocating and made a rapid (up to 6.5m/s) descent from 1060m to 1160m. The whale then made a long slow ascent for 65 min, moving about 8 km away from the sound source before surfacing. During this interval, the whale fluked strongly and continuously, sustaining swimming speeds over 4m/s for 10 min, the highest observed among 13 *Ziphius* Dtagged to date in different locations. The interval until the next deep foraging dive was 6.6 hours, the longest observed for any Dtagged *Ziphius*. The intense fluking and high speed swimming observed here differ from responses observed in Blainville's beaked whales, *Mesoplodon densirostris*, but the reactions of both species include early cessation of clicking and a prolonged ascent. This high speed response could be a risk factor for stranding when exposure is more prolonged, intense or complex due to reverberant conditions or the presence of multiple or fast moving sources of sound.

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Social behavioural responses of pilot whales and killer whales to tagging and sonar sounds

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During controlled exposure experiments of the 3S behavioural response study off Norway, social behavioural responses of pilot whales and killer whales to tagging and sonar exposure were investigated. Behavioural parameters including group size, spacing, surfacing synchrony and display events were recorded for the focal group, in synchrony with tracking of the focal individual and data recording by suction-cup tags. Tagging phases were sampled for 11 pilot whale groups and
3 killer whale groups. Sonar exposure was sampled for 3 pilot whale groups and
1 group of killer whales. The data suggest alternative strategies of social behavioural responses to the different stimuli, as well as contrasting responses between species. During tagging, pilot whales showed increased coordination, with a preference for smaller groups and (very) tight group spacings, in combination with increased surfacing synchrony. Focal groups stopped logging and showed little display. Alternatively, asynchronous patterns associated with the start of foraging were recorded. In contrast, during sonar exposure, pilot whales preferred less coordinated states, showing a preference for larger groups with tight-loose spacing and medium-low surfacing synchrony, while starting logging, spyhopping and milling. While the limited sample size warrants caution in the interpretation of our data, interestingly, killer whales showed the opposite pattern, maintaining asynchronous patterns of surface behaviour -decreased surfacing synchrony, increased spacing, decreased group size, tailslaps and loggings- during the first period of tagging, while sonar exposure immediately induced a synchronous, tightly spaced, lined up travelling state, without display events. This indicates that potential disturbances, (close) vessel presence and sonar signals, are perceived differently by cetaceans, and elicit different, potentially tailored and species-specific responses.

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Underwater noise and the EU Marine Strategy Framework Directive

Leo de Vrees

The EU Marine Strategy Framework Directive (2008/56/EC) aims at achieving Good Environmental Status in European marine waters (the Mediterranean Sea, the Baltic Sea, the Black Sea and the North-east Atlantic Ocean) in 2020. This binding legislation was the EU response to the continuous high pressure on natural marine resources and high demand for marine ecological services. It was recognized that the marine environment is a precious heritage that must be protected, preserved and, where practicable, restored with the ultimate aim of maintaining biodiversity and providing diverse and dynamic oceans and seas which are clean, healthy and productive. In that respect, this Marine Directive should, inter alia, promote the integration of environmental considerations into all relevant policy areas and deliver the environmental pillar of the future maritime policy for the European Union.

The Commission is concerned with the potential impact of which certain frequencies of underwater noise could have on the marine environment, and especially marine mammals. Therefore underwater noise is one of the 11 descriptors of the MSFD.

In the last years Commission Decision (2010/477/EU) on Criteria and Methodological standards on Good Environmental Status, two indicators describe the potential pressure of underwater noise on the marine environment: one indicator is related to loud, low and mid frequent impulsive sounds; and the other indicator is related to continuous low frequency sound. Both aspects could have an impact on marine mammals but also other forms of live in the seas.

According to the MSFD, Member States are obliged to give an initial assessment of the status of the marine environment with regard to the 11 descriptors in 2012, describe what they consider Good Environmental Status and set targets to reach this status in 2020. A strategy with measures is expected from Member States in 2015.

At this stage we do know to some extent which type of mammal is sensitive to which frequency and energy level. What it means for its behaviour is less understood. Before measures can be taken, more knowledge is required on the source of the noise and the impact it has on certain species and their behavior. An EU technical working group assists Member States in standardizing the monitoring and assessment of the two indicators.

See also http://ec.europa.eu/environment/water/marine/directive_en.htm

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Introduction to the ONR Population Consequences of Acoustic Disturbance (PCAD) Working Group

Weise, Michael J

Sound in the oceans is generated by a variety of natural and anthropogenic sources, and may affect marine life at multiple levels from behavioural disruption to population level effects. Recent observations of marine mammal strandings coincident with loud, anthropogenic sounds have focused attention on the potential effects of such sounds on individual whales and populations. Numerous scientific and government panels and task forces have called for directed behavioural response studies to identify the causal link between sound exposure and behavioural responses that could lead to strandings and/or population level effects. Recent federally funded behavioural response studies are designed to obtain direct measurements of responses to simulated sonar and other sound exposure that indicate onset of behavioural disruption in different contexts. There is a need, however, to differentiate between disturbance resulting in minor behavioural changes and the disruption of biologically significant activities. In 2005, the National Resource Council set out to clarify the term 'biologically significant'. In the broadest sense, any action or activity becomes biologically significant in an individual animal when it affects the ability of the animal to grow, survive, and reproduce. The scientific work presented in the session represents a substantial advance in understanding of the population-level effects of multiple sources of disturbance, including sound, on marine mammals. In this presentation, we will explore the motivations for exploring effects of anthropogenic sound on marine mammals and examine the implications for government agencies and, potentially, industry.

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Effects of stress on marine mammals from acoustic exposure

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Marine mammals are exposed to a variety of potentially stressful anthropogenic inputs into or changes upon the environment, including noise, pollutants, threatening stimuli, and habitat disruption. The stress response in captive marine mammals has been shown to conform to the classical definition of the generalized stress response, which is defined by the activation of the hypothalamic–pituitary–adrenal (HPA) axis and which results in elevated levels of glucocorticoid (GC) hormones and neurohormones norepinephrine and epinephrine (i.e. catecholamines). Prolonged exposure to stress may result in immune system suppression, reproductive failure, accelerated aging, and slowed growth.
To effectively characterize the hormonal stress response, it is important to understand the natural variability of GC and catecholamines that support an animal's normal biological functions, so that the impact of additional stressors can be quantified. In 2005, the U.S. National Resource Council set out to clarify the term 'biologically significant', and recommended that the use of GC and markers to assess stress should be developed, validated, and calibrated for various marine mammal species, age-classes, and life-history conditions. GCs and other biomarkers were specifically identified in the report as potentially being mechanistically involved in the cascade of effects leading from behavioral changes to alterations in survival and reproduction. In this presentation, we will provide an overview of recent ONR workshop recommendations for stress-related research on marine mammals and related technological needs, and recently supported ONR research to evaluate and measure neuroendocrinological and biochemical indicators of stress in free-ranging marine mammals.

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Simulating exposure-avoidance strategies of killer and pilot whales using data from controlled sonar experiments

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Behaviour of killer and pilot whales exposed to low-frequency (1–2 kHz, SL=214 dB re 1μPa m) and mid-frequency (6–7 kHz, SL=199 dB 1μPa m) active sonar during the 3S-08 and 3S-09 research trials in the Vestfjorden area of Norway suggested that cetacean species may use different avoidance strategies in response to an approaching sound source. Hence, the sound reduction potential of 5 simple vertical and horizontal avoidance strategies was investigated. Whale movements were simulated with a Monte Carlo method, and the cumulative sound exposure levels the whales received were estimated using the beam-tracing model Bellhop. Simulations were based on the whale and source properties and propagation conditions during two actual 3S field experiments. Killer whales received slightly higher levels during foraging than travelling, while pilot whales received substantially lower levels when deep-diving. The highest levels were received by animals that kept diving in one location. For travelling killer whales approached by the sound source, the optimal course in terms of sound exposure reduction for animals with a fixed heading and for animals moving relative to the bearing of source was 100° and 130°, respectively. For foraging pilot whales the results were similar; 90° and 120°, respectively. Results are compared to the avoidance responses of free-ranging cetaceans to sonar observed during the 3S cruises.

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Using DTAG data to assess the diving physiology of Cuvier's beaked whales

Walter MX Zimmer (1) and Peter L Tyack (2)

Beaked whales are one of the least known groups of mammals, but have attracted increasing attention due to reports that connect naval sonar exercises to atypical mass strandings. Recent field studies using noninvasive archival tags that measure detailed behavioural parameters have revealed that beaked whales are extreme divers with behaviours that challenge standard physiological models. Extended breath-hold durations, which frequently exceed 60 min and may reach 87 min, make the Cuvier's beaked whale (*Ziphius cavirostris*) a champion among deep diving cetaceans. Understanding the physiology of such extreme diving capabilities is challenging, but analyzing the details of the diving behaviour should provide some insight into physiological limits. Here I present modeling of the oxygen intake of Cuvier's beaked whales that is derived from the dive profiles of whales that were tagged in the Mediterranean Sea. A total of 59 deep dives of 13 Cuvier's beaked whales were available for this analysis. By analyzing the long term dive behaviour and in particular number of the surface respirations one can show that, while the availability of oxygen is limited, the oxygen intake is on average compliant with the allometric expression found by Williams (1999) for the total cost of transport (COT) of swimming marine mammals. The dive profiles indicate further that the oxygen storage capacity of Cuvier's beaked whale is not sufficient to support substantial aerobic metabolism during long deep dives requiring either swimming gaits that are tuned to save oxygen consumption or temporary anaerobic metabolism.

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Passive acoustic monitoring of rare and elusive species

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Beaked whales can remain submerged for an hour or more and are difficult to sight when they come to the surface to breathe. Passive acoustic monitoring PAM not only complements traditional visual-based methods for detecting these species but also can be more effective because beaked whales produce clicks regularly to echolocate on prey during deep foraging dives. The effectiveness of PAM for beaked whales depends not only on the acoustic behaviour and output of the animals but also on environmental conditions and the Objective of the PAM implementation. Marine mammal risk mitigation is ideally served by establishing absence in the area of interest. Risk assessment and mitigation is normally performed by identifying and avoiding areas where animals are likely to occur (or be abundant), since data availability and high spatial and temporal variability of cetacean populations limit confidence in predicting absences. At the same time, rare species can be uncommon even in their preferred habitat, also because animals may not be detected all the time; if operational requirements force planners to choose such areas for naval exercises, establishing absence can become critical. If risk mitigation surveys are not designed properly it is very likely that elusive deep-diving beaked whales may be missed. Here we address and discuss the question of how much PAM observation is needed to qualify for a successful implementation.

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MAPS-IR: Automatic whale detection and identification using a shipborne 360° High Resolution Thermal Imager

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Both, non-governmental organizations and governmental agencies increasingly criticize the use of air-guns for marine geophysical research due to the enhanced noise levels these instruments introduce to the aquatic environment. To remedy possible detrimental effects to the marine fauna, mitigation measures are commonly requested by regulatory agencies, requiring in most cases visual observation of the ship's perimeter and shut down of seismic operations when cetaceans are sighted within a predefined exclusion zone around the airguns. To facilitate such observations, the MAPS-IR project aims at developing an automatic whale blow detection system on the basis of a 360° thermal imaging sensor, FIRST-Navy provided by Rheinmetall Defense Electronics, Bremen.

Here we present results from three recent RV Polarstern expeditions into polar waters (Arctic and Antarctic) during which we collected over 1500 thermal signatures of whale blows (e.g. Fig 1a). This data are being used to implement a learning algorithm which is capable of automatically detecting whale blows in a thermal image. During a three week real-time test at sea, the algorithm detected 145 whale blows at a reasonable false positive rate within ranges of up to 5 km distance.

Concurrent to the operation of the IR system, we logged over 1000 visual sightings of whale blows to the second to optimize and characterize system performance. Ongoing analysis tests these visual detections for their visibility in the thermal images. First results of these comparisons will be presented, including efficiency studies of the automatic detection algorithm.

Most recent system enhancements aim at species identification by use of an integrated high resolution visual camera system (PiP). During the last RV Polarstern cruise (ANT XXVII/2) the system was tested for the first time, successfully collecting several dozens of close-up images of whales (Fig 1c).

Fig 1. Concurrent infrared (a) and visual image (b) of blow of minke whale at 1525m distance (c). Recordings were automatically triggered by infrared detector.

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Underwater sounds and E&P industry from a NL EIA & regulatory point of view.

E. Dorenbos

Underwater sounds and E&P industry from a NL regulatory point of view.

For the E&P Industry in the Netherlands underwater noise is recognized as an area where further study is required. This is also driven by environmental impact assessment procedures as part of permitting processes. An update of the chosen way forward for underwater noise and the E&P industry NL will be presented.

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4 Abstracts (posters) – in alphabetical order

An Integrated Decision Aid for assessing the risk to marine mammals from naval active sonar: concept, perspectives and challenges

Arnold B-Nagy

The NATO Undersea Research Centre (NURC), through its Marine Mammal Risk Mitigation program, has played an active role in supporting naval exercise planners with information and expertise, in order to improve the effectiveness of their environmental scoping efforts. As part of this process, NURC is developing an Integrated Decision Aid (IDA), which specifically addresses the issue of estimating risks to marine mammals associated with the use of active sonar. The IDA is a risk assessment tool running on a web-based geographic information system, with two key components: a sound propagation model which displays maximum received sound levels corresponding to user-specified source characteristics and location; habitat suitability maps for the species of interest (focusing but not limited to beaked whales), derived from predictive models using known occurrences. By overlaying the resulting information we can plot areas of high vs. low risk areas to marine mammals stemming from different operational scenarios. Through its graphic interface the IDA can display additional relevant information, including NURC's marine mammal sighting and stranding data. We discuss the utility and place of the IDA as a risk assessment tool, relevant issues related to data quality/quantity when modelling species distributions and prospective work to improve the system.

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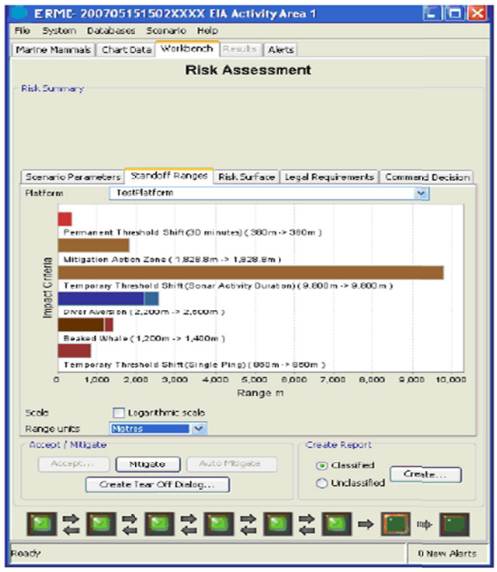
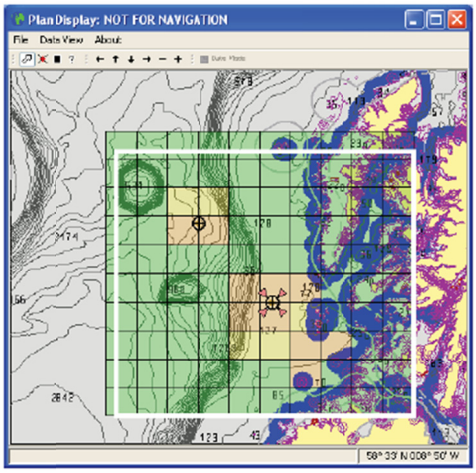
Environmental Risk Management Capability (Sonar) (ERMC(S))

Ric Elkington



The ERMC EIA defines standoff ranges for threshold shifts, diver injury aversion and species impact



ERMC allows geospatial assessment of an EIA in relation to environmental buffer zones, including an overlay of a risk surface showing the statistical impact upon marine fauna

ERMC(S) is the world's first fully integrated environmental impact assessment system suitable for Military and Naval use, with the capability to place world leading scientific advice at the fingertips of those responsible for operating active sonar.

ERMC(S) provides an automated solution for assessing the potential impact of underwater noise on marine fauna, allowing environmental risks to be quickly assessed and mitigated on-shore, or at sea as the scenario changes.

ERMC(S) is unique in its use of SAFESIMM algorithms developed by the world leading Sea Mammal Research Unit (SMRU) at the University of St Andrews in Scotland. These advanced risk assessment models account for the uncertainty in scientific knowledge of marine fauna densities and biological reaction to underwater sound, giving a better understanding of the risk. Risks are presented as a unique, intuitive, traffic light based display.

ERMC(S) is based upon an extensible knowledge matrix incorporating data, functions and rules that govern the EIA process. Tools are provided in the software to upload and incorporate the latest Conservation Area and Legal Boundary data. The core ERMC(S) package is supplied with global Environmental and Fauna datasets, which can be supplemented with available high resolution data for specific areas of operations.

The open system architecture employed in ERMC(S), uses technologies compliant with internationally recognised open standards, ensuring flexibility of hosting options and the replacement, upgrade or addition of new modules to the core system in order to exploit emerging technologies, new algorithms and legal or science developments.

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A bayesian multi-state model to quantify the impact of sonar exposure on sperm whale foraging

Isojunno, Saana (1), Petter Kvadsheim (2), Frans-Peter A. Lam (3), and Miller, Patrick J. O. (1)

We propose a Bayesian multi-state model for quantifying individual baseline foraging behaviour, and detecting changes that may lead to reduced prey encounter rate during 3S experiments off Norway. Detailed high-resolution data can be collected on individual diving and foraging behaviour by visual and acoustic tracking and onboard digital tags (DTags), and changes to individual behaviour in response to sonar exposure can be evaluated on a case-by-case basis. We estimated transition probabilities between different phases of dives (surface, descend, bottom and ascend) using conditional multinomial logistic regression. Acoustic recordings allowed for identifying searching and encountering prey, but not capture. Probability of silence, searching and encountering prey were estimated given current diving phase. Although the model is first-order, time-dependent covariates allowed for incorporating longer-term information. Available air, cumulative prey encounter rate in the current dive and exposure rate were used as covariates. Available air was estimated using current dive duration and strong priors on aerobic dive limit and oxygen loading. The model was fitted to an exposed individual that was tagged and tracked for 15 hours.
The odds of buzzing was reduced by factor of 0.75 during exposed bottom phases (Bayesian 95% credibility interval [0.52, 0.98]). No other significant changes could be detected in the acoustic states during the different dive states. Probability of surfacing tended to increase during exposure, but the parameter estimate 0.39 had wide credibility intervals [-0.07, 0.93]. The model will be fitted to another three exposed and three non-exposed whales using a mixed-effects model.

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The Aerial Rocket Tag System (ARTS) - a novel tool for tagging marine mammals

Lars Kleivane (1), Alessandro Bocconcelli (2), Petter Helgevold Kvadsheim (1), Michele Pelletier (2) and Patrick Miller (3)

The ARTS (Aerial Rocket Tag System) was originally developed by LKARTS-Norway and Restech Norway AS in order to deploy invasively attached VHF and satellite tags on fast moving baleen whale such as the minke whale. A number of research groups have used this compressed air launcher system for marine mammal research projects involving tagging and biopsies, and the ARTS has become a well-tested and established technique for such work.
The ARTS launcher has recently also been used to deploy the Woods Hole Oceanographic Institution (WHOI) digital recording suction cup tag (DTAG) during the 3S research cruises in Norway. After initial tests conducted at sea and in laboratory, the correct ratio of target distance and launcher power (pressure) was determined in order to obtain successful deployments on marine mammals without making the tag re-bounce back off, damaging the delicate electronics of the DTAG or harming the animal. A rugged version of the DTAG has now been built and the ARTS carrier has been modified in order to absorb the impact of the tag on the targeted animal. During cruises in Norway in 2009 and 2010 the ARTS launcher was successfully used to deploy DTAGs on pilot whales, killer whales and one minke whale. The ARTS system is particularly useful when tagging marine mammals that are fast moving and/or that are difficult to approach closely enough to deliver the DTAG with the traditional long carbon fiber poles (handpoles or cantilevered poles). The ARTS system thus has the potential to greatly enhance tagging efficiency, especially when working with difficult animals, such as beaked whales, killer whales and minke whales.

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Protection of Marine Mammals (PoMM)

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The European Defence Agency (EDA) project 'Protection of Marine Mammals' (PoMM) between the Ministries of Defence for Germany, Italy, the Netherlands and Norway started in August 2010 and will run for 3 years. The additional membership of Sweden and the United Kingdom is awaiting formal confirmation. The project aims to protect marine mammals against the impact of active sonar and maintain the ability to operate active sonar at the same time. A comprehensive common marine mammal database, being essential for risk mitigation tools, will be established. The database will provide knowledge on marine mammals with focus on the abundance, seasonal distribution and density of different species in areas of operational interest for European Navies. Special investigations on marine mammal acoustics, like the development of technological devices and algorithms, will help to improve the detection and classification of marine mammals.
This project will involve the collection and exchange of marine mammal data like seasonal density and distribution, sightings, strandings and species' characteristics. Due to the co-operation spatially limited data sets can be combined to a common global database, which is important for effective risk mitigation measures. Navies of the contributing members will be able to use the common database, both in the planning and in the operational phases, to avoid negative impact on marine mammals by military active sonars.

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Simulation of the effect of sonar emissions on toothed whales during ASW exercises and evaluation of mitigation protocols.

Laurent Mifsud(1), Martine Glemarec(1)
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Measuring animal sound exposure at sea is a risky initiative because of the difficulty to find species that are often elusive, the unavoidable danger on the animals involved by such experiments and the meteorological uncertainties. For these reasons, modelling the sonar effects using a simulation software appears to be the best way to go beyond these limitations.
The objective is firstly to develop a general tool allowing the assessment of ASW exercises relative to environmental mitigation and secondly, the assessment of mitigation protocols.
The animats are at the beginning uniformly distributed in the exercise area. Their behaviour is then managed by a Petri place/transition net taking into account the acoustic disturbances and their auditory sensitivity. Assets activities and the sonar emission schemes are modelled. An acoustic propagation model has been used after validation at sea. Variables of effectiveness are the received level and the cumulated sound energy along with time. The number of takes relative to the behavioural response is also calculated.

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SONATE – sonar effects on marine life

Nina Nordlund, Petter Kvadsheim

Since 2006 the Royal Norwegian Navy has implemented guidelines for sonar operations and the decision aid tool SONATE. The purpose of these guidelines are to minimize environmental impact of sonar operations and conflicts with maritime activities such as fisheries, whaling, fish farming and whale watching. Operations within the recommendations given by SONATE for different areas and time periods ensure that the operations are executed in compliance with the guidelines. Within the navy, all units using active sonar and all staff involved in planning of exercises which involves use of sonar, have access to SONATE. Foreign military units are also requested to comply with these guidelines during operations within Norwegian territorial waters, and are given access to SONATE upon request. SONATE contains data on the distribution of marine species, fishing activity etc. Information about species distribution and abundance as well as whaling is delivered by Institute of Marine Research, information about fisheries and fish farms is delivered by the Directorate of Fisheries, and information about whale watching activities is delivered by the tour operators themselves. SONATE is developed by FFI for the Norwegian Defense. SONATE is currently being developed from a standalone software into a web-based tool (WMS).

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Validation of the auditory tolerance limit in harbour porpoises (*Phocoena phocoena*) for exposure to construction noise from windmill turbines

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The planned construction of a large number of offshore wind farms in the German Bight and the high level of anthropogenic activities in the North and Baltic Sea raise concerns over the potential auditory impact on marine mammals. Therefore, an auditory study (Lucke et al. (2009)) has been conducted to derive data on the auditory tolerance limit in harbour porpoises (*Phocoena phocoena*) for exposure to construction noise from windmill turbines. Lucke et al. found a temporary threshold shift (TTS) at 4 kHz at a received sound pressure level (SPL) of 199.7 dB_{pk-pk} re1µPa and a sound exposure level (SEL) of 164.3 dB re1µPa²s. This level was only tested in one animal.
Therefore, the current project aims to verify TTS onset at the same level and to investigate the impact of exposure duration on the TTS onset level. This will be achieved using two different approaches. In the first project part wild porpoises, by-caught in pound nets along the Danish Baltic Sea coast, will be tested for the level published by Lucke et al. using an airgun as sound source. This will provide information about auditory tolerance from several animals. The second approach will be conducted on one porpoise in captivity at the Fjord & Bælt Centre (Denmark) to characterize TTS onset and the effect of exposure duration using a 3 kHz tone as a stimulus.
In July 2011, two by-caught animals were successfully tested in the Baltic Sea, resulting in the first data on hearing sensitivity from free-ranging harbour porpoises.

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SAKAMATA : a tool for risk assessment and mitigation

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SAKAMATA is a risk assessment and mitigation tool developed by TNO for use by the Royal Netherlands Navy. It supports the user in planning and carrying out active sonar operations in an environmentally responsible way. In SAKAMATA a scenario can be defined by positioning a platform on a map and selecting a sonar. A marine mammal database provides information on all marine mammals present. Environmental information is taken from a database or specified manually by the user. An exposure assessment is carried out based on these input parameters, sound propagation as computed by the TNO ALMOST model, and a behavioral avoidance response model.

The risk assessment is calculated by comparing the computed exposure with risk thresholds for temporary hearing impairment, and is presented to the user using a traffic light system to indicate the overall risk level. More detailed information on, for instance, stand-off ranges is provided per marine mammal group.

SAKAMATA also provides mitigation advice to reduce the risk. This includes advice on monitoring and ramp-up. SAKAMATA can also be used to assess the effect of mitigation measures, such as varying the sonar parameters or choosing a different area or time of year for the sonar operation.

Currently a new version of SAKAMATA is under development. In this version, the risk assessment will be based on various effects (permanent threshold shift, temporary threshold shift and avoidance). Also, more detailed marine mammal population densities will be used to estimate the number of animals involved.

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Extending our capability to determine distribution and abundance of marine mammals from line transect data

Len Thomas(1), Laura Marshall (1), Jay Barlow (2), Tim Gerrodette (2)

Line transect surveys are the most widely used method for obtaining estimates of marine mammal density and population size worldwide. We describe a project that is extending the capabilities of such surveys to provide robust estimates of density and distribution of marine mammals, by extending the industry-standard software Distance. The project has four components:
(1) To implement improved methods for spatial density surface estimation.
(2) To implement methods for analysis of complex survey designs.
(3) To extend methods for analysis of towed acoustic surveys so that they account for animal depth.
(4) To develop a simulation engine to allow realistic survey planning and optimization.
We give a brief overview of each.

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Novel approaches to calculating a C-POD detection function for the harbour porpoise (Phocoena phocoena)

Daniel Wennerberg (1,2), Len Thomas (3), Jakob Tougaard (4), Nick Tregenza (5), Jens C. Koblitz (6), Line A. Kyhn (4), Michael Dähne (7), Jonas Teilmann (4), Hanna K. Nuutila (8), Mats Amundin (1,2)

SAMBAH (Static Acoustic Monitoring of the Baltic Harbour porpoise) is an international European Union LIFE-funded project aiming to estimate density and abundance, and produce distribution maps of harbour porpoise in the Baltic Sea. To this end, static acoustic monitoring devices (C-PODs) will be deployed for 2 years at 300 locations on a randomly allocated grid covering most of the Baltic. The C-PODs contain on-board processing software and record the number and timing of detected echolocation clicks, together with summary statistics about each click. Estimating density from the resulting data requires calculating the area effectively surveyed by each C-POD; this involves estimating the relationship between probability of detection and range (the "detection function"). Several methods supplementing already published results will be employed some of which are playback trials, modeling based on theoretical porpoise click propagation, visual observations in an area with a grid of C-PODs, acoustic localization using a large array and acoustic tags on opportunistically caught porpoises recording their acoustic activity. We detail some of these, and discuss their pros and cons. One major constraint is that porpoise density is extremely low in many parts of the Baltic, hence finding a method that can estimate how detectability varies spatially is challenging.

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Anymals.org – a community driven biodiversity information tool for mobile phones

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The assessment of local biodiversity still mostly relies on the numbers produced by visual surveys. Those remain costly in realization. To maximize the effect of existing and newly gathered survey data projects like the Global Biodiversity Information Facility (GBIF) made huge progress in the distribution of such data by maintaining standardized easy and freely accessible database which can be used for scientific purposes.
Yet the amount of new observational data fed into GBIF remains on quite a low level. For the common Harbor Porpoise (Phocoena phocoena) there's only 862 occurrences in the last 10 years within the European seas.
The Long-finned pilot Whale (Globicephala melas) shows only has 37 occurrences in the last decade in the same region.
Here we present a new tool for information and logging purposes of local biodiversity. The main purpose of anymals is to inform people about the biodiversity around their current location. The core component is the anymals client. A software for ANDROID® based mobile Devices (smartphones and tablets) which retrieves Biodiversity information dependent on the users location from the GBIF and anymals Databases, and presents the available Information with automatically localized names (English, German, French, Spanish, Italian are available right now) and a picture of the occurring species. Further information about the species is provided by an automatic integration of the available content in corresponding Wikipedia articles. Furthermore the anymals software allows the citizen scientist to log sightings, of every share it with everyone.
Each sighting then will be directly fed into GBIF. We hope that this software can bridge the skilled observing community with a rapidly growing smartphone market. Such an active community could highly increase the input of current local biodiversity information into GBIF with huge benefits for the scientific community.

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