OCS Study
BOEMRE 2011-002

Status and Applications of Acoustic Mitigation and Monitoring Systems for Marine Mammals

Workshop Proceedings

November 17-19, 2009
Boston, Massachusetts

U.S. Department of the Interior
Bureau of Ocean Energy Management, Regulation and Enforcement
Gulf of Mexico OCS Region

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Editor

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FOREWORD

Any potential impacts that the Bureau of Energy Management, Regulation and Enforcement (BOEMRE) activities may have on marine mammals are significant program concerns and require mitigation and monitoring to lessen them. Although a variety of monitoring tools are currently employed, the most promising tool at present is acoustic monitoring.

The BOEMRE hoped at this workshop to identify, discuss and better understand the current status of acoustic hardware and software tools for marine mammal monitoring and mitigation as applied to offshore industries, along with some potentially beneficial applications under development. Both passive and active acoustic monitoring systems are currently available and in use. These systems are not only the most promising, but passive acoustic monitoring is also readily accessible, and active acoustic monitoring continues to be improved.

The BOEMRE appreciates all who were involved in this three-day workshop. The workshop was attended by over 200 people, with a wide range of interests and backgrounds, including industry, federal agencies, state agencies, non-governmental organizations, consultants, academics, and students.

We at BOEMRE hope to continue this dialogue with all interested parties as technology improves. Similar to the Joint Subcommittee on O cean Science and Technology (JSOST), BOEMRE would like diverse ocean science entities engaged, individually or through partnerships, to address research areas of utmost concern.

Thank you,
BOEMRE

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LIST OF ACRONYMS

AAM	active acoustic monitoring
ADB	automatic detection buoy
AR	autonomous recorder
BRP	Bioacoustics Research Program (at Cornell University)
BOEMRE	Bureau of Energy Management, Regulation and Enforcement
CETASS	cetacean towed array sonar system
DASAR	directional autonomous seafloor acoustic recorder
DET	detection error tradeoff
E&P	exploration and production
EIS	Environmental Impact Statement
ESA	Endangered Species Act
EPP	Environmental Protection Plan
FCH	fixed cable hydrophones
HARP	high-frequency acoustic recording package
HSE	health, safety and environment
HSEC	healthy, safety, environment and community
IHA	incidental harassment authorization
ITA	incidental take authorization
ITS	incidental take statement
JIP	Joint Oil and Gas Industry Program
LOA	letter of authorization
MARU	marine autonomous recording units
MMPA	Marine Mammal Protection Act
MMC	Marine Mammal Commission
MMO	marine mammal observer
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NMFS	National Marine Fisheries Service
NTL	Notice to Lessees
OBS	ocean bottom seismometer
PAM	passive acoustic monitoring
RLH	radio-linked hydrophones
ROC	receiver operating characteristic
SAC	Special Area of Conservation
SEL	sound exposure level
SNR	signal-to-noise ratio
TS	target strength
TTS	temporary threshold shift
USFWS	U.S. Fish and Wildlife Service
WHOI	Woods Hole Oceanographic Institution

EXECUTIVE SUMMARY

A workshop on the "Status and Applications of Acoustic Mitigation and Monitoring Systems for Marine Mammals" was held November 17-19, 2009, sponsored by the Bureau of Energy Management, Regulation and Enforcement (BOEMRE) and attended by over 200 participants. The objectives of the workshop were stated as follows:

> "Learn about, discuss, and better understand the current status of acoustic hardware and software tools for marine mammal monitoring and mitigation as applied to offshore industries. This will include the capability, applicability, feasibility, availability, cost and other benefits and limitations of acoustic systems as they pertain to different marine mammal and operational contexts. The discussion will focus on currently available acoustic systems, along with some potentially beneficial applications under development."

Following a workshop with such ambitious objectives, consolidation of key conclusions is obviously valuable, but taking a step towards closure is a challenge, due to the inherent complexity of the subject matter. These brief notes represent an attempt by the workshop's technical advisors to capture key conclusions.

Conclusion 1: Many of the basic software and hardware technologies to meet marine mammal monitoring and mitigation requirements exist, but most of these technologies have not been specifically designed for offshore industrial development. The appropriate combination of technologies for a project will likely require a site/case-specific, integrated approach because no one technical approach will satisfy all or even most marine mammal monitoring and mitigation requirements for the offshore industry. Simply put, "one size does not fit all." Furthermore, it should be clearly noted that all PAM systems (e.g., fixed, towed, or drifting[1]) only work if an animal produces a sound that can be detected with the system. An active acoustic monitoring system circumvents this limitation, but raises some concern because it also introduces sound into the environment.

Conclusion 2: Choosing and evaluating the best acoustic monitoring system for a specific project requires a thoughtful and thorough assessment of a project's objectives, coupled with a thorough evaluation of the regulatory monitoring and mitigation requirements, and the capabilities of the available acoustic technologies. This coupling of objectives with regulations and technical capabilities is an ongoing iterative process, where objectives may have to be modified as a result of specific monitoring and mitigation regulatory requirements and/or the inherent limitations of available systems.

Conclusion 3: Three general types of acoustic systems are available: fixed passive acoustic monitoring (fixed PAM), towed passive acoustic monitoring (towed PAM), and active acoustic

[1] Drifting PAM systems, such as Navy sonobuoys, were not discussed.

monitoring (AAM) systems. Each of these system types has somewhat unique data processing (including signal processing) requirements. Data processing needs and capabilities are an integral requirement in the design, operation, and evaluation of acoustic systems. As an example, most data processing software that is well suited to a fixed PAM system is not usually designed to work with a towed PAM system, and data processing software that is designed to work with one particular towed PAM system may not work at all with a different towed PAM system.

Conclusion 4: Fixed PAM technologies appear to be more mature than towed PAM or AAM technologies, although this does not necessarily indicate that a fixed PAM approach is the most effective in all situations. Fixed PAM has been used with great success in many settings, including predevelopment baseline studies, assessment of marine mammal responses to offshore facilities, and management of ship traffic to reduce the risk of collisions with whales. Despite these successes, a number of limitations and challenges were highlighted (see Conclusions section at end of report).

Conclusion 5: Towed PAM technology seems to be somewhat less mature than fixed PAM technologies, but more mature than AAM technologies. Towed PAM systems have been used with some success to supplement visual monitoring of exclusion zones in the North Sea, the Gulf of Mexico, and elsewhere. Despite these successes, a number of limitations and challenges were highlighted (see Conclusions section at end of report).

Conclusion 6: The AAM technology is less mature than either fixed PAM or towed PAM technologies. However, active acoustics is the only acoustic method capable of detecting animals that are not producing sounds. Despite the relative immaturity of active acoustics, recent tests indicate that it can be useful in some circumstances. Limitations or challenges associated with active acoustic systems are provided in the Conclusions section at end of report.

Conclusion 7: In some circumstances, the effectiveness of marine mammal monitoring and mitigation could be increased by using a combination of approaches. For example, a combination of marine mammal observers, towed PAM, and active acoustics would improve the likelihood of detecting and identifying marine mammals in the vicinity of potentially harmful activities. Similarly, a combination of fixed PAM and active acoustics may provide an improved understanding of apparent changes in the distribution of calling whales responding to industry sounds, a problem that has plagued at least some studies that relied only on a fixed PAM system.

Conclusion 8: The effectiveness of the marine mammal monitoring and mitigation process would significantly benefit from the development, establishment, and maintenance of a national (at least) or international (preferable) standardized, web-accessible ecosystem database (consisting of species seasonal presence/abundance and as many other important behavioral features as possible), coupled with a marine acoustics database (including marine mammal sounds, natural abiotic sounds, and anthropogenic sounds). This conclusion is consistent with many previous recommendations (e.g., NRC, 1994; 2000; 2003; Southall et al., 2007), including those expressed as a high priority by a task force of U.S. federal agencies considering this subject (Southall et al., 2009).

INTRODUCTION

The potential impacts of noise-producing activities on marine mammals from oil and gas exploration, sand and gravel resource assessment, future offshore renewable energy sources, and other offshore human activities are subject to review by the National Marine Fisheries Service (NMFS), the U.S. Fish and Wildlife Service (USFWS), the Marine Mammal Commission (MMC) and the Bureau of Energy Management, Regulation and Enforcement (BOEMRE) under the Endangered Species Act (ESA) and the Marine Mammal Protection Act (MMPA). Any potential impacts that regulated activities may have on marine mammal populations require monitoring for mitigation purposes under the ESA and the MMPA.

Both passive and active acoustic monitoring systems are currently available and in use for a variety of applications. Passive acoustic monitoring (PAM) for marine applications uses hydrophones placed in fixed underwater locations or towed behind vessels to detect vocalizations or other sounds that indicate the presence of animals. Active acoustic monitoring (AAM) is another method of determining the presence of marine mammals and other animals using sonar. Non-vocalizing marine mammals are potentially detectable with AAM, but only vocalizing animals are detectable with PAM. Many variations exist within these categories (that is, within fixed PAM, towed PAM, and AAM), both in the choice of hardware and in the design of a specific configuration for specific purposes. Significant improvements in the technology involved have occurred over the last several years, affecting the applicability of each technique. Recent improvements also underscore the potential usefulness of an integrated approach using both PAM and AAM in some circumstances.

As part of its regulatory responsibilities, and consistent with the coordinated science and technology objectives of U.S. federal agencies on monitoring the environmental effects of offshore industrial activity expressed in a task force report by the Joint Subcommittee on Ocean Science and Technology (Southall et al., 2009), BOEMRE convened a workshop in November 2009 to explore the capabilities and limitations of acoustic monitoring. Specifically, the workshop was designed to involve individuals from a wide variety of perspectives and expertise to learn, discuss, and better understand the current status of acoustic hardware and software tools for marine mammal monitoring and mitigation as applied to offshore industries. Speakers and participants discussed the capability, applicability, feasibility, availability, cost and other benefits and limitations of acoustic systems as they pertain to different marine mammal and operational contexts. The discussion focused on currently available acoustic systems, along with some potentially beneficial applications under development. The workshop was attended by about 200 people, with a wide range of interests and backgrounds, including industry, federal agencies, state agencies, non-governmental organizations, consultants, academics, and students.

Five experts in marine bioacoustics, marine mammal biology and conservation, or industry operations were asked to serve as advisors in planning this workshop and ensuring that it achieved meaningful results. They were: Dr. Christopher W. Clark, Cornell University; Dr.

William T. Ellison, Marine Acoustics, Inc; Dr. Bill Streever, BP; Dr. Brandon L. Southall, Southall Environmental Associates, Inc. and University of California, Santa Cruz; and Dr. Howard Rosenbaum, Wildlife Conservation Society. These experts provided context about the different types of underwater acoustic monitoring technology, regulatory requirements, environmental factors including implications for potential population and ecosystem baselines and impacts, and other related activities so that this workshop would complement previous work. The advisors suggested several dozen additional experts to consult in planning the workshop, many of whom were interviewed during the planning process and/or ultimately contributed to the workshop in various ways.

The design of the workshop was based on the results of this consultation process. Session I attempted to frame the discussion from three vantage points: existing regulatory requirements, technology, and the acoustic ecology of the marine mammals. Session II was organized into three sections, each highlighting a different type of acoustic monitoring technology. The first section focused on fixed passive acoustic systems. The second section focused on towed passive acoustic systems. The third section focused on active acoustic systems. Each of these three sessions included an overview presentation and three case studies. Session III included the technical aspects of signal processing and metrics. For each of the three sessions, a question and answer period followed the presentations. The last session of the workshop was an interactive panel that provided an opportunity to discuss operational issues that affect the success of acoustic monitoring technology and primarily focused on mechanisms that mitigate potential influences on marine mammals.

This report begins with an executive summary that describes the primary conclusions from the workshop developed by the team of technical advisors. This is followed by chronologically ordered summaries of the presentations in each of the three sessions, including various points that arose during the question and answer period following each session. The three topics discussed throughout the workshop are summarized as themes rather than chronologically.

PART I

PRESENTATION SUMMARIES

SESSION I: SETTING THE STAGE

The first session of the workshop was intended to provide a background understanding of the present requirements for acoustic monitoring and mitigation of industry activities that fall within the jurisdiction of the Bureau of Energy Management, Regulation and Enforcement (BOEMRE) and to highlight key concepts and criteria for assessing what kinds of improvements are desirable and the capabilities of existing tools to provide solutions.

Requirements for acoustic monitoring and mitigation of industry activities that fall within the jurisdiction of the BOEMRE and the National Marine Fisheries Service (NMFS) provide the framework for defining the desired capabilities for acoustic monitoring systems in a mitigation context, assessing the capabilities of existing tools to provide solutions, and determining what kinds of improvements are needed. Dr. James Kendall and Mr. Shane Guan offered perspectives from BOEMRE and NMFS, respectively (see below).

Dr. William Ellison discussed what is required for effective environmental compliance by offshore industries (compliance with existing regulations, effective monitoring and mitigation, and coordinated research and development), with emphasis on communication among personnel addressing these simultaneous needs. He specifically related this compliance approach to the design and implementation of PAM and AAM in the marine environment.

Dr. Christopher Clark completed the introduction by emphasizing the importance of understanding the acoustic ecology of the animals and the acoustic habitat of the environment within which an acoustic monitoring and mitigation system must perform.

Regulatory Framework

Dr. James Kendall, BOEMRE Chief Scientist and Chief of the BOEMRE Environmental Division, began by presenting an overview of the BOEMRE; a Bureau of the Department of the Interior under the Assistant Secretary for Land and Minerals Management.

Dr. Kendall articulated the BOEMRE mission: To manage the ocean energy and mineral resources on the Outer Continental Shelf and Federal and Indian mineral revenues to enhance public and trust benefits, promote responsible use, and realize fair value.” Or, more simply, and more pertinent for our audience today, “to provide the American public with ocean energy, minerals, and resulting economic value in a safe and environmentally responsible manner.”

BOEMRE is given statutory oversight over four main program areas:

- oil and gas;
- renewable energy and alternate use;
- marine minerals; and,

- the Coastal Impact Assistance Program, or CIAP.

The BOEMRE's authority comes from three sources: the Outer Continental Shelf Lands Act, Section 388 of the Energy Policy Act of 2005, and the Gulf of Mexico Energy Security Act of 2006.

Dr. Kendall then briefly described how BOEMRE incorporates state-of-the-art scientific and engineering information provided through its Environmental Studies Program (ESP) and its Technology Assessment and Research (TA&R) Branch into its different program functions. (See Figure 1.) The BOEMRE funding for marine mammal studies is divided roughly equally between the impacts of sound on marine mammals, and monitoring and mitigation. Some of these efforts (i.e. studies) also provide vital baseline information on marine mammals.

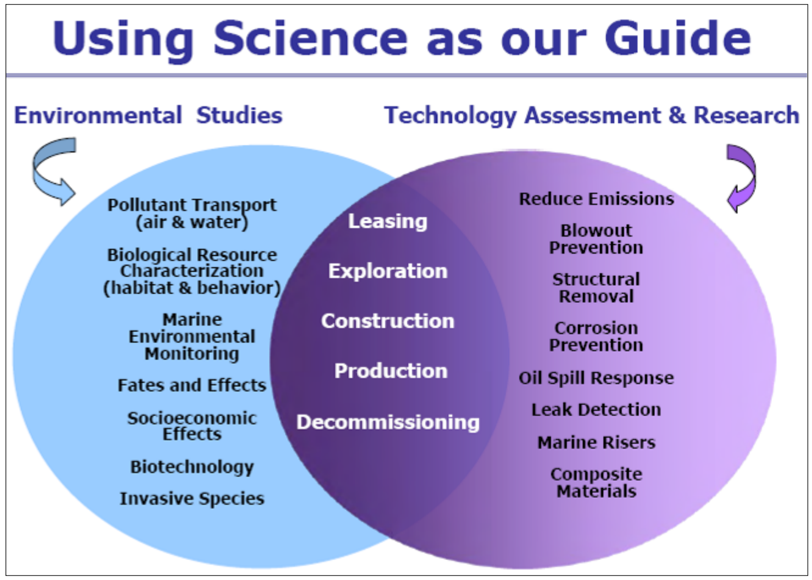

Figure 1. How BOEMRE uses and incorporates science into different programmatic functions.

In addition to its authorizing statutes, BOEMRE also must comply with other laws, including, for example, the National Environmental Policy Act (NEPA), the Endangered Species Act (ESA), and the Marine Mammal Protection Act (MMPA), to name but a few. The BOEMRE works closely with other natural resource agencies and DOI Bureaus, such as National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NMFS) and Fish and Wildlife Service (FWS), respectively, to ensure compliance. Dr. Kendall described how the BOEMRE utilizes an adaptive and ecosystem-based approach to management as it conducts its activities. Scenarios are re-evaluated; new information, research, and monitoring results are incorporated into decisions and process; and engineering and environmental safeguards and regulatory processes are reviewed.

Dr. Kendall listed examples of mitigation requirements typically employed by BOEMRE during the permitting process to minimize or eliminate the potential for impacts to marine mammals during regulated activities. These included requirements pertaining to avoiding vessel strike; eliminating marine debris; "ramp-up" for seismic surveys; exclusion zones for seismic activities; mitigations pertaining to pile driving and explosive removal; and shut down and reporting requirements. These factors are incorporated into permit requirements and lease stipulations. The BOEMRE also requires visual monitoring for mitigation purposes before, during, and after the offshore activity. Passive acoustic monitoring is also an option for activities in the Gulf of Mexico.

Dr. Kendall then noted that the effectiveness of mitigation is based largely on the ability to monitor effectively, and that many challenges affect the ability to detect marine mammals visually. Thus, BOEMRE is interested in exploring what is currently known about the applicability or effectiveness of alternative monitoring technologies. The goal is to develop the most effective monitoring methods to detect, locate, and track marine mammals.

Mr. Shane Guan of the National Marine Fisheries Service (NMFS) within the National Oceanic and Atmospheric Administration (NOAA) added information about the role NMFS plays in protecting marine mammals. He noted that NMFS has jurisdiction over all cetaceans and pinnipeds species (except walrus), a number of which are listed as endangered or threatened under the Endangered Species Act (ESA).

Under the Marine Mammal Protection Act (MMPA) and the ESA, NMFS has the authority to issue incidental take authorizations (ITAs) upon request. The criteria under the MMPA for issuing an ITA are: (1) negligible impact on the species or stock(s); (2) no unmitigable adverse impact on the availability of the species or stock(s) for certain subsistence uses; and (3) permissible method of taking and the implementation of mitigation and monitoring measures to minimize the potential impacts. The ESA criteria are that the activity is not likely to jeopardize the continued existence of the species and reasonable and prudent measures to minimize the impact of taking. Under the ESA, an Incidental Take Statement (ITS) is issued upon completion of a Section 7 consultation and only after MMPA authorization is obtained. Both the MMPA and the ESA require monitoring and reporting measures for compliance purposes as part of determining whether these criteria have been met.

For certain activities, NMFS may require passive acoustic monitoring to supplement visual monitoring for both incidental harassment authorizations (IHA) and associated Letters of Authorization (LOA) under the MMPA and ITS under the ESA. Passive acoustic monitoring (PAM) has several advantages. The objectives for PAM include: detecting marine mammals in poor visibility; improving detection, identification, localization and tracking capability; alerting visual observers to look for a marine mammal in the area; and helping determine a post-activity impact assessment.

Mr. Guan then used the examples of the Northeast Gateway LNG Port operations in Massachusetts Bay and the Lamont-Doherty Earth Observatory geophysical surveys to highlight some passive acoustic monitoring measures for mitigation purposes. The LNG Port uses passive auto-detection buoys (a form of fixed PAM) to provide near real-time information regarding the presence of vocalizing North Atlantic right whales in the vicinity of shipping lanes. The LNG vessels are required to reduce speed to ten knots if right whales are acoustically detected in the area. Mitigation requirements for the Lamont-Doherty Earth Observatory open ocean seismic surveys require continuous towed PAM when the air gun array is operational and stipulate that the towed PAM operator notify visual observers of detection in the safety zones so that a power-down or shutdown can be initiated. The NMFS also requires long-term monitoring of anthropogenic noise. For example, nineteen marine autonomous recording units (MARUs), which are a form of fixed PAM, are deployed in the vicinity of the Northeast Gateway LNG Port facility for the purpose of long-term assessment of anthropogenic noise (port construction & operations, shipping) on endangered whales (North Atlantic right whales, humpback whales, fin whales, and sei whales).

Mr. Guan also noted several issues related specifically to acoustic monitoring, including: personnel training and easy use of acoustic hardware and software; technology limitations such as detection of low-frequency calls using towed PAM arrays; engineering design for high quality acoustic detection systems (e.g. with low self-noise and low interference); and equipment affordability for both hardware and software.

Mr. Guan highlighted NOAA's PAM guidelines, issued in October 2008. These guidelines serve as recommendations for general procedures, system requirements, and reporting needs in planning or designing PAM. They recognize the case-by-case nature of PAM planning and design, and provide recommendations for a minimum set of procedures and system requirements. Mr. Guan noted that in order for passive acoustic monitoring to become the standard, acoustic monitoring systems need to be handled by MMOs with minimum training, the equipment affordable by most permit holders, and the training more available.

The "Three-Legged Stool"

Figure 2. The "three-legged stool."

Dr. William Ellison of Marine Acoustics put forth a conceptual framework within which to view the issues presented at the workshop. He highlighted the long history of these issues by describing the first major workshop on this subject, sponsored by the Acoustical Society of America, with proceedings published in 1980. He noted that the fundamental issues have not changed much since then, but our understanding of them and our tool set for evaluating them have improved significantly. He noted that we are now at a critical time for evaluating the 'state of the art' in acoustic monitoring and mitigation: there are a variety of well-developed monitoring systems in use, we have a better understanding of how marine mammals hear and react to sound, and a better ability to predict and model sound sources and the propagation of sound into the ocean.

Dr. Ellison defined "monitoring" as the tools and methods used to investigate the marine environment, identifying the vocal animals that live in it, their normal behavior, and the acoustics aspects of anthropogenic sound sources. He defined "mitigation" as the process by which we attempt to prevent harm to marine mammals. Mitigation is typically accomplished either through a geographical or temporal (diurnal or even seasonal) exclusion of industrial operations, or actual shutdown of activity - through a triggering event, usually. The latter usually happens by establishing an exclusion zone whereby if broached by a marine mammal the source be to identify the capabilities and limitations of the monitoring and mitigation tools currently available and under development.

Dr. Ellison then described a concept he termed the "three-legged stool" (See Figure 2) — for delineating and emphasizing the three main components needed for effective environmental compliance. These components are:

- Compliance with existing regulations;
- Mitigation as required; and
- Monitoring and research to document the process and develop better understanding for future operations.

All three of these elements are grounded in and improved by communication (e.g., sharing results with other researchers, regulators, users, and the public). Dr. Ellison emphasized the importance of being transparent about the research and any issues.

Another way to approach the issue is within a lifecycle framework, and activities may differ depending on the lifecycle stage of the activity. Each stage has its own set of issues and requirements that need to be addressed. By using an environmental compliance lifecycle framework to identify issues, planners can then identify tools to address those specific issues.

Dr. Ellison concluded by suggesting the following issues for the workshop participants to consider:

- Establish the adequacy of monitoring, mitigation and research tools currently available
- Do we have a consistent view of what is required (3-legged stool requirements) for each stage of the lifecycle?
- Determine where shortfalls exist in:
    - Capability of tools
    - Ease of use
    - Schedule and cost issues
    - Compilation and availability of databases
    - Consistency and understanding of regulatory issues

An Acoustical Ecology Perspective

Dr. Christopher Clark of the Bioacoustics Research Program at Cornell University then framed the discussion from an acoustical ecology perspective. He noted that marine mammals have an acoustic ecology and live in an acoustic habitat, and that these are the appropriate contexts by which to think of marine mammal monitoring and mitigation activities associated with offshore industry activities. He laid out a process by which to evaluate the potential impact of a human activity and achieve environmental compliance from an acoustical ecology perspective. He noted that the process of evaluating potential impacts is not restricted to acute effects (e.g., injury), but includes effects that are chronic such as habitat displacement and sound masking. This approach emphasizes the need and requirement to document and understand the potential effects of multiple sources, multiple stressors and cumulative impacts over biologically appropriate temporal, spatial and frequency scales.

Dr. Clark showed that species occupy different acoustic habitats, which can be viewed as part of their ecological requirements. The acoustical-ecological habitats for a species, or for a group of species with similar ecological requirements, are primarily bounded by the spatial, temporal and frequency scales over which the animal's acoustic activity (e.g., calling for communication, echolocation for foraging) occurs. He showed, for example (see Figure 3), that the sounds produced by humpback whales, melonheaded whales, and beaked whales occupy different time-space-frequency regions within the total acoustic space utilized by whales, dolphins and porpoises for basic life functions. He also showed examples of how anthropogenic sounds, such as the noise from shipping and generated by the seismic industry for oil and gas exploration, can mask whale communication sounds, and that the level of masking depends on the acoustical niche of the animal. Another point he made with these examples was that many of the technical tools and concepts for monitoring and mitigation already exist, but they have not really yet been integrated into a system with standardized procedures and metrics that address both short-term and long-term requirements.

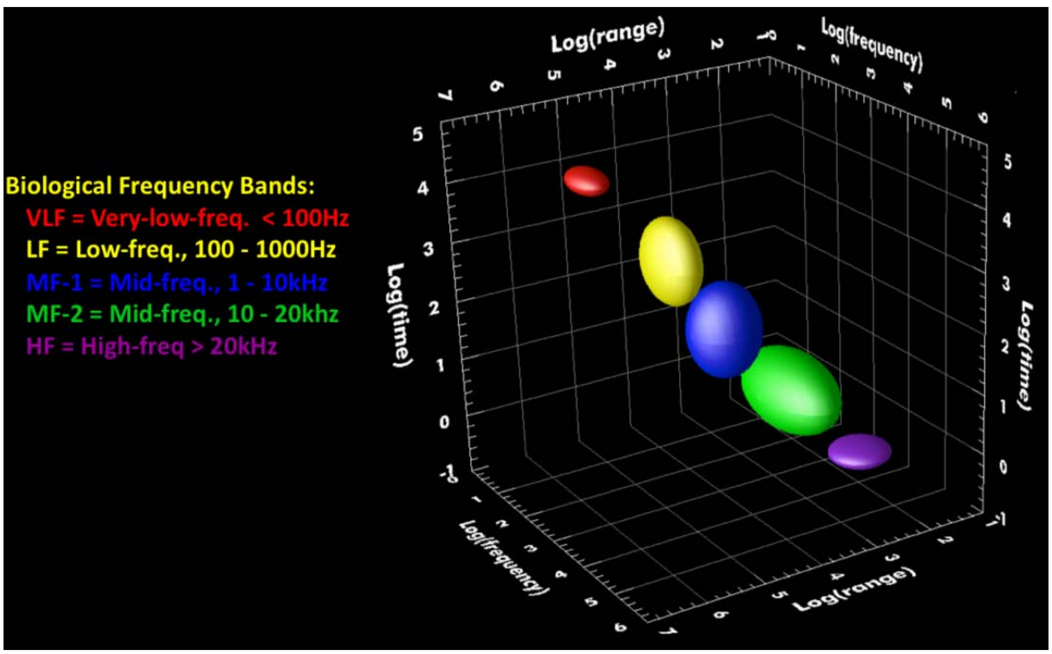

Figure 3. Conceptualization of acoustic ecological regions for different groups of marine mammals depending on their spatial, temporal, and frequency characteristics.

Dr. Clark listed the following two needs, in order to more effectively acoustically monitor for marine mammals and to develop responsible mechanisms to reduce risks to individuals and populations:

- a large bioacoustics database of marine animal and ambient noise recordings, which is essential for effective and efficient species identification or categorization; and

- baseline data on the ecological conditions, animal behavioral activities, and acoustical ecological landscape in an area prior to the human activity.

Throughout his presentation, Dr. Clark emphasized that knowledge of conditions prior to the start of a project is critically important. Knowing what species are likely to occur in an area at a particular time, and what the animals may be doing, allow for the PAM operators to more effectively mitigate potential impacts and monitor and comply with environmental objectives, given the best available science-based knowledge and the available set of tools.

Dr. Clark concluded his presentation with three basic questions to be addressed during the workshop. These questions were:

1. How do the space-time-frequency dimensions of an offshore industry activity overlap with and intersect the acoustic behaviors and habitats of the different animals?
2. What spatial and temporal "monitoring" specifications are necessary and sufficient to determine the level of any biological impact from an offshore industry activity?
3. What mitigation and monitoring tools are necessary, available and capable of providing those spatial and temporal resolutions at the agreed upon standards?

Question and Answer Session

A short question and answer session followed the Session I presentations.

In response to questions from workshop participants, the presenters made the following points:

- Each mode of monitoring (visual, PAM, and AAM) has its benefits and limitations.
- The use of PAM relies on the animal producing a sound at a sound level that the system can detect.
- The AAM technology would be useful in detecting animals that do not often produce sounds or that do not vocalize at all. The AAM signals tend to be very high frequency, and therefore the effective range is limited.
- Visual observation is limited.
- In many cases, it is unnecessary to know the exact species of the animal detected. Mitigation by animal "type" should be sufficient in most cases, and one form of type is the acoustical-ecological type.

Participants also made the following comments:

- If an acoustical system detects an animal, identification of the specific species may not matter if the goal is to mitigate potential harm.
- The BOEMRE may want to consider funding or supporting research that assesses the influences and impacts of multiple sources of noise over a

regional scale, to better understand the sound environments to which individual animals and populations of animals are exposed.

SESSION II: THE SENSOR – PASSIVE MONITORING ("FIXED" SYSTEMS)

Fixed passive acoustic monitoring (PAM) systems have the capability to monitor underwater sounds over a wide range of spatial and temporal scales. Renata Sousa-Lima of the Bioacoustics Research Program at Cornell University provided an overview of the existing fixed PAM technology. Dr. Sousa-Lima divided fixed PAM systems into three categories: autonomous recorders (AR), radio-linked hydrophones (RLH), and fixed cable hydrophones (FCH). She gave an overview of the characteristics and capabilities of each type.

The ARs are electronic recording systems that acquire and store acoustic data internally, i.e., without cable or radio links to a fixed platform or receiving station. They are deployed semi-permanently underwater via a mooring or buoy, or attached to the seafloor, and are retrieved after the deployment period to access the data. Over 30 ARs were reviewed for the Joint Oil and Gas Industry Programme on Sound and Marine Life (JIP). The 30 systems vary greatly in price and capabilities, from small hand-deployable units for detecting dolphin and porpoise clicks in shallow water, to units that are deployed from a large research vessel in deep water and record at very high frequencies for almost two months.[2]

The ARs were inspired by Ocean Bottom Seismometers (OBS) that may detect low-frequency sounds and have been used in the past to study blue and fin whale calls obtained during a seismology experiment. Two examples of ARs were described to illustrate the range of capabilities of these types of units. Large High-frequency Acoustic Recording Package (HARP) from Scripps Institution of Oceanography can be deployed in deep water and sample high-frequency sounds for almost 2 months. Smaller Pop-up Recorders from Cornell's Bioacoustics Research Program record lower-frequency sounds. Dr. Sousa-Lima also described various deployment and retrieval methods depending on the deployment area and depth, such as acoustic triggers, mechanical release systems, grappling and diver retrieval.

The AR capabilities may include continuous recording; automatic detection/classification of sounds; and collection of non-acoustic data. The ARs are constrained by their self-contained power supply. Many tradeoffs are involved in using ARs - for instance, systems that can be deployed at greater depths are usually more expensive due to special housings. Added capability to record for longer periods of time will decrease the available sampling frequency and/or increase the power supply needed and the instrument size. In general, as one increases the size and complexity of the system, one also needs to increase the budget.

Radio-linked hydrophone systems consist of hydrophones that are moored or fixed to the bottom and transmit the audio signal via radio waves to a receiving station on shore. This enables acoustic data to be monitored and processed in real or near-real time, or it can be post-processed.

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[2] Sousa-Lima, R.S.; Norris, T.F., Owsald, J.O. A Review and Inventory of Fixed Autonomous Recorders for Passive Acoustic Monitoring of Marine Mammals. Submitted to JIP 2010.

Because RLHs transmit data to locations on shore, they are limited by bandwidth, range of transmission, and data transfer rates (for example, must use available VHF/UHF radio-channels or satellite networks).

Two example of RLH were described: QUE Phone from NOAA, which records sound at the ocean bottom, rises to the surface to transmit, and then returns to the bottom; and the Right Whale Monitoring System, from Cornell's Bioacoustics Research Program (BRP) and Woods Hole Oceanographic Institute (WHOI), designed specifically to study marine mammals and monitor sound in real time, minimizing mooring noise.

Fixed cable hydrophone systems are typically located on the seafloor in a permanent configuration. They have the capability to be continuously powered by an external source and can continuously send data to a receiving station. Dr. Sousa-Lima said that the U.S. Navy has a low-frequency FCH system called Sound Surveillance System (SOSUS) - long arrays of cable hydrophones in secret locations with receiving stations in the North Atlantic. Other systems include the U.S. Navy underwater test ranges in the Bahamas, California, and Hawaii; smaller scale arrays designed specifically for marine mammal studies; and large scientific efforts that can opportunistically collect information on marine mammals and anthropogenic noise. As an example of the latter, Ocean Observatories Initiatives (OOI) are planned that will construct a networked infrastructure of sensor systems to measure variables. Regional OOI are being implemented in the ocean and seafloor in North America (Canada and the U.S.) and in Europe.

Characteristics of, applications for, and differences among the three fixed PAM systems (AR, RLH, FCH) were explained. In general, setup and infrastructure costs are highest for FCHs and RLHs and lowest for ARs. However, acoustic data bandwidth and collection capabilities are highest for FCHs. The AR systems are more flexible in their configuration, timing, and locations of deployment, but require instrument retrieval and post-processing of data.

Dr. Sousa-Lima concluded that there is no one best system to use. Each has different characteristics, and it is best to tailor the technology to the specific situation. Users should consider their objectives carefully, as well as costs and benefits of an integrated approach. The total cost (including the instrument, deployment, retrieval, and data processing) is important and may be limiting. Users also should consider the timeframe for monitoring, the area to be monitored, bandwidth and characteristics of sounds to be monitored (i.e. marine mammal call types and noise sources), and the need for real-time vs. post-processing of data. It is critical to factor in the biology of the target species as well, as this will affect all aspects of the study design and choice of monitoring system.

Case Study: Construction and Operation of LNG Terminals in Massachusetts Bay

Leila Hatch of the Stellwagen Bank National Marine Sanctuary, under NOAA, provided a case study of how PAM was used to mitigate and monitor impacts associated with the construction and operation of LNG terminals in Massachusetts Bay. See Figure 4 for the location of this study.

Cornell University BRP deployed a NOAA-approved bottom-mounted archival PAM system for monitoring four endangered whale species (North Atlantic right, humpback, fin, and minke) in the vicinity of proposed LNG terminals in Massachusetts Bay. The monitoring system was designed to characterize the acoustic footprints of the new port activities, to monitor the distribution and behavior of the whales, estimate levels of exposure, and monitor changes in acoustic habitat. The archival PAM array is composed of 19 MARUs designed by Cornell and temporarily moored in a broad area surrounding two LNG ports. The MARUs are anchored by sand bags and rotated every three months. The MARU array was deployed two months prior to construction, and is being used to monitor the acoustic footprints of both ports before and during construction for a minimum of five years of operation.

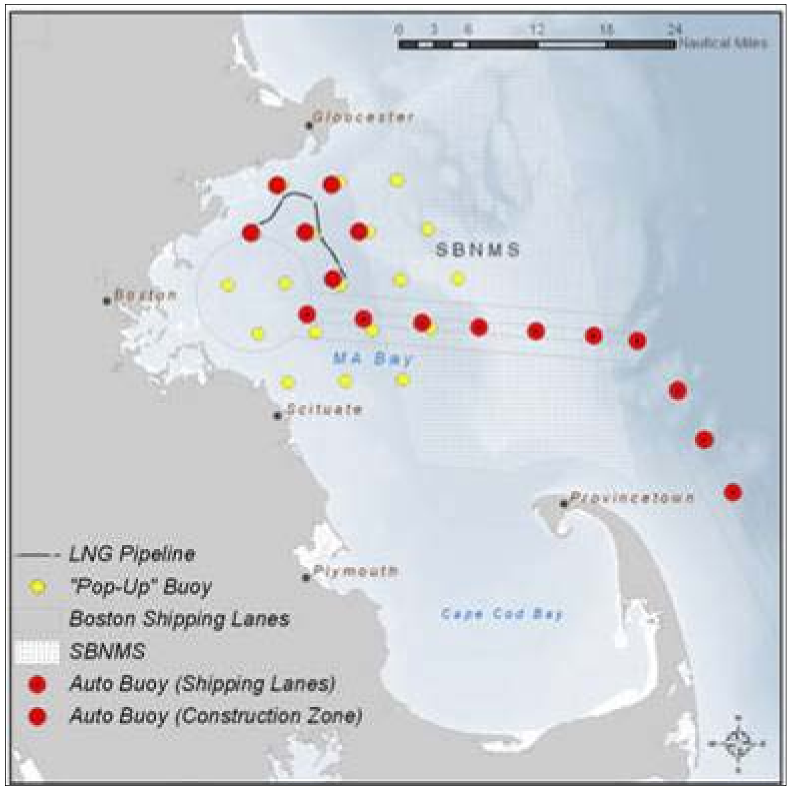

Figure 4. Three arrays (two types of technology) in place during construction and operation of two LNG terminals in Massachusetts Bay adjacent to the Stellwagen Bank National Marine Sanctuary. (Courtesy of Cornell University Bioacoustics Research Program.)

Figure 5 displays construction monitoring results using three scales important to noise impact assessment: time, space and spectral (frequency). The x-axes of both charts show time in days during pre-construction and active construction periods. The y-axes show the percents of time in which noise was greater than 120dB re 1uPa on those days. The top chart is scaled to 50% of the time in which noise was greater than 120dB, and the bottom chart is scaled to 35% of the time in which noise was above 120dB. In the top chart, the lines represent different frequency bandwidths tuned species-specifically—the red and blue lines show that construction noise was significant in both humpback and right whale bandwidths, but insignificant within the fin whale bandwidth. The lower chart looks only at the right whale bandwidth, and the lines now represent different areas within the array—the yellow line shows that construction noise was significant on recorders near the pipeline corridor, but was highly localized, and other areas around the array were much less noisy. These measurements provided managers with important empirical information about the scale of ensonification resulting from the construction activities; these data, coupled with information about how different species use biological signals of similar frequencies for critical biological functions, can provide a basis for assessing and mitigating impacts. Limitations encountered in measuring source levels of individual types of construction noise (i.e. units in array too far away from construction sources, unsatisfactory data collection methods and insufficient information sharing between construction personnel and acoustic analysts to allow noise to be linked to activity types) led to improvements in the mitigation and monitoring plan finalized for the second port.

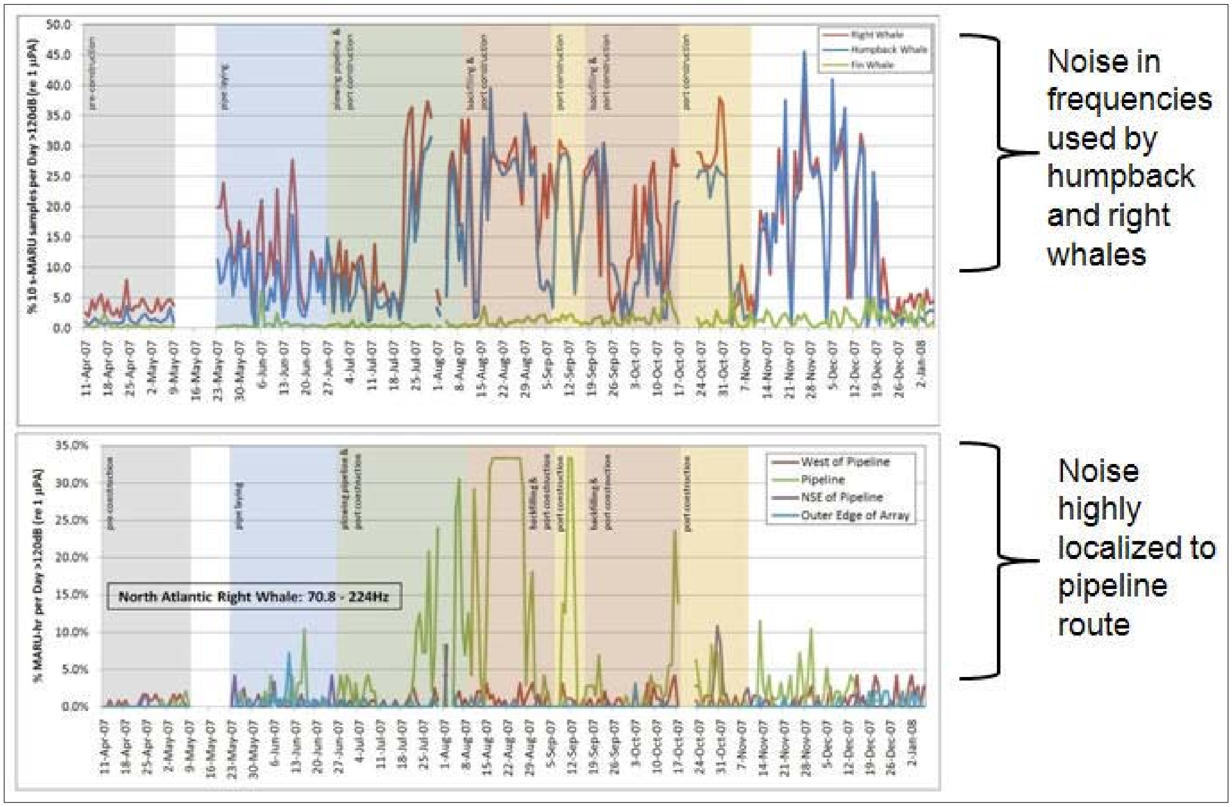

Figure 5. Results from acoustic monitoring during LNG construction. (Courtesy of Cornell University Bioacoustics Research Program & Northeast Gateway, LLC.)

In conjunction with WHOI, BRP also deployed bottom-moored buoys with surface expression that were intended for real-time mitigation during port construction and operation, to protect the whales the noise of pipe laying and dynamic positioning activities during construction and operation of the LNG terminals, and from collisions with LNG carriers.

These arrays use automatic detection buoys (ADBs) with hydrophones and computer software to detect the contact calls of North Atlantic right whales and transmit alerts in near-real time via iridium satellite to technicians at Cornell for verification. A confirmed call is then used to trigger mitigation actions in the area around the detecting buoy. Dr. Hatch displayed a diagram showing what actions were triggered by the various data received, from temporary shutdown of construction activity to reduced speed and increased alertness of LNG carriers. Six ABs were installed near the sites of port and pipeline construction and ten ABs were installed in the Boston shipping lanes; all sites were maintained regularly.

Monitoring occurs twenty-four hours a day, as right whales call at all hours. However, peak calling activity has been documented during the evening hours. Figure 6 shows the relative seasonal right whale calling activity on the auto-detection buoys moored in the shipping lanes during the first year of LNG port operation. These results show that while calling activity is highly seasonal, with bursts of activity in the spring, late fall and winter months, there were relatively few months and listening locations that received no calls at all during the year. A pilot system is now being developed to transmit information on confirmed right whale calls via the Automatic Identification System to LNG ship captains and crew to allow them to view these notifications (including where and when slow speed and heightened awareness responses are mandated) with other streams of data on nearby vessels.

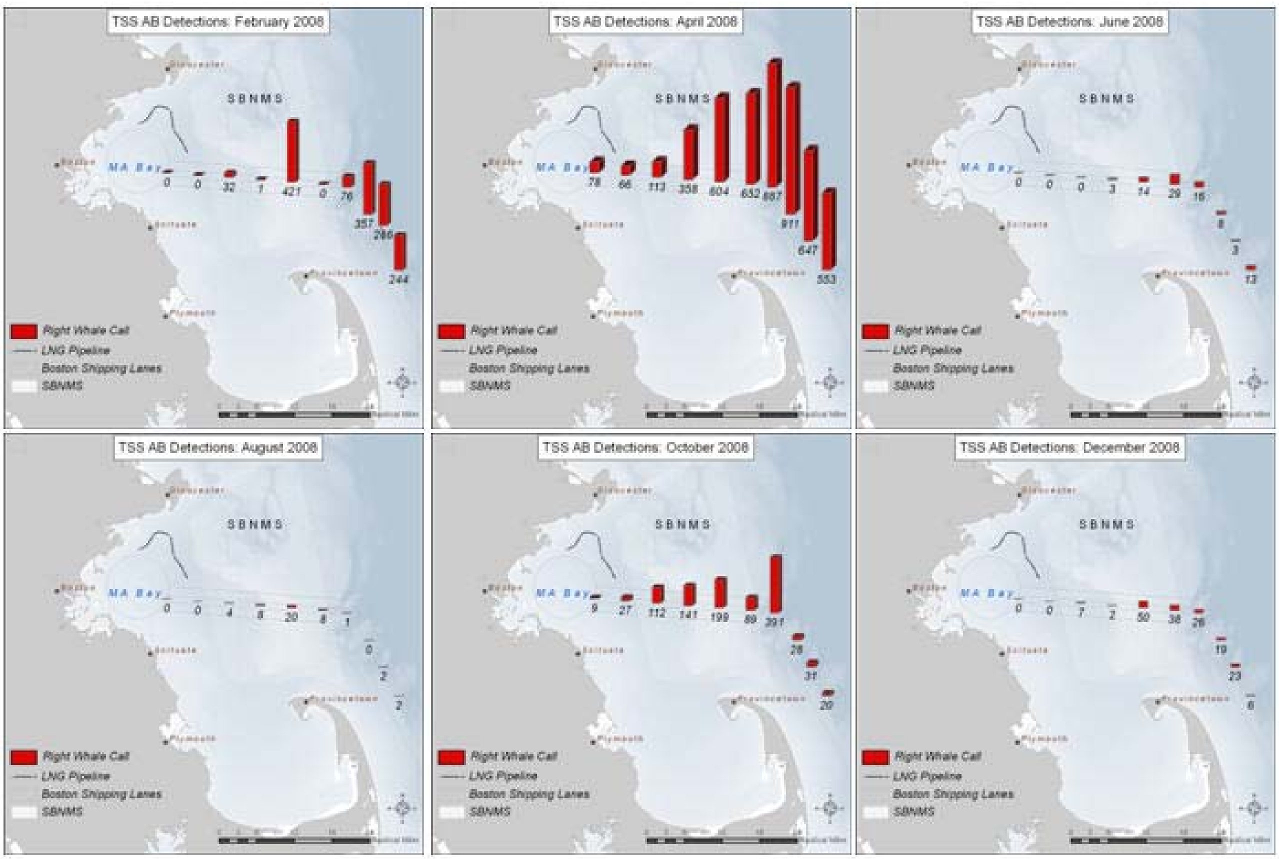

Figure 6. *Seasonal North Atlantic right whale up-calling activity on ten auto-detection buoys moored in Boston shipping lanes during LNG operation in Massachusetts Bay. (Courtesy of Cornell University Bioacoustics Research Program & Northeast Gateway, LLC.)*

Case Study: DASARs at BP's Northstar Production Facility in the Alaskan Beaufort Sea

Use of a fixed PAM system at BP's Northstar Production Facility in the Alaskan Beaufort Sea was described by Bill Streever, BP Alaska's Environmental Studies Program Director. The objective of the program was to understand the impact of BP's Northstar operations on bowhead whales. Corporate policy requires BP to understand its impacts. The MMPA Letter of Authorization required a bowhead whale displacement study, and the North Slope Borough Ordinance NSBMC19.70.050(B)(1) and 2.4.3(b) part b calls for a monitoring program assessing "distribution of fall migrating bowhead whales. . . for as many years as needed to clearly show that there is no impact. . . ." One specific question was whether whales move away from shore when there is increased operational noise from Northstar.

When the whales pass Northstar during migration in September, sounds associated with the Northstar facility are recorded using a hydrophone positioned about 450 m from the facility. Simultaneously, whale calls are localized using an array of Directional Autonomous Seafloor Acoustic Recorders (DASARs) that are, in essence, fixed, directional Passive Acoustic Monitoring (PAM) recorders. When a calling whale is heard on two or more DASARs it can be localized (Figure 7). The relationship between varying sounds associated with the facility and whale call distributions can then be assessed.

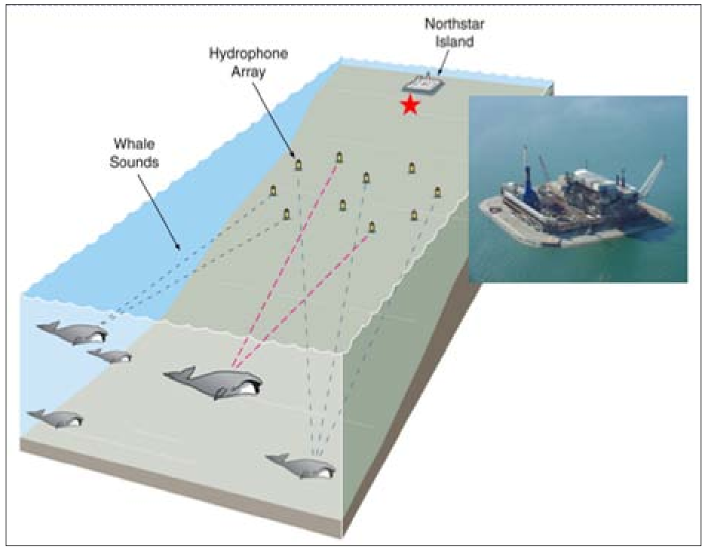

Figure 7. Northstar (inset) is a man-made gravel island used for oil production in the Alaskan Beaufort Sea. An array of directional hydrophones localizes whale calls and an additional hydrophone (red star) records sounds associated with Northstar activities.

Each DASAR includes an onboard battery pack, a hard drive to record data, and a clock to allow meaningful compilation of recorded calls from different DASARs. Each DASAR also includes an omnidirectional sensor and two horizontal, orthogonal particle motion sensors with outputs that are proportional to the cosine and sine of the direction of the source. The omnidirectional sensor records sound pressure levels (of, for example, whale calls), while the particle motion sensors determine the direction (the vector) to the sound source. When a sound is recorded on two or more DASARs, the intersection of the vectors corresponds to the whale call location.[3]

The Northstar DASAR array has provided nominal locations of thousands of whale calls each year since 2001. Statistical analyses of these whale call locations suggest that whales are responding to sounds associated with Northstar, including sounds with received levels that would be close to ambient sound levels in the vicinity of the whales. The response may represent bowhead whale movements away from the sound source, a change in calling behavior, or both. Detailed explanations of the overall study are presented in various reports on file with the National Marine Fisheries Service.

The DASARs and the DASAR array approach have proven to be remarkably reliable. Although a small number of instruments have failed during the course of well over one hundred instrument deployments, redundant DASAR locations built into the array design have prevented meaningful data gaps. Occasionally, DASARs have moved on the seabed, rendering data collected after movement less useful, but redesign of the DASAR frames and housings have improved stability

[3] A detailed description of the DASARs can be found in C.R. Greene, Jr., M.W. McLennan, R.G. Norman, T.L. McDonald, R.S. Jakubczak, W.J. Richardson, Directional frequency and recording (DIFAR) sensors in seafloor recorders to locate calling bowhead whales during their fall migration. J. Acoust. Soc. Am. Volume 116, Issue 2, pp. 799-813 (August 2004).

and appear to have eliminated problems with movement. On one occasion (the 2008 field season), the relationship between whale call distribution and Northstar sounds was obscured by the presence of extraneous industry sounds, mainly related to nearby seismic shoots.

While in general the DASARs themselves performed well, success in achieving the objectives of the study have been mixed. On the one hand, whale call distributions have been successfully mapped and statistical analyses have identified significant but subtle relationships with Northstar sounds. In addition, the approach allows for numerous analyses that will improve our understanding of bowhead whales and their response to anthropogenic sounds. For example, recordings have been used to assess directionality of bowhead whale calls and to inventory whale call types during the fall migration. On the other hand, complexities associated with the data analyses and interpretation can be challenging. For example, identifying independent samples of whale calls and determining appropriate “time windows” (the time over which Northstar sounds should be integrated) requires judicious application of numerous assumptions and caveats. More problematic is the interpretive challenge presented by the inability to know if changes in call distributions are related to changes in the locations of calling whales, changes in calling behavior, or both. Ultimately, it is possible to conclude that whale call distribution changes in association with changes in Northstar sounds, but it is not possible to determine if the distribution of the whales themselves changes in association with changes in Northstar sounds, which was a key initial objective of this work.

Dr. Streever noted that the approach used in this project is most applicable where whales call fairly frequently, where the number of whales or location of whales is less important than changes in whale call distributions or where whales call regularly (or with calls that can be linked to individual animals), and where ice floes will not allow the use of floating recorders. He emphasized that it is extremely important to articulate clearly the objectives of the studies. Redundancy is important for DASARs, as is preseason testing. Processing the recordings is difficult and expensive, and a multi-disciplinary team and significant long-term funding are important. Dr. Streever concluded by saying that the approach used for the project worked generally, and reviews have been positive.

Case Study: Static Deployment of PAM During Pile Driving

Roy Wyatt of SEICHE Measurements provided case studies involving construction of a wind farm in Scotland with large diameter piles offshore, and construction of two different jetties in shallow water off the coast of Wales, one involving large and the other small diameter piles.

The wind farm construction involved two offshore turbines requiring the use of a pile driver. Each of the two turbine constructions required four piles to be driven into the seabed. The piles were 1.8m in diameter and 44m in length. The piles were driven into the seabed by a hydraulic hammer weighing 25 tons mounted from a special construction platform. Maximum force was 500 kN, with strike rate at maximum energy level of 45 bpm. Construction took place in water 45 m deep, 24 km outside a Special Area of Conservation (SAC).

The area is important habitat for bottle-nosed dolphins; harbor porpoises, seals, and minke whales are also present. Construction happened during peak seasonal activity for the mammals, and the Environmental Protection Plan (EPP) called for visual observation combined with static passive acoustic monitoring (PAM). An exclusion zone of one km, where pile driving was restricted, was calculated based on sound pressure levels likely to cause a Temporary Threshold Shift (TTS) in marine mammals.

Within the 1 km exclusion zone, start-up of pile driving was required to occur during daylight hours and was prohibited if mammals were detected within 30 minutes of start-up. If a marine mammal were detected in the area during this time the commencement of piling would be delayed until the area had been clear for 30 minutes. A soft start procedure was required before the pile driver was allowed to work at maximum energy. The soft start procedure involved a series of single strikes at decreasing intervals and then a gradual ramp up in pile driving energy.

Range of bandwidth to be monitored was between 20 Hz and 175 kHz. One remote PAM buoy (Figure 8) was deployed 100 m from the pile site, with two observers (one operating the PAM) on a fishing boat. The PAM system consisted of two vertical arrays and four hydrophones suspended 3 m below the sea surface. Acoustic data from the buoy was transmitted to the fishing boat. Standard International Fund for Animal Welfare (IFAW) software was used. Visual observation consisted of 20 km transects made twice daily, weather permitting.

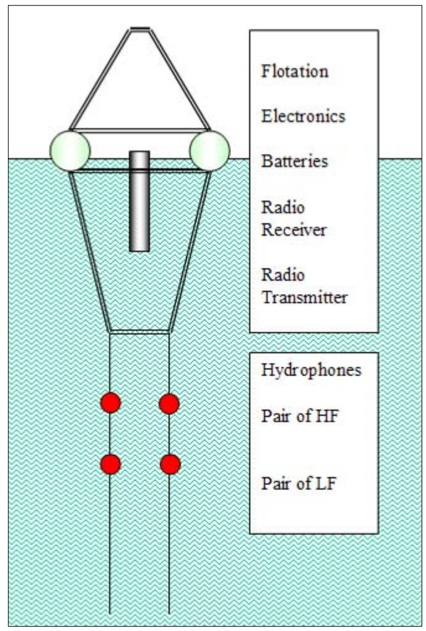

Figure 8. Diagram of the PAM buoy.

During the operations no visual or acoustic detections were made during the 30-minute survey periods before commencement of pile driving operations.

The main lesson learned was that due to the position of the buoy the acoustic pile driving noise prohibited the use of passive acoustics while piling was in progress. This could be improved by using a series of buoys moored at a greater distance from the piling operation. The monitoring of the exclusion zone before the pile driving was initiated was unaffected by vessel noise.

Visual observation (90 hours) was limited because of the position of the monitoring vessel (the fishing boat), and acoustic monitoring (27 hours) was hindered by noise from pile driving with the equipment located too close to the pile driver and the presence of other vessels. Acoustic levels were higher than predicted; and, because gradual ramp up did not always occur, the resulting series of abrupt changes in noise level was not ideal. Other challenges included the wide bandwidth to be monitored, limited resources, and the large area to be surveyed. Monitoring would be improved, Wyatt said, by using a series of buoys moored at a greater distance from the piling operation. During the operations, no sightings or acoustic detections were made within the 1 km zone during the 30-minute periods before start-up.

Since this project, there have been improvements in buoy technology and in software (PAMGUARD, for example).

Two other smaller jetty construction operations were described briefly. These used piles of smaller diameter and had smaller exclusion zones. For these projects mitigation was based on actual measurements at the commencement of the pile driving activity. One case example involved pile driving during construction of a shallow-water LNG jetty off the Welsh coast, within an SAC. Visual observation took place from the jetty, with PAM deployed from the jetty for night monitoring or at times of poor visibility.

Challenges included problematic communication with the pile drivers. There were many hours of inactivity while on stand-by. Because of poor visibility, another dedicated MMO would have helped. The acoustic monitoring occurred in a very noisy environment, highlighting that the equipment needs to be as far from the noisy operation of the pile driving as possible while still being effective, and limitation of large vessel movements during a period before piling is desirable. Measurement of actual sound pressure level (SPL) at the start of the project was also critical. Wyatt observed that technology is only one consideration. Reliability in the field is of prime importance. Health and safety are major concerns, and PAM operators and health and safety (HSE) personnel need training and experience in regards to safe working loads, deployment methods and other aspects of job safety analysis. He also recommended measuring the sound levels on the first pile and setting the exclusion zone accordingly.

Question and Answer Session

A short question and answer session followed the Session II presentations about fixed PAM systems.

In response to questions from workshop participants, the presenters made the following points:

- Mr. Wyatt achieved the needed bandwidth using two sets of hydrophones in the water, each with different frequency bands.
- The cost for processing and analyzing the data and write-ups was well over 70 percent of the costs associated with the Northstar acoustic monitoring program, which had an annual operating cost of approximately one million dollars.
- Any long-term project would require a cable to the shore. In the early days of the Northstar project, a cable hydrophone was used but it was lost several times due to ice. Reliance on battery power limits recording times.
- One of the big issues to be addressed is how to mitigate over a very large area.
- A technology for real-time detection with localization capabilities is a huge leap from the current technology.
- The tendency in developing these technologies right now is to reduce costs. Future systems will therefore be smaller, cheaper, and easier to deploy.
- One of the goals of mitigation is to satisfy the human stakeholders. Communication is just as important as the science.

SESSION II: THE SENSOR – PASSIVE MONITORING ("TOWED" SYSTEM)

Towed PAM systems were one of the earliest PAM configurations to be applied to monitoring of marine mammals, and are used extensively with seismic surveys and for close-range mitigation of the effects of other mobile activities. Aaron Thode of the Scripps Institution of Oceanography, University of California, San Diego provided an overview of current towed PAM systems and their capabilities and limitations. He explained how a basic towed array allows bearing estimation of an animal via the measurement of relative arrival times of a vocalization. He reviewed the challenges of distinguishing between port and starboard, and he discussed how PAM operators can overcome some of the limitations of towed array systems.

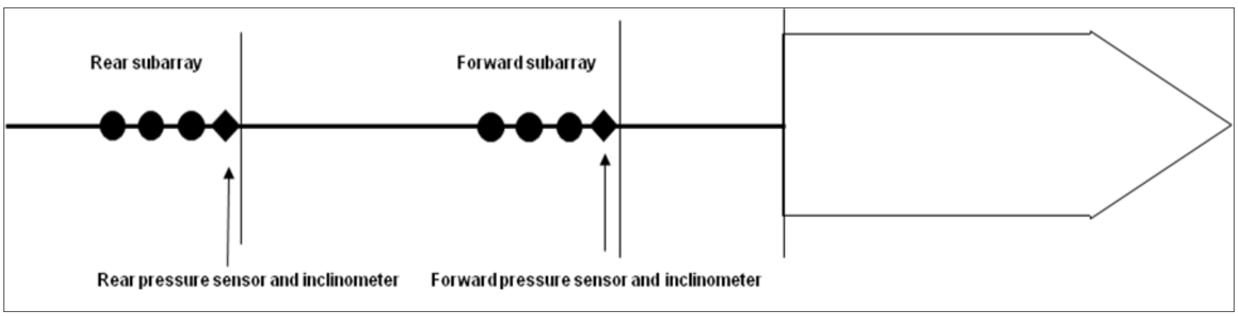

Figure 9. Diagram of a towed array system.

Dr. Thode showed a diagram of a towed array system (See Figure 9), noting that often there are two sub-arrays in sequence. By measuring the relative arrival times of a vocalization to each sub-array, PAM operators can calculate the bearing to the animal. If the animal is swimming relatively slowly, is near the surface, and is calling constantly, a sequence of acoustic bearings measured from a moving ship can yield a range estimate of the animal as well. However, a linear array cannot determine a signal arriving from the left from one arriving on the right. Dr. Thode noted that this limitation can be overcome by maneuvering the vessel or by using a second lateral array.

Towed arrays have the great advantage of mobility and large spatial coverage and, thus, are very useful for monitoring when the active source is mobile and for detecting high-frequency marine mammal activity over a large spatial area. However, in addition to the limited directional capabilities and the added challenges of both sound sources and receivers being mobile, towed systems have short time coverage, limited detection range, and are prone to masking problems from tow vessel noise, flow noise, and seismic source noise, including airgun reverberation in shallow water. Dr. Thode compared this to "listening for birds next to a waterfall." In addition, the use of towed arrays is limited to ship availability. Also, they are particularly vulnerable to at-sea damage, have difficulties localizing whale calls, and are difficult to use for detection in front of the vessel.

Operators can overcome some of these limitations, particularly directionality and localization, by using the following methods to help pinpoint direction:

- Use multiple bearings to determine distance;
- Use an array below the surface to exploit "echoes" from the ocean surface; and
- Measure pressure and velocity of the sound.

Vector sensors are a relatively new device that can localize by triangulating or "measuring angles from a single point." They will calculate a precise bearing by measuring the pressure and the velocity through accelerometers. One potential problem is that accelerometers are sensitive to vibration, therefore mechanical vibration from the vessel, other operating devices or "flow" noise could affect localization. With this advanced technology, localization may be made more viable through passive towed arrays.

Case Study: BHP Billiton Multi-Vessel Survey

Mary Jo Barkaszi, an independent consultant, presented a case study for a commercial application of PAM for regulatory compliance in the Gulf of Mexico; this was the first fully commercial deployment of PAM under the regulatory guidelines established by BOEMRE Notice to Lessees (NTL) Number 2007-G02, *Implementation of Seismic Survey Mitigation Measures and Protected Species Observer Program.* Since 2003, NTLs have included the option of using experimental PAM instead of continuous shooting or potential work stoppage during times of reduced visibility, when visual observers cannot effectively detect whales. Fixed PAM has been in use in the Gulf of Mexico (GOM) since 2003, but the BHP Billiton multi-vessel survey operation between July and September 2008 was the first use of towed PAM in a full commercial application in the GOM.

Ms. Barkaszi outlined the project's objectives, highlighting that the primary objectives were to obtain absolute and full compliance with environmental regulations and do zero harm to marine mammals, which includes reducing noise into the water. She reviewed the logistics of the project, which included two towed hydrophone arrays that were deployed off the stern, in front of the airguns. While only two of the four vessels had PAM arrays, each vessel had three marine mammal observers (MMOs) on board conducting visual observations during daylight hours. One of the MMOs on each of the PAM-equipped vessels was an experienced PAM operator. One dedicated PAM technician provided continuous nighttime monitoring for compliance. Sperm whales were the main species of concern due to their prevalence and protection status in the GOM. The regulatory requirements, however, include mysticetes, delphinids, and marine turtles. All species were subjects during both visual and acoustic surveys.

One success was that the use of PAM allowed operations to continue after dark. This was significant because during the project period, two major hurricanes occurred, disrupting daytime operations, and PAM allowed the vessels to operate at night. Without the implementation of PAM, significant downtime of four working vessels would have occurred.

The PAM system had a detection rate for sperm whales that was higher than visual observations and a similar detection rate for dolphins. The PAM system had a lower detection rate for other whales, however. During the course of this project, there was only a single visual sighting of a *Kogia* species. The PAM system is not able to detect turtles because they do not vocalize and therefore detection rates for turtles were greater with visual observations. Using PAM saved significant amounts of fleet-wide and individual vessel time, and allowed for a significant reduction in the operation's noise footprint.

Ms. Barkaszi outlined the following lessons learned from the operation:

- Better coordination and communication could have made pre-installation, crew changes, and on-going operations smoother.
- Planning is important, and planning how to equip each vessel as soon as possible is absolutely critical.
- There is an experience gap between a PAM "user" and a PAM "technician." Ms. Barkaszi acknowledged that it was nearly impossible to get commercial experience with PAM, and while she approved of an apprenticeship program, she noted that vessels often have space limitations for personnel. However, this is a critical issue and needs to be addressed.
- The PAM system is a useful monitoring tool and a compliance tool. However, use of PAM for compliance still needs improvement, to verify distances in regard to the 500-meter exclusion zone and more commercial applications in the field.
- The industry is encouraged to get involved with using and testing PAM rigorously in commercial applications and to provide input as to its use and development, or the future of PAM could be driven by regulation and research without commercial input.

Case Study: Lessons Learned from CIBRA – RIGHT WAVES

Claudio Fossati of CIBRA (Center for Bioacoustics at the University of Pavia) and RIGHT WAVES presented lessons learned from fifteen years of towed PAM application. Mr. Fossati began by providing a brief history of CIBRA and RIGHT WAVES, which was founded by the CIBRA team as a vehicle for the services it can provide. The CIBRA team has studied and implemented PAM techniques for mitigation purposes during active acoustic experiments, both military and civilian.

Mr. Fossati reviewed some of the benefits and limitations of towed arrays generally and then gave a case study of how towed PAM was installed and operated on the Seismic R/V Langseth, of the Lamont-Doherty Earth Observatory at Columbia University. The team had two dipole arrays (one for backup) that were manufactured at CIBRA-RIGHT WAVES based on fifteen years of experience, and used the SeaPro PAM software suite, also designed and written at CIBRA, that assisted the operator during the long shifts with automated data entry. The software also self-managed and stored navigation and geographical data and was able to be run off a single laptop. Mr. Fossati highlighted the software's acoustic display, which he says has to be as accurate as possible to assist the operator in detection and classification of sounds.

Out in the field, the team experienced some challenges due to handling of equipment, interaction with other gear, electronic interferences, and the temporary arrangements of equipment due to space limitations. The team worked around those challenges and developed a very lightweight array that was a single reliable system. The array had to be deployed between the stern and the gun array and used a depressor wing as a depth controller.

Mr. Fossati concluded by emphasizing that, as with fixed PAM and basically all of the technologies discussed in the workshop, no one system fits all situations. Every installation has to be designed on a case-by-case basis given the requirements, environment, and resources available, and PAM operators often have to work in less than optimal conditions. He listed some systems criteria that he considered important: ability to monitor a wide frequency band, very low self-noise, proper array depth, good spectrographic display, and a very skilled operator.

Case Study: Directional Towed Array Pilot

Bruce Martin of JASCO Research provided a case study of JASCO Research's towed array trial of their new Cetacean Towed Array Sonar System (CETASS) in the Canadian Beaufort Sea. CETASS incorporated directional sensor technology, which improved PAM performance by providing a location for each detected vocalization. This ideally results in fewer false shutdowns and easier tracking. JASCO Research wanted to demonstrate the potential for detecting lower-frequency mammals, such as bowhead whales, while also broadening the range to look for higher range species, such as beluga whales.

The field trial was conducted in shallow water and involved three vessels: the source vessel plus two support vessels. The depth of the arrays was controlled via the length of the tow cable. The directional sensors contain omni-phones that can indicate fore-aft directionality and dipoles that can indicate left-right and up-down directionality.

In the field, the researchers did not detect any marine mammals during opportunistic monitoring. Mr. Martin speculated that the animals were not vocalizing during the period they were close to the array, and that additional structured trials were required.

Experiments did show that the directional sensors were effective, but the aft sensors did not function for part of the trial. The researchers could not localize without data from the aft sensors. The bearing results were excellent, with the directional sensors being effective for transient and tonal sources. The directional sensors provided left-right ambiguity resolution, solving a common problem with towed arrays. The sensors could detect certain sounds up to ten nautical miles away. The WADER-32 program was used for modeling sensor performance, and showed that bowhead detections should be possible at a useful range in excess of 2 nm. Bearing results showed that the sensors can significantly improve the speed and accuracy of mammal localizations, and further trials will provide additional evidence of the technology's effectiveness. Measured noise levels and modeling indicate the directional sensors should be effective at providing single call localizations for low frequency mammals, even from noisy tow platforms. Mr. Martin stated that if the whales were vocalizing, the sensors should be able to detect and track them.

Question and Answer Session

A short question and answer session followed the Session II presentations about towed PAM systems.

In response to questions from workshop participants, the presenters made the following points:

- Hull-mounted hydrophones pick up f low noise and noise from the vessel itself.
- A directional sensor would reject some noise generated by the ship, but probably not flow noise.
- Systems need to be calibrated in order to get an idea of their capabilities. In particular, both the sounds received and the background ambient noise must be measured to determine the effective range of detection at any given time.
- It is very difficult to test a system with a known source because of the changing ocean environment.
- Broadcasting a sound in order to calibrate a towed PAM system could be problematic as it might require a separate permit.
- The depth of the sensor array is very important. If the array is too shallow, then the resolution will not be as three-dimensional. If there is a thermocline and the hydrophone array is above that thermocline, this may result in the loss of detection range.
- One possible way of evaluating the detection capabilities of a towed PAM has been to compare its detection performance with the results from visual observation.
- Towed PAM performance varies depending on a number of factors, including the species, the technology used, the setup, and the ocean conditions.

Participants also made the following comments:

- The U.S. Navy has installed hydrophones on the bows of their destroyer class ships. These could potentially be used for monitoring certain types of marine mammal sounds.
- There are a lot of sound sources in the ocean. If information is available on where some of those are, then that information can be used to test the capabilities of acoustic monitoring systems.
- The depth of the towed array has a strong influence on detection capabilities of a towed system.
- Seismic streamers with PAM technology are in development, and might be commercial in 2010.

- Some companies want clear telemetry, but vessels are required to have a clear exclusion zone. Both are needed because BOEMRE wants to collect useful information on PAM trials on commercial seismic vessels.
- Towed hydrophones can be used on s ilent vessels and on g liders, so they would not disturb animals.
- The Office of Naval Research sponsored studies involving five different autonomous underwater vehicles (AUVs), and all PAM tests were conducted with gliders. The results of these should be available soon.
- One of the problems with using underwater autonomous gliders is that they are already slow vessels, and attaching towed arrays to them introduced additional drag, slowing them down further.
- Using both fixed and towed PAM simultaneously would fulfill regulatory requirements for monitoring, while collecting information of the acoustic ecology of specific animals.

SESSION II: THE SENSOR – ACTIVE MONITORING

The session on Active Acoustic Monitoring (AAM) provided information on the capabilities and limitations or concerns about the available AAM technologies, and highlighted case studies of how AAM has been used in the field.

Jim Theriault of Defense Research & Development Canada provided an overview of how AAM can be used to detect marine mammals. He showed that AAM is an effective tool and broke down the performance of sonar into the following equation:

$$SE = SL + T - 2PL - NL \oplus RL + TS - DT - S_{loss}$$

He then reviewed some of the variables of the equation.[4] The sonar can only perform as well as the inherent quality of the water allows.

Mr. Theriault expanded on Target Strength (TS) by walking through a modeling experiment testing the hypothesis that lung collapse would decrease TS. Ultimately, the modeling, based on a humpback whale, did not support the hypothesis. Mr. Theriault noted that minimal data were available, and in order to fully understand the relationship between lung collapse and TS, researchers would need to consider multiple species.

Mr. Theriault showed an example of images of a single target from sixteen active acoustic receivers and noted that, in addition to the variables in the equation, there are other elements that affect the performance and effectiveness of AAM, including the operator.

He then summarized a study his team undertook for the Joint Industry Programme on Marine Life and Sound, addressing the potential effectiveness of AAM during exploration and production (E&P) activities, given the concept of use, the platform type, the size of the marine mammal in question, and that animal's diving characteristics.

Mr. Theriault concluded with the observation that there is no one perfect system. The technology that would best fit a given situation has be determined in a top-down, bottom-up approach by looking at the context within and the objectives towards which the technology would be used.

Case Study: Using Echosounders and Sonars to Detect Marine Mammals

Frank Reier Knudsen of Simrad provided an overview of two types of active acoustic monitoring systems: echosounders and sonars.

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[4] For the definitions of the different parts of the equation, please refer to Mr. Theriault's presentation, available in Appendix VI.

Echosounders transmit short pulses in a narrow beam, an acoustic ping, and are typically used to detect targets in the water column below a vessel. They are sensitive enough that they can detect a wide range of sizes, from plankton to whales. Echosounders can potentially be used as an ecosystem monitoring tool by combining frequencies, which gives them the capability of differentiating between different types of organisms and even species. They are very versatile and can be mounted onto a number of platforms, including buoys, and can transmit both vertically and horizontally. Dr. Knudsen showed how echosounders were used in Norway to detect and differentiate killer whales and schools of herring.

The sonar is a promising tool for whale detection because it has an instantaneous 360° coverage with a range of several kilometers where both bearing and range to a target are displayed in every transmission. However, there are some challenges associated with sonar. More work is needed to be able to convert whale detection on a sonar display into a quantitative measure of target strength. Its effectiveness is also dependent on water temperature gradients. Because the sonar is transmitting horizontally the acoustic beam is subject to bending according to temperature gradients and this can lead to misinterpretation of whale position. Therefore, actual measurements of temperature gradients and simulation of sound transmission are a prerequisite to any evaluation of whale observations on sonar. Sonar has some potential for species identification, as researchers noticed that the sonar patterns of killer whales and minke whales are different from one another. Much more work needs to be done with sonar; in particular, determining the target strength of a whale when it is diving, and on species identification.

Dr. Knudsen's study had several encouraging conclusions. One sonar configuration, SP90, detected whales up to 1500 meters. In addition to the direct echo from the whale, both vocalization and wake echoes from swimming were seen on the sonar screen, providing strong criteria for whale detection. There was no indication that the echo of the whale was reduced with depth. Animals were clearly detected to a water depth of 200 m. The whales showed no apparent reaction to sonar transmissions, even near the vessel (<50 m). Dr. Knudsen suggested that one reason for this lack of reaction is because the whales have become habituated to the sound produced as they forage among fishing vessels using the same sonar. The specifications of the transmission are: Frequency: 20-30 kHz, Power: high 218 dB, medium 212 dB, low 206 dB. The sound energy level falls off with range as discussed in Mr. Theriault's presentation, and reaches less than about 180 dB in a few tens of meters.

Case Studies: Three Examples of AAM

Peter Stein of Scientific Solutions, Inc. presented three examples of how active sonar systems are currently being used to monitor for marine mammals.

The High Frequency Marine Mammal Monitoring Sonar (HF/M3) is used by the U.S. Navy as part of the Surveillance Towed Array Sensor System (SURTASS) Low Frequency Active (LFA) Sonar System. It is one of the Navy's most effective systems to detect and track quiet diesel-electric submarines. They use a ramp-up method for the low frequency sonar to reduce impact on marine mammals. Ramp-up is also used for the HF/M3 system when trying to detect marine mammals. Hull mounting the sonar would not have been effective. It had to be towed well below the ship to be low enough to project sound into the desired region in all environmental conditions. It was therefore integrated with the Low Frequency Transmit array, which is also towed well below the ship for similar reasons. Dr. Stein and his team tested the effectiveness of the HF/M3 to detect a simulated whale target and found that the system was able to track the target's movement.

The Integrated Marine Mammal Monitoring and Protection System (IMAPS) is meant to be a combination of several types of marine mammal detection, including active and passive acoustic and visual monitoring. Dr. Stein tested the effectiveness of the active acoustics portion of IMAPS by deploying it twice in the path of the grey whale migration – once in 2004 and again in 2008. The 2008 test employed a sensor in mid-water column. Visual observers were stationed on the shore to complement the use of active sonar. The specifications of the transmission are: 21-25 kHz, with a source level up to 215 dB re 1Pa @ 1m, and 60 receivers, electronically steered. Since grey whale hearing is at upper edge of the frequency range of sonar they were not surprised to see some avoidance reaction when the sonar was operating. Gray whale target strength at 21-25 kHz varies from around -5 to + 13 dB re 1 m depending on aspect. This also falls within Jim Theriault's target strength estimates for grey whales, 23kHz/ 8.7 dB.

The Swimmer Detection Sonar Network (SDSN) was designed to detect terrorist swimmers. Scientific Solutions set out to design a less expensive system than phase arrays. In pilot tests and in operational use, the SDSN system was often more effective than much more expensive phased arrays systems – it was also so sensitive that the system could detect marine mammals and fish. Future versions of this system could be used very effectively for marine mammal monitoring.

Dr. Stein noted some of the limitations and capabilities of active sonar. He noted that it can detect whales up to a distance of about two kilometers, depending on the sea conditions, the animal size, and the sonar design. Sonar is best used when high-probability of detection is absolutely necessary, and a 500-meter exclusion zone is completely within the range of active acoustics given a proper system design. However, Dr. Stein noted that the sonar cannot generally be hull mounted. He added that there needs to be more studies on the effectiveness of active sonar to detect marine mammals. The grey whale migration was a good data-gathering opportunity because there were many targets.

He ended his presentation by stating that the best solution would integrate different methods – visual, passive and active acoustics – the combination of which would provide the highest probability of detection.

Case Study: Monitoring and Mitigation at an Underwater Tidal Turbine in Strangford Lough

Ian Boyd of the Scottish Oceans Institute at the University of St. Andrews presented, on behalf of Gordon Hastie, a case study of how high frequency active sonar was used at Strangford Lough, Northern Ireland, to detect seals, harbor porpoises, and dolphins near an underwater tidal energy turbine. The use of AAM allowed SeaGen, the owners of the turbines, to operate in a conservation area. SeaGen decided on the site for a number of logistical reasons despite the need to take marine mammals into consideration. The company realized that, given the amount of wind, wave, and tidal resources in the UK (and the rest of Europe), this was an issue that had to be addressed if the industry was to advance.

The company had to consider a number of potential interactions, including habitat exclusion, attraction towards the devices for foraging opportunities, and direct physical interactions. It contracted the Sea Mammal Research Unit Ltd (SMRU Ltd), part of the Scottish Oceans Institute, to study and attempt to quantify close range interactions between the tidal device and the marine mammals.

Dr. Boyd briefly listed some of the criteria for the type of sonar to use: the sonar had to be high frequency, have a rapid repeat time, and not be too expensive. He noted that sonar systems do not typically work to the manufacturer's specifications. The instruments the researchers used, Tri-Tech Sonar, were louder than in the specifications, and the animals could hear them and reacted aversively to the sonar when it was on. Dr. Boyd observed that this was not necessarily a negative outcome if animals were deterred from going near the area. The study, however, did not show much evidence that the animals avoided the turbine. Dr. Boyd hypothesized that they did not see the turbine in time to avoid it.

There were several conclusions regarding how well the sonar worked in terms of its goal. Small mobile targets can be detected over relatively short ranges using high frequency imaging sonar. However, only sixteen percent of the targets detected were marine mammals. Sonar can be used to detect marine mammals around tidal turbines, but tidal turbulence needs to be taken into account in terms of its impact on the probability of detection, especially for animals in the upper few meters of the water column. The detection of marine mammals may be variable, and visual confirmations could improve this.

Ultimately, the research team wants the system to auto-detect animals, triggering an automatic slowing down of the blade speed until the animal has passed through the area. According to Dr. Boyd, this could be implemented in the next year and a half. Due to the presence and use of sonar, the regulators felt comfortable enough with the project to allow nighttime operations. The sonar was moved to the shore, and an operator can shut down the turbine if a target is observed.

Dr. Boyd summarized some of the limitations of the sonar technology: it picked up a lot of targets that could have been something besides an animal of interest, and the sonar does not perform well in the first few meters at the water's surface or in shallow water.

He concluded by informing the group that SMRU is going to work with BioSonics to develop a sonar device with more classification capabilities and that cannot be heard by marine mammals.

Question and Answer Session

A short question and answer session followed the Session II presentations about AAM systems. In response to questions from workshop participants, the presenters made the following points:

- High-frequency sound does not travel as far as low-frequency sound. Therefore, an AAM system's zone of influence on the sound environment will be proportional to the AAM's frequency.
- Clutter is greater in shallow water, which limits the effective source level and range of the AAM system.
- Several AAM systems are commercially available, though systems for seismic vessels are not yet available. The individual hardware costs for AAM are relatively inexpensive, but the larger the system, the more expensive it would be.
- Hardware is not the only cost associated with the technology – deployment is a significant portion of the cost and could be more than the hardware cost.
- Many of the high-frequency systems can detect smaller species (e.g., turtles) below the surface, but not at the surface.
- Although interference from underwater communication systems can be mitigated through the set-up procedures, notch filters can also be used to mitigate this interference.
- All AAM systems are currently using FM waveforms.

Participants also made the following comments:

- An important question regarding mitigation is whether the mitigation action was successful based on an observable difference in an animal's behavior.
- Further research may explore the possibility of using the sound source being mitigated as a bistatic source for detecting marine mammals.

SESSION III: SIGNAL PROCESSING AND ANALYSIS (DETECTION, CLASSIFICATION AND LOCALIZATION OF MARINE MAMMAL SOUNDS)

Signal processing and analysis techniques are widely used for analyzing data from acoustic monitoring equipment to detect and classify which sounds are from marine mammals and to determine the mammals' location. Dr. David Mellinger provided an overview of signal processing and how it can be used in monitoring for marine mammals. The techniques used depend on both the goal of the acoustic analysis as well as the acoustic characteristics of the calls from the marine mammals of interest, and a number of factors must be considered in choosing techniques. Dr. Mellinger reviewed the factors that go into the choice of signal processing techniques and the context in which those techniques are employed.
He reviewed the analysis chain, which is how information is derived from sound. The steps of the chain are:

- Hydrophone
- Analog signal conditioning
- Data acquisition (to a computer)
- Signal processing and analysis
- Data reduction
- Interpretation
- Results

The analysis chain goes from sound to knowledge (See Figure 10). This process starts with a sound input, which goes through signal conditioning in order to facilitate detection. At the detection point, classification and measurement occur simultaneously and come together through statistical analysis to support interpretation of the meaning of those sounds, which in turn informs the appropriate action.

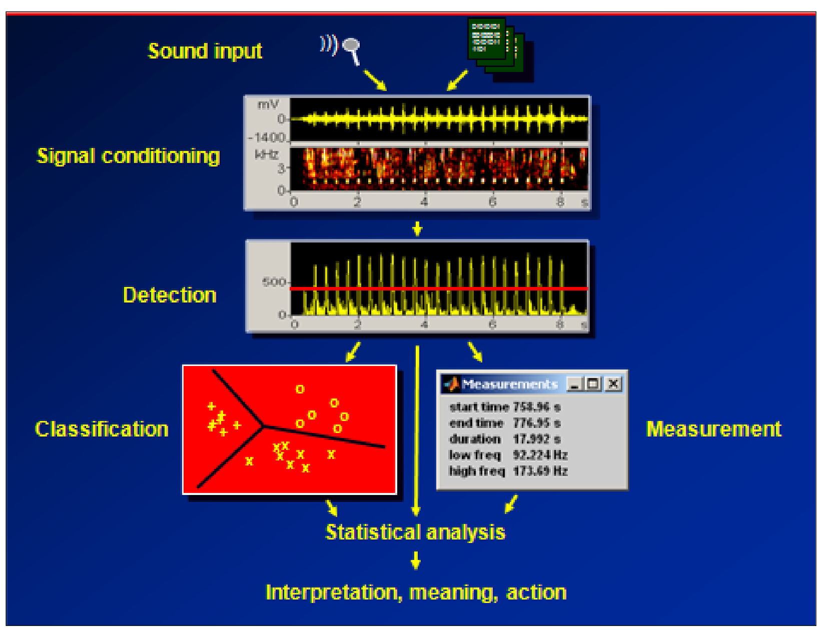

Figure 10. The analysis chain.

Dr. Mellinger noted that processing depends on what type of impacts may be of concern. For physical harm (e.g. hearing damage) one needs to measure the received spectrum (either instantaneous or over time) and locate the animals in the range (either two dimensionally or in three dimensions). To address masking of important sounds, one needs to measure the duty cycle or spectrum of received sound at the receiver and examine behavioral change due to signals not received (e.g. predators or prey not heard or breeding partners not found). Other behavioral changes may be of concern, including disruption of critical activities such as foraging, displacement from important habitat for feeding, breeding, or resting, displacement and effects on migration, etc.

Detection, i.e. deciding whether a sound of interest is present, normally is a yes-or-no decision. It usually involves a decision criterion such as a detection threshold. Dr. Mellinger emphasized that the choice of criterion (threshold) is always a *tradeoff between false detections and missed calls.* If the threshold is set high, true calls will be detected, but low calls might be missed. By setting the threshold lower, some calls will be detected, but then false detections caused by background noise might be a problem.

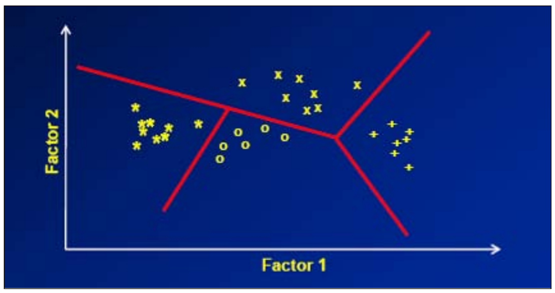

Figure 11. A diagram showing the categorization of a sound, usually with a multi-way decision.

There is no r igid boundary between detection (deciding whether a sound of interest is present) and classification (identifying a sound). Some methods such as template matching techniques combine both. Difficulty of detection depends on how stereotyped the calls are. Highly stereotyped calls are usually easier to detect and classify. Highly stereotyped calls can use template-matching methods. Other relevant variables include the type of sound (click, moan, burst pulse, whistle, etc.) and what other sounds are present in the same frequency band. For example, difficulty of detection and classification is affected by the similarity of the sounds to other species' sounds and to other call types (See Figure 11).

Decisions must be made about the calls that must be detected, i.e., where should the line be drawn between calls that should be counted and those determined to be too faint to count. This is contingent upon the goal of the analysis. For detecting rare species, one wants to find as many calls as possible, and therefore one sets the detection threshold low to detect fainter calls. With more common species, the threshold would be set higher so there is less false detection. To count total calls, the detection threshold should be set at an intermediate level so the false detections are balanced by missed calls.

Another issue associated with detections and classifications is how general a method is needed. More general methods such as monitoring changes in energy within a frequency band can detect more species and call types. These methods are useful in detecting a wide variety of species and species with highly variable vocalizations, such as humpback whales. Highly specific methods such as template matching are better at detecting one call type of one species. With this method, some of the target calls may be missed if they vary from the template. Finally, there are methods with intermediate specificity such as click and whistle detectors that capture a group of call types in a certain frequency band.

The degree of automation is another issue that takes into account how involved humans are in the detection and classification process. Full automation is easy and quick, but is prone to errors, particularly when the type of sound changes over time. On the other end of the spectrum where there is no automation, the spectrogram is displayed for humans to view and decide which signals are mammal calls and (optionally) classify them. This may be the most accurate, but takes the most time. It is useful when calls are highly variable. Automation with checking and automation with partial checking produces a set of putative calls, which are checked. This is somewhat labor intensive but helpful for weeding out false detections. Missed calls can be a problem, but people can sample periods of time with no calls to estimate the missed-call rate. Mellinger stressed the need to sample whenever the noise changes due to changes either in human activity; in physical processes such as wind, storms, ice, or flow noise; or in calling patterns of either target species or interfering species.

All these methods require training and testing. Mellinger pointed out the need for data sets for this purpose and emphasized that data used for training should not be used for testing. Real data sets are important. Also, the greater the variety of training data, the more robust the detector. Variety can come from recordings from different places, populations, and times; recordings made in different noise conditions (physical, human, or non-target-species noise); and different recording arrangements (towed vs. fixed hydrophones or different models of hydrophones, conditioning equipment).

A final issue is performance evaluation of the detectors and classifiers to characterize how well a method works. The description of the performance should include signal to noise ratio (SNR) of the calls, because high-SNR calls are easier to classify. However no metric fully characterizes a method, as changes in noise can strongly affect performance. The Receiver Operating Characteristic (ROC) curve shows the rates of correctly detected calls (true detections) and false detections, as does the Detection Error Tradeoff (DET) curve. The false alarm rate measures the number of false detections per unit time. Finally, the confusion matrix shows how often calls are classified correctly, or when incorrect, into which incorrect categories.

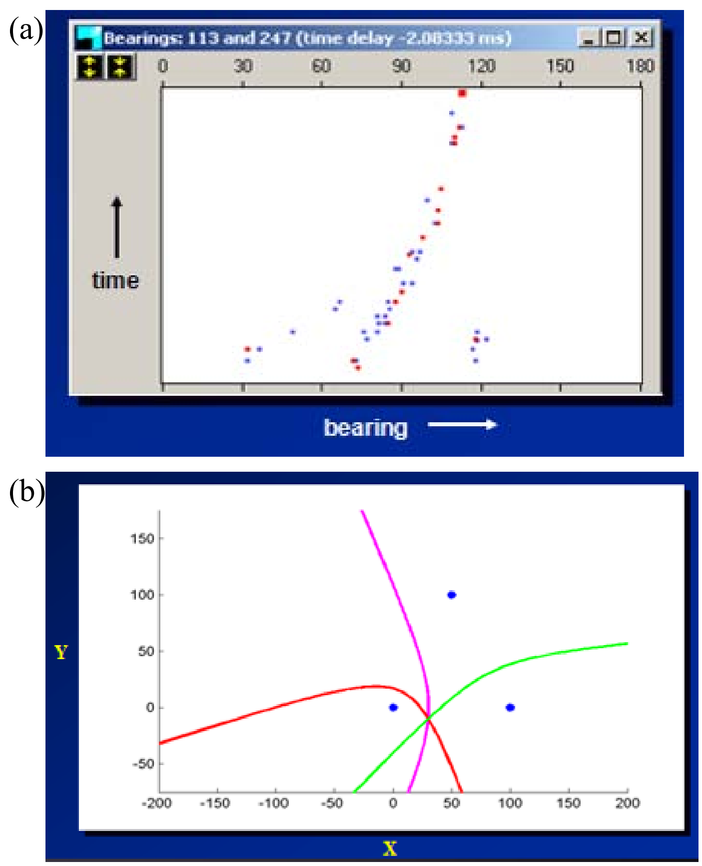

Figure 12. (a) Bearing-time plot; (b) Hyperbolic localization plot.

Dr. Mellinger reviewed localization and tracking. He defined localization as using a sound to estimate the location of a sound source. He defined tracking as combining successive locations to estimate movement. Both can be done in 1-, 2-, or 3-dimensions, and are usually done by noting differences in arrival time at several hydrophones. Dr. Mellinger then demonstrated localization for each dimension, noting that localization methods only produce an estimation of position and that there is always some degree of uncertainty. One-dimensional localization estimates the bearing to the animal. Two-dimensional localization estimates the position of the animal (azimuth and range, or x and y). Three-dimensional localization estimates the location of the animal in three dimensions (range, depth, and azimuth, or x, y, and z). Localization accuracy depends on the duration of the call times, its bandwidth, the signal-to-noise ratio, the number and geometry of the hydrophones, sometimes the geometry of the environment, and the degree of automation. (See Figure 12 on the previous page.)

In conclusion, Dr. Mellinger noted:

- Overall the method to use depends on the type of result desired.
- The amount of human involvement in the process is a crucial choice and determines the quality of the results.
- There are always tradeoffs between wrong detections and missed calls.
- With classification, one should make sure training data is independent of testing data.
- Localization methods produce an estimate, whose quality depends on the call that is localized and the array geometry.

Case Study: Detection and Localization of Clicks and Whistles Using Passive Acoustics

Dr. Doug Gillespie reviewed issues in signal processing associated with detection and localization of clicks and whistles from marine mammals. He spoke of the difficulties involved in some classifications, and the ease of others.

As far as researchers know, all odontocetes (toothed whales and dolphins) produce clicks, though some vocalize frequently and others appear to vocalize rarely, and there are several species that have not yet been recorded. Clicks vary greatly from species to species.

Dr. Gillespie highlighted sperm whales, which produce broadband, short duration pulses, and the harbor porpoise, which produces much quieter ultrasonic narrow band pulses. Generally, odontocete vocalizations all are highly directional in nature, focused in a narrow beam directed ahead of the animal.

The detection range for clicks is best when the animal is pointing towards the hydrophone, but detection is sometimes still possible when the animal is oriented away (e.g. for sperm whales). Aural detection is possible only if the vocalization is in the human audio band. However, visual detection is possible beyond that via a spectrogram display. Generally, the unit of detection is a click train (repeated clicks) rather than a single click. Automatic detectors can work at any frequency if the right hardware is used.

Localization of clicks is more difficult when groups of animals are present and when sub-arrays are farther apart. Localization of single clicks may not be possible with directional sounds in that, if the hydrophones are far enough apart to get a good location, some hydrophones will not be in the same 'beam.'

When using small aperture arrays, target motion analysis is a commonly used method for localizing animals. As the vessel proceeds along its track, multiple bearing measurements are made to different vocalizations from the same animal; location is then derived from the point at which the bearing lines cross. Target motion analysis requires the animals to be relatively slow moving (compared to vessel speed) and to vocalize frequently, so that different sounds from each individual can be linked together. It does not work with large groups of animals and fast-moving species. (See Figure 13.)

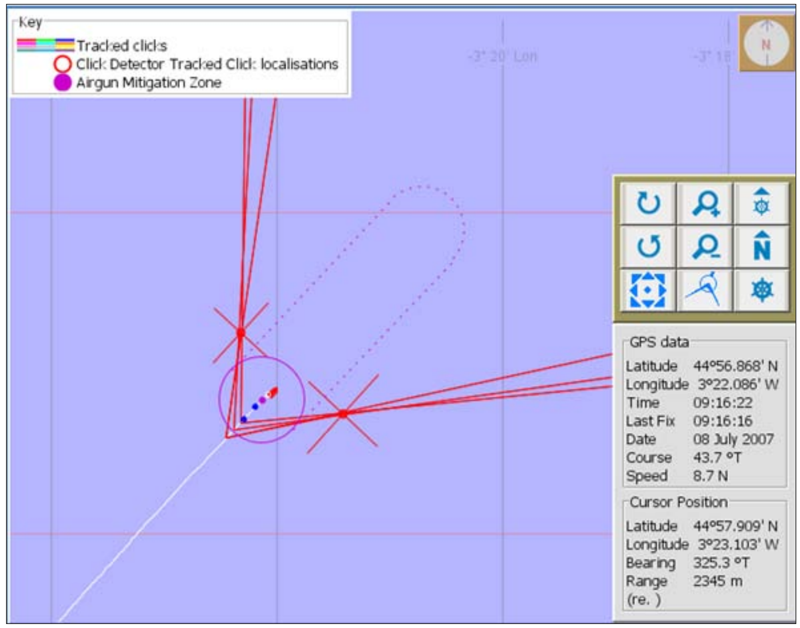

Figure 13. Target motion analysis. The white track represents the passage of the survey vessel (heading in a NE direction). The red lines are bearings to individual clicks from the same animal. The red crosses indicate where the bearing lines cross. Note the left-right ambiguity and the overall uncertainty in the animal's position represented by the length of the crosses. As more bearings are added to the target motion analysis calculation, the estimate of position becomes increasingly accurate.

Dr. Gillespie noted that PAM operators hope to have a detection probability of 1.0 within a mitigation zone (e.g. 500m), with a decreasing probability outside that zone. Detection probability is dependent on the probability close to the track, which is a function of behavior (did the animal vocalize?), the detector (is it sensitive to that sound?), and luck (is the beam of sound pointing at the array?); and of the detection range, which is a function of evolution (how loud is the species?), noise (at what range are sounds masked?), and technology (how good is the equipment?). (See Figure 14.)

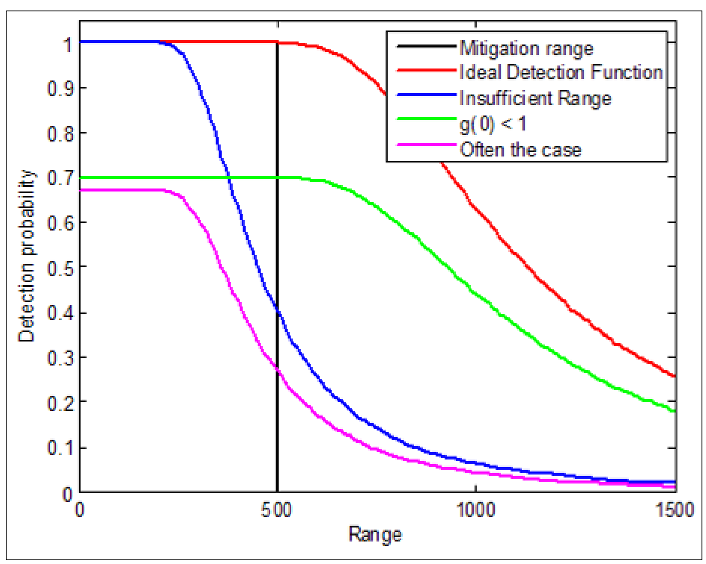

Figure 14. Detection probability decreases outside the mitigation zone.

Dr. Gillespie then discussed these variables with respect to detecting sperm whales, harbor porpoises, and beaked whales. Sperm whales, probably the loudest in the ocean, can be heard up to 30 km away. Harbor porpoises, on the other hand, vocalize more quietly and thus are more likely to be heard in the range of about 200 m, require special equipment to detect, and the sounds are not likely to be detected if the animal is swimming away. The challenge in detecting beaked whales is that they vocalize much less frequently – generally while diving. However, it is possible to detect at least some clicks over a dive cycle out to a range of nearly 1km.

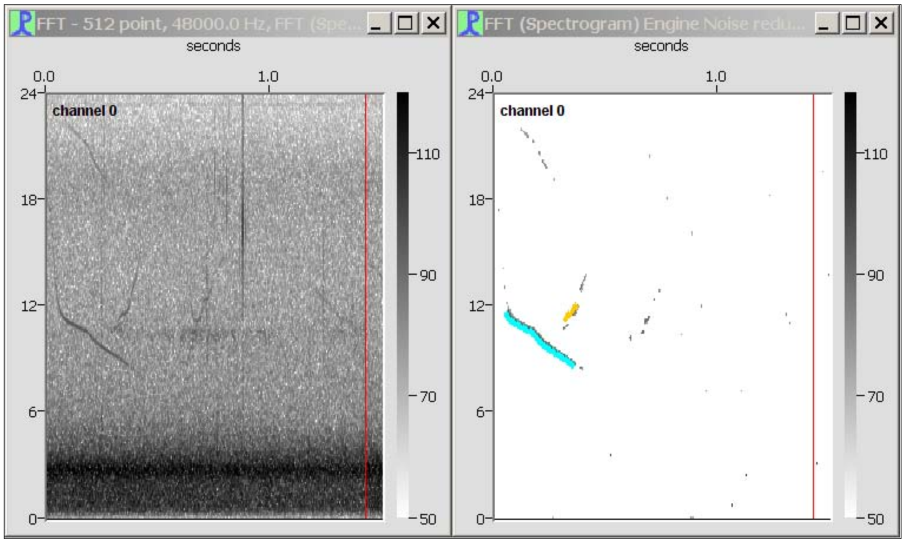

Figure 15. Detection is generally achieved through some kind of noise removal and contour tracing on a spectrogram.

Dr. Gillespie noted that where all odontocetes click, not all odontocetes whistle. For those species that do whistle (e.g., dolphins, killer whales, pilot whales, etc.), the sound seems dependent on the behavioral state of the animal and is more of a social signal. Whistles vary in time and frequency. Whistles are relatively easy to detect on a spectrogram display because they are distinctive sounds and are less directional than clicks Automatic detection generally involves some method of noise removal and contour tracing on a spectrogram such as in Figure 15. Multiple element hydrophone arrays can be used to calculate bearings to whistles and longer arrays can be used to estimate both bearing and range. Target motion analysis is unlikely to work since these species are often fast moving and in large groups, making it impossible to cross bearing lines to individual animals in a meaningful way. More information is needed on detection range for whistles.

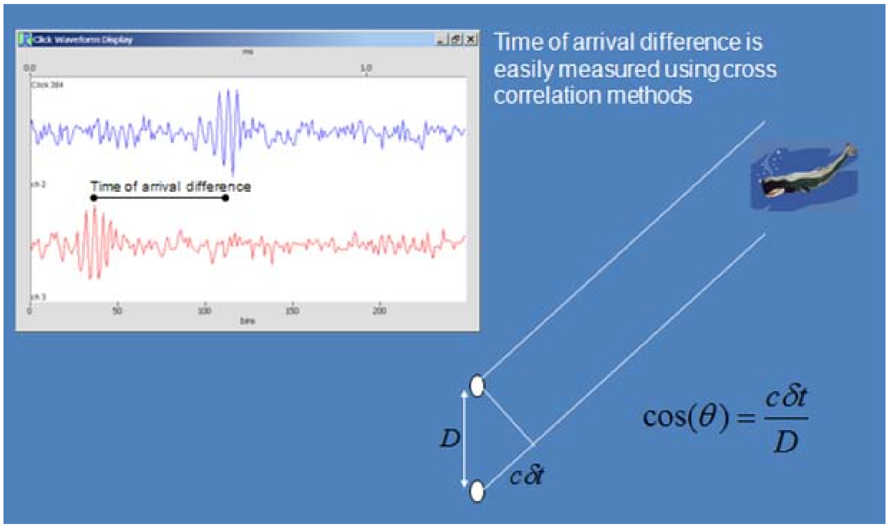

Figure 16. Localization using bearings.

Determining bearings from closely spaced hydrophones is relatively straightforward. In Figure 16, the time arrival difference is depicted, which, using the correct equation, can determine bearing.

Dr. Gillespie summarized his talk with the following points:

- Clicks from odontocetes can be easily detected, and whistles are distinctive sounds that also are easily detected.
- Some clicks are indistinct from other background noises, in which case the 'click train' is a better unit of detection (visually seeing the clicks on a screen).
- Bearings are easily calculated.
- Some species may be tracked using simple, two-hydrophone arrays and target motion analysis.
- Where target motion analysis cannot be used, longer multi-element arrays can be used to estimate ranges to individual sounds.
- Detection probability varies by species, thus there is a n eed to consider detection range and detection probability at short distance on a species-by-species basis.
- More information on detection range is required.

Case Study: In Search of a Software Solution

Dr. Christopher Clark addressed signal processing challenges in the context of marine mammals operating over a wide range of the basic acoustic dimensions of duration, frequency and space. At one end of this bioacoustical-ecological domain are the very low-frequency whales. These are the animals that sing in the infrasonic frequency range with notes that last 20-25 seconds and with voices that can be heard across an ocean basin. In the middle of this acoustical space are the odontocete species with whistles and clicks that are both humanly audible and ultrasonic. And at

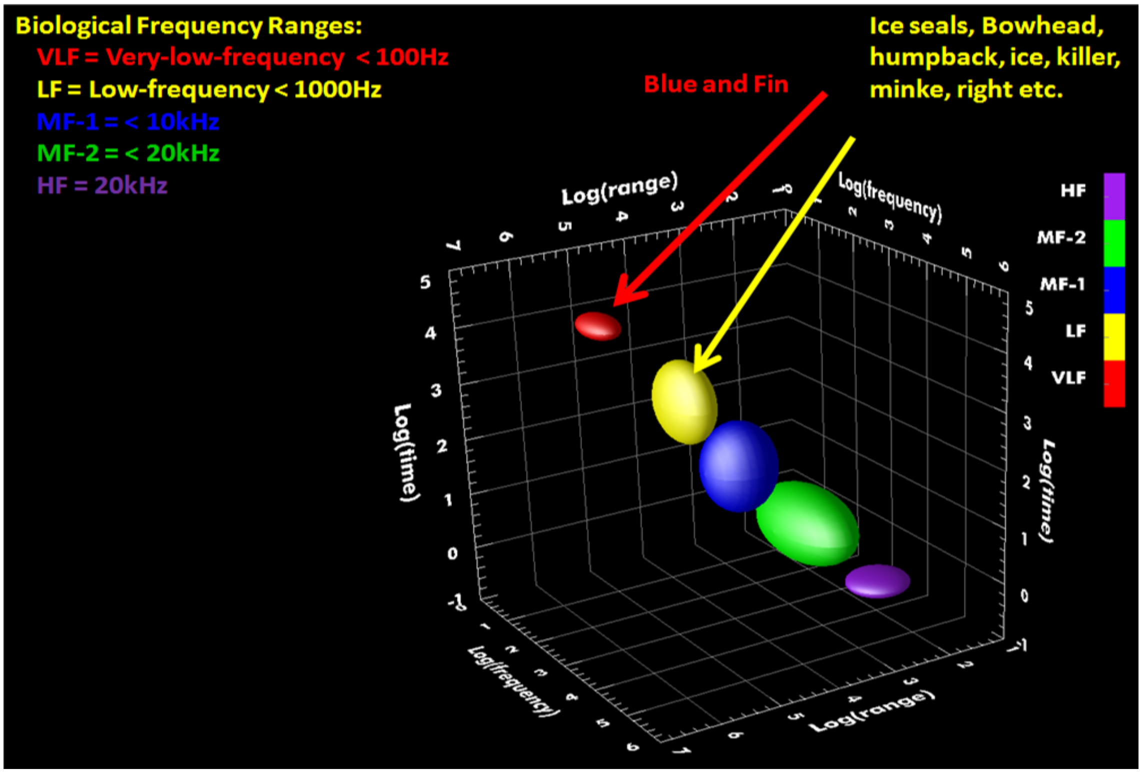

Figure 17. The bioacoustical-ecological domain in which marine mammals operate over a wide range of the basic acoustic dimensions of duration, frequency, and space.

the other end of the spectrum are the toothed whales, dolphins and porpoises that click and chirp at the very highest frequencies; high ultrasonic sounds that last 40 microseconds and cover just hundreds of meters of space. The ranges needed to cover the full expanse of the temporal, frequency and spatial scales used by all these species cover five orders of magnitude (e.g., 40 µsec to 20 sec).

The acoustic dimensions that contain the sounds of a single species can be thought of as a species' ecological-acoustic space, just as the acoustic dimensions that define the sounds of a species or clade (e.g., baleen whales; highly social, fission-fusion toothed whales) can be thought of as the ecological-acoustic space for that group of animals. Conceptually and pragmatically these ecological spaces, or niches, for the different groups are mostly distinct but partially overlap with each other as illustrated in Figure 17.

Increasingly, however, and of importance for this workshop, these natural ecological-acoustic spaces of the marine mammals are coming under increasing pressure from anthropogenic noise sources; or, if viewed from the perspective shown in Figure 17, the natural space-time-frequency domains of the whales, their ecological-acoustic niches, are being invaded and in some cases dominated by the space-time-frequency domains of industry projects.

Some challenges for the detection task include not just determining whether a signal is from a particular species or clade of marine mammals given the presence of other signals that occupy some of the same acoustic space and time, but also the fact that the actual structure of the signal of interest has a different appearance depending on its distance from the sensor. By analogy, the signal may appear as a distance nebula in the universe of sound space when far away, but the details of that sound can change quite dramatically when it is closer. Thus, the optimum detection process and parameter settings for that process can vary as a function of distance depending on the sound's features. Furthermore, the sound itself may or may not include a complex mixture of frequency-modulation, amplitude-modulation, broadband pulses, and bi-phonation. Thus, there is not a neat, tidy package to constrain the identification, classification and localization of sounds in the multi-dimensional space called marine mammal bioacoustics. The solution is to simplify the metrics by which to define, constrain and solve the problem.

Starting with an initial set of questions helps structure the thought process:

- What is the actual problem to solve?
- Is this a research project, or an operational requirement?
- Do we need to know what species is producing the sound?
- Do we need to know exactly where the sound source is?
- Do we need to know what the animal is doing?

By this process, marine mammal signal detection then requires a sequence of steps, beginning with energy detection in a frequency band (the acoustic "event" or "object") followed by a method to represent the acoustic object visually for human inspection, both visual and acoustic (Figure 18). From this display, a decision can be made by a person or computer about what that visual depiction represents.

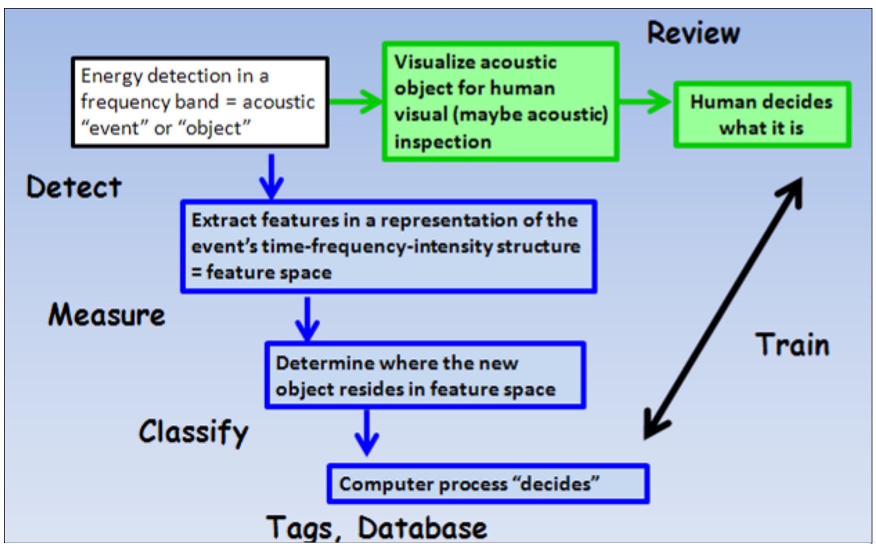

Figure 18. Example flow chart for marine mammal signal detection-recognition.

Figure 19 illustrates the problem of detecting and recognizing right whale contact calls, a relatively simple signal to detect, but one that can be hard to delineate and recognize within the ocean's acoustically complex and dynamic noise environment. The depicted noise background in the time-frequency displays looks like static due to the dynamic noise environment. This background noise also makes locating and tracking whales that much more difficult.

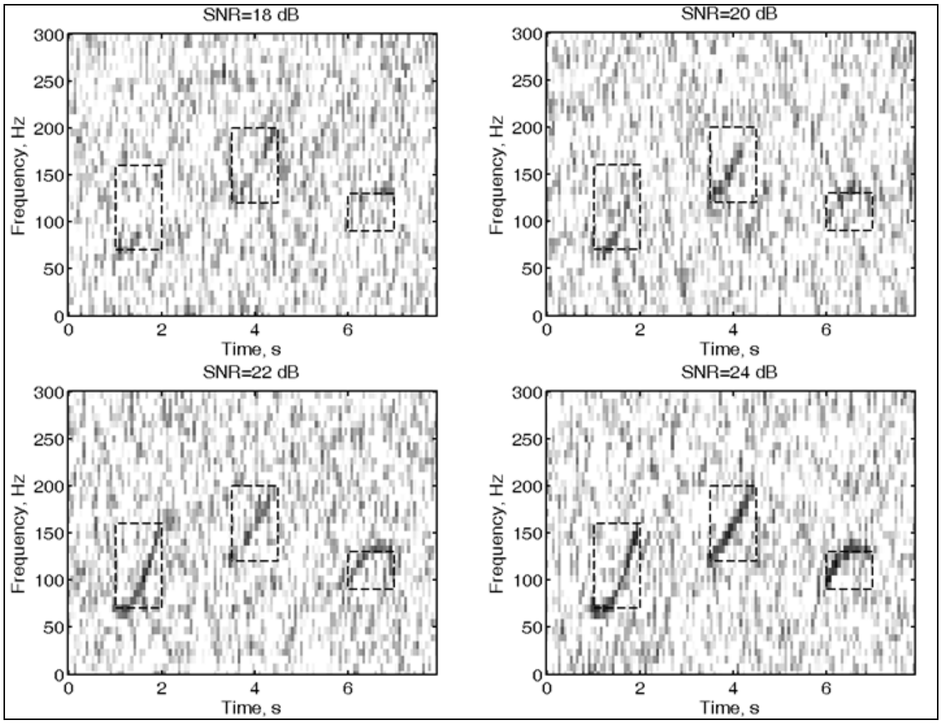

Figure 19. Example showing how the ability to detect three right whale calls changes with the amount of background noise.

Now add to this the complications that arise because even for relatively simple sound types (e.g., contact calls, signature whistles), there is intra- and inter-individual variability, which makes it hard to stereotype vocalizations, and whales can imitate each other. If a system is designed to only detect one very specific form of a vocalization, it will miss detecting other forms.

The flow chart in Figure 20 depicts the steps in the marine mammal signal detection-recognition stream. Upon detecting a signal, the computer first measures the signal, often in some representation of its time-frequency-intensity structure. It then classifies the signal and then tags the signal in the database. At the same time the human operator would confirm the detection and its tag in the database. This double-checking helps to cross-validate automatic results and allows one to build a performance metric.

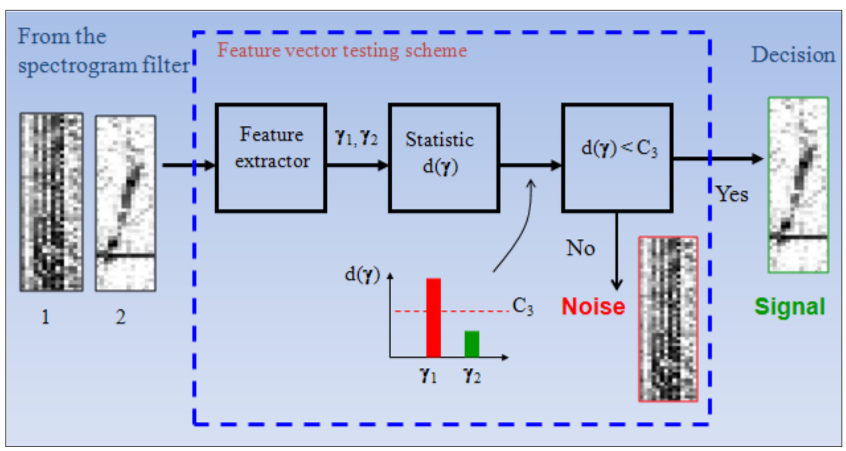

Figure 20. Searching for a specified signal "type."

The computer portion of this analysis includes a filter to reduce background noise followed by processes to extract features. Then statistical analysis determines whether the event is noise or a signal. This process is essentially a feature vector testing scheme when searching for a particular signal type. When a particular signal is recognized, it is then processed through a multi-channel detection scheme whereby finer detection is attempted to determine the whale species.

Dr. Clark emphasized the importance of an operator understanding multiple aspects of the acoustic environment, including the environmental context and how well the system performs in different noise conditions, but especially the ambient and background noise fields. There are standard metrics available to validate how well the system and operators perform given a particular noise condition, which can greatly influence performance. Dr. Clark displayed some examples of the receiver operating characteristic (ROC) curves for low and high noise conditions, pointing out that the false alarm probability increases in high noise conditions. There is a real cost associated with each point along the ROC curve, whether in terms of hours looking at screens or in data processing.

As noted throughout the workshop, an effective approach begins with understanding the regulatory requirements and the bioacoustical environment, choosing appropriate simplifying assumptions, and tailoring the approach to the situation. Regulations provide a starting point for choosing where to sit on the performance curve.

He noted that it is possible to engineer the problem, but only up to a point. The true limiting factor is biology: the uncertainty and variability in the behavior of the animals. Therefore, all those involved – researchers, operators, regulators, and developers – need to accept that there will always be uncertainty in acoustic monitoring results and capabilities. The greater the resolution requirements - whether in terms of recognition at the species level, an animal's location relative to an anthropogenic activity, or an estimation of its exposure history- the greater the amount of resources (e.g., time and money) needed to meet those requirements. Given biological variation and our present lack of knowledge regarding biological impacts, biology is the rate limiting factor. Thus, the challenge is to find a logical balance between the data resolutions needed to constrain the biological risk, the benefits to the animals from monitoring at some level of risk, and the costs associated with the mitigation and monitoring program.

Question and Answer Session

A short question and answer session followed the Session III presentations.

In response to questions from workshop participants, the presenters made the following points:

- Many of the signal processing methods can be considered data reduction methods.
- Whether or not detection by receiving the sound and processing it with software is going to be more accurate than detection by visual observation is dependent on the species of animal.

- Researchers are trying to develop a semi-automatic system so that it would be humanly possible to review the data, which goes by very fast on the screen.
- These data are typically archived to allow for post-processing, so that it is possible to reanalyze and review the data afterward.

Participants also made the following comments:

- The BOEMRE would require both acoustic and visual monitoring; acoustic monitoring would not replace visual monitoring. Shutdowns would be at the quickest level of detection.
- For species-dependent take allotments, there is pressure to turn around the data very quickly.
- Signal processing will never get 100 percent of everything with 100 percent certainty. Neither does visual monitoring. It should be possible to have acoustics operate alone with as much confidence as visual monitoring.
- For most cases, in the real-time mitigation task, the identification of the specific species is not as important as the actual detection of the animal. There needs to be an improvement in training and the database of sounds available on ship, and improved tracking accuracy.
- Time motion analysis would work for relatively few species, but for those species for which it does work, it works very well. For other species, it can be an improvement on localization methods.
- The objective of mitigation is focusing on detection, lowering false detections, and localization within the zone of exclusion. Then periodically within the activity, adjust the take assessment. Then a longer-term impact assessment.
- For the activities being mitigated for, the stakeholders should consider lowering the source levels, which would reduce the area of impact.
- There may be logistical and training issues associated with semi-automated systems.

SESSION IV: METRICS

Dr. Thode explained the importance of selecting appropriate metrics for passive acoustic research and determining the effect of anthropogenic sounds on marine mammals. Defining quantitative measurements helps focus vague discussion. Metrics are a "system or standard of measurement" that determine criteria, which determine exclusion zones, which determine PAM configurations, so it should be the first step in any discussion on evaluating the impact of sound on marine mammals and evaluating what PAM configuration to use.

Dr. Thode discussed three potential ways that sound affects marine mammals. There are metrics for each category of impact, with the intention of minimizing biological assumptions in a metric while preserving its long-term relevance.

1. Causing direct injury or mortality. Studies have shown that marine mammals may be injured by sound (root mean square [rms]) pressure or peak pressure at close range. A focused, well-developed sound could also be harmful. The pulse from a seismic airgun would be an example. More recent studies indicate that the sound exposure, which is the time-integrated square pressure of the sound, may be a more relevant measure when predicting whether a given sound causes a temporary or permanent hearing threshold shift (TTS or PTS).

2. Reducing the ability to hear or detect; thereby altering "normal" behavior (masking). An animal's behavior can be altered if there is too much noise or sound of a certain frequency inhibiting it from hearing other marine mammals, or in the case of odontocetes, affecting their ability to find prey using sonar, since they will not be able to hear the sound reflecting off the prey. Masking can be short-term and local or longer-term thereby affecting whole populations of marine mammals due to its cumulative disturbance effect. Thus there is potential for a population-based impact based solely on signal level, signal to noise ratio, or energy. Shallow water seismic reverberation is an example of a source producing this type of masking sound.

3. Causing changes in behavior due to particular features in the signal other than intensity, energy or signal-to-noise ratio. It is assumed that these sounds are biologically relevant to marine mammals. An example of this for humans could be a baby crying in church. The behavioral response of people to this sound may be greater than that of a sound with greater intensity or energy. For a marine mammal, there are studies that show a "fright" and "flight" response to a particular signal that sounds a great deal like a killer whale call.

It is important to clarify that metrics are not a criteria; they are simply a measurement. There is no known "threshold" for any of these categories, although some consensus may be emerging for the first category (direct injury).

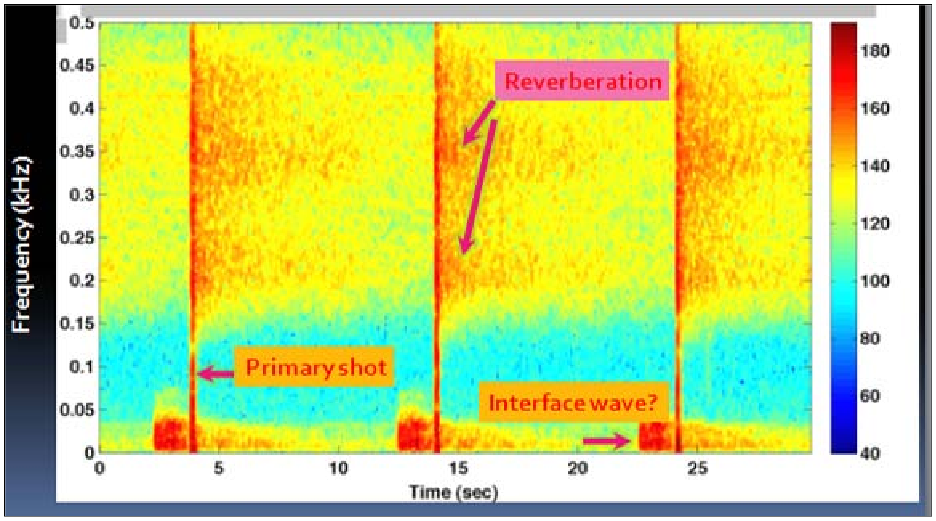

Figure 21. Measuring seismic pulses in the Beaufort Sea.

Dr. Thode described the 2008 Beaufort Sea Acoustic Project off the north coast of Alaska. Researchers measured the bowhead whale migration near large-scale seismic activities. The project had bottom-mounted DASARs in five sites; seismic activity was mainly located between sites 3 and 4. The anthropogenic activity produced short-term pulses, which resulted in a sound like rolling thunder after each pulse. These pulses varied in duration and structure with range, and also produced waves that propagated through the ocean bottom – a "head wave." (See Figure 21.)

Thus, even for a single pulse, the effects of acoustic propagation can create complexities in structure that make estimation of pulse duration, rms pressure, and sound exposure less than straightforward. A particular challenge is deciding over what bandwidth to conduct the measurement.

<u>*Direct Injury*</u>

Dr. Thode spoke in more detail about the components of direct injury to marine mammals. He explained that injury could be caused by intensity, cumulative energy density, or peak pressure. He then briefly reviewed some of the different definitions for intensity, and how the duration of the pulse is a critical component of the measurement. It is possible to have very high pressure but a short duration sound. Given the curve developed for intensity, the area under the curve represents the energy of the signal. Because of the variability in the definitions and references for intensity that can lead to different numbers, the operator needs to be specific on the definitions used when characterizing sounds. An example of this is re: 1uPa (max), which means re 1 microPascal at 1 meter and measures peak pressure. Conversely 20uPa (rms), which is considered the threshold for human hearing, refers to rms pressure. Finally sound exposure (SE) is referenced uPa $^{\wedge 2-s}$ and is a rough measurement of energy flux.

Dr. Thode then reviewed how to determine transient sound duration (the length of the signal). To begin the process, estimate ambient noise to differentiate from the value of X^2 which should then be tracked for the rest of the signal. The signal length is estimated by taking the mean square pressure (X^2) just before the pulse and subtracting the entire square pressure time series. Then the cumulative energy density function is calculated and normalized such that its maximum value is one. After this point, there could be a few seconds of reverberation. This makes up only a small fraction of total energy. Depending on the frequency band, filtering will change the metric results.

Dr. Thode then explained how to minimize biological assumptions in “injury” metrics. He noted that while researchers want metrics that are biologically relevant, they do not want so many assumptions behind the metrics that the numbers become meaningless. He proposed that a set of narrowband SEs permits the incorporation of a biological hearing curve for a given species. An advantage of this is that when information about a species’ hearing sensitivity evolves, the curve can be updated without invalidating the original measurements.

An unresolved issue regarding sound exposure is whether sound exposure measurements from a sequence should be added together, which makes them cumulative, or whether measurements stand alone. If they cannot be added together, then at what interval should the pulses be separated in order to be accepted as discrete events? Dr. Thode noted that a twenty-four hour period has been suggested as the division between events, but noted that his own inclination was to treat each impulse as a separate event because it is easier to combine them later than to separate them out. He cited an example: in a 24-hour period with10-second intervals, there were 8640 pulses. Is that 8640 214 dB re 1uPa^2-sec pulses? Or is that a cumulative 214 +10log (8640)=254 dB re 1uPa^2-sec exposure? (Southall et al, 2007) As shown, the difference is substantial. In general, he felt it was more robust to compute metrics for each component of a sequence, from which various cumulative measures could be derived at future times.

Masking

Dr. Thode then discussed metrics for long-term, chronic, and cumulative effects, or masking. He noted that signals contribute to increases in the background ambient noise – for example, the background rumble from seismic activity, which is only about two percent of the total energy, is greater than and adds to the background noise. Important aspects are signal level and signal to noise ratio. He then explained how to quantify the reverberation levels and how to translate that into “masking” levels.

Dr. Thode listed two steps to get to the masking level. First, report the minimum measured levels over thirty-minute intervals. Second, use an environmental modeling approach.

By selecting the minimum value over several cycles, PAM operators can capture the long-term trend of the curve and extract background / reverberation noise (See Figure 22 on the next page). Dr. Thode showed plots from different locations at the activity site, and noted that reverberations are greater in deeper water. He then gave three options on how to convert the background noise levels into a masking metric: time invariance, space invariance, and environmental modeling. Time invariance involves subtracting ambient noise levels from a quiet day and comparing them with subtracting ambient noise levels from an active day. Space invariance is somewhat similar in that ambient noise is subtracted from a quiet location and an active location. Environmental modeling, which shows that normal ambient levels depend on environmental parameters (wind and sea state), is one of the more accurate methods to determine masking. It can be measured independently.

Dr. Thode then described Step 2, which involves the empirical wind noise model approach to estimate masking by subtracting ambient noise fields and quantifying non-wind noise contributions. A conservative estimate of masking subtracts ambient noise fields and quantifies non-wind contributions. To the right, airgun activity is evident above background levels at Sites 2, 3 and 4.

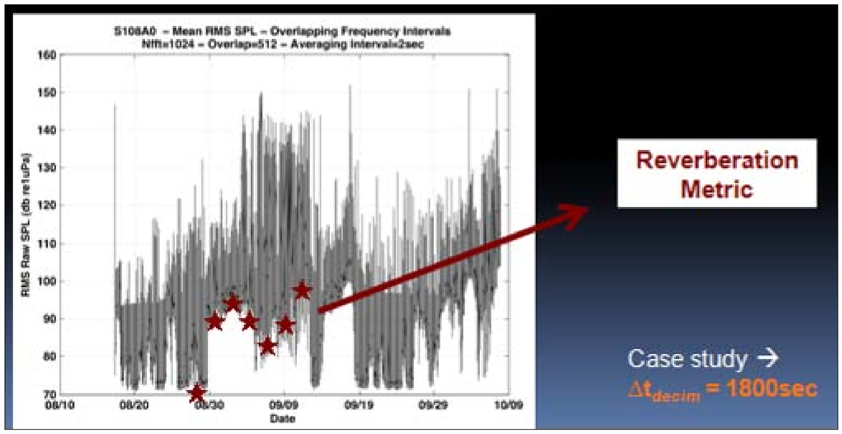

Figure 22. Determining the reverberation metric by selecting the minimum value over several cycles.

Dr. Thode suggested that this was an area where more discussion was needed because results cannot be quantified into a single masking metric.

Non-masking Behavioral Impacts

Dr. Thode pointed out that the biological significance of an animal vocalization is dependent on sex, age, behavioral state, and time of day. As one potential example, he noted that there was no overlap on the frequency between beaked whale vocalizations and the MFA naval sonars, but the naval sonar signals are similar to the calls of killer whales, as first suggested by William Ellison. He suggested that techniques like spectrogram correlation and other techniques could be used to derive "similarity" indices between particular anthropogenic sounds and naturally-occurring sounds of biological relevance. Anthropogenic sounds with a high similarity score may be more likely to initiate behavioral responses at low received levels.

Dr. Thode concluded that metrics are a fundamental step in PAM because they force PAM operators to think about what data to collect and how to collect them. However, behavior must be separated from the physics involved in order to minimize assumptions about animal hearing capability or behavior. It is also a way to get an "intermediate result."

Metrics for injury are relatively well-developed, metrics for masking are still under development, and metrics for biological significance still require a lot of research and are difficult to understand.

Regarding metrics for injury, he shared some hypotheses based upon anecdotal evidence and his expertise:

1. Reporting spectral density (or a set of values measured over narrow bandwidths) has greater value than a broadband measurement because it separates physics from biology; that is, the spectral density can be converted into a broadband frequency-weighted measure, but not the other way around.

2. For a series of repetitive events it is better to provide the metric for a single event, then the total number of events (% time present).
3. The background ocean environment fluctuates greatly, and measurements of ambient noise are important, including statistical measurements of long-term properties, and also cataloging various types of naturally-occurring transients.

Regarding masking metrics Dr. Thode summarized the components still under research. The three concurrent uses of collecting environmental data measurements with PAM and estimating background noise (wind, shipping activity, etc.) will become very valuable in the absence of anthropogenic activity. These uses are: as a proxy or predictor of marine mammal presence, to help estimate transmission loss and to prove the effects of masking. He also said that the masking metric should be a function of the frequency (density). He reminded the workshop attendees of the two measurements of the “masking metric” (dB) and duty cycle (%).

The last metric, “Biological Significance,” is very difficult to comment upon and it may not be practical. Dr. Thode suggested that a biologist would be more qualified to comment.

Question and Answer Session

A short question and answer session followed the Session IV presentation.

During the discussion, participants made the following comments:

- The notion of considering masking relative to some ambient noise is critical.
- For cases involving subsistence hunting, regulators rely on acoustic measures to help estimate the point at which a whale avoids an area with industry activity and therefore becomes unavailable to hunters.
- Barotrauma can cause injury and requires a different metric, Pa-sec. This may be an important issue for animals very close to activities that produce impulses such as seismic airgun arrays, explosions or pile driving.
- When evaluating the effect of a pulsive event, it is appropriate to use an energy level metric such as SEL.
- Using a 10-log factor may overestimate the cumulative effect from multiple exposures to an intermittent sound source such as a seismic airgun array or pile driving.
- Extrapolation between species should be approached very carefully, because little is known about how different species perceive sound.
- There is almost no information on the recovery rate for different species. One participant related that in a particular study, the researchers conservatively assumed no recovery between pulses, which is not true for longer periods.

PART II

WORKSHOP THEMES

Several topics were raised by speakers and participants at multiple points during the workshop and are summarized below as general themes of the workshop. This summary reflects the views of participants and is drawn from notes from plenary and small group discussions and from worksheets submitted by participants at the conclusion of the workshop. The section on operations and operators also includes the points made during an interactive panel discussion during a plenary session.

REGULATORY FRAMEWORK AND PROJECT DESIGN

Operating Within a Regulatory Framework

The importance of the regulatory framework within which the design of acoustic mitigation and monitoring systems for detecting marine mammals has to operations was a major theme throughout the workshop. Participants noted that a company's senior management needed to be educated on the regulatory requirements so that company policies could be consistent with the requirements for compliance. The regulators also have to be clear about the different performance requirements for these different systems, so that project design, communications between the regulators and the regulated, communications within project teams, and education at all levels are aligned to achieve success.

A BOEMRE participant noted that 2003 regulations required seismic operations to have visual observers on board the vessels. The resultant cooperation from the industry to ensure compliance and understanding of the requirements has been tremendous. This participant expressed a hope that industry will cooperate in the same way with PAM, and was of the opinion that the problems and issues related to PAM can be solved quickly with industry cooperation.

The workshop participants underscored the importance of being clear about the distinction between "mitigation" and "monitoring," both of which are regulatory requirements. Participants also noted the different purposes for monitoring, and that monitoring can have different spatial and temporal requirements, which then have different design implications. Monitoring for mitigation purposes is more immediate and mostly directed at observing short-term effects, whereas monitoring for research purposes or for the assessment of population level impacts can have both immediate and long-term requirements. In almost all cases the inclusion of post-activity monitoring is important for comparative assessment of possible changes as a result of the activity.

Exclusion Zone

A specific regulatory decision is the determination of an appropriate exclusion or mitigation zone. Current regulation requires operation shutdown if there is an animal detected within a 500-meter exclusion zone around an operational seismic activity.

A number of workshop participants questioned the 500-meter zone, sometimes used as the mitigation radii. One participant suggested that the real boundary is when mitigation action can still occur and be effective (e.g., maneuvering to avoid striking a whale). Participants acknowledged that more research is needed to determine if there is a more appropriate exclusion zone. The ideal exclusion zone may differ by situation and animal. Whatever exclusion zone is decided upon, regulators need to understand that they are determining parameters for mitigation. A workshop participant noted that mitigation monitoring technologies are still evolving and that the regulators and industry need to work through the issues together so that both sides are comfortable with the implementation and the standard operating procedures of the technologies.

Another participant outlined a set of shutdown procedures used in the Gulf of Mexico if a whale is detected in the exclusion zone, either visually or acoustically. If a marine mammal is detected within the exclusion zone, the seismic activity stops for thirty minutes followed by ramp up. This participant also noted that even with a good PAM operator, there is still a risk of not detecting a marine mammal. One benefit of acoustic monitoring is that it increases the probability of detection and that the acoustic data are recorded and can be reanalyzed and evaluated at a later date after the industry activity is over.

Standardization

Standardization was another theme raised at various times throughout the workshop. Standardization can impact several different components in a seismic operation. For example, it can inform project planning by helping to define what is required for configuring the vessel, conducting the operations, training the crew and certifying the credentials of PAM operators. Good communication throughout all the stages of a project and between all vested parties is critical, but is particularly important in situations where variation in circumstances (e.g., field conditions, species composition) makes standardization difficult. Understanding regulatory agency requirements is important as well.

A number of BOEMRE participants noted that much good work has been done in the Gulf of Mexico with very few standards. For example, the current requirements for mitigation were never designed to deal with multi-source shoots, yet pilot projects have led to some creative solutions.

At the end of the discussion, many workshop participants reiterated the need for more regulatory guidance and advice in the future on many aspects of operations, including standards for operator training and experience. Other issues included:

- Clarification on the level of certainty that an animal is in the exclusion zone before initiating a shutdown of operations;
- Defined shutdown criteria and guidance on the process for a shutdown of operations, and clarification on when and how to re-start operations after a detection;
- Requirements for PAM installation; and
- A work-shift schedule for PAM operators that includes standard breaks and downtime. This is important because PAM is a twenty-four hour activity, and long shifts can lead to fatigue and impact the effectiveness of the monitoring effort.

Pre-planning

A number of participants noted the importance of contextual information during the pre-planning phase of the project. Ideally, a vessel would go to the planned seismic survey location, gather ecological data and assess risk. However, what more likely happens is that there is a very limited time window for a seismic vessel to survey an area prior to its seismic survey operation. If the survey is in a new area, baseline data are most likely not available – for example, what animals occur in the area, when they are there, what they do in the area, what sounds they produce, and the environmental context. This point reinforces the necessity for the establishment of collaborative, multi-dimensional databases.

Before the regulators approve a survey process, it generally has to undergo a National Environmental Policy Act (NEPA) review process. For areas without a lot of available information, regulators try to design a more conservative mitigation strategy. The design of the operations has to be clear to all parties, including whether operations can continue during the night or under bad weather conditions when visual monitoring is ineffective.

As part of the PAM installation process, having existing background information on previous installations and operations would be very helpful. One participant suggested developing a PAM database including the type of vessel, the type of operation, and environmental information about various locations. Many others brought up this database issue and the lack of adequate databases on marine mammal seasonal distributions and occurrences, biological sound types, associations with oceanographic features and environmental factors; and the need for some sort of standardized mechanism for integrating old and new information from ongoing visual and acoustic monitoring efforts.

One System Does Not Fit All

The theme of "one size does not fit all" was repeated throughout the workshop in a number of contexts. Because of the variety of vessel types, animals for which to monitor, acoustic monitoring systems, software, weather and ocean conditions, and activities that produce noise, there is no one solution for acoustic monitoring of marine mammals. Regulators are cognizant of this fact and attempt to write monitoring requirements with enough flexibility to encompass all situations. However, at the same time, industry and operator participants asked for more specific guidance.

A number of participants advised that monitoring objectives should be made very clear to all parties, including regulators, early on, so that the monitoring can be designed towards those ends. The selection of the hardware and software systems depends on the objectives, the type of operation, the animals being monitored for, and other variables.

In selecting a monitoring system, the operator has to consider which types of animals are targeted (e.g., low-frequency baleen whales, high-frequency toothed whales, or both), and therefore the frequency range requirement of the PAM. There is a tradeoff between the frequency range produced by an animal and the distance out to which it can be reliably detected (see Figure 3). The higher the frequency, for the same source and noise levels, the smaller the area over which the animal's sound is detectable, and the less likely it is to be detected. Therefore, it is important that the detection range be defined and probability of detection be evaluated. When selecting a monitoring system, some participants acknowledged that the instrument specifications do not always match the specifications that the developer provides.

One workshop participant suggested that the operating capacities of different systems should also be collated into a database. That way, during the project design stage, operators could compare the advantages and disadvantages of different systems.

The capabilities of the actual hardware systems are also important to consider. There is no set method to choose hardware configuration, and it currently must be redesigned for each vessel. One workshop participant suggested that engineering solutions may take a lot of guesswork out of selecting hardware systems.

Once the hardware and software are selected, operators should calibrate the equipment. One participant suggested that to calibrate the ability of towed arrays to detect vocalizations, the operator should put known signals in known places with known characteristics. This is standard operating procedure for some types of towed PAM work, in order to validate the quality and capabilities of the system. Calibration should be performed when there are no animals in the area so that the calibration team can focus on how well the system is performing.

OPERATIONS AND THE OPERATOR

[Much of this section was taken from the Session V panel discussion. However, it is not written as a chronological summary of the panel, in order to integrate comments about operations and operators made by workshop participants in other sessions into this section of the workshop proceedings. Conversely, some points that were discussed during the Operations and Operator panel are included in the relevant sections of the proceedings. The panel members included: Philip Fontana, Polarcus; David Hedgeland, PGS; Major Smith, BHP Billiton; Bernard Padovani, CGGVeritas; and Roy Wyatt, Seiche Measurements Limited.]

Session V of the workshop featured a panel discussion on the issues associated with operating acoustic monitoring systems on a variety of vessel types and configurations. It also addressed concerns related to those who have the jobs of actually operating the systems in the field. These concerns included such items as operator qualifications and training, standardization of operator credentials and ship operations, safety issues, and coordination of acoustic monitoring with other ship operations. Regulatory issues were also raised by the panel but have been discussed previously in the project design section of this report.

The challenges facing operators and associated with acoustic monitoring operations were mentioned throughout the workshop. Offshore industrial operations can be significantly affected by malfunctioning passive or active acoustic monitoring systems with ramifications ranging from unnecessary shutdown of an operation to operating with marine mammals in an area due to lack of detection.

Three overarching questions were asked of the panel members. Since the conversation during the entire session was so rich and included the participants, this report will focus on the general themes that emerged related to the operation of the acoustic monitoring systems and the operator. These themes included:

- The importance of advance planning, including the establishment of operator roles and clear lines of communication;
- Variations in vessel design that present challenges to equipment installation and operator location;
- The demand for competent, experienced PAM operators, and the difficulty of providing opportunities for adequate training; and
- The overall challenges of operating an effective PAM system onboard an operational seismic survey vessel.

Planning and Communication

Throughout the workshop, participants repeatedly acknowledged the importance and necessity of communication among the regulators, the company, the vessel captain or party chief, the crew, and the operator. The earlier clear communication occurs, the better, as it ensures that all parties understand the purpose of the monitoring and the course of action necessary should mitigation be required.

Communication onboard the seismic airgun survey source vessel is also necessary for smooth operations. A typical source vessel may have sixteen people. Of those, three are required Marine Mammal Observers (MMO), one is a health, safety and environmental (HSE) client representative, one is a medic, one to two may be PAM operators, and the rest are seismic and maritime crew. Because a third of the crew on the source vessel has little, if anything, to do with the operation of the vessel, effective communications among these personnel are essential. The panelists emphasized that it is critical to foster a good and flexible relationship between the crew and the PAM operator. Because the PAM operator has to work within the overall operations of the ship, and can initiate a shutdown of work, the ship's crew has to trust the PAM operator to make the right decision.

The source vessel's crew has to understand PAM operation because it represents a change in the standard operating procedures for the vessel. One panelist suggested that using written procedures to clarify pathways of communication (e.g., how MMOs and PAM operators will alert the crew of a detection of a marine mammal, precipitating a shut down) would reduce confusion and clearly define roles. In a multi-vessel operation, he suggested the best scenario includes someone from the MMO/PAM team acting as the coordinator. This person can interact with the PAM operator and party chief of the seismic company to ensure information is available to all stakeholders and is consistent across all vessels.

Good communication between the crew and the PAM operator may be easier to achieve with permanent PAM installations, which can sometimes be integrated into the vessel design. Another panelist mentioned that in his experience with permanent installations, the crew feels like part of the PAM operation and that the operation becomes part of the source vessel's culture, because the crew has been trained to understand how the PAM system works. He has also found that locating the PAM station in the recording room could automate findings and integrate that system with the rest of the ship's installations. Moreover, an external PAM operator can then be in a more comfortable environment and benefit from the crews' understanding and support.

Panelists and workshop participants noted that, for the most part, PAM operators are welcomed by crews, and that good communication and understanding plays an important role in forming mutually supportive relationships.

Variation in Vessel Design and Installation

Due to variations in individual vessel design, the installation and integration of a PAM system must be planned on a case-by-case basis. According to panelists and other workshop participants, this is one of the major challenges PAM operators face in the field. According to one panel member, there are three opportunities during the planning process when PAM issues are considered: deployment; PAM operator location; and considerations for HSE conditions.

Deployment varies from vessel to vessel. Because PAM equipment is small compared to other operations on seismic vessels, PAM operators generally try to keep out of the way of equipment and lines associated with other ship activities. To accomplish this, they should work closely with the Chief Gunner on the back deck who guides overall ship operations.

The location of the PAM operator on the ship is important and varies due to the size and operation of the vessel. In order to design the monitoring and mitigation system as well as place the PAM operator, several aspects need to be considered, including the role of the PAM operator in relation to operations and marine mammal detection. The PAM operator's location is contingent upon whether he or she is also serving as an MMO. If the PAM operator is also an MMO, this involves both watching as well as listening. If operating in conjunction with an MMO, this involves listening and ensuring that the PAM equipment is operating properly. Historically, all instrumentation has been located in the vicinity of the PAM operator's station below deck. With advances in wireless technology, instruments can be situated in the instrument room and then linked to the internal wiring of the ship to forward data to wherever the operator is located.

Before a vessel leaves the dock, the operator needs to identify the purpose(s) PAM will serve. There are differences between monitoring for mitigation and monitoring for research. The best method is to identify the relevant expectations for PAM monitoring with all parties on board. Additionally, as vessels and operations vary in size, complexity and construction, the PAM operator must be able to adapt to these differences and know how to optimize equipment installation and minimize vessel noise.

Health, Safety and the Environment is another critical component that must be considered for a PAM operation. It is critical to have all safety issues covered during PAM installation in order to comply with the ship's rules and regulations. Often when the crew includes people who are not specialists, the HSE standard is raised to avoid possible accidents. In this case, risk levels must be managed and PAM operators need to work even more closely with the ship's crew.

One way to make PAM operations smoother is by integrating the PAM system and operator into the vessel's regular operating procedures. One panelist noted that on his vessels, the PAM station is located in the recording room, and automated and integrated with the rest of the vessel's installations. Another panelist noted that on his ships the navigation department downloaded PAMGUARD and evaluated its integration within the telemetry system in a multi-vessel/PAM application. In this case, the crew also reviewed the PAM installation on each vessel and suggested improvements to increase system reliability. Because each vessel is unique and needs its own plan, the crews are the best resource to determine how PAM installation should occur and be managed.

By placing permanent PAM installations on each vessel, according to one panelist, benefits accrue to both business and operations in the following ways:

1. The integrity of the signal path (both acoustically and electrically) is improved.

2. The position of the PAM equipment (its proper space relative to seismic streamers and airgun array) is improved.
3. The deployment-retrieval procedures are built into the crew's standard operating procedures.
4. The efficiency and safety of PAM operations are maximized.
5. The PAM information is integrated with other information being gathered from the seismic operation. For example, PAM metadata are combined with vessel position and time stamp information.
6. Collection of the acoustics data are integrated into a quality controlled system.
7. The crew accepts PAM monitoring and mitigation as part of the ship's standard installation and operating procedures.

In the Gulf of Mexico, some companies are integrating PAM systems at the planning and execution phases for construction of new vessels. For existing vessels, there are appropriate ways by which to retrofit. On a big seismic vessel with build-on capability, a PAM system can be installed permanently. On either a retrofitted or new vessel, the crew should be involved as early as possible to identify and manage any conflicts.

When source vessels are small it is a challenge to integrate a permanent PAM installation on board, and strategic choices have to be made. Most likely a compromise is developed, which may lead to non-optimal PAM equipment deployment and higher levels of vessel noise. Seaport vessels are even smaller and more compromises may be needed with regard to PAM installation.

One panelist described a survey in which it was a challenge to install PAM equipment and accommodate PAM personnel. Wide-azimuth surveys include multiple vessels and multiple energy sources. Many of these are vessels of convenience and finding adequate space on them for monitoring equipment is difficult. The panelist suggested that everyone, including regulators, be cognizant of such challenges; that safe and optimal installation procedures be established; and that a spacious wheelhouse facilitates the proper correlation of visual and acoustic observation efforts.

Operator Training

The qualifications of the PAM operator can make a significant difference in the efficacy of the marine mammal monitoring effort. Expectations and qualifications for PAM operators vary, and throughout the workshop participants touched on the many concerns related to operators. These concerns included training requirements, the many tasks an operator is expected to perform, challenges related to setting and/or meeting standards, implementation, and the difficulties faced by new operators in obtaining experience at sea. The panel delved more deeply into these issues, and acknowledged that the industry could face a shortage of trained and experienced operators in the future.

One panelist stated there is an art to marine mammal monitoring, both visually and acoustically. PAM presents a special challenge, given the variety of hardware and software in different systems, the variety of sounds produced by different species, and the evolving technology.

However, one workshop participant noted that while it is virtually impossible to train someone to be a good visual observer, it is possible to train someone to be competent at acoustic monitoring. Another panelist added that PAM operators are expected to be biologists, engineers and everything in between. In addition to being able to operate the system and identify when and what animals were acoustically present, PAM operators need to be able to recognize when systems are not operating properly and be able to fix them if they malfunction, which happens often. Ideally a backup system can be switched in, but the cost of a duplicate system is prohibitive, and there is often inadequate space on board a vessel for a backup system. The PAM operator may want as much backup equipment as possible, but the client may not be willing to pay for it. Furthermore, because a non-working PAM system could mean that a noise-producing activity cannot be undertaken, PAM operators need to know not only how to fix the system, but how to fix it quickly, so as to minimize disruption to ship operations. One workshop participant added that a PAM operator should also know how well the system is going to work in a specific ocean environment.

There are currently no standard qualifications for PAM operators. The panelists noted that while there are training courses for PAM operators, nothing can substitute for field experience. One panelist noted that PAM operator training requires more than a class and a textbook before one is qualified to go out into the field alone. PAM operators have to be knowledgeable and competent since they have the responsibility of stopping an operation, which can lead to a significant economic loss for the company. However, panelists underscored the conundrum of obtaining field experience when it is not likely that someone without experience would be sent out to sea. The same panelist noted that experienced PAM operators would likely come from a research background. If so, they would need to be brought up to speed on commercial operations and configurations.

One participant observed the dichotomy relating to where PAM operators come from: they tend to be from a biology background and have to learn the technology, or come from a technology background and have to learn the biology. He suggested that training requirements recognize this distinction. Another participant observed that the level of training required of an operator also varies given the vessel context. For example, on-the-job training could be possible on a scientific vessel but not on a military vessel where sounds are much harsher and it may be more difficult to differentiate vocalizations among marine mammals.

Throughout the workshop, participants repeatedly suggested an apprenticeship program for PAM operators. This would allow inexperienced operators to get field experience while allowing an experienced operator to be on board. Since a broad range of experience is necessary, cross-skills need to be taught in tune with vessel-to-vessel variations. In response to such a suggestion, though, one workshop participant noted that the often limited space on vessels for personnel could make taking on an apprentice operator infeasible. Also, an apprentice taking shifts at the PAM system would limit the time available for others to use the system. This participant acknowledged the possibility of supporting apprenticeship programs during long transects of otherwise empty ship time.

The panelists also discussed what monitoring operator training should entail. Existing software can help with training. PAMGUARD has a software tutorial, which some workshop participants had used. One workshop participant suggested the possibility of a PAM simulation program to train PAM operators on detection and identification. Another participant suggested that since acoustic data are stored in complete records they can be recreated with most software packages. However, he questioned the level of training possible without experience at sea. Another participant noted that software models might also help out in lieu of field experience, allowing a less-experienced operator to build confidence.

Related to training was the issue of monitoring experience. One person questioned the meaning of "experienced operator," which is what some jurisdictions require. A participant from NOAA said that when NMFS issues a permit, the agency reviews the curriculum vitae of the MMOs and determines their experience levels on a case-by-case basis. One workshop participant suggested an operator could maintain a log book to keep track of his or her training, experience at sea, and qualifications. This would be similar to a sailor's discharge book that would be stamped on every vessel served and allow the monitoring system operator to build up a track record of experience, in addition to a curriculum vita.

One panelist also mentioned the importance of training not just the PAM operator, but people involved at all levels of the operation, in the basics of PAM and acoustics to manage expectations of what PAM can or cannot do.

During the panel discussion, and throughout the course of the workshop, participants touched on the issue of standardization of operator training and qualifications. One participant who was an operator spoke of the need for an international standard because of the huge variations in operator qualifications. Another participant, from NMFS, informed the group that NOAA is expected to release a technical memo in early 2010 on a presentation made at the International Monitoring and Observer Conference in July 2009 regarding developing international standards. This participant assured the group that if such standards were ever to be adopted as policy or regulation, there would be a prior opportunity for public comment. Some agencies are currently conducting workshops for PAM operators. Regulators do not necessarily want to set the standards, but are willing to meet with industry to develop some recommendations.

One panelist pointed out that global PAM operators frequently find themselves in "frontier" areas of the world where environmental issues may not be as critical to local governments. In order to help these global PAM operators, their trade organization, the International Association of Geophysical Contractors, recently adopted a set of mitigation guidelines – based on JNCC guidelines.[5] The Association is moving toward a voluntary adoption of the regulations. However, when PAM operators go into the Gulf of Mexico or Australia, they have to adopt the more stringent local regulations.

One participant noted that at a recent workshop in Monterey, California, attendees acknowledged an upcoming crisis in the shortage of trained personnel in marine science and oceanography.

[5] As mentioned in a previous IAGC Member Alert, the UK's Joint Nature Conservation Committee (JNCC) has released a revised version of their *Guidelines for Minimizing the Risk of Disturbance and Injury to Marine Mammals from Seismic Surveys (June 2009)*.

Given the global competition for people with that type of training, there needs to be effective ways to entice more students into these fields.

THE ECOSYSTEM CONTEXT

Data Collection, Integration, and Creation of a Database

Throughout the workshop, participants reiterated the importance of having baseline environmental and marine mammal data prior to any monitoring for offshore technology activities. Baseline data provide an opportunity for comparative analyses in order to evaluate such things as how the industrial activity has modified background sound levels, and whether or not animals are reacting to the anthropogenic activities. Several participants noted that using PAM to better establish baseline conditions would help BOEMRE determine how effective the monitoring and mitigation processes are during the industrial activity. A number of participants also suggested the critical need for a database of all known ecosystem data; this included a broad list of things such as marine mammal, oceanographic, and ecological data. Participants suggested also including data regarding acoustical monitoring systems; each system's success rate; and details on which systems worked, didn't work and why. Such a communal database would be available to researchers, regulators, PAM operators, developers, and other interested stakeholders, and would provide baseline ecosystem data for a given area at a given time of year, as well as what and how different PAM systems were used.

Having baseline ecosystem data would be critical during a project's design phase. For example, marine mammal data on seasonal occurrence and density could help a PAM operator better define the operational requirements of the PAM system. If PAM operators knew what animals to expect in a given area, the likely behavioral-ecological context of those animals, and if those animals were likely to produce sounds, the operators would be more likely to detect and correctly identify those animals. This could also help in terms of mitigation: by accumulating shared knowledge as to when and what marine mammals are in an area, operators could avoid those areas and reduce the risk of environmental impact.

There are several efforts underway to compile existing data into a database, but because the data are not standardized, collating these data is a time-consuming and expensive task. It was also noted that in many cases valuable data have been collected but not analyzed. Some of the workshop participants listed possible existing or emerging data sets that can be used to develop an ecosystem database. These included:

- An Australian government initiative to develop an integrated marine observing system that includes PAM, which will be used on the country's eastern, western and southern coasts. The data from the system will be publicly available, and the first data stream should be available in early 2010. The government hopes to launch more buoys and set up a repository of the data collected.
- A number of different efforts currently underway to characterize metadata for the environmental datasets. The Navy and Duke University both have metadata projects.

- A number of people are currently working to build databases of fish populations. This would include the location and behavior of the fishes at a given time of year.

There was some agreement that stakeholders need to identify and standardize the data to be collected.

One workshop participant pointed out that for some ecosystems, the ocean has become so infiltrated with anthropogenic noise that it would be impossible to determine a natural baseline. However, there are relatively pristine areas around the world where baseline research can be done, and data from such areas could serve as control environments.

Ancillary to the issue of baseline background and ambient noise data is the question of how data should be collected. A number of workshop participants advocated integrating the collection of environmental data whenever acoustic systems are being used. One participant noted that as acoustic systems continue to be further developed, they will collect more advanced and accurate data sets, and these data could be used as baseline for future offshore activities.

Major Smith articulated that health, safety, environment, and community (HSEC) screening data have been collected. He suggested all operators build a register of environmental information for every destination, and share it with others to expedite the six to twelve months of baseline data needed for operations. Although this would not alleviate the requirement of producing an Environmental Impact Statement (EIS) in a new country, valuable data would accumulate, and the EIS would be made easier.

Workshop participants repeatedly mentioned the necessity of a database of not only environmental data, but a database that would include sound and noise characteristics, and most likely the kinds of sounds that a PAM operator would encounter in the area. This would help PAM operators identify if and when there are marine mammals in the area and increase the operators' comfort level. Additionally, one researcher talked about the fact that marine mammal calls can vary depending on a variety of factors such as location, gender, time of year and social activity. Therefore, it would be very helpful to have a repository of marine mammal calls qualified by such factors and associated with validated data, as this would increase the likelihood of identifying unusual or infrequently produced sounds.

A few workshop participants suggested that the first step in getting acoustic data integrated with other ecosystem data would be to integrate PAM into data collection systems. That way, both biological and abiotic data could be collected at the same time and integrated. This would also allow for a better understanding of where the acoustic ecology fits into the ecology and the physical environment. For monitoring of long-term impacts, it is important to collect as many types of data as possible, not just on species of interest but also including anthropogenic sounds such as shipping noise, and environmental sounds such as volcanoes and earthquakes.

Cumulative Effects

A number of workshop participants touched on the issue of cumulative effects. These effects are not just from anthropogenic noise, but also from other stressors in the environment (e.g., chemical toxins) that in conjunction with noise could affect an individual animal's behavior, ability to communicate, and fitness; or eventually have an effect at the population level. One participant noted that if federal agencies ascribe to ecosystem-based management and adaptive management strategies, they need to adopt this level of holistic thinking and perform an assessment of cumulative impacts that goes beyond short-term impact based on sound exposure levels and the monitoring of only the specific industrial activity.

One workshop participant acknowledged that money is a limiting factor, and suggested that all the stakeholders should identify cumulative impact assessment as an objective toward which they should all be moving. This participant added that developing the long-term databases discussed above is critical for understanding the host of issues that coalesce into cumulative impacts.

One workshop participant identified some work that is being done on cumulative impacts. The Okeanos Foundation held a workshop in August 2009 on the potential cumulative impacts on marine mammals from underwater noise and other anthropogenic stressors.[6] In addition, the National Center for Ecological Analysis and Synthesis at the University of California, Santa Barbara has done work on cumulative impact analysis on habitat, looking at different stressors along with ecological characteristics and habitat recovery, and developing a map of habitat impacts. This workshop participant noted that the Okeanos Foundation is attempting to adopt a similar approach to look at cumulative impacts, including noise, on a species and population basis.

One NOAA representative said that federal agencies are starting to understand that in order to get at a cumulative impact assessment, data collection and database management are necessary.

[6] The proceedings from the August 25-29, 2009 Workshop on Assessing the Cumulative Impacts of Underwater Noise with Other Anthropogenic Stressors on Marine Mammals: From Ideas to Action is available online at http://www.okeanos-stiftung.org/topics-and-projects/symposia/completed-symposia/assessing-the-cumulative-impacts-of-underwater-noise-with-other-anthropogenic-stressors-on-marine-mammals-from-ideas-to-action-en-GB/.

CONCLUSIONS

The objectives of the 2009 BOEMRE "Workshop on the Status and Applications for Acoustic Monitoring of Marine Mammals" were stated as follows:

> "Learn about, discuss and better understand the current status of acoustic hardware and software tools for marine mammal monitoring and mitigation as applied to offshore industries. This will include the capability, applicability, feasibility, availability, cost and other benefits and limitations of acoustic systems as they pertain to different marine mammal and operational contexts. The discussion will focus on currently available acoustic systems, along with some potentially beneficial applications under development."

Following a workshop with such ambitious objectives, consolidation of key conclusions is obviously valuable but a challenging step toward closure: valuable because few if any participants would have been able to capture all of the key conclusions on their own, but challenging because of inherent complexity. These brief notes represent an attempt to capture key conclusions.

Conclusion 1: The basic software and hardware technologies to meet many marine mammal monitoring and mitigation requirements already exist and have been demonstrated and implemented under a wide range of operational conditions. However, most of these were not specifically designed for marine mammal monitoring and mitigation for offshore industrial developments. No one technical approach has the capacity to satisfy all or even most marine mammal monitoring and mitigation requirements for the offshore industry, and in fact, all evidence presented and discussed at the meeting points to a site/case-specific integrated approach. There is no one acoustic system, even assuming availability of well-designed and fully functional hardware and software, that will satisfy all or even most marine mammal monitoring and mitigation requirements for the offshore industry. Simply put, "one size does not fit all." Furthermore, it should be clearly noted that all passive acoustic monitoring (PAM) systems (e.g., fixed, towed) only work if an animal produces a sound that can be detected using the system. An active acoustic monitoring system circumvents this limitation but raises some concern because it introduces sound into the environment.

Conclusion 2: Choosing and evaluating the best acoustic monitoring system for a specific project requires a thoughtful and thorough assessment of project objectives coupled with a thorough evaluation of the regulatory monitoring and mitigation requirements and the capabilities of available acoustic technologies. This coupling of objectives with regulations and technical capabilities may be an iterative process. That is, objectives may have to be modified as a result of specific monitoring and mitigation requirements and/or the inherent limitations of available systems.

Conclusion 3: Three general types of available acoustic systems that were discussed at the workshop include: fixed passive acoustic monitoring (fixed PAM), towed passive acoustic monitoring (towed PAM), and active acoustic monitoring (AAM) systems. Each of these system types has somewhat unique data processing (including signal processing) requirements. Data processing needs and capabilities are an integral requirement in the design, operation and evaluation of acoustic systems. As an example, most data processing software that is well suited to a fixed PAM system is not usually designed to work with a towed PAM system, and data processing software that is designed to work with one particular towed PAM system may not work at all with a different towed PAM system.

Conclusion 4: For mitigation and monitoring of marine mammals during offshore industry activities, fixed PAM technologies seem to be more mature than towed PAM or active acoustics, although this may not necessarily indicate that these approaches are the most effective. Fixed PAM has been used with great success in many settings, including predevelopment baseline studies, assessment of marine mammal responses to offshore facilities, and management of ship traffic to reduce the risk of collisions with whales. Despite these successes, a number of limitations and challenges should be highlighted:

1. The range out to which an animal can be detected varies with the characteristics of the call (i.e., frequency, bandwidth, source level, and directionality), oceanographic and bathymetric conditions, and the design of the PAM system itself. Some calling animals under some circumstances can be detected from hundreds of kilometers away while others cannot be detected beyond a distance of a few tens of meters.
2. For autonomous, fixed PAM systems (that is, systems that are not attached to power or data transmission cables), power and memory limitations may force users to make choices between duty cycle, deployment duration, and recording bandwidth. Extension of power and memory capacity should be an area of focused research and development.
3. Cabled, fixed PAM systems (that is, those attached to power or data transmission cables) may not be useful in remote areas or in areas where ice gouging or wave surge can destroy cables.
4. Processing of the increasingly large sets of recorded data gathered using PAM systems presents real challenges. Automated acoustic detection processing software can provide rapid data analysis but will not detect the occurrence of every call. Manual call processing, in which a person listens to and observes visual renderings of recordings (e.g., spectrograms), is more likely to detect (but not necessarily identify to species) marine mammal calls missed by automated call processing methods, but is extremely time-consuming. Machine-aided, interactive acoustic processing, in which an analyst uses software to direct and/or guide the analytical process, shows promise. Further work is needed to improve methods for automated detection and classification of marine mammal sounds.
5. Management of the tremendous quantity of recorded data obtained using PAM systems poses real challenges. Such enormous data sets are typically not accessible via a database system.

Conclusion 5: For mitigation and monitoring of marine mammals during offshore industry activities, towed PAM technology seems to be somewhat less mature than fixed PAM, but more mature than active acoustic monitoring. Again though, this may be more reflective of how these systems have developed historically as opposed to which may be most effective in a specific operational situation. Towed PAM systems have been used with some success to supplement visual monitoring of exclusion zones in the North Sea, the Gulf of Mexico, and elsewhere. It has also been effectively used to locate animals for research. Despite these successes, a number of limitations and challenges should be highlighted:

1. The range out to which an animal can be detected varies with the characteristics of its sounds (e.g., frequency, bandwidth, source level, directionality), oceanographic and bathymetric conditions, design features of the towed array (e.g., number, spacing and depth of the individual sensor elements), design features of the PAM software, the speed at which the vessel is traveling, and the characteristics of the noise generated by the vessel. Some acoustically active animals under some circumstances can be detected out to distances of many tens of kilometers (e.g., very-low-frequency whales), while others cannot be detected beyond a few tens or hundreds of meters (e.g., very high-frequency marine mammals).
2. In general, the effective application of a towed PAM system requires well-trained PAM technicians operating the towed PAM system onboard the ship. For greatest effectiveness, 24-hour coverage by a trained operator must be maintained throughout an operation or at least during certain operations. The scarcity of trained PAM operators and the absence of a well-developed training program or apprenticeship program could become a significant problem as use of towed PAM systems becomes more common.
3. With most currently available towed PAM systems deployed from seismic vessels, estimating the location of a calling animal requires multiple detections of the same animal in order to compute multiple bearings to that animal as the vessel steams forward.
4. Although recent tests have shown some promise, currently available towed PAM systems do not have a proven ability to detect marine mammals that call in frequencies overlapping those of vessel noise. This can be a particularly difficult problem for detecting baleen whales if their sounds are masked by the noise from the vessel towing the array.
5. Estimating the location of a calling marine mammal becomes problematic when it is in line with (forward and aft of) the axis of the towed PAM hydrophone streamer.
6. Resolving whether a detected animal is on the left or right side of the towed PAM streamer (i.e., left-right ambiguity) is problematic when using a single, straight hydrophone streamer.

Conclusion 6: For mitigation and monitoring of marine mammals during offshore industry activities, active acoustic technology is less mature than either fixed PAM or towed PAM systems. However, active acoustics is the only acoustic method capable of detecting animals that are not producing sounds. Despite the relative immaturity of active acoustics, recent tests suggest that it can be useful in some circumstances. For example, an active acoustic system has been used to manage a subsea power turbine in an effort to decrease the likelihood of killing seals. Limitations or challenges associated with active acoustic systems include:

1. By their nature, active acoustic systems add sound energy to the water, and this could influence the behavior of some marine mammals. For some systems, some animals could be harmed if they come very close to the sound source (i.e., within a few tens of meters).
2. Active acoustics suffers from the inherent trade-off between the sizes of animals that can be detected (i.e., resolution, determined by center frequency and bandwidth), and the distances out to which those animals of different sizes can be detected (i.e. source level and especially frequency due to rapid fall-off from absorption with increasing frequency). The apparent practical limit imposed by this inherent trade-off seems to be about one kilometer for whales of about 7 meters or greater in length, and is presumably less for seals and smaller cetaceans.
3. The aspect of the animal relative to the active acoustic source will impact detectability. In general, animals directly facing toward or away from the source will be more difficult to detect than animals swimming at a right angle to the source.
4. Animals may be more difficult to detect at depth, when their lungs are more collapsed, than when they are closer to the surface. However, animals close to the surface can be more difficult to detect because of signal reflections off surface waves.
5. Active acoustics cannot penetrate significant thermoclines or haloclines, so animals swimming beneath thermoclines or haloclines will be more difficult or impossible to detect with hull mounted systems. Towed active systems may be required in these circumstances.
6. Active acoustics may not be useful in very shallow water, especially in rough seas.
7. In general, the AAM operator must be well trained in the use of the active acoustic system. For full effectiveness, 24-hour coverage by a trained AAM operator must be maintained throughout an operation or at least during certain operations. Use of active acoustics remains in the realm of research and development, but as it progresses to become a useful tool for monitoring and mitigation, an operator training and apprenticeship program will most likely become necessary.

Conclusion 7: In some circumstances, the effectiveness of marine mammal monitoring and mitigation could be increased by using a combination of approaches. For example, a combination of marine mammal observers, towed PAM, and active acoustics would improve the likelihood of detecting and identifying marine mammals in the vicinity of potentially harmful activities. Similarly, a combination of fixed PAM and active acoustics may provide an improved understanding of apparent changes in the distribution of whales responding to industry sounds, a problem that has plagued at least some studies that relied only on a fixed PAM system.

Conclusion 8: The effectiveness of the marine mammal monitoring and mitigation process would significantly benefit from the development, establishment, and maintenance of a national (at least) or international (preferable) standardized, web-accessible ecosystem database (consisting of species seasonal presence/abundance and as many other important behavioral features as possible) coupled with a m arine acoustics database (including marine mammal sounds, natural abiotic sounds, and anthropogenic sounds). This conclusion is consistent with many previous recommendations (e.g., NRC, 1994; 200; 2003; Southall et al., 2007), including those expressed as a high priority by a task force of U.S. federal agencies considering this subject (Southall et al., 2009).

APPENDICES

I. Workshop Agenda
II. Workshop Participants
III. Background Documents
IV. References
V. Presentation Abstracts
VI. Speaker Biographies
VII. Presentation Slides

APPENDIX I

WORKSHOP AGENDA

Workshop on the
Status and Applications of Acoustic
Mitigation and Monitoring Systems for Marine Mammals

November 17-19, 2009
Boston Park Plaza Hotel & Towers
50 Park Plaza at Arlington Street, Boston, MA 02116

WORKSHOP AGENDA

Meeting Objective: Learn about, discuss, and better understand the current status of acoustic hardware and software tools for marine mammal monitoring and mitigation as applied to offshore industries. This will include the capability, applicability, feasibility, availability, cost, and other benefits and limitations of acoustic systems as they pertain to different marine mammal and operational contexts. The discussion will focus on currently available acoustic systems, along with some potentially beneficial applications under development.

Tuesday, November 17, 2009

8:30 am Registration

9:00 am Welcome, Meeting Objectives and Agenda, Participant Introductions

James Kendall, Chief, Environmental Division, BOEMRE
Gail Bingham, RESOLVE, *facilitator*

9:45 am Session I: Setting the Stage

Goals: Understand the present requirements for acoustic monitoring and mitigation of industry activities that fall within the Bureau of Energy Management, Regulation and Enforcement's jurisdiction and highlight key concepts for assessing what kinds of improvements are desirable and the capabilities of existing tools to provide solutions.

James Kendall, Chief, Environmental Division, BOEMRE *[15 min]*
Shane Guan, NMFS *[15 min]*
Questions and Discussion *[15 min]*

10:30 am BREAK

10:45 am Session I: Setting the Stage *[continued]*

Presentation: *"A Pragmatic Approach: Finding Functional Solutions Recognizing the Capabilities and Limitations of Existing Technology" [25-30 min]*
William T. Ellison, Marine Acoustics
Presentation: *"Framing the Discussion Using an Acoustical Ecology Perspective" [25-30 min]*

Christopher Clark, Cornell University Bioacoustics Research Program
Questions and Discussion (for both presentations) *[30-45 min]*

12:15 LUNCH on your own

1:30 pm Session II: The Sensor - Passive Monitoring ("fixed" systems)

Goals: Understand the state-of-the-art regarding existing, fixed passive acoustic monitoring tools applicable to basic requirements for regulated offshore industries (e.g., animals present, and what kind) and to special cases where some form of research must accompany the basics (e.g., How many animals? What are they doing?). Information in this session will address questions such as: What can be learned from long-term fixed or short-term fixed passive acoustic recording systems? For what kinds of sounds and under what conditions are these technologies best suited and most applicable? What monitoring and mitigation protocols are needed to achieve scientifically acceptable levels of resolutions so as to adequately address risk criteria requirements? What are the limitations and concerns of different existing solutions, under different circumstances, and when/how can these limitations be overcome? What is the commercial availability of these systems? (Operational issues will be discussed in Session V.)

Overview Presentation:
Renata S. Sousa-Lima, Cornell University Bioacoustics Research Program

Case Examples:
Leila Hatch, Stellwagen Bank National Marine Sanctuary, NOAA
Bill Streever, BP
Roy Wyatt, Seiche Measurements Limited

Discussion (with response panel)
David Moretti, Naval Undersea Warfare Center
Amy Scholik-Schlomer, NOAA
Michael Macrander, Shell
Kris Ohleth, Deepwater Wind

3:45 am BREAK

4:00 pm Session II: The Sensor - Passive Monitoring ("towed" systems)

Goals: Understand the capabilities of towed passive acoustic systems as applied to basic requirements (e.g., animals present, what kind, and within mitigation range) and to special cases where some form of research must accompany the basics (e.g., Distribution of animals? How did they respond?). Information in this session will address questions such as: Under what situations might this technology be useful or most applicable? For what kinds of sounds and under what conditions is this technology best suited and most applicable? What are the limitations and concerns, under different circumstances, and when/how can these limitations be overcome? What is the commercial availability of these systems? What other practical considerations should be understood? (Operational issues will be discussed in Session V)

Overview Presentation:
Aaron Thode, Scripps Institution of Oceanography

Case Examples
Mary Jo Barkaszi, RPS Energy
Bruce Martin, JASCO Research
Claudio Fossati, Cibra, University of Pavia

Clarification Questions *[plenary discussion resumes in the morning]*

5:30 pm Adjourn

6:00 pm Social opportunity reception

Wednesday, November 18, 2009

8:00 am Coffee/Tea and Informal Conversation

8:45 am Open Day 3

9:00 am Session II: The Sensor - Passive Monitoring ("towed" systems) *[continued]*

Discussion (with response panel)
Kevin Deal, WesternGeco (invited)
Howard Rosenbaum, Wildlife Conservation Society
Terry Rooney, BP (Invited)
Deborah Epperson, BOEMRE

10:00 Session II: The Sensor – Active Acoustic

w/break *Goals: Learn about the capabilities and limitations or concerns about available technologies and discuss the circumstances, if any, in which these technologies could be used in a way that addresses concerns.*

Overview Presentation:
Jim Theriault, Defence Research & Development Canada

Case Examples:
Frank Reier Knudson, Simrad
Peter Stein, Scientific Solutions, Inc.
Gordon Hastie, SMRU Ltd

Discussion (with response panel)
Bob Gisiner, Marine Mammal Commission
Brandon Southall, Sea, Inc.
Greg Silber, NOAA
Cheryl Zimmerman, FarSounder

Noon LUNCH on own

1:15 pm Session III: Signal Processing

Goals: Understand the capabilities and limitations of various software options currently available. Discuss desired performance characteristics in different situations, and the pros and cons, and feasibility, of standardization.

Overview Presentation:

David Mellinger, Oregon State University Hatfield Marine Science Center

Case Examples:

Doug Gillespie, Scottish Oceans Institute, University of St. Andrews

Christopher Clark, Cornell University Bioacoustics Research Program

Discussion

3:45 am BREAK

4:00 pm Session IV: Reporting Metrics

Overview Presentation:

Aaron Thode, Scripps Institution of Oceanography

Discussion

5:00 pm Adjourn

Thursday, November 19, 2009

8:00 am Coffee/Tea and Informal Conversation

8:30 am Open Day 3

8:45 am Session V: Operations and the Operator

Goals: Discuss the operational issues associated with operating acoustic monitoring systems on a variety of vessel types and/or other circumstances, operator qualifications and training, the pros and cons of standardization and certification, safety issues, etc.

Interactive Panel

Philip Fontana, Polarcus

David Hedgeland, PGS

Major Smith, BHP Billiton

Bernard Padovani, CGGVeritas

Roy Wyatt, Seiche Measurements Limited

Discussion

10:45 am BREAK

11:00 am Session VI: Open Session

Goals: General participant discussion of issues identified during the workshop that need additional time to explore.

12:00 pm LUNCH on your own

1:15 pm Session VII: Closing Panel with a View to the Future

Goals: Summarize and provide perspectives on the highlights of the workshop, including lessons learned about capabilities of currently available technology, limitations and/or important gaps that could potentially be addressed in the next three to five years. Identify technology and/or advances in signal processing software that are on the near horizon to meet these needs.

Interactive "Listening Panel" *[60 min]*

Christopher Clark, William T. Ellison, Jill Lewandowski, Howard Rosenbaum, Brandon Southall, Bill Streever, John Young

General Discussion and Participant Perspectives *[90 min]*

Closing Remarks *[15 min]*

James Kendall, Chief, Environmental Division, BOEMRE

4:00 Adjourn

APPENDIX II

WORKSHOP PARTICIPANTS

WORKSHOP PARTICIPANTS

Patrick Abgrall
LGL Limited

Lisanne Aerts
LGL Alaska

Michel Andre
Laboratory of Applied Bioacoustics, Technical University of Catalonia (UPC)

Alyson Azzara
Texas A&M University

Mike Bahtiarian
Noise Control Engineering

Chris Bajdek
ESS Group, Inc.

Kyle Baker
National Marine Fisheries Service

Mary Jo Barkaszi
Independent consultant

Adam Baukus
Gulf of Maine Research Institute

Dana Beldon
Office of Naval Research

Kim Benjamin
NUWC

Susanna Blackwell
Greeneridge Sciences, Inc.

Caroline Blanco
NSF

Ian Boyd
University of St. Andrews

Eric Boyer
HTI

Robin Brake
Office of the Assitant Secretary of the Navy/Environment and Installations

Ron Brinkman
BOEMRE

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APPENDIX III

BACKGROUND DOCUMENTS

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The following are background documents provided to workshop attendees.

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APPENDIX IV

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APPENDIX V

PRESENTATION ABSTRACTS

PRESENTATION ABSTRACTS

Session I: Setting the Stage

A Pragmatic Approach: Finding Functional Solutions Recognizing the Capabilities and Limitations of Existing Technology

William T. Ellison, *President and Chief Scientist, Marine Acoustics*

The intent of this presentation is to foster a logical framework for selecting and evaluating a given monitoring/mitigation application by matching system capability to the requisite environmental compliance (EC) objectives. This proposed framework can be viewed as a decision-based tool for evaluating existing capabilities as well as current shortfalls. Successful EC actions are typically founded on t hree underlying objectives: compliance with existing regulations; furnishing effective monitoring and mitigation capability; and, if required; identifying and supporting research shortfalls.

Further levels of detailed capabilities can be achieved by evaluating the three base objectives at each life cycle stage of an offshore development. This approach facilitates determining the capability (and shortfalls) of existing EC tools, including: their ease of use, schedule and cost issues, need for supporting databases, and consistency and understanding of regulatory issues. Underlying this process is the continuing need for good communication between the activity sponsors, regulators and other governing agencies and the public.

Framing the Discussion Using an Acoustical Ecology Perspective

Christopher Clark, *Imogene P. Johnson Director, Bioacoustics Research Program, Cornell University*

This presentation focuses on the intersecting connectivities of the space-time-frequency scales of a project's activities and the acoustic ecologies and habitats of the animals of concern, while recognizing that projects range from strictly operational to those that might require a research component. Pre-emptive evaluations of potential effects and empirical metrics of actual effects on marine mammals require knowledge of species occurrence (What's there?), species distribution (Where is it?), seasonal occurrence (When is it th ere?), basic activity (What is it doing?), and bioacoustical-ecological type (e.g., LF, MF, HF, shallow, shelf, pelagic). Optimization of the evaluation process is achieved by matching the required resolutions of the environmental compliance objectives with the resolutions of the science-based knowledge and the functional set of available tools. This approach underscores the need for tool sets that have specifications matched to the spatial-temporal-frequency scales of the bioacoustical-ecological concern and the environmental compliance requirements.

Session II: The Sensor - Passive Monitoring ("fixed" systems)

A Review of Fixed Passive Acoustic Monitoring Systems

Renata S. Sousa-Lima, *Research Scientist, Bioacoustics Research Program, Cornell University; in collaboration with Tom Norris, Bio-Waves Inc. and Julie Oswald, Oceanwide Science Institute*

Fixed Passive Acoustic Monitoring (fixed PAM) systems have the capability to monitor underwater sounds over a wide range of spatial and temporal scales. This capability has resulted in interest by organizations and research groups evaluating technologies for monitoring marine mammal sounds and the effects of anthropogenic noise on marine mammals. For example, the Joint Oil & Gas Industry Programme on Sound and Marine Life (JIP) is interested in cost-effective ways to collect data to determine marine mammal distribution, occurrence, movement and habitat use in relation to exploration and production (E&P) activities. We have been tasked with providing an inventory and review of fixed PAM technologies for the JIP and are basing much of this review on the information gathered for that effort.

Our general approach consisted of researching and compiling primary information from the peer-reviewed literature, with additional sources of information from the grey literature, abstracts, conference presentations, websites and product brochures. Online search engines such as Google as well as all scientific and engineering literature databases available from Cornell University and the University of Hawaii and the University of California were used during our review. Several developers and users were contacted directly to provide further details on their systems. Finally, requests for information were sent to Bioacoustics_L and MARMAM listserves. The relevant bibliography was compiled as an EndNoteWeb library.

We review three main types of fixed installation PAM systems: 1) Autonomous recorders (ARs); 2) Radio-linked hydrophones (RLHs); and 3) Fixed Cabled hydrophones (FCHs). Each system type has different capabilities and applications.

We define a fixed autonomous acoustic recording device (AR) as any electronic recording system that acquires and stores acoustic data internally (i.e., without cable or radio links to a fixed platform or receiving station), is deployed semi-permanently underwater (via a mooring, buoy or attached to the sea-floor), and is retrieved after the deployment period to access the data.

We reviewed over 30 ARs that are available for recording marine mammal sounds. These vary greatly in price and capabilities from small hand-deployable units for detecting dolphin and porpoise clicks in shallow water, to units that can be deployed in deep water, record at high frequency bandwidths for a year, but must be deployed from a large research vessel.

Radio-linked hydrophone systems (RLHs) consist of hydrophone(s) that are moored or fixed to the bottom and transmit the audio signal via radio-waves to a receiving station on shore. This enables acoustic data to be monitored and processed in real- or near-real-time Some examples of RLHs include the Comprehensive Test Ban Treaty Organization's (CTBTO) International Monitoring System and the WHOI/Cornell Right Whale Detection Buoy System, which has been designed specifically to study marine mammals.

Fixed cabled hydrophone systems (FCHs) are typically located on the seafloor in a permanent configuration. They have the capability to be continuously powered by an external source and can also continuously send data to a receiving station. Examples include the U.S. Navy's low-frequency SOSUS arrays, U.S. Navy underwater test ranges (e.g. AUTEC, SCORE, PMRF), smaller scale arrays designed specifically for marine mammal studies, and large scientific efforts that can opportunistically collect information on marine mammals and anthropogenic noise (e.g. ocean and neutrino observatories).

Autonomous recorders, radio-linked hydrophone systems, and fixed cabled hydrophones each have specific advantages and disadvantages. In general, setup and infrastructure costs are highest for FCHs and RLHs and lowest for ARs. However, acoustic data bandwidth and collection capabilities are highest for FCHs. AR systems are more flexible in their configuration, timing and locations of deployment, but require instrument retrieval and post-processing of data. RLSs have the same real-time data acquisition capability of FCHs but at an intermediate cost and limited frequency bandwidth and data transfer rates (must use available VHF/UHF radio-channels, satellite, or cell-phone networks). RLHs are usually located relatively close to shore and require a land-based receiving station but data can be processed in real-time or post-processed.

In summary, each of the 3 main types of fixed installation PAM systems reviewed here has its own unique advantages / disadvantages. Considerations when selecting which device to use include available budget, time-frame for monitoring, area to be monitored, the bandwidth and characteristics of sounds to be monitored (i.e. marine mammal call types and noise sources), and the need for real-time versus post-processing of acoustic data. Each of these considerations must be weighed and evaluated in order to properly decide which type of technology is best suited for the goals and questions to be answered. Once the type of fixed PAM system is chosen, additional choices may be made concerning system specific requirements and configuration relative to the project goals.

Finally, it is critical to factor in the biology of the species that being monitored or studied using fixed PAM technology. The target species biology will affect all aspects of the study design and monitoring system choices. This aspect is beyond the scope of this review but is addressed in detail by others at this workshop.

Application of Passive Acoustic Technologies to Mitigate and Monitor Impacts Associated with the Construction and Operation of LNG Import Terminals in Massachusetts Bay

Leila Hatch, *Marine Ecologist, Stellwagen Bank National Marine Sanctuary, NOAA/NOS*

The Gerry E. Studds Stellwagen Bank National Marine Sanctuary (SBNMS) is home to many marine species that are protected and/or managed under multiple US statutes, including the National Marine Sanctuaries Act (NMSA), the Marine Mammal Protection Act (MMPA), the Endangered Species Act (ESA) and the Magnuson-Stevens Fisheries Conservation and Management Act. Placed in the middle of Massachusetts Bay, the sanctuary is also a busy place for human commerce. Meeting protection and management objectives in the SBNMS thus necessitates characterizing patterns of ecological importance and human activity, and devising innovative ways to reduce or eliminate impacts when and where uses overlap.

In 2005, two companies, Northeast Gateway Energy Bridge, LLC (Gateway) and Neptune, LLC (Neptune), applied for deepwater port licenses to install liquefied natural gas (LNG) import terminals and associated pipelines in the waters adjacent to the SBNMS. Both companies proposed operating for 30-40 years within habitat utilized by at least four endangered whale species (North Atlantic right, humpback, fin and minke whales) for feeding, nursing and/or migration. At their closest points, the proposed terminal locations were 1.2 nautical miles (nm) from the sanctuary's western border, with the farthest being 2.8 nm. Based on the findings that the ports "might affect" sanctuary resources, the National Oceanic and Atmospheric Administration's (NOAA's) Office of National Marine Sanctuaries (ONMS) initiated formal consultation with the licensing agencies, the US Coast Guard and the Maritime Administration (USCG and MARAD) under the National Marine Sanctuaries Act.

Under the NMSA, the ONMS recommended a series of conditions to be included if the project licenses were approved in order to minimize the impacts of port construction and operation on sanctuary resources. Three recommendations called for implementation of passive acoustic arrays to detect and/or monitor the presence of whales and levels of noise relative to LNG port construction and operation. These recommendations were accepted by the USCG and MARAD and included as conditions to the licenses issued to both ports in 2007. The arrays were also included in the project descriptions for the ports and associated applications for Incidental Harassment Authorizations evaluated by NOAA's National Marine Fisheries Service (NOAA Fisheries) under the ESA and MMPA, respectively.

Recommendations for each array specified system components and operating procedures necessary to meet the mitigation or monitoring goals identified by NOAA. As examples, the recommendations identified technologies already in use in Massachusetts Bay by Cornell University's Bioacoustics Research Program (Cornell) and Woods Hole Oceanographic Institution's Applied Ocean Physics and Engineering Department (WHOI), but stipulated that alternatives could be utilized so long as they met performance requirements. Performance requirements were similar to those subsequently highlighted in the "NOAA Guidelines for Passive Acoustic Listening Systems for Monitoring in Mitigation Programs" (including as a background document for this workshop).

Both Gateway and Neptune contracted Cornell and WHOI to implement the three passive acoustic mitigation and monitoring requirements. The first array, deployed in spring 2007, is composed of nineteen autonomous recording units (ARUs), designed by Cornell, placed in a broad area surrounding the port, including the western SBNMS. The ARU array was deployed two months prior to construction of the first port (Gateway), and is being used to monitor the acoustic footprints of both ports before and during construction and for a minimum of five years of operation. The remaining two arrays use automatic detection buoys (ABs) to detect the contact calls of North Atlantic right whales and transmit alerts to their presence in near real-time via Iridium satellite to technicians at Cornell for verification. A confirmed call is then used to trigger mitigation actions in the area around the detecting buoy. Six ABs were installed near the sites of port and pipeline construction (summer to winter 2007 for Gateway and summers of 2008 and 2009 for Neptune) and ten ABs were installed between the Boston shipping lanes in winter 2008. Verified acoustic detections close to pipeline and port construction activities alerted construction teams and visual observers to the presence of right whales within ranges that could lead to acoustic harassment. Confirmed acoustic detections in the shipping lanes are used to alert transiting LNG vessels and avert vessel-whale collisions by slowing speeds and increasing visual awareness.

Both the mitigation actions themselves (i.e., temporary shut-downs of noisy construction activities, slowing vessels below 10 knots, heightening visual awareness etc.) and their spatial and temporal characteristics (i.e. within 100 and 500 yard "zones of influence", until the whale leaves the zone or has not been seen for 30 minutes, within 5 nautical miles of the detecting AB, for 24 hours after a confirmed detection etc.) were developed by NOAA managers through consultations and permitting and were further refined during finalization of the Operations Manuals for both ports by representatives from Gateway and Neptune (environmental managers and environmental consultants, including Cornell), the USCG and NOAA. These operational procedures are a reflection of 1) what was known at the time they were developed about whale behavior, distribution and density, baseline noise conditions and the impacts of LNG construction and operation within Massachusetts Bay and 2) the application of the precautionary principle in the face of considerable scientific uncertainty and high risk due to the critically endangered status of the North Atlantic right whale. These procedures have been and should continue to be adapted to reflect technological advance and knowledge gained through experience, and examples of both will be discussed in the presentation of this case study.

Fixed Passive Acoustic Monitoring Using DASARs at BP's Northstar Production Facility in the Alaskan Beaufort Sea

Bill Streever, ***Environmental Studies Leader, BP Exploration***

Since 2000, the Northstar study has assessed the distribution of bowhead whale calls exposed to sounds associated with the Northstar oil production facility in the Alaskan Beaufort Sea. During September, bowhead whales migrate past the Northstar facility. While the whales pass Northstar, sounds associated with the Northstar facility are recorded using a hydrophone positioned about 450 m from the facility. At the same time, whale calls are localized using an array of Directional Autonomous Seafloor Acoustic Recorders (DASARs), which are, in essence, fixed directional Passive Acoustic Monitoring (PAM) recorders. When a calling whale is heard on two or more DASARs, it can be localized. The relationship between varying sounds associated with the Northstar facility and whale call distributions can then be assessed. This presentation focuses on the DASARs themselves and the DASAR approach rather than on the detailed methods or results of the overall Northstar study. It should be noted that this presentation reflects the views of BP's project manager and may not reflect the consensus viewpoint of the many scientists involved with this project.

DASARs were built using both the principles and components associated with Directional Frequency and Recording sonobouys. However, unlike sonobouys, DASARs are intended to sit on the seabed and record directional acoustic data for thirty days or longer. This allows long-term deployment in areas where floating ice, surface activities, or other factors might prevent the use of sonobouys. Each DASAR includes an onboard battery pack, a hard drive to record data, and a clock to allow meaningful compilation of recorded calls from different DASARs. Each DASAR includes an omnidirectional sensor and two horizontal, orthogonal particle motion sensors with outputs that are proportional to the cosine and sine of the direction of the source. In short, the omnidirectional sensor records sound pressure levels (of, for example, whale calls) while the particle motion sensors determine the direction to the sound source. When a sound is recorded on two or more DASARs, the crossing point of the vectors (one vector from each DASAR) corresponds to the whale call location. Greene et al. (2004) provides a detailed description of the DASARs.

The Northstar DASAR array has provided nominal locations of thousands of whale calls each year since 2001. Statistical analyses of these whale call locations suggest that whales are responding to sounds associated with the Northstar facility, including sounds with received levels that would be close to ambient sound levels in the vicinity of the whales. The response may represent bowhead whale movements away from the sound source, a change in calling behavior, or both. Detailed explanations of the overall study are presented in various reports on file with the National Marine Fisheries Service.

The DASARs and the DASAR array approach have proven to be remarkably reliable. Although a small number of instruments have failed during the course of well over one hundred instrument deployments, redundant DASAR locations built into the array design have prevented meaningful data gaps. Occasionally, DASARs have moved on the seabed, rendering data collected after movement less useful, but redesign of the DASAR frames and housings have improved stability and appear to have eliminated problems with movement. On one occasion (the 2008 field season), the relationship between whale call distribution and Northstar sounds was obscured by the presence of extraneous industry sounds, mainly related to nearby seismic shoots.

While in general the DASARs themselves have performed exceptionally well, the overall approach has met with what is best described as mixed success. On the one hand, whale call distributions have been successfully mapped and statistical analyses have identified significant but subtle relationships with Northstar sounds. In addition, the approach allows for numerous analyses that will improve our understanding of bowhead whales and their response to anthropogenic sounds. For example, recordings have been used to assess directionality of bowhead whale calls and to inventory whale call types during the fall migration. On the other hand, complexities associated with the data analyses and interpretation can be challenging. For example, identification of independent samples of whale calls and determination of appropriate "time windows" (the time over which Northstar sounds should be integrated) requires judicious application of numerous assumptions and caveats. Far more problematic is the interpretive challenge presented by our inability to know if changes in call distributions are related to changes in the locations of calling whales, changes in calling behavior, or both. Ultimately, it is possible to conclude that whale call distribution changes in association with changes in Northstar sounds, but it is not possible to determine if the distribution of the whales themselves changes in association with changes in Northstar sounds, which was a key initial objective of this work.

The Use of Passive Acoustic Monitoring During the Construction of a Wind Farm Demonstration Project

Roy Wyatt, ***Seiche Measurements Limited***

The construction of two offshore wind turbines during 2006 required the use of a pile driver to place 8 piles into the seabed. A mitigation plan was put in place to reduce the potential impact of underwater noise made by the pile driving operation on marine mammals.

The two wind turbines were constructed in 45m of water approximately 24km outside a special area of conservation on the eastern coast of Scotland. The area was an important habitat for bottle-nosed dolphins and as such a detailed mitigation plan for the underwater noise generated by the pile driving activity was developed. The plan included the use of visual observation combined with the use of a static Passive Acoustic Monitoring (PAM) system.

Each of the two turbine constructions required four piles to be driven into the seabed. The piles were six feet in diameter and 44m in length. The piles were driven into the seabed by a hydraulic hammer weighing 25 tons mounted from a specialist construction platform.

An exclusion zone of 1km had been calculated for the pile driving activity based on sound pressure levels that were below those likely to cause a Temporary Threshold Shift in marine mammals. The exclusion zone was visually and acoustically monitored for a period of 30 minutes before piling commenced. If a marine mammal were detected in the area during this time the commencement of piling would be delayed until the area had been clear for 30 minutes.
A soft start procedure was utilised before the pile driver was allowed to work at maximum energy. The soft start procedure involved a series of single strikes at decreasing intervals and then a gradual ramp up in pile driving energy.

Two Marine Mammal Observers (MMO's) were utilised to survey the area before the commencement of pile driving. One MMO visually observed the area the other operated and monitored the PAM equipment.

The PAM equipment used was a remotely operated buoy that suspended 4 hydrophones at a depth of 3m below the sea surface. The buoy transmitted acoustic data back to the PAM operating desk where the data was processed and displayed.
The challenges of using PAM in this application is that operating vessel noise and pile driving noise itself can limit the detection capability of passive acoustic monitoring. The buoy was used to enable the hydrophones to be distant from any noise source.
During the operations no visual or acoustic detections were made during the 30 minute survey periods before commencement of pile driving operations.

The main lesson learned was that the due to the position of the buoy the acoustic pile driving noise prohibited the use of passive acoustics whilst piling was in progress. This could be improved by using a series of buoys moored at a greater range from the piling operation. The monitoring of the exclusion zone before the pile driving was initiated was unaffected by vessel noise.

Later analysis of the acoustic sound pressure levels showed them to be in excess of the predicted levels and that an exclusion zone of 2km radius would have been more in keeping with the pile driving noise. Two other smaller jetty construction sites are briefly presented. These used piles of smaller diameter and had smaller exclusion zones. For these projects mitigation was based on actual measurements at the commencement of the pile driving activity.

Session II: The Sensor - Passive Monitoring ("towed" systems)

Towed Acoustic Arrays

Aaron Thode, ***Associate Researcher, Scripps Institute of Oceanography; University of California, San Diego***

Towed passive acoustic monitoring (PAM) systems have been one of the earliest PAM configurations to be applied to marine mammal mitigation, and is one of the most pervasive, with numerous academic and commercial systems being deployed by a variety of organizations. The great advantage of these systems is mobility; thus they are the PAM workhorse for monitoring marine mammal presence in close vicinity to mobile active sources, and for censusing high-frequency marine mammal activity over large spatial areas. However, towed systems suffer from a variety of disadvantages, including masking from the towing vessel and flow noise, limited tracking capabilities, a limited (and frequency-dependent) bearing resolution, and a general inability to distinguish port from starboard sources. Some of these limitations can be overcome with new or more expensive technology; others are inherent limitations to this type of configuration. This presentation focuses on research efforts to extend towed array systems from one to three dimensions, and the use of vector sensors to solve the port/starboard ambiguity problem.

BHP Billiton Multi-Vessel Survey: A Case Study for the Commercial Application of Passive Acoustic Monitoring (PAM) for Regulatory Compliance in the Gulf of Mexico, USA

Mary Jo Barkaszi, ***Vice President of Protected Species Compliance Programs, RPS Energy***

Two towed hydrophone arrays were deployed during a multi-vessel geophysical survey operation in the Gulf of Mexico between July and September 2008. This deployment represents the first fully commercial deployment of PAM under the regulatory guidelines established by the BOEMRE Notice to Lessees Number 2007-G02, *Implementation of Seismic Survey Mitigation Measures and Protected Species Observer Program.* A total of 635 hours of PAM monitoring was conducted with 42 detections of protected species. There were 22 acoustic detections of sperm whales and 25 visual detections of sperm whales. Acoustic detections for sperm whales showed a higher detection frequency and longer detection time than visual detections. Utilization of PAM saved approximately 33 hours of fleet-wide downtime and increased the data quality of 22 hours of survey time. Success of the project was also judged by the ability to reduce the overall noise footprint of the vessel fleet by optimizing silent periods.

Towed Arrays and PAM: 10 Years of Field Application

Claudio Fossati, ***CIBRA Center for Bioacoustics, University of Pavia and RIGHT WAVES, in collaboration with Gianni Pavan and Giovanni Caltavuturo***

Right Waves is a young Italian company that shares members, experience, technology with CIBRA, Center for Bioacoustics, University of Pavia, IT. The team has more than fifteen years of experience in organizing acoustic and visual research cruises, designing experiments, making instruments, writing software, getting out at sea, finding the animals, tracking them, and recording their sounds.

Ten years ago we started to study and implement Passive Acoustic Monitoring techniques for mitigation purposes during active acoustic experiments, both in military and civil contexts.
In our experience, towed arrays are the best suited and practical tools for PAM activities from moving vessels, e.g. seismic vessels and during naval exercises. These instruments present a series of capabilities that match very well with mitigation objectives.

They allow 24-hour continuous monitoring and recording of vocalizing marine mammals and sound sources even for very long periods. Their performance is less affected by weather conditions than visual observation. They can be towed from a wide variety of vessels and, if properly designed, made, and installed, assure a great detection capability. On the contrary, since they are generally towed by the source vessel, they may be exposed to interaction with other seismic gear. If not carefully installed and operated, it may take a long time to get acceptable results. In the present case study, we installed and operated towed arrays for PAM on the Seismic RV Langseth, of LDEO, Columbia University. Array design and towing solutions varied in the last few years to avoid mainly interaction problems with other seismic gear.

According to results coming from our recent academic research, we also extended the monitored bandwidth. As a result, we now have 2 "compact" arrays (one as a backup), 15 m long, with 2 channels, relatively short lead in cable, coupled with a hydrodynamic depressor that guarantees safe towing up to Beaufort 8. Acoustic software evolved as well to assist the operator during the long shifts with automated data entry. The software in use, SeaPro Suite, designed at CIBRA, rely on a series of applications that self-manage and store navigation and geographical data.
The spectrographic display provides a clear but accurate image of the sounds, and has some interesting tools like the Red/Blue function that (automatically and in real time) gives a very intuitive cue of the sound-source position.

Directional Towed Array Pilot in the Canadian Beaufort Sea

Bruce Martin, ***Systems Division Manager, JASCO Research***

JASCO Applied Sciences performed a towed array trial of their new Cetacean Towed Array System (CETAS) for passive acoustic monitoring of marine mammals in the Beaufort Sea. CETAS has two acoustic modules separated by 400 meters, towed 400 meters behind the vessel. Each module has two high frequency (150 kHz) omni-directional hydrophones and two low frequency (100 – 2000 Hz) directional hydrophones. Localizations of marine mammals are obtained by combining cross-dipole calculations of two bearings and a time difference of arrival hyperbola. Vocalization playbacks were used to test the data acquisition systems and to determine the ranges of detections and signal-to-noise requirements. The goal of this trial was to quantify the detection performance of the directional sensors in the presence of high tow ship noise levels. The recorded data were archived and analyzed for marine mammal vocalizations, seismic shots, and ambient sound levels. The greatest challenge to the localizations was the signal-to-noise ratio of low frequency bowhead calls above the noise of the anchor-handling tug used to tow the array. The technical details of the array and data processing will be presented as well as results from the trial.

Session II: The Sensor – Active Acoustic

Fine Scale Movements of Marine Mammals Around a Marine Renewable Tidal Stream Device; Application of High Frequency Imaging Sonar

Gordon Hastie, ***Research Fellow, Scottish Oceans Institute, University of St. Andrews; in cooperation with Beth Mackey[1], Andrew Murray[1], Jennifer Snowball[3], and Ian Boyd[4].***

[1] SMRU Ltd, Scottish Oceans Institute, New Technology Centre, North Haugh, University of St Andrews, Fife KY16 9SR, United Kingdom;

[2] Centre for Social Learning and Cognitive Evolution and Sea Mammal Research Unit, School of Biology, University of St. Andrews, Fife KY16 8LB, United Kingdom;

[3] Royal Haskoning, 10 Bernard Street, Leith, Edinburgh, EH6 6PP, United Kingdom;

[4] Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, Fife, KY16 8LB, United Kingdom;

Marine renewable energy devices are being deployed as part of ambitious targets on renewable energy production. Their interactions with marine mammals are unknown but may include habitat exclusion, attraction towards devices due to increased foraging opportunities, or physical interactions. The aim of this study was to quantify fine-scale underwater movements of small marine mammals (harbor porpoises and harbor seals) around a recently installed tidal stream energy device. Underwater movements of marine mammals (confirmed using visual observations at the surface) were measured using high frequency imaging sonar. We deployed two Tritech Super SeaKing sonar systems on the SeaGen tidal turbine in Strangford Lough, NI. Each sonar head provided approximately 120-180^o horizontal coverage x 40^o vertical coverage around the turbine and provided full water column coverage from at least 15 metres from the turbine out to approximately 80 metres. Results showed that small marine mammals (and other mobile targets) can be detected in a tidally turbulent water column in real time using high frequency imaging sonar. A total of 159 moving targets were detected using the active sonar. Comparison of these to sightings made by a visual observer suggested that a percentage of these (22 targets; 16% of all targets) were marine mammals. Within areas directly upstream of the turbine (up to 100m), the percentage of visual sightings that were detected using the sonar was 46.7%. Mean target speed of confirmed marine mammals was significantly faster than ‘other’ targets. In addition, the angle and distance of tracks during turbine operation and non-operation were analysed using a Generalised Linear Mixed Model. Results of the GLMMs on the influence of turbine activity on sonar track trajectories suggests that turbine activity (operational vs. non-operational) did not significantly influence the track trajectories; there was little evidence to suggest that angle and distance of the tracks upstream of the turbine were significantly influenced by the operation of the turbine. If sonar is going to be used as an efficient monitoring and mitigation tool in the future, it is important that marine animals can be reliably differentiated from other underwater targets. The results of this study suggest that certain target features (e.g. speed, movement in relation to tidal direction, etc.) appear to provide the basis for differentiating marine mammals from other targets (including other wildlife species). The results of our study into the capabilities (marine mammal detection and tracking) and limitations (e.g. behavioural changes due to hearing sonar signals and communication interference) of imaging sonar for this application will be discussed in detail.

Using Echosounders and Sonars to Detect Marine Mammals

Frank Reier Knudsen, ***Fishery Biologist, Simrad***

Active acoustic monitoring systems (echosounders and sonars) and their ability to detect marine mammals, will be presented. Particular attention will be given to a case study where fisheries sonars were used to detect killer whales.

The *echosounder* transmit short pulses in a narrow beam typically from the surface towards the bottom and detect targets in the water column ranging in sizes from plankton to whales. The acoustic beam can also be pointed horizontally, a configuration often used to detect targets around man-made structures. The *sonar* transmits omnidirectionally with simultaneous 360° horizontal coverage in every transmission or vertically in a 180° fan. The horizontal beam can be tilted downwards from the surface to detect targets in the whole water column and the vertical fan can be rotated. The sonar detection range can be several kilometers. Distance to the target, bearing and target depth are displayed.

The International Association of Oil and Gas Producers (OGP) funded a study where we evaluated the ability of traditional fisheries sonars to detect killer whales. The reason is that marine geophysical explorations based on air guns may harm marine mammals (Richardson et al. 1995). Therefore, establishing safety zones for seismic surveys has high priority. Methodology that can reliably detect marine mammals within the established safety zones during all operational conditions for seismic surveys is required for cost-efficient operations and to secure that marine mammals are not injured or affected.

A commercial fishing vessel equipped with sonar was used to survey an area with a large number of killer whales in the northern part of Norway in November 2006. Two fisheries sonar systems were used: Simrad SP90 and SH80 operating at 20-30 kHz and 110-120 kHz, respectively. Maximum source levels (RMS) were 218 dB re 1 μPa (SP90) and 211 dB re 1 μPa (SH80). The sonar transmitted both horizontally (omnidirectionally) and vertically. The fishing vessel was searching randomly in the survey area during the day, and whale detections were always verified by visual observations. Sound-speed profiles were collected to model ray traces, sound transmission loss, and detection probability.

Whales appeared as distinct echoes on both sonar systems. Detection range on the SP90 sonar was at least 1,500 m, and for the SH80, reliable detections were obtained up to 400 m. In addition to the direct echo from the whale, vocalization was picked up on the sonar. It was easy to discriminate whistles and calls (long tones) from clicks, the fundamental social tones in killer whales (Thomson et al. 2001). Killer whale vocalization frequencies are within the operating frequency range of the SP90 sonar (>20 kHz) (Diercks et al. 1971) but not within the range for the SH80. The pickup on the sonar should therefore be both the fundamental vocalization frequencies and the harmonics. Wakes from swimming whales (surfacing) were also picked up by the sonar systems. The source of the wake is most likely echoes from whale air release and air being mixed into the water during surfacing.

Whales were detected during dives with no effect of water depth as one would assume due to lung volume compression and resulting reduction in whale echo strength. The whales did not show any apparent behavioral reactions during sonar operations, but this could be due to previous sonar transmission exposure from other fishing vessels in the area.

Simulations of ray tracing, transmission loss, and detection probability were in good agreement with actual observations. It is critical that sound-speed profiles are measured and simulations conducted as beam bending can lead to serious misinterpretation of the sonar detections.

Considerations on methodology for detecting whales in relation to seismic survey operations should include fisheries sonar. Sonar effectively detects the direct echo from whale at ranges sufficient for suggested safety zones (<500 m). In addition to the direct echo from the whale, both vocalization and wakes provide strong criteria for positive detection and classification of the target and can possibly be used to discriminate between species. Sonar is not limited by visibility, darkness, or sea state and is not dependent on whale vocalization as passive listening methods would be.

Two Examples of Active Acoustic Sonar Systems for Marine Mammal Monitoring

Peter Stein, ***President and Founder, Scientific Solutions, Inc.***

Scientific Solutions, Inc. has developed and tested two active acoustic sonar systems for marine mammal monitoring. One is the High Frequency Marine Mammal Monitoring Sonar (HF/M3). This system is currently part of the U.S. Navy's SURTASS LFA and CLFA[7] sonar systems and to our knowledge is the only operational active sonar system specifically used for marine mammal protection. This novel system uses rotating parabolic reflectors and scans for marine mammals with an effective range out to 2 km. The second system is the active acoustic component of the Integrated Marine Mammal Monitoring and Protection System (IMAPS). This system is a 60 receive channel phased array sonar system and was deployed twice off the coast of San Louis Obispo, California within the grey whale migration. Detection and tracking ranges on the order of 1 km in shallow water were demonstrated. Also, although deemed to be minor, there was a statistically significant avoidance reaction to the active IMAPS sonar. The design and performance of both of these systems will be discussed to exemplify the benefits and limitations of using active acoustics for the detection of marine mammals. Indeed, each individual application will need a level of customization in order to be effective, and there may still be limitations that depend on the characteristics of the animals and the local acoustic propagation, noise, and clutter conditions. There is also the potential issue of the effects on the

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[7] Surface Towed Array Sensor System Low Frequency Active and Compact Low Frequency Active. For more information, see http://www.surtass-lfa-eis.com/.

environment of using an active sonar system for marine mammal monitoring. It seems clear that no one method of detection and tracking will suffice under all conditions and for all applications. The IMAPS program was intended to fuse together many modalities of marine mammal detection into one system. If the goal is to provide near 100% safety for marine mammals during harmful activities deemed necessary for national security and economic survival, then an integrated system needs to be developed and deployed along with active and passive acoustics and non-acoustic techniques.

Session III: Signal Processing

Signal Processing Overview

David Mellinger, ***Associate Professor, Senior Research, Cooperative Institute for Marine Resources Studies, Hatfield Marine Science Center, Oregon State University***

Signal processing and analysis techniques are widely used for analyzing marine mammal sounds. Which techniques are used depends both on the goal of the acoustic analysis as well as the nature of the marine mammal sounds themselves, and a number of factors must be considered in choosing techniques. Here I review the factors that go into the choice of signal processing techniques and the context in which those techniques are employed. Call frequency is a primary consideration for choosing equipment and analysis techniques; frequencies of marine mammals range from below 20 Hz for large baleen whales to more than 100 kHz for some dolphins and porpoises. In assessing the impact that an action may have on marine mammals, one must assess whether impacts are likely to be cause by hearing damage, either temporary or permanent; by masking of important sounds such as predators, prey, or echolocation; or by behavioral change, such as diving disruption, displacement from important habitats, or disruption of movements such as migration. A common signal processing need is for automated detection and classification of marine mammal vocalizations. The type of technique to be used depends on the degree of specificity required: Does one need to detect all marine mammal sounds? A certain taxonomic group, such as beaked whales? A group defined by frequency, such as animals that use low frequencies for communication? All threatened or endangered species? A single species, such as bowhead whales or right whales? The effectiveness of automatic detection and classification methods depends on the call type(s) to be detected and classified and the degree of stereotypy of these calls: highly stereotyped calls are amenable to template-matching techniques, while highly variable calls require more flexible approaches that are often more difficult to tune. The degree to which the desired call type(s) matches calls of other species is also critically important in assessing the likely effectiveness of an automatic detection method. Localization of calling marine mammals is another common signal processing task. The factors affecting the use of localization techniques include the desired accuracy of localization, which is affected by the call type's time and frequency characteristics, the intensity with which the target species produces calls, the distance over which localization must be performed. Localization can mean estimating bearings (1-D localization), estimating X-Y (or lat-long) positions (2-D localization), or estimating X-Y-Z position (3-D position). In using these signal processing techniques, it is essential to consider the context that the techniques are embedded in. There is a crucial difference between an overall analysis procedure that is fully automated and one that includes a human. The fully automated arrangement is of course significantly less labor-intensive and therefore less expensive, but it is also prone to errors caused by unexpected sounds in the marine environment, equipment failures, wrong detections and localizations, and so on. Most marine mammal signal processing today occurs in an arrangement in which a person checks at least some fraction of the results produced by the analysis.

Detection and Localisation of Click Vocalisations Using Passive Acoustics

Douglas Gillespie, ***Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, Scotland***

So far as we know, all odontocetes produce clicks, although there are still several species which have not yet been recorded. Clicks are primarily used for echolocation, but can also play an important role in communication.

The types of clicks produced by different odontocete species vary widely. Two well studied examples are the sperm whale, which produces broadband, short duration pulses and the harbor porpoise, which produces much quieter ultrasonic narrow band pulses.

Despite the differences in waveform and frequency range, what does seem common to all species, is that the clicks are highly direction in nature, being focussed into a narrow beam directed ahead of the animal. Detection ranges are therefore greatest when an animal is pointing towards the receiving hydrophone, although this does not rule out detection of off-axis clicks at shorter ranges even when the animal is oriented away.

Detection

Odontocete clicks are readily detected using a variety of signal processing techniques. More challenging however is telling them apart from other impulsive sounds such as noise from ships propellers, etc. While some species, such as beaked whales and harbor porpoise have very distinctive spectra and waveforms, which are readily identified even at low SNR, individual clicks of other species, such as the sperm whale, are relatively indistinct at low SNR and it is generally easier to identify click trains, i.e. consistently spaced sequences of clicks on a consistent bearing.

Localisation

The short duration of odontocete clicks makes it relatively easy to measure bearings to the click source from the time of arrival difference of a click on multiple, closely spaced, hydrophones. However, to measure range, widely-spaced hydrophones are required and due to the directional nature of the clicks it may be impossible to space hydrophones far enough apart to get a reasonable location, but close enough to both fall within the beam of individual clicks. For sperm whales, this “shorter” range is generally still several km, however for many species, the off-axis detection range may be too low to be of any practical benefit.

It should also be noted, that many species, particularly of the smaller odontocetes produce clicks which are too high in frequency to hear with the human ear. These clicks can only be detected by either viewing a spectrogram of sound data or by using a high frequency automatic detector.

For several species, target motion analysis can be used to track animals over time. That is to say, bearings measurements are made to multiple clicks from the same individual over a period of time as the vessel progresses along its track. The positions at which the bearings lines cross gives the animals location. For this to be effective a number of conditions need to be satisfied. It must be possible to unambiguously associate the clicks of an individual animal for long enough to get crossed bearings and the movement of the animal must be small over the period for which it is tracked. This is relatively easy for sperm whales and we have has some success in applying this method to harbor porpoises, beaked whales and other species. It is however likely that the method is invalid for small, fast-moving dolphin species which are relatively close to the hydrophone array.

Detection Range

Detection range is primarily a function of how loud the clicks are and how loud local ambient noise is which might mask detection. From quiet vessels, sperm whales are generally detectable at several km, but this range can be reduced to 100's of meters in the vicinity of industrial activities. Harbor porpoise clicks, on the other hand, are both relatively quiet, and the high frequency sounds are attenuated rapidly in sea water, so detection range is limited to approximately 200m.

Detection Probability

If an animal is within the detection range, detection probability is a function of two things. The first is the animals behaviour – how often it produces a click and how likely it is to orientate itself towards the receiving hydrophone. The second is how long you are prepared or are able to listen for. For instance, sperm whales generally click almost continuously for 40 or 50 minutes during a dive and then spent 10 or 15 minutes silent at the surface. So if you can listen for 20 minutes or more, you are unlikely to miss one. Beaked whales click only during long feeding dives and there can be periods of several hours between these dives, acoustic detection probability for beaked whales is therefore likely to be extremely low.

Detection and Localisation of Whistle Vocalisations Using Passive Acoustics

Douglas Gillespie, *Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, Scotland*

Unlike clicks, not all odontocete species produce whistles. Since an important role of whistles appears to be social, whistle production may also be very dependent on the behavioural state of the individual or group of animals. Whistles are however commonly detected from most dolphin species. Their distinctive nature can make them easier to identify and separate from other noises than clicks which can often be confused with industrial noise sources.

Detection

Detection of whistles is nearly always achieved by either viewing or automatically analysing a spectrogram of incoming sound data. Although there is plenty of evidence for whistles well above the limits of human hearing, to the best of our knowledge, all species which whistle, produce at least some of those whistles within the human audio band, making operator aural detection a possibility. Automatic detectors generally perform some sort of noise analysis and noise removal from the spectrogram data and then search for connected regions in the spectrogram.

Classification

A number of researchers have developed software tools which can automatically or semi-automatically assign whistles to species. None of the classifiers we are aware of are error-free. It is also highly likely that whistles from a single species evolve over time and that different populations, or subspecies, produce distinctive whistles, so these classifiers may not be robust between locations and over time.

Localisation

Once detected, the high time-bandwidth product of whistles means that bearings from time of arrival differences of a whistle detected on multiple hydrophones are easily derived.

It is not possible to perform target motion analysis with whistles in the same way that it is with clicks since a) it is generally impossible to associate multiple whistles from the same individual over time and b) it is likely that the animal producing the whistle will have moved considerably between successive whistles.

Whistles are much less directional than clicks, so detection on multiple widely-spaced hydrophones is much easier. The problem is then associating whistles on different hydrophones, which may be extremely difficult if multiple animals are vocalising simultaneously.

Detection Probability

Since whistle production is highly dependent on the behavioural state of the animals, detection probability is likely to be highly variable.

Signal Processing for Detection-Recognition, Location and Tracking: Large, Low-frequency Marine Mammals

Christopher Clark, *Imogene P. Johnson Director, Bioacoustics Research Program, Cornell University*

This presentation outlines the signal processing specifications needed to meet the environmental compliance requirements of both operational and scientific projects, with particular focus on animals operating in the low-frequency (LF, < 1000Hz) and very low-frequency (VLF, < 100Hz) bioacoustical-ecological domains. By definition, the spatial-temporal-frequency features of such species intersect to a large degree with the space-time-frequency domains of industry projects. Many species of concern are endangered, broadly distributed over very large areas, communicate with LF or VLF sounds, and are impacted by multiple anthropogenic stressors. The issues of biological concern are not in the category of acute impact such as injury or damage, but rather in the category of chronic impact on life functions such as displacement from critical habitat or interference with communications. LF and VLF animals produce intense, omnidirectional, stereotypic and redundant signals that are species specific. Software system specifications for detecting-recognizing, locating and tracking are relatively well-advanced and available, and there are multiple examples of successful implementation.

Session IV: Reporting Metrics

Metrics

Aaron Thode, ***Associate Researcher, Scripps Institute of Oceanography; University California, San Diego***

The end result of any passive acoustic monitoring effort is a set of numbers and figures embedded in a report, which is then read by researchers, regulators, and interested third-parties for guidance and insight. The selection of metrics that consolidate thousands of hours of acoustic recordings into a set of key statistics is an aspect of passive acoustic research that receives less attention than technology or technique, but no other aspect of PAM strikes as closely to the heart of questions concerning the effect of anthropogenic sounds on marine mammals. This talk reviews three potential ways sound affects marine mammals: (1) direct injury and mortality; (2) reducing the efficacy of "normal" behavior (masking); and (3) changes in behavior in response to particular features in the signal other than intensity or signal-to-noise ratio. Metrics for each category of impact are reviewed or suggested, with a particular emphasis on how to minimize biological assumptions in a metric while preserving its long-term relevance.

APPENDIX VI

SPEAKER BIOGRAPHIES

SPEAKER BIOGRAPHIES

Mary Jo Barkaszi
Vice President of Protected Species Compliance Programs
RPS Energy

Mary Jo Barkaszi is a vice president in RPS where she manages the protected species compliance programs for North America from the RPS office in Florida. Ms. Barkaszi has over twenty years of experience planning and conducting ecological research and environmental monitoring including extensive work with threatened and endangered species, GIS analysis, environmental impact assessment, and conservation planning. Ms. Barkaszi has a B.A in Biology from Wittenberg University in Ohio and an M.S. in Biological Oceanography from Florida Institute of Technology. Prior to Joining RPS, Mary Jo was a conservation biologist for the NASA life Sciences Contract on John F. Kennedy Space Center, Florida where her work included banding studies of the Florida Scrub jay, radio telemetry of Eastern Indigo Snakes and Gopher Tortoises, and population studies for marine mammals and turtles. Prior to joining RPS Ms. Barkaszi successfully established a woman-owned environmental consulting company focusing on conservation assessment and planning with an emphasis on construction and operational impacts on protected species. Her work with listed species has involved field surveying through publication with much information used for NEPA compliance, Environmental Impact Assessment, and EA documentation and regulatory compliance. Ms. Barkaszi currently manages the protected species program for RPS Energy working with field staff, clients and agency personnel.

Christopher Clark
Imogene P. Johnson Director
Bioacoustics Research Program, Cornell University

Dr. Christopher W. Clark is the Imogene P. Johnson Director of the Bioacoustics Research Program at the Cornell Lab and Senior Scientist in the Department of Neurobiology & Behavior at Cornell University. He holds advanced degrees in Electrical Engineering (M.S.E.E., SUNY-Stony Brook, 1974) and Biology (Ph.D., SUNY -Stony Brook, 1980). As an NIH postdoctoral fellow and assistant professor at The Rockefeller University he conducted research on vocal learning in songbirds. His research interests concentrate on animal acoustic communication with a particular focus on the development and application of advanced acoustic methods for scientific conservation of marine mammals. He leads the Bioacoustics Research Program in the design, development and application of computer-based systems for quantitative analysis of animal vocalizations, and acoustic techniques to detect, locate, track, and census free-ranging animals. Scientists and engineers in the Bioacoustics Research Program (http://www.birds.cornell.edu/brp/) conduct a multitude of basic scientific and applied research projects around the globe (Africa, Australia, Europe, North America, Central America, South America; Arctic, Atlantic, Pacific, and Southern Oceans) on a diversity of species and taxonomic groups. These efforts are directed at understanding the hows and whys of animal acoustic communication, often with a special focus on determining the impacts of human sound-generating activities on individuals and populations over a wide variety of spatial, spectral and temporal scales.

William T. Ellison
President and Chief Scientist
Marine Acoustics
Bill Ellison has been President and Chief Scientist, of Marine Acoustics, Inc., since 1983. MAI is a principal contributor in a wide range of engineering and scientific efforts. MAI serves as the primary test and at-sea test and evaluation agent for a number of the U.S. Navy's key development programs for surface, submarine, and air underwater sound initiatives, and has been at the forefront of environmental noise issues in the ocean, helping design and implement experimental plans to investigate these issues as well as formulate new national standards in this rapidly emerging field. Dr. Ellison has developed numerous computer-based models in active use including the Acoustic Integration Model (AIM), a state of the art real-time virtual model for assessing the net impact of sound. AIM is the primary analysis tool for numerous environmental investigations, as well as a variety of research programs including, NOPP, SBIR and STTR awards. He has served on the U.S. Delegation to the Scientific Committee of the International Whaling Commission. He has been an invited subject matter expert at national workshops sponsored by the Office of Naval Research and the National Marine Fisheries Service, and serves on the working groups of two ANSI Standards panels under the auspices of the Acoustical Society of America, focused on the impact of noise on marine animals, fish, and turtles and the associated metrics standards. He currently serves on the Technical Advisory Panel for the Oil and Gas Producers Joint Industry Panel. He is a Fellow of the Acoustical Society of America and the Explorers Club.

Philip Fontana
Chief Geophysicist
Polarcus
Phil Fontana is currently employed as Chief Geophysicist for Polarcus, a new towed streamer seismic survey company. He has over 30 years experience in marine geophysical survey techniques and technologies. During his career, and especially during the last 8 years, he has provided technical advice on seismic source characteristics to industry, government, and academic groups concerned with the issue of potential impacts of anthropogenic noise on marine fauna. He holds a BS in Geology and an MS in Geophysics, both from the University of Connecticut.

Claudio Fossati
CIBRA, University of Pavia
Claudio Fossati was born in Italy in 1969. Got his University degree in Natural Science in 1997, and is actually a Ph.D. student in Animal Behavior on the acoustic behavior of feeding striped dolphins in the Mediterranean Sea. He started to work on underwater bioacoustics in 1992 on snapping shrimp. He has co-operated with CIBRA (www.unipv.it/cibra) since 1994. In these years he got extensive experience in design and make of underwater equipment. He installed and operated towed arrays and other acoustic equipment on a wide variety of vessels. Started to work on PAM in 1999 for NURC NATO Udersea Research Centre (www.nurc.nato.int) and in 2004 for LDEO, Columbia Univ. (www.ldeo.columbia.edu). Recently he started a company with his CIBRA colleagues , RIGHT WAVES, to provide PAM services (hardware, software, personnel, training) based on the unique skills of CIBRA's Academic team.

Doug Gillespie
Researcher
Scottish Oceans Institute, University of St. Andrews
Doug Gillespie is a physicist by training. Since 2005 he has been developing software for the detection and tracking of marine mammals using passive acoustics. He currently manages and is a key developer of the PAMGUARD software. He is based at the Sea Mammal Research Unit at the University of St Andrews, Scotland.

Gordon Hastie
Research Fellow
Scottish Oceans Institute, University of St. Andrews
Dr Gordon Hastie is a Senior Research Scientist at SMRU Ltd in the University of St Andrews Scottish Oceans Institute. His main research interests lie in the functional aspects of marine mammal habitat use and the impacts of anthropogenic activities on marine mammal behavior. He currently leads a number of research projects investigating the use of active sonar technology and passive acoustics as monitoring and mitigation tools for marine renewable energy applications.

Leila Hatch
Marine Ecologist
Stellwagen Bank National Marine Sanctuary, NOAA
Dr. Leila Hatch is a Marine Ecologist at the Gerry E. Studds Stellwagen Bank National Marine Sanctuary (SBNMS), a marine protected area managed by the US National Oceanic and Atmospheric Administration (NOAA). In her current position, Dr. Hatch focuses on characterizing the relative inputs of different source types to the total underwater noise budgets of local marine environments, and using this information to better manage acoustically-sensitive marine species. Dr. Hatch began working at the SBNMS in 2006 after working in the US Congress on marine mammal and fisheries legislation for the House of Representatives' Resources Committee. She received a doctoral degree from Cornell University in Evolutionary Biology, where her research used molecular genetic and acoustic tools to identify population boundaries among northern hemisphere fin whales. Prior to her graduate work, Dr. Hatch participated in a variety of international studies that sought to document the behavioral ecology of cetacean populations and/or assess impacts to cetaceans associated with human activities (i.e., whale-watching, vessel traffic, low-frequency active sonar, active acoustic research sources, etc.).

David Hedgeland
Environmental Manager
PGS
David Hedgeland is currently the PGS HSEQ Environment Manager. He is the primary focus point for PGS Geophysical worldwide activities to address environment subject areas including activities related to the interaction between seismic operations and marine life. He has been involved in marine mammal acoustic monitoring subject for over 10 years. Mr. Hedgeland was on full-time loan from PGS to IAGC as Vice President, Marine Environment between February 2005 and January 2007, where he provided a dedicated technical and managerial resource for geophysical industry activities related to the global marine mammal effort.

He began seismic life as an assistant observer on the back deck of seismic vessels with Seismograph Service Ltd. before GecoPrakla in 1993, and then PGS Exploration in 1997. He earned his first Master's degree in Exploration Geophysics at Imperial College, London in 1995, and his second Master's degree in Environment, Earth Resource Management at the University of Kingston in 2001. He joined PGS Research in 1998 as part of the Geophysical Support group responsible for seismic survey design and planning. He was responsible for coordinating environment research/support activities related to seismic operations and the marine environment.

James Kendall
Chief of the Environmental Sciences Branch
Bureau of Energy Management, Regulation and Enforcement
Jim has been with BOEMRE since 1988 when he joined the Environmental Studies Section as an oceanographer in the Gulf of Mexico regional office. Jim then became Chief of the ESS in 1994 and served in that position until June 2000 when he moved to BOEMRE headquarters to assume his present position as Chief of the Environmental Sciences Branch.

Frank Reier Knudsen
Fishery Biologist
Simrad
Dr. Frank Reier Knudsen received his MSc (1990) and PhD (1994) in Fish Physiology from University of Oslo. From 1994 to 1998, he did his post doc at the University of Oslo, which included several longer visits to labs abroad to study the effect of antropogenic substances on fish and the use of sound to modulate fish behavior. He has been employed as scientist and business development manager for Simrad since 1998. Recent research topics include the impact of sound on aquatic life and hydroacoustic monitoring and assessment of fish and plankton.

Robert LaBelle
Deputy Associate Director
Offshore Energy & Minerals Management, BOEMRE
Robert LaBelle, Deputy Associate Director for Offshore Energy at the Bureau of Energy Management, Regulation and Enforcement, oversees management of the U.S. Offshore Energy Program, including policy development and program planning. In addition to oil and gas, as mandated in the Energy Policy Act of 2005, this now includes authority for development and regulation of offshore wind, wave, and marine current energy in all U.S. Federal waters. He also has served as the BOEMRE representative on the FACA Advisory Committee on Acoustic Impacts on Marine Mammals.

He has received both the Citation for Distinguished Service (2008) and the Citation for Meritorious Service (1996) from the Department of the Interior in recognition of his scientific and management accomplishments. Previously, as Chief of the Environmental Division, Mr. LaBelle was responsible for offshore oil and gas industry compliance with all environmental requirements, including water and air quality, seafloor impacts, endangered species, oil spill risk analysis, and cultural resources. He has managed large environmental and technology research programs and overseen the preparation of numerous Environmental Impact Statements and other decision documents used for US offshore energy permitting. Mr. LaBelle is a graduate of the University of Massachusetts (BS), the University of Maryland (MS), and Loyola College, MD (MBA).

Jill Lewandowski
Protected Species Coordinator
Environmental Division, Bureau of Energy Management, Regulation and Enforcement
Jill Lewandowski is a protected species biologist with the headquarters office of the Bureau of Energy Management, Regulation and Enforcement in Herndon, VA. Her primary role at BOEMRE is assessing and mitigating for impacts to marine mammals and endangered or threatened species from BOEMRE-regulated activities with an emphasis on effects from anthropogenic sound. Jill holds an M.S. in Environmental Science and Policy and is currently pursuing a Ph.D. in Environmental Science and Policy at George Mason University.

Bruce Martin
Systems Division Manager
JASCO Research
Bruce Martin is JASCO's Systems Division Manager. Bruce has worked as an acoustic sensor systems engineer since graduating from Canada's Royal Military College in 1990. He then completed the Naval Combat Systems Engineering program in 1993 and joined the Naval Sonars group at the Defence Research and Development Center (Atlantic) where he worked on new acoustic projector and sensor technologies. He completed a Master's degree in Physics at Dalhousie University in 1995 and joined MacDonald Dettwiler and Associates in 1996. There he spent two years developing acoustic detection systems, and two more as the project engineer for the development of a SOSUS processing system. In 2000 he joined General Dynamics Canada and worked on a variety of high-performance distributed sonar sensor processing systems. Bruce joined JASCO in November 2007 as senior lead of a development project for automated acoustic analysis systems that are used to rapidly process large datasets from autonomous ocean bottom acoustic measurements. These systems perform detection and classification of both industrial and biological sound data, including marine mammal vocalizations. He has lead the design, development and testing of JASCO's AMAR's autonomous recorders and CETAS towed arrays.

David Mellinger
Associate Professor
Cooperative Institute for Marine Resources Studies
Hatfield Marine Science Center, Oregon State University
Dr. David K. Mellinger is an Associate Professor in the Cooperative Institute for Marine Resources Studies at Oregon State University. A specialist in analyzing whale sounds, Dr. David Mellinger has worked since the early 1990's on ways to learn more about whales from the sounds they make. He has worked extensively on developing methods for automatic call recognition, and has applied these methods to studying sperm, blue, fin, minke, bowhead, and right whales and harbor seals. He has developed software for acoustic processing, including the widely-used programs Ishmael and PAMGUARD for acoustic analysis. He has applied his expertise in bioacoustics to projects in the Pacific from the tropics to the Bering and Beaufort Seas, in the Atlantic from the tropics to Nova Scotia, in the Indian Ocean, and off Antarctica. Dr. Mellinger received B.S. degrees in Math and Philosophy at MIT in 1983, and a Ph.D. in Computer Science from Stanford in 1992. He studied whale sounds in the Bioacoustics Research Program at Cornell from 1992-96 and worked on seal sounds at the Monterey Bay Aquarium Research Institute

from 1997-99. Since 2000, he has been at a joint Oregon State University/NOAA laboratory in Newport, Oregon, where leads a group of researchers studying bioacoustics.

Howard Rosenbaum
Director, Ocean Giants Program
Wildlife Conservation Society

Dr. Howard Rosenbaum directs the Wildlife Conservation Society's Ocean Giants Program, which aims to secure the future of whales, dolphins, sea turtles, and sharks. He received his Ph.D. in Biology from Yale University and has been involved in marine mammal research for over 20 years on projects investigating the ecology, behavior, genetics, and conservation of a whale and dolphin species, and development of innovative marine mammal research techniques. His main areas of research are conservation of large whale populations, applying genetic techniques to promote conservation of endangered species, and evaluating the potential impacts of industry exploration and development activities on marine mammals and their critical habitats. Dr. Rosenbaum's work has provided valuable information concerning levels of genetic diversity and relationships among a number of endangered species, including novel insights into North Pacific and North Atlantic right whales, Bowhead whales, and Humpback whales.

With a diverse field staff throughout the world's major oceans, Dr. Rosenbaum's conservation programs focus on wildlife and wild places through innovative research and implementation of conservation strategies. Dr. Rosenbaum is also a Senior Scientist at The Sackler Institute for Comparative Genomics at the American Museum of Natural History, an adjunct faculty member at New York University and Columbia University, and he has been an Associate Editor for Marine Mammal Science. He currently serves as a member of the United States delegation to Scientific Committee of the International Whaling Commission and is a member of the Cetacean Specialist Group of the World Conservation Union's Species Survival Commission (IUCN / SSC).

Major Smith
Survey Project Manager
BHP Billiton

Major Smith has been working in the oil and gas exploration industry since 1982, and has been involved primarily in the acquisition of seismic data. During this time he has lived and worked around the world, in places like Africa, Latin America, and Kazakhstan. For the past few years, Mr. Smith has been working for BHP Billiton Petroleum in Houston, in their exploration department, where he manages their geophysical surveys in Colombia, the Falkland Islands, and the Gulf of Mexico.

Renata S. Sousa-Lima
Research Scientist
Bioacoustics Research Program, Cornell University

Renata Sousa-Lima was born and raised in Belo Horizonte, Minas Gerais State, Brazil, where she graduated from the *Universidade Federal de Minas Gerais* (UFMG) with a Bachelor's Degree in Vertebrate Zoology. She also received a Master's Degree in Ecology, Conservation and Management of Wildlife from UFMG studying manatee acoustic communication under the supervision of Dr. Gustavo A. B. da Fonseca. Shortly thereafter, Renata accepted a Research Fellowship to support the continuation of her manatee research with Dr. Vera M. F. da Silva in the Aquatic Mammal

Laboratory of the *Instituto Nacional de Pesquisas da Amazonia*, located in Manaus, Amazonas State, Brazil. Renata received a full scholarship from the Brazilian Federal Government (CAPES) in 2003 allowing her to pursue a doctorate at Cornell University, USA. Her dissertation research in the Field of Zoology at Cornell focused on the acoustic ecology of humpback whales and was conducted under the supervision of Dr. Christopher W. Clark. Dr. Sousa-Lima returned to Brazil in October 2007 where she continues to pursue her research in animal communication as a Post-doctoral Researcher at UFMG. Renata also maintains a formal affiliation with Cornell as a Research Scientist in the Bioacoustics Research Program. Renata is currently teaching and advising a number of undergraduate and graduate students in several different universities throughout Brazil and works as a professional consultant on initiatives to review current technologies in underwater passive acoustic monitoring.

Brandon Southall
President and Senior Scientist
SEA, Inc.
Dr. Brandon Southall is President and Senior Scientist for Southall Environmental Associates, Inc. based in Santa Cruz, CA, and a research associate with the University of California, Santa Cruz. He is currently involved in research to measure behavioral responses of marine mammals to various human sounds, primarily military sonar signals, the effects of impulsive noise on hearing in seals and sea lions in laboratory settings, efforts to implement quieting technologies on the largest commercial ships in the oceans, and developing environmentally-responsible ways of capturing offshore energy. Dr. Southall has an extensive background in both laboratory and field research on the effects of noise on marine mammals, and has worked directly in the policy and regulatory arenas within the U.S. and internationally on this issue. He has published over 30 peer-reviewed publications on hearing and the effects of noise on marine life and has given hundreds of presentations on the subject to technical, regulatory, Congressional, and international audiences.

Peter Stein
President and Founder
Scientific Solutions, Inc.
Dr. Peter Stein is President and founder of Scientific Solutions, Incorporated (SSI). He received his PhD from the MIT/WHOI Joint Program in Oceanographic Engineering 1986. As an undergraduate he was awarded the Wallace Bruce Academic Prize from the Massachusetts Institute of Technology, Department of Ocean Engineering, 1981. His work as a student concentrated on ocean acoustics, sound and structural vibration, signals and systems, digital signal processing, and marine data systems. Dr. Stein's thesis work studied the sound radiation from ice cracks in the Arctic, as applied to Arctic Ocean ambient noise, and elastic wave propagation in floating ice plates. He founded SSI in 1992 and under his leadership SSI has been involved in a wide variety of projects centered on underwater acoustics and novel system development. A partial list of innovative underwater acoustic research and development projects conducted by SSI include marine mammal monitoring systems, swimmer detection sonar networks, fishing-proof range-bearing nodes for shallow water tracking ranges, ocean modeling, ice penetrating buoys for Arctic research, and software integration systems for the Department of Defense. Dr. Stein is an active member of the Acoustical Society of America and the American Geophysical Union. Dr. Stein is also a Corporate Member of the Woods Hole Oceanographic Institution.

Bill Streever
Environmental Studies Leader
BP Exploration
Dr. Bill Streever works as BP's global Underwater Sound and Marine Life research program technical director and BP's Environmental Studies Program Director on Alaska's North Slope. He edited the technical journal Wetlands Ecology and Management for five years, and edited the compendium An International Perspective on Wetland Rehabilitation. He has authored or coauthored more than fifty technical publications. He recently served on the University of Alaska's Vision Task Force and he currently serves as Chair of the North Slope Science Initiative's Science and Technical Advisory Panel. He hikes, camps, scuba dives, and cross country skis as often as conditions allow. His latest book, Cold: Adventures in the World's Frozen Places (Little Brown, 2009), reached the New York Times bestseller list and was critically acclaimed as a new contribution to the literature of the north. He lives with his son, fiancé, and dog in Anchorage, Alaska.

Jim Theriault
Defence Research & Development Canada
Mr. Theriault joined Defence Research Establishment Atlantic (DREA) in 1985 after completing an MSc in Mathematics at Dalhousie University. Upon joining the establishment, he immediately started working on passive towed array tracking. By the late eighties, he had made a transition to active sonar; having carried out research on submarine and mine detection using the Canadian Navy's hull mounted sonar, dipping sonar performance evaluations for helicopter procurement, active sonobouy evaluations, and Acoustic Range Prediction Systems.. Starting in the early nineties, Mr. Theriault's interests began shifting to the study of acoustic impact mitigation technologies. He currently leads Defence R&D Canada's research programme on mitigating the potential impact of anthropogenic noise on marine mammals.

Aaron Thode
Associate Researcher
Scripps Institute of Oceanography
Aaron Thode is an associate research scientist in the Marine Physical Laboratory at Scripps Institution of Oceanography, University of California, San Diego. He received a B.S. in Physics and M.S. in Electrical Engineering (specializing in antenna and radio propagation) in 1993 from Stanford University. He received his Ph.D. in Oceanography from Scripps in 1999, with thesis work focusing on 3-D passive acoustic tracking of blue whales off California. He was a postdoctoral scholar in ocean engineering at the Massachusetts Institute of Technology from 1999-2001, before joining Scripps in 2002 as a research scientist. Thode's research covers underwater acoustic propagation, geoacoustic inversion, ambient noise analysis, and marine mammal acoustic call detection and tracking. In 2003-05 he was a principal investigator for the Sperm Whale Seismic Study for the U.S. Department of the Interior's BOEMRE. The study collected data on towed arrays in order to estimate 2-D dive profiles of sperm whales. Currently he is researching the use of vector sensors to resolve left/right ambiguities on towed arrays, and has developed automated detection and tracking software for migrating bowhead whales off the coast of Alaska, in collaboration with Greeneridge Sciences and Shell Exploration and Production Company. Other current interests include marine mammal depredation, 3-D acoustic tracking of baleen whales in shallow water environments, and acoustic censusing.

Roy Wyatt
Seiche Measurements Limited
Following university and further specialist studies, Roy specialised in underwater engineering and sonar research. As head of research and development for a leading UK company he was responsible for researching and developing a variety of sonar and underwater technologies for civil and military use. Following board-level positions in major engineering companies Roy founded Seiche Measurements Limited (SML) in 1996 to undertake research in underwater acoustics. SML has achieved two awards for research projects in advanced sensor design.

John Young
Seismic Expert
ExxonMobil Exploration Company
John V. Young is a seismic expert with ExxonMobil Exploration Company having spent over 31 years in the application of seismic imaging technology. During his career, he has worked with and managed seismic research, seismic survey design, and seismic acquisition in many countries around the world. Mr. Young serves as Senior Technical and External Network Advisor to ExxonMobil's Sound and Marine Life Issue Team. As part of his current duties, he is the Chairman/Executive Committee of the joint industry project (JIP) on marine sound research. The JIP, under the auspices of the International Association of Oil and Gas Producers (OGP) is funding over $USD 24 million (2006-2009) to study the potential impacts of energy industry sound sources on marine life. He has been active in working with international marine mammal scientists and has participated in ocean acoustics science and policy forums including the International Whaling Commission's Scientific Committee (2005-2009) and OSPAR sub-committees on environmental quality. In recent years, he has provided leadership in the development of a joint industry program to address alternative seismic imaging technology i.e., marine vibroseis as a possible supplement or replacement for current airgun seismic technologies in certain environmental and geophysical settings.

Mr. Young holds an Electrical Engineering degree from Old Dominion University. He is a member of the Society of Exploration Geophysicists, the European Association of Engineers and Geophysicists, and The Society for Marine Mammalogy. Mr. Young is also ExxonMobil's representative for the International Oil & Gas Producers Marine Mammal Task Force and American Petroleum Institute's Wildlife Issues Group.

APPENDIX VII

PRESENTATION SLIDES

Setting the Stage: MMS Perspective

Workshop on Acoustic Monitoring and Mitigation Systems: Status and Applications for Use by MMS-Regulated Offshore Industries

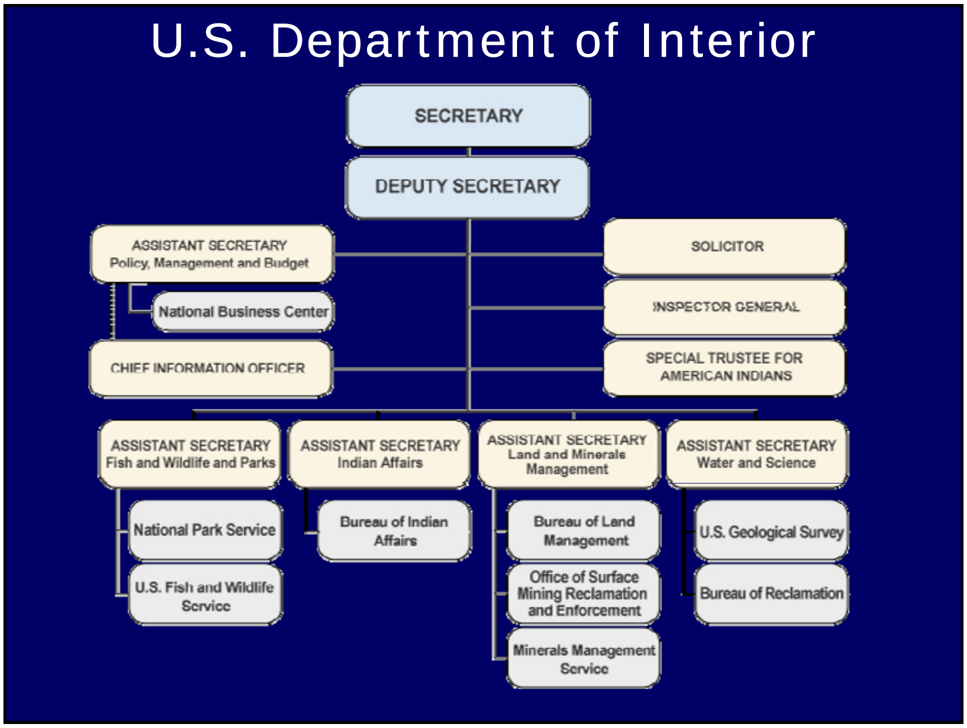
Dr. James J. Kendall
Chief Scientist &
Chief, Environmental Division
Offshore Energy and Minerals Management

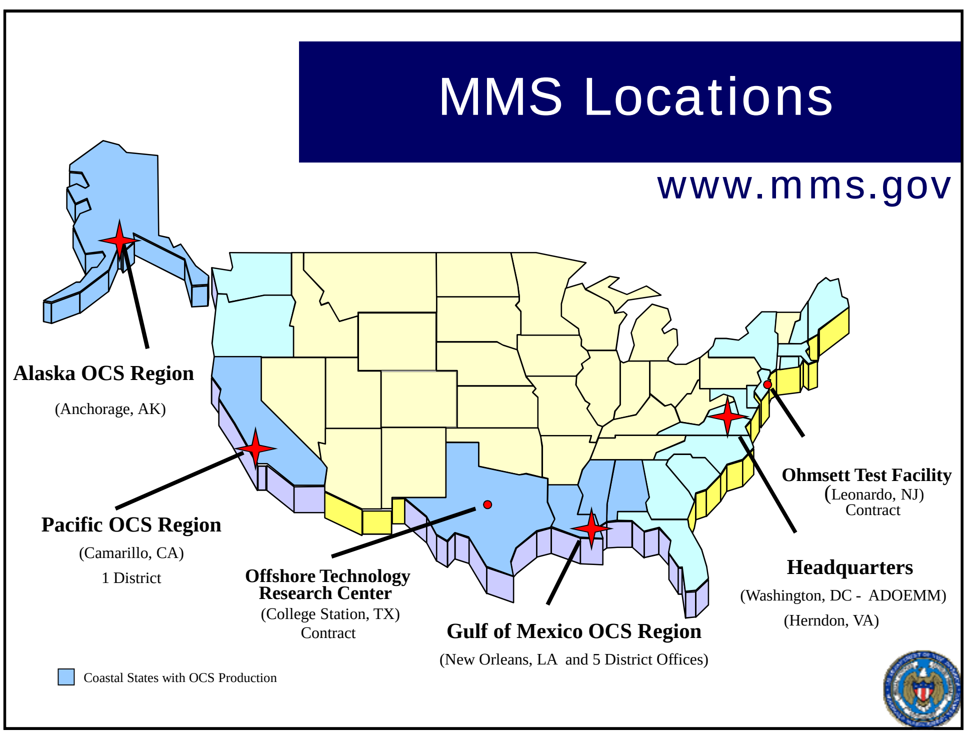
safe operations *environmental protection* *fair value*

MMS *People Promoting Energy, the Environment, and the Economy*

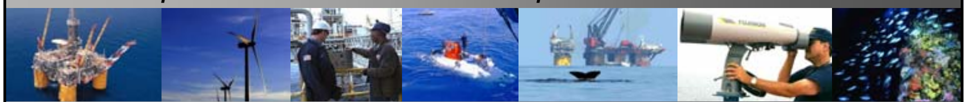
Overview

- MMS Background
- Importance of Science and Technology
- Current Mitigation and Monitoring Requirements
- Integration of Acoustic Monitoring
- Goals for the Workshop


U.S. Department of Interior
SECRETARY
DEPUTY SECRETARY
ASSISTANT SECRETARY Policy, Management and Budget
SOLICITOR
National Business Center
INSPECTOR GENERAL
CHIEF INFORMATION OFFICER
SPECIAL TRUSTEE FOR AMERICAN INDIANS
ASSISTANT SECRETARY Fish and Wildlife and Parks
ASSISTANT SECRETARY Indian Affairs
ASSISTANT SECRETARY Land and Minerals Management
ASSISTANT SECRETARY Water and Science
National Park Service
U.S. Fish and Wildlife Service
Bureau of Indian Affairs
Bureau of Land Management
Office of Surface Mining Reclamation and Enforcement
Minerals Management Service
U.S. Geological Survey
Bureau of Reclamation


MMS Locations
www.mms.gov
Alaska OCS Region
(Anchorage, AK)
Pacific OCS Region
(Camarillo, CA)
1 District
Offshore Technology Research Center
(College Station, TX)
Contract
Gulf of Mexico OCS Region
(New Orleans, LA and 5 District Offices)
Headquarters
(Washington, DC - ADOEMM)
(Herndon, VA)
Ohmsett Test Facility
(Leonardo, NJ)
Contract
Coastal States with OCS Production

safe operations *environmental protection* *fair value*



Stewardship for America with Integrity and Excellence

Mission

Provide the American public with ocean energy, mineral resources, and resulting economic value in a safe and environmentally responsible manner.

Statutory Oversight

oil and gas

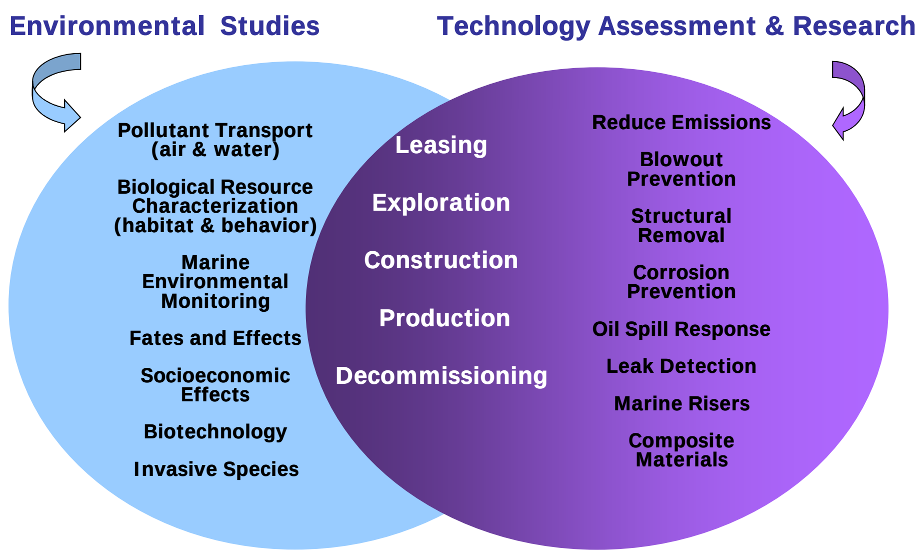
renewable energy and alternate use

sand and gravel

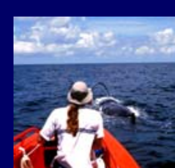
coastal impact assistance

- Outer Continental Shelf Lands Act
- Section 388 of the Energy Policy Act of 2005
- Gulf of Mexico Energy Security Act of 2006

Using Science as our Guide



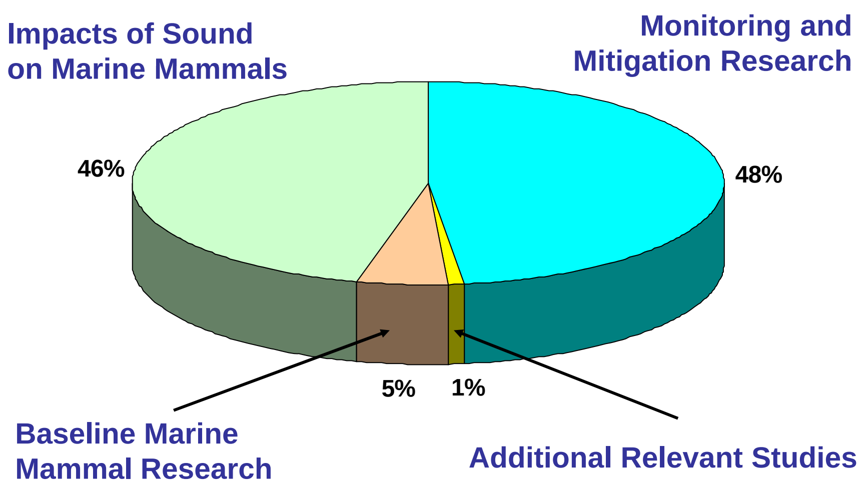
Notable Marine Mammal Studies



Over $50 million funded to date!

- SWAMP and SWSS (GOM)
- BWASP and BOWFEST (Arctic)
- funding of NRC reviews and *Marine Mammals and Noise* (1995)
- funding of domestic and international conferences, workshops & symposia
- Participation in NOPP BAAs

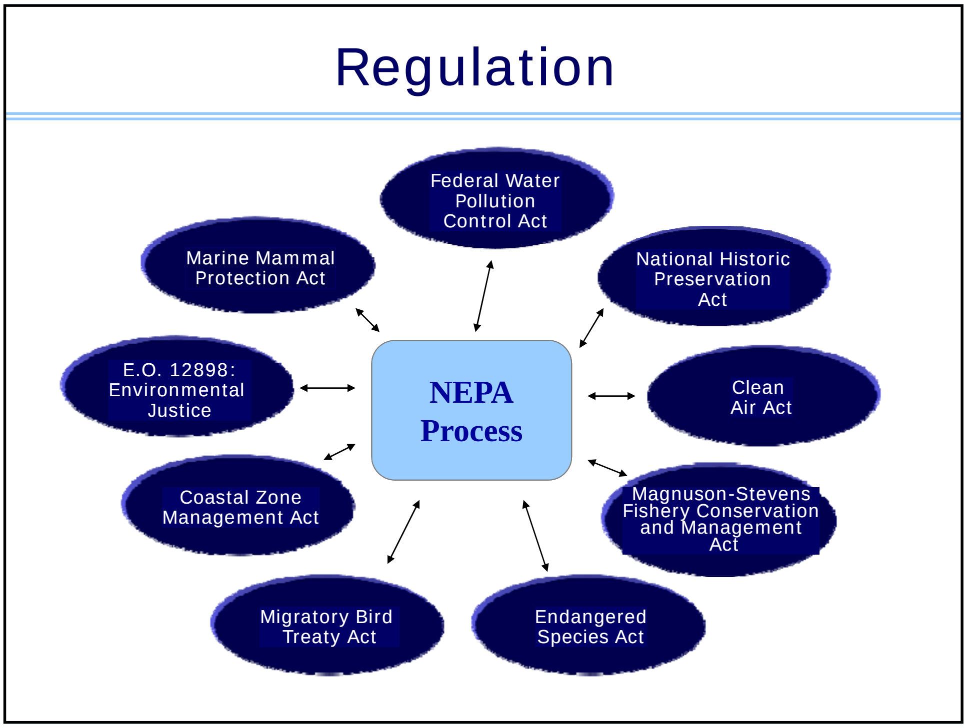
Marine Mammal Funding

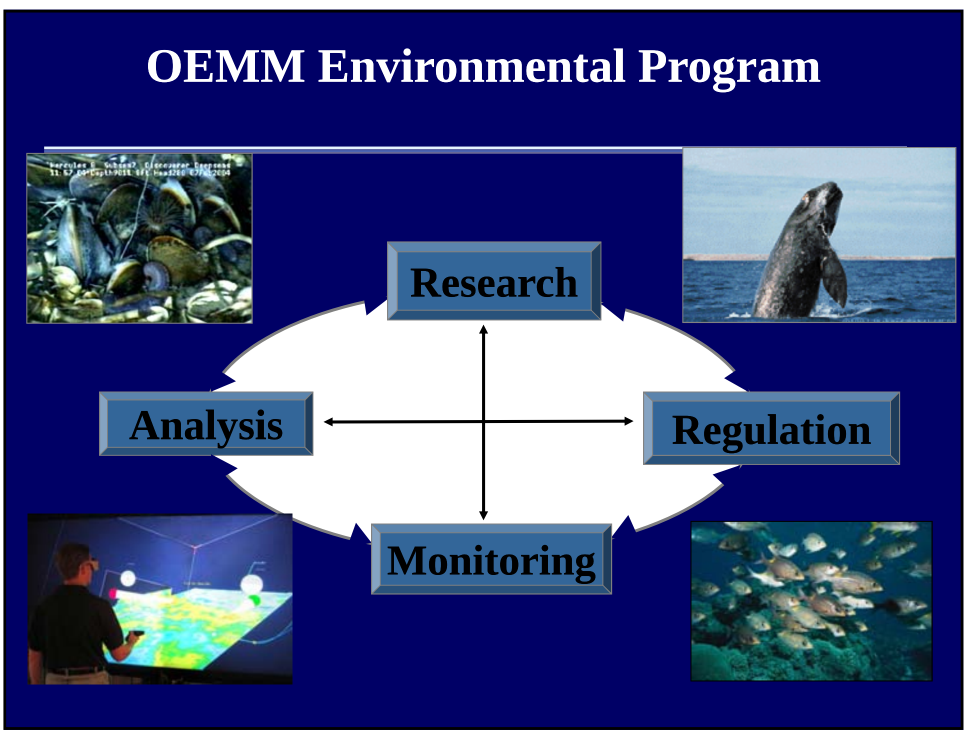


Linking Science to Decision-Making

MMS uses best available information to...

- analyze potential impacts from MMS-regulated activities
- develop, implement, and assess environmental mitigation and monitoring efforts
- ensure compliance with the environmental policies and laws


Regulation
Federal Water Pollution Control Act
Marine Mammal Protection Act
National Historic Preservation Act
E.O. 12898: Environmental Justice
NEPA Process
Clean Air Act
Coastal Zone Management Act
Magnuson-Stevens Fishery Conservation and Management Act
Migratory Bird Treaty Act
Endangered Species Act

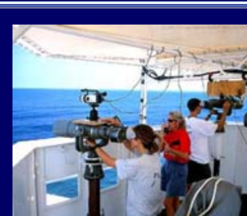

OEMM Environmental Program
Research
Analysis
Regulation
Monitoring

Mitigation and Monitoring for Offshore Industry

Typical Mitigation Requirements

- vessel strike avoidance
- marine debris elimination
- ramp up of seismic survey sound sources
- exclusion zone for seismic surveys, pile driving and explosive removals
- shut down of seismic surveys or explosive removal operations
- reporting requirements

Associated Monitoring (for mitigation purposes)



- pre- and post-activity
- monitoring of zone during activity
- mainly visual (vessel or aerial based)
  - passive acoustic monitoring is currently optional in the GOM

Challenges with Monitoring Methods

- effectiveness of visually detecting marine mammals within/near zone
- applicability or effectiveness of alternative monitoring technologies

MMS Goals for Workshop

- better understand current acoustic monitoring technology
- identify potential research needs to develop acoustic monitoring to better meet regulatory needs

Science, Service, Stewardship

Acoustic Monitoring & Mitigation for NMFS Marine Mammal Incidental Take Authorization

Shane Guan
Howie Goldstein

Status and Applications of Acoustic Mitigation and Monitoring Systems for Marine Mammals
November 17, 2009, Boston, MA

NOAA FISHERIES SERVICE

NOAA FISHERIES SERVICE

Marine Mammal Protection Act

- Afford protection of all marine mammal species
- National Marine Fisheries Service has jurisdiction on all cetaceans and pinnipeds except walrus

2

NOAA FISHERIES SERVICE

Endangered Species Act

- Conservation of species listed under the ESA and their habitat (critical habitat)

Number of ESA-listed Species/Stocks Under NMFS Jurisdiction

	Endangered	Threatened
Cetacean	15	0
Pinnipeds	4	2

3

NOAA FISHERIES SERVICE

Marine Mammal Take Authorizations

Section 101(a)(5)(A) and (D) of MMPA:

Incidental Take Authorizations

- Incidental harassment authorization (IHA)
- Letter of authorization (LOA)

Section 7 of ESA:

- Incidental Take Statement (ITS) issued upon completion of section 7 consultation
- Issuance of ITS only after MMPA Authorization

4

NOAA FISHERIES SERVICE

Marine Mammal Take Authorizations

MMPA:

- Negligible impact on the species or stock(s)
- No unmitigable adverse impact on the availability of the species or stock(s) for certain subsistence uses
- Permissible methods of taking – Mitigation, monitoring, and reporting measures

ESA:

- Not likely to jeopardize the continued existence of the species
- ITS specifies reasonable and prudent measures to minimize impact of taking, monitoring, reporting and any MMPA requirements

5

NOAA FISHERIES SERVICE

Passive Acoustic as Monitoring & Mitigation Measures

- Detect marine mammals during poor visibility (at night or in bad weather);
- Improve detection, identification, localization, and tracking capability;
- Alert visual observers
- Post activity impact assessment

6

NOAA FISHERIES SERVICE

Mitigation Measures for Northeast Gateway LNG Port Operations

- **Passive auto-detection buoys (ABs) in Massachusetts Bay to provide near real-time information on the presence of vocalizing whales in the Boston shipping lanes**
- **LNG vessels to reduce speed to 10 knots or less and alerting personnel responsible for navigation and lookout duties when right whales are detected acoustically in the vicinity.**

7

NOAA FISHERIES SERVICE

Monitoring Measures for Lamont-Doherty Earth Observatory Geophysical Surveys

- **Require all time passive acoustic monitoring (PAM) when the air gun array is operating.**
- **PAM operator(s) to notify marine mammal visual observers immediately of a vocalizing animal so a power-down or shutdown can be initiated when marine mammals are detected in the safety zones.**

8

NOAA FISHERIES SERVICE

Long-term Monitoring on Anthropogenic Noise

- Nineteen marine autonomous recording units (MARUs) deployed in the vicinity of Northeast Gateway LNG Port facility
- Long-term assessment on anthropogenic noise (Port construction & operations, shipping) on endangered whales (North Atlantic right whales, fin whales, and sei whales)

9

NOAA FISHERIES SERVICE

Issues Related to Acoustic Monitoring

- Personnel training – knowledge in acoustics & experience of operating hardware & software systems
- Technology limitation – e.g., detection of low-frequency calls by using towed array
- Engineering undertake – design of a high quality acoustic detection system (e.g., low self-noise, low interference, etc.)
- Equipment affordability – hardware and software

10

NOAA FISHERIES SERVICE

NOAA PAM Guidelines (2008)

- Serve as recommendations for general procedures, system requirements, and reporting needs in planning or designing PAM.
- Provide recommendation on a minimum set of procedures and system requirements
- Recognize the case-by-case basis for specific PAM planning and designs

11

NOAA FISHERIES SERVICE

To Make Acoustic Monitoring a Standard

- Foolproof technology – acoustic monitoring systems can be handled by MMOs with minimum training
- Inexpensive equipment – hardware and software that are affordable to the majority of permit holders
- More availability for acoustic monitoring training

12

NOAA
FISHERIES
SERVICE

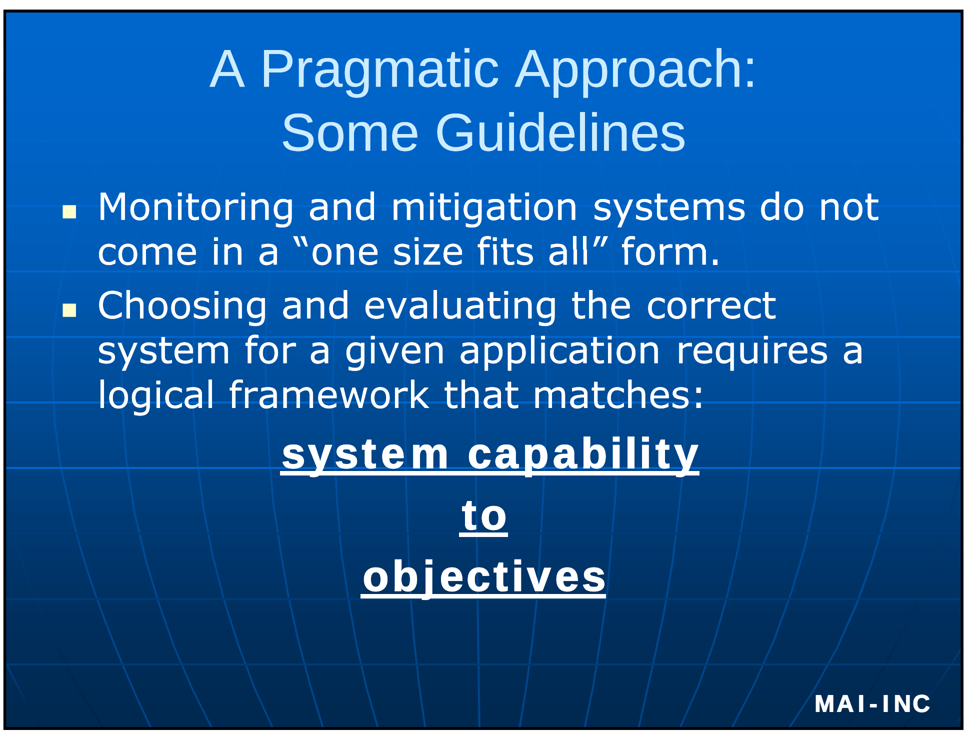
What's in the Future?

- Specific requirements for acoustic monitoring (systems and operators)
- Active acoustic monitoring?

13

NOAA
FISHERIES
SERVICE


A Pragmatic Approach:
Finding Functional Solutions Recognizing the Capabilities and Limitations of Existing Technology
Wm. T. Ellison, PhD
Marine Acoustics, Inc.
809 Aquidneck Ave.
Middletown, RI 02842
MMS Workshop
Acoustic Monitoring and Mitigation Systems
November 17-19, 2009
MAI-INC

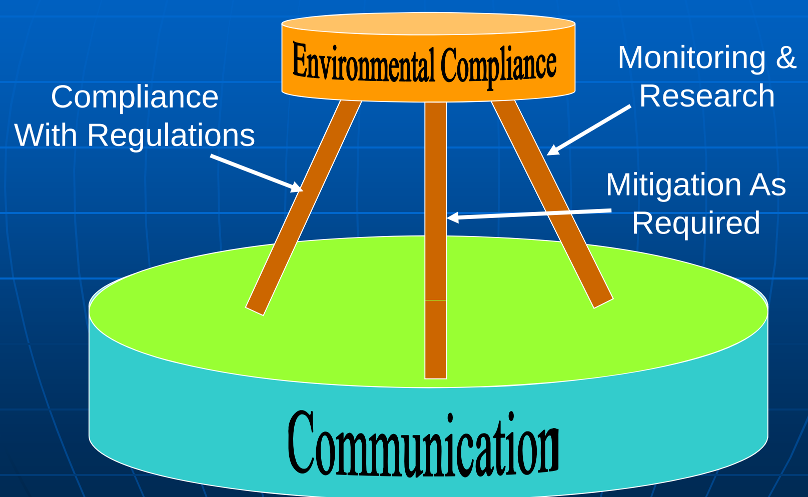

A Pragmatic Approach:
Some Guidelines
Monitoring and mitigation systems do not come in a "one size fits all" form.
Choosing and evaluating the correct system for a given application requires a logical framework that matches:
system capability
to
objectives
MAI-INC

A Pragmatic Approach:
The Elements of Environmental Compliance

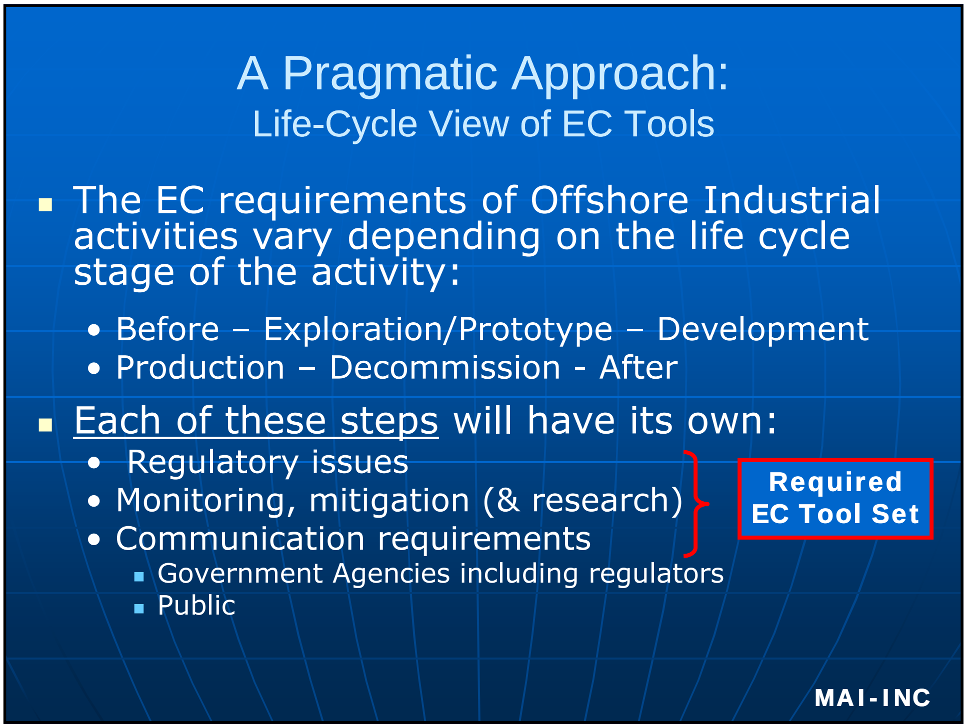
- Successful Environmental Compliance (EC) actions are founded on three underlying **objectives**:
  - Being compliant with existing **regulations,**
  - Providing elements of **mitigation**, if required,
  - Providing **monitoring**, and possibly coincident **research** as well.
- Further, the process is always improved in terms of timeliness, cost and effectiveness by good **communication** between all parties

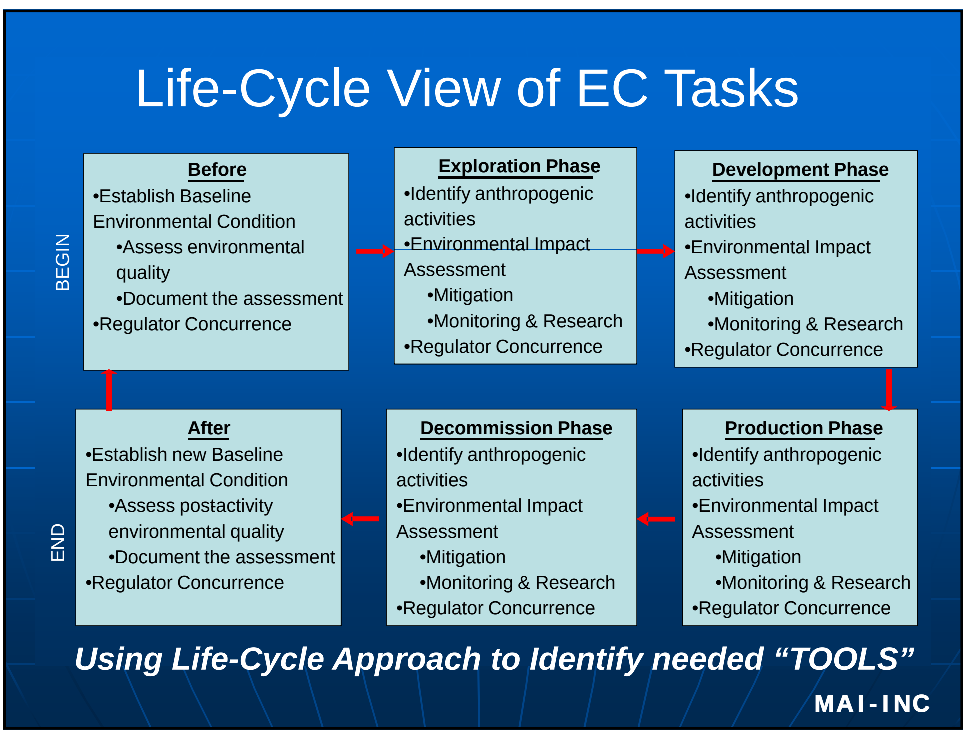
MAI-INC

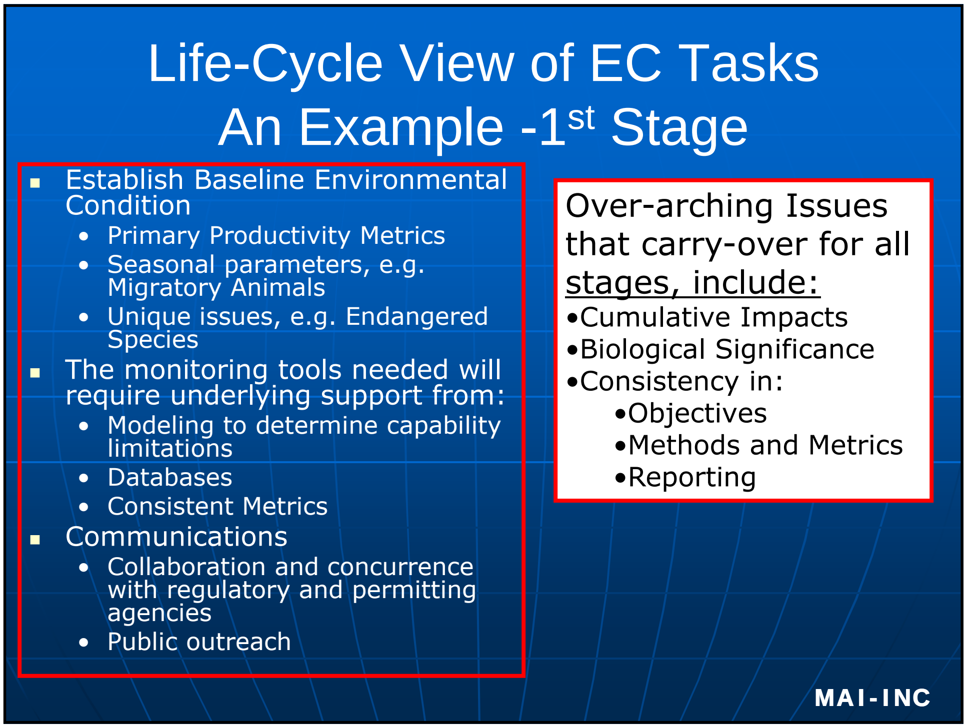
A Pragmatic Approach:
The 3-Legged Stool of Environmental Compliance

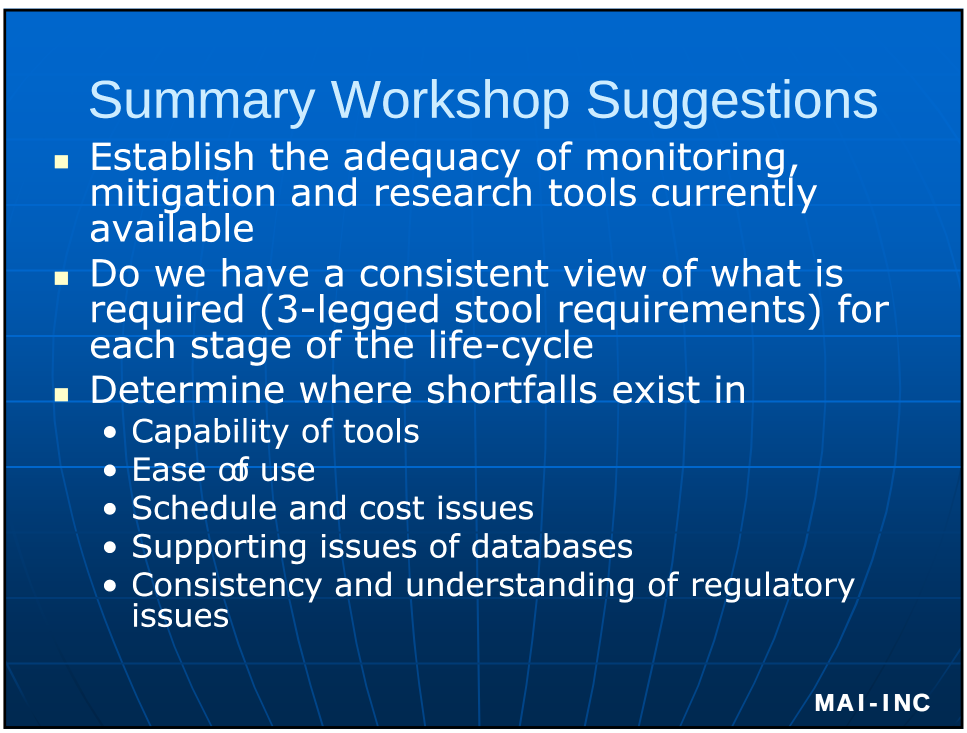


MAI-INC


A Pragmatic Approach:
Life-Cycle View of EC Tools
The EC requirements of Offshore Industrial activities vary depending on the life cycle stage of the activity:
Before – Exploration/Prototype – Development
Production – Decommission - After
Each of these steps will have its own:
Regulatory issues
Monitoring, mitigation (& research)
Communication requirements
Government Agencies including regulators
Public
Required EC Tool Set
MAI-INC


Life-Cycle View of EC Tasks
BEGIN
Before
•Establish Baseline Environmental Condition
•Assess environmental quality
•Document the assessment
•Regulator Concurrence
Exploration Phase
•Identify anthropogenic activities
•Environmental Impact Assessment
•Mitigation
•Monitoring & Research
•Regulator Concurrence
Development Phase
•Identify anthropogenic activities
•Environmental Impact Assessment
•Mitigation
•Monitoring & Research
•Regulator Concurrence
END
After
•Establish new Baseline Environmental Condition
•Assess postactivity environmental quality
•Document the assessment
•Regulator Concurrence
Decommission Phase
•Identify anthropogenic activities
•Environmental Impact Assessment
•Mitigation
•Monitoring & Research
•Regulator Concurrence
Production Phase
•Identify anthropogenic activities
•Environmental Impact Assessment
•Mitigation
•Monitoring & Research
•Regulator Concurrence
Using Life-Cycle Approach to Identify needed "TOOLS"
MAI-INC


Life-Cycle View of EC Tasks
An Example -1st Stage
Establish Baseline Environmental Condition
Primary Productivity Metrics
Seasonal parameters, e.g. Migratory Animals
Unique issues, e.g. Endangered Species
The monitoring tools needed will require underlying support from:
Modeling to determine capability limitations
Databases
Consistent Metrics
Communications
Collaboration and concurrence with regulatory and permitting agencies
Public outreach
Over-arching Issues that carry-over for all stages, include:
•Cumulative Impacts
•Biological Significance
•Consistency in:
•Objectives
•Methods and Metrics
•Reporting
MAI-INC


Summary Workshop Suggestions
Establish the adequacy of monitoring, mitigation and research tools currently available
Do we have a consistent view of what is required (3-legged stool requirements) for each stage of the life-cycle
Determine where shortfalls exist in
Capability of tools
Ease of use
Schedule and cost issues
Supporting issues of databases
Consistency and understanding of regulatory issues
MAI-INC

Outline & Main Points

The approach is similar to what is done in an EIS:
evaluate a potential impact using biological dependencies of the animals of concern.

Here the process:

•uses an acoustical ecology lens to evaluate the potential impact and achieve environmental compliance (EC),

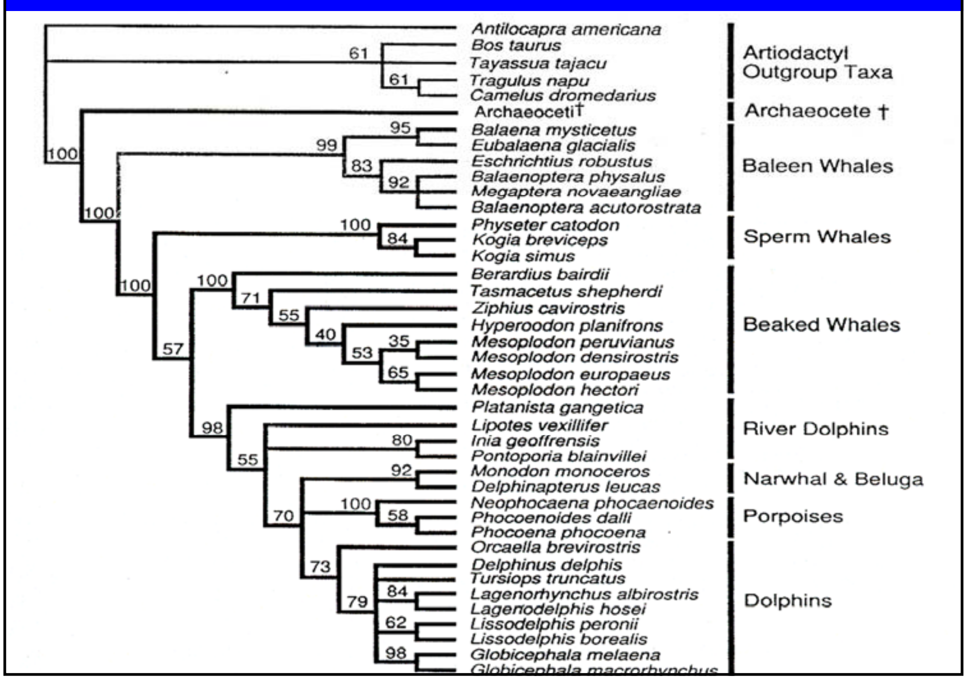
•is not restricted to acute effects such as injury, and includes effects that are chronic and impacts such as habitat displacement and masking, and

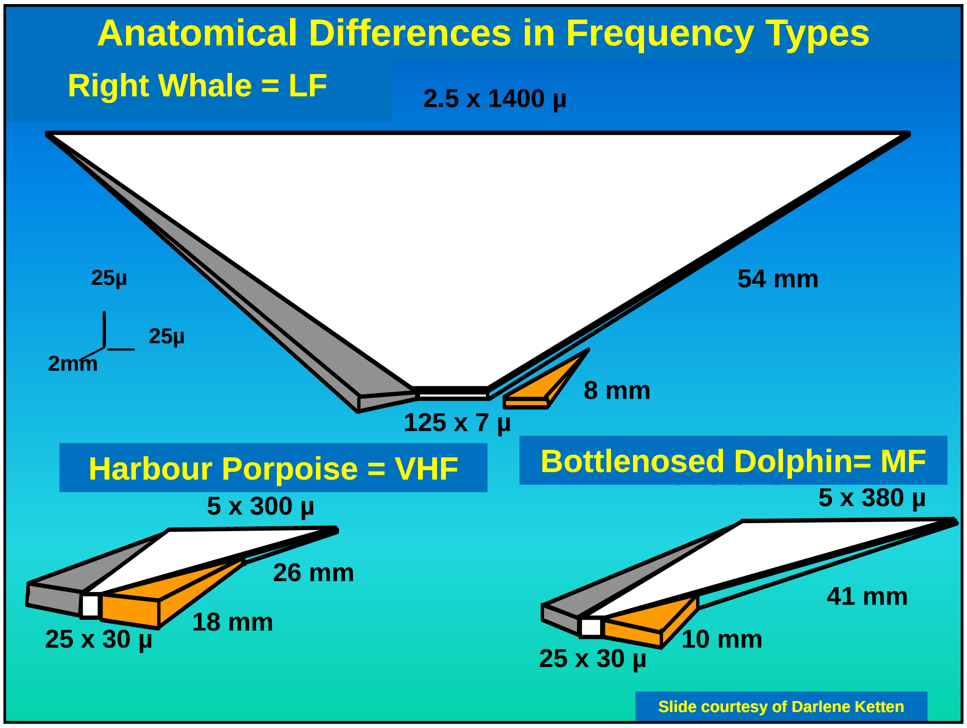
•emphasizes the need and requirement to document and understand the potential effects of multiple sources, multiple stressors and cumulative impacts.

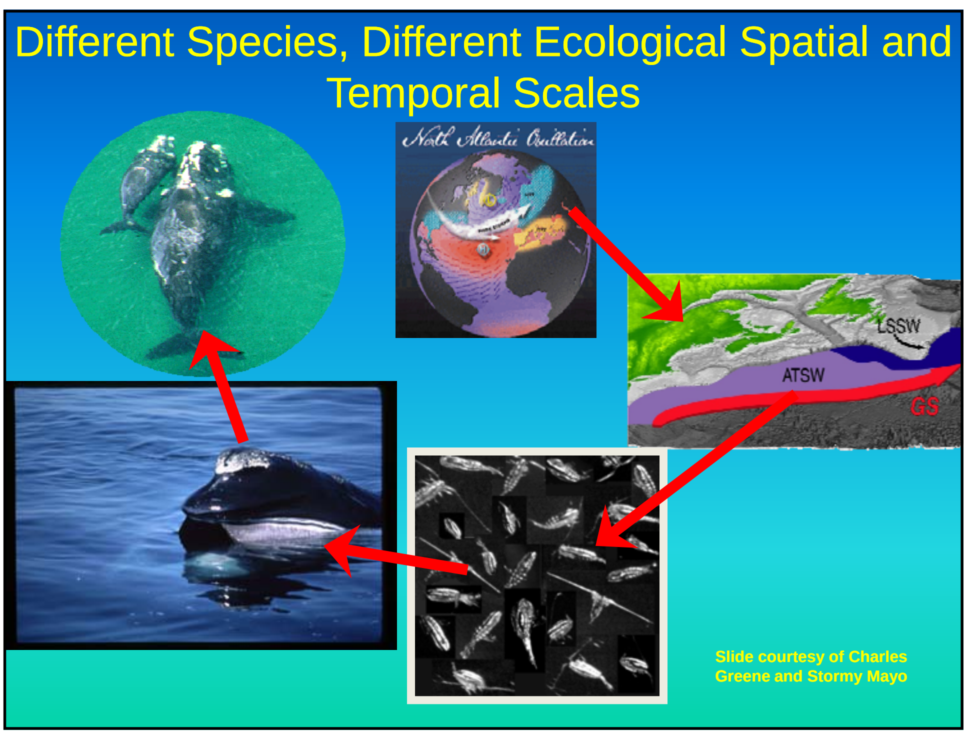
Some Terms

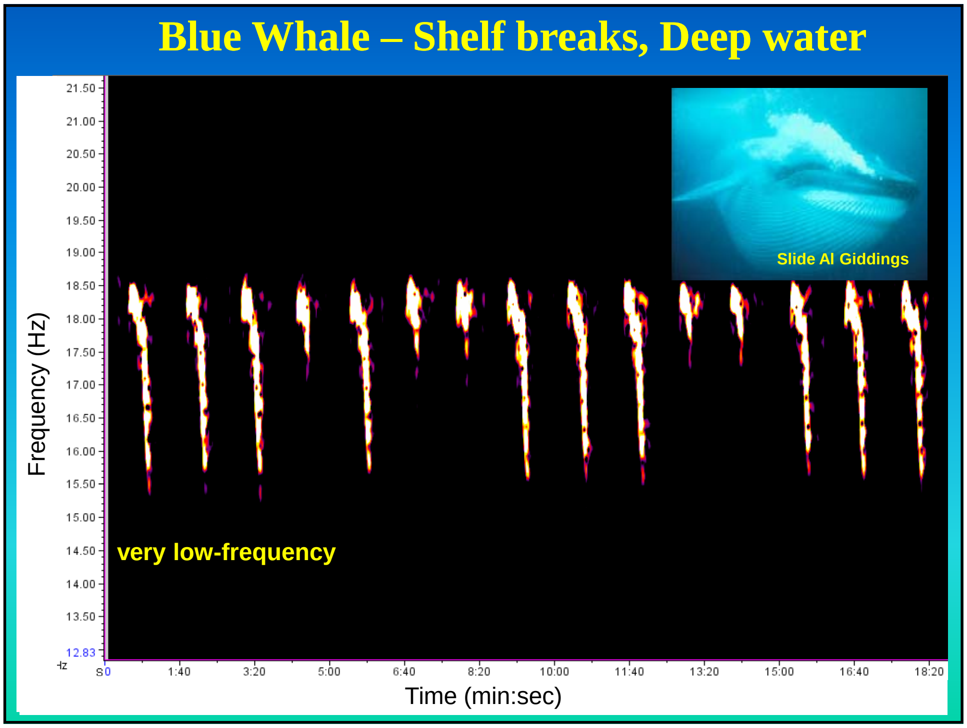
- **Bioacoustic-ecological spatial-temporal scales – specs for the spatial and temporal scales over which animals with different acoustic ecologies and requirements occur in a project area.**
- **Project activity space-time-frequency scales - specs for the project's area, duration, and acoustic sources.**
- **Project EC requirements – specs for the EC resulting from the intersections of project activities with the bioacoustic-ecologies for the animals occurring in the project area.**

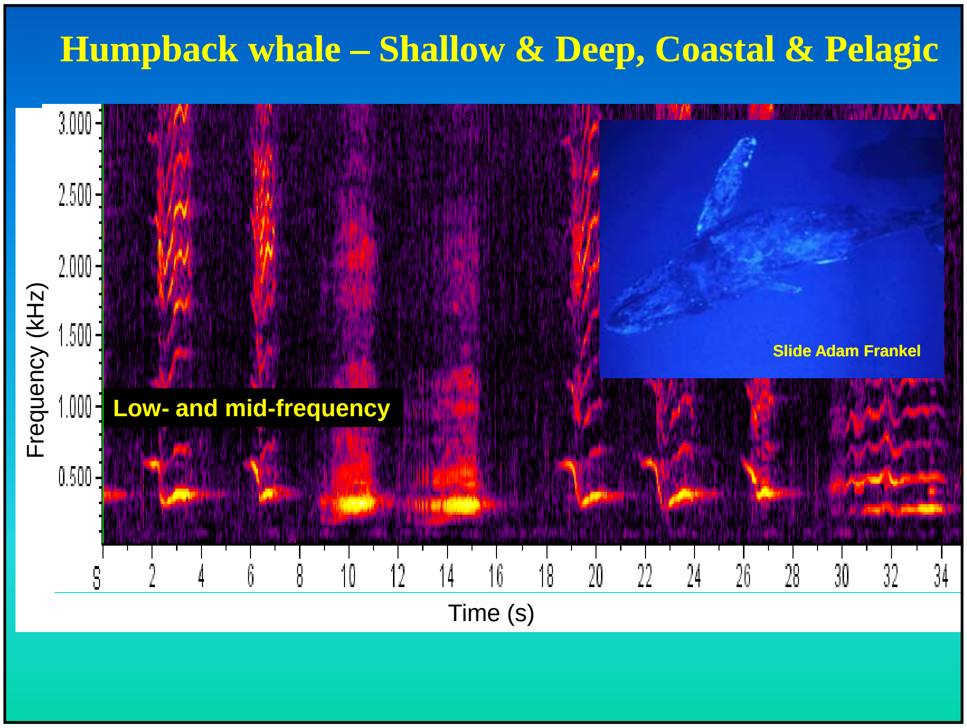
Bioacoustic & Genetic Relatedness

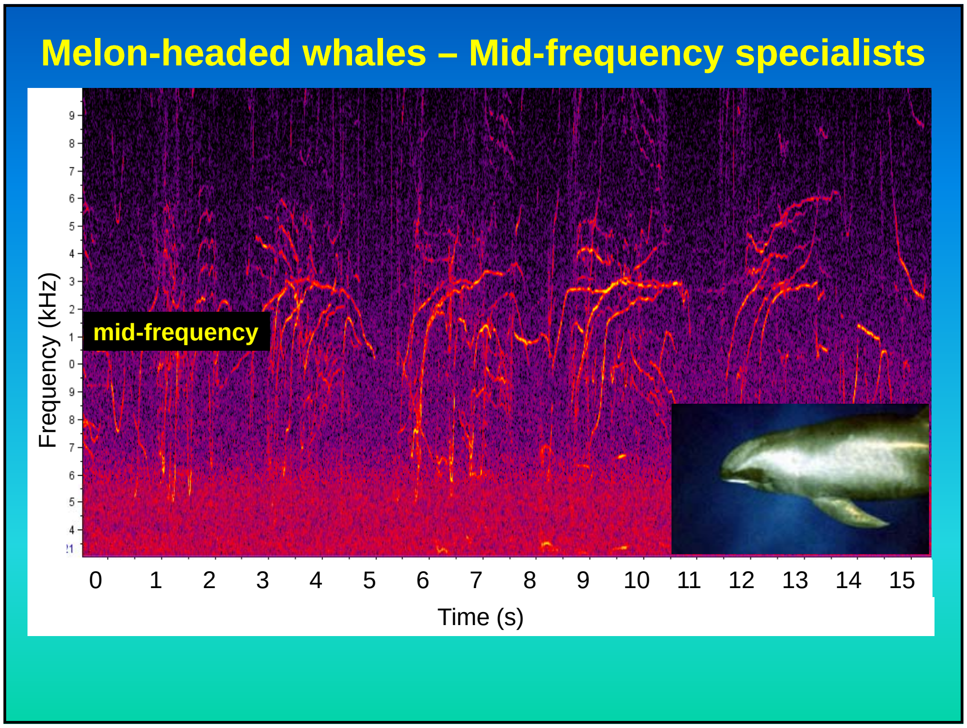


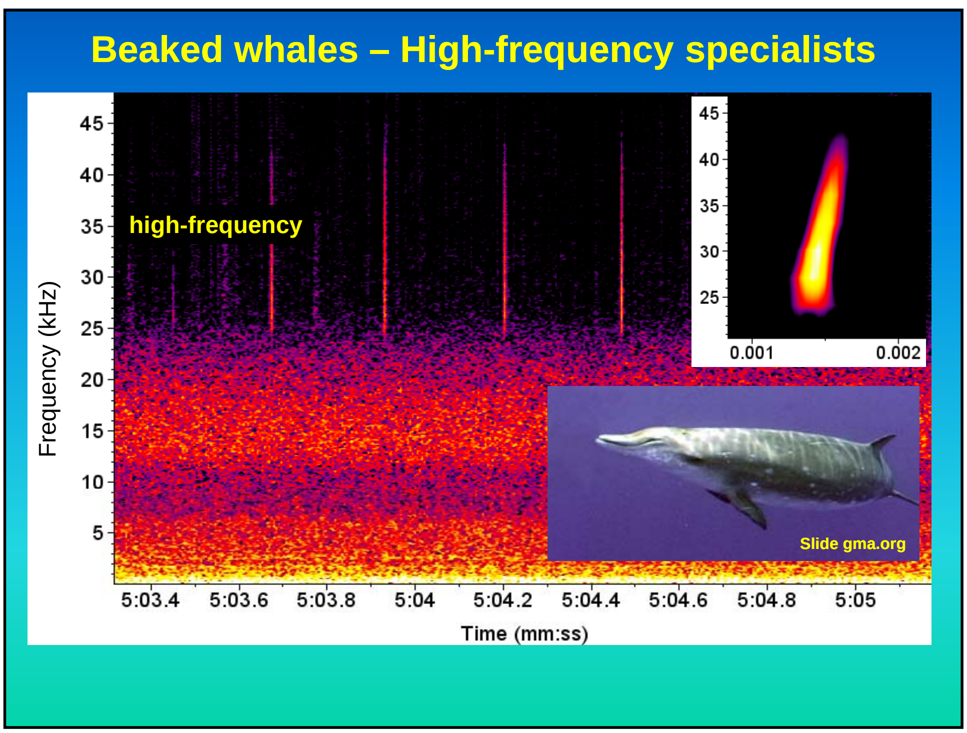

Anatomical Differences in Frequency Types
Right Whale = LF
2.5 x 1400 µ
25µ
25µ
2mm
54 mm
8 mm
125 x 7 µ
Harbour Porpoise = VHF
5 x 300 µ
26 mm
18 mm
25 x 30 µ
Bottlenosed Dolphin= MF
5 x 380 µ
41 mm
10 mm
25 x 30 µ
Slide courtesy of Darlene Ketten

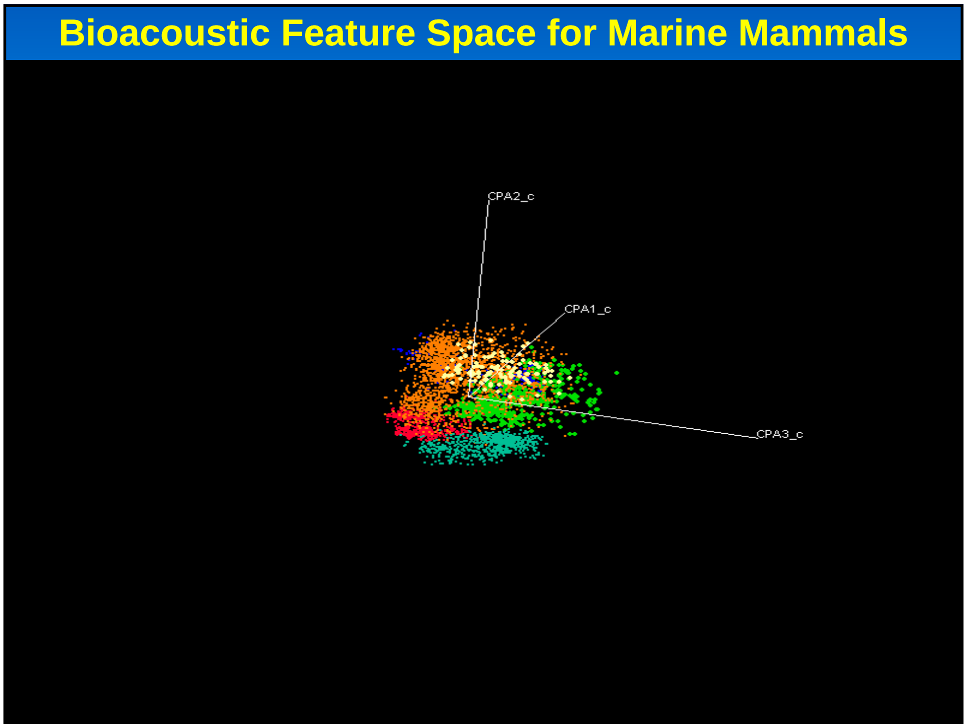

Different Species, Different Ecological Spatial and Temporal Scales
LSSW
ATSW
GS
Slide courtesy of Charles Greene and Stormy Mayo

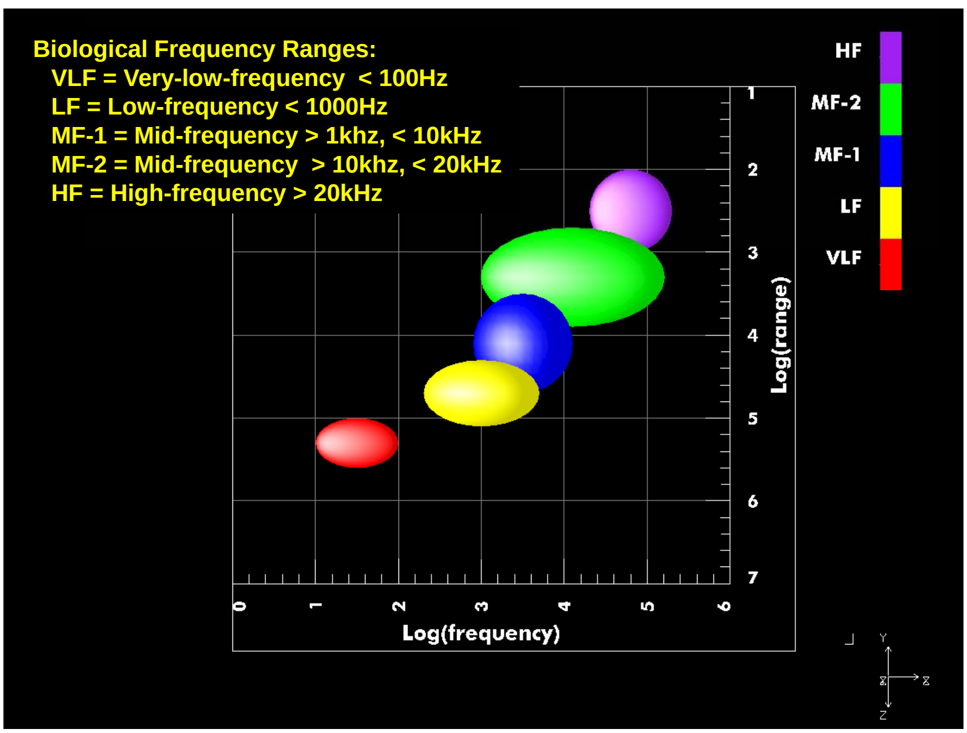

Blue Whale – Shelf breaks, Deep water
Slide Al Giddings
very low-frequency
Frequency (Hz)
Time (min:sec)

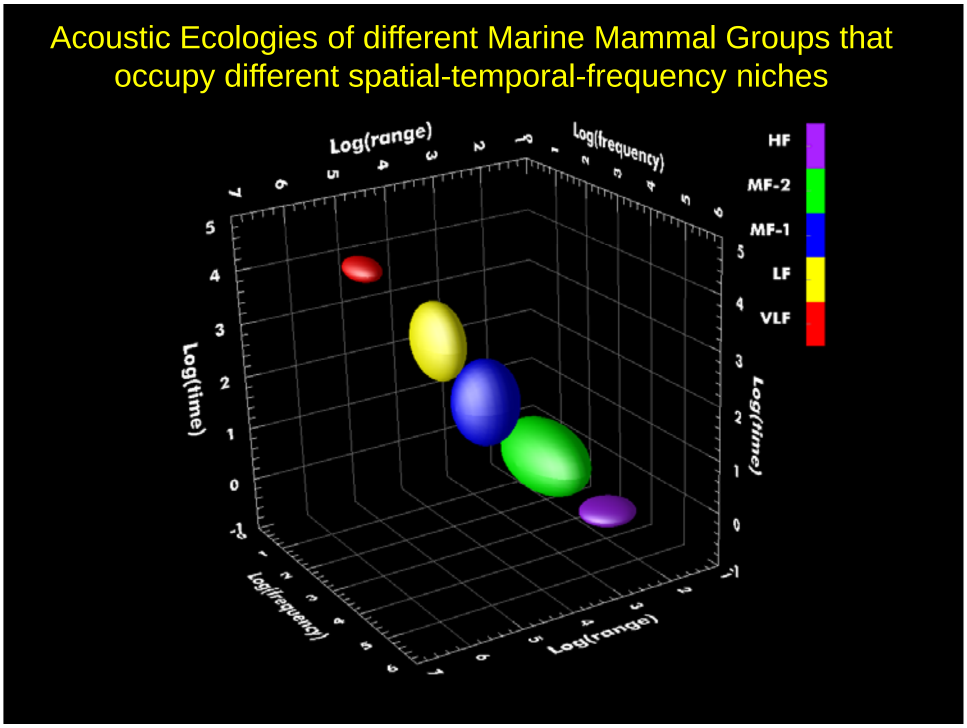

Humpback whale – Shallow & Deep, Coastal & Pelagic
Slide Adam Frankel
Low- and mid-frequency
Frequency (kHz)
Time (s)

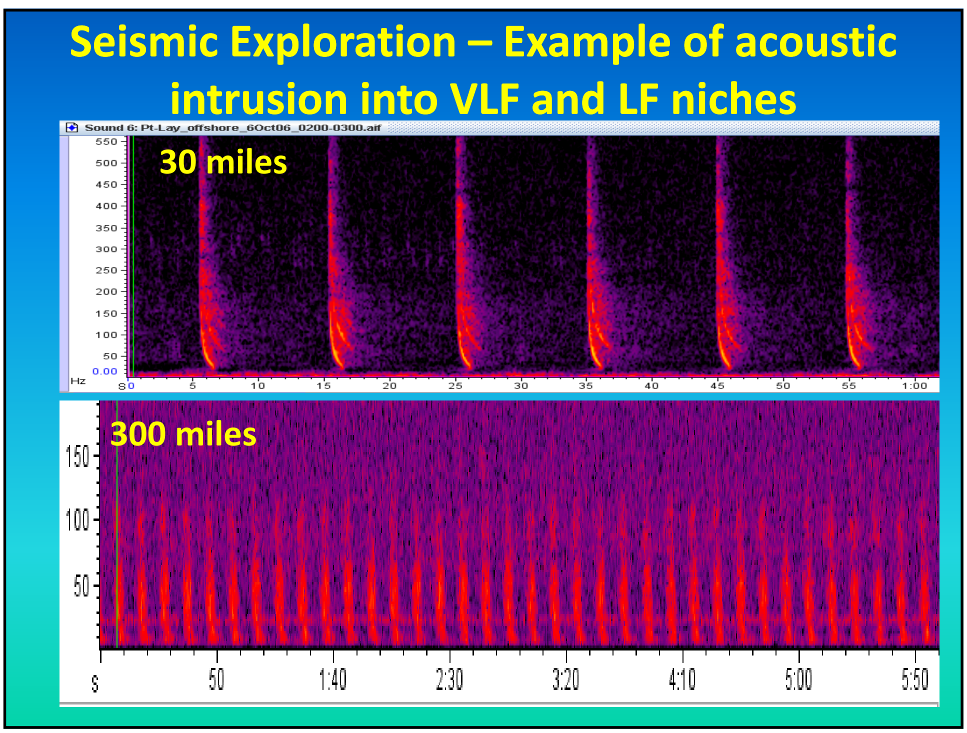

Melon-headed whales – Mid-frequency specialists
Frequency (kHz)
mid-frequency
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Time (s)

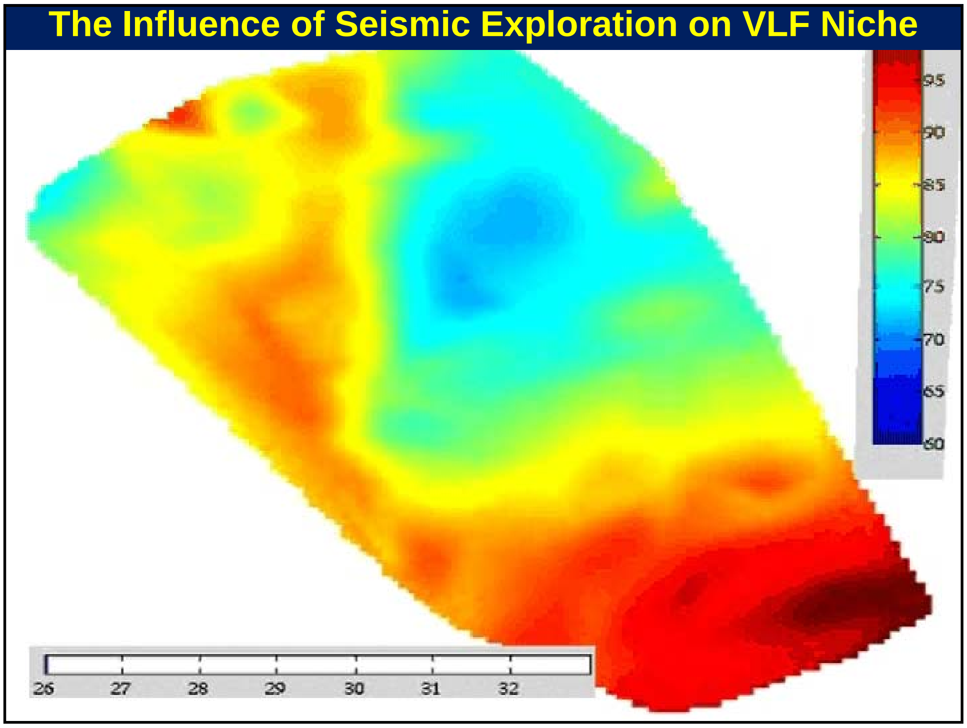

Beaked whales – High-frequency specialists
Frequency (kHz)
45 40 35 30 25 20 15 10 5
high-frequency
45 40 35 30 25
0.001 0.002
Slide gma.org
5:03.4 5:03.6 5:03.8 5:04 5:04.2 5:04.4 5:04.6 5:04.8 5:05
Time (mm:ss)

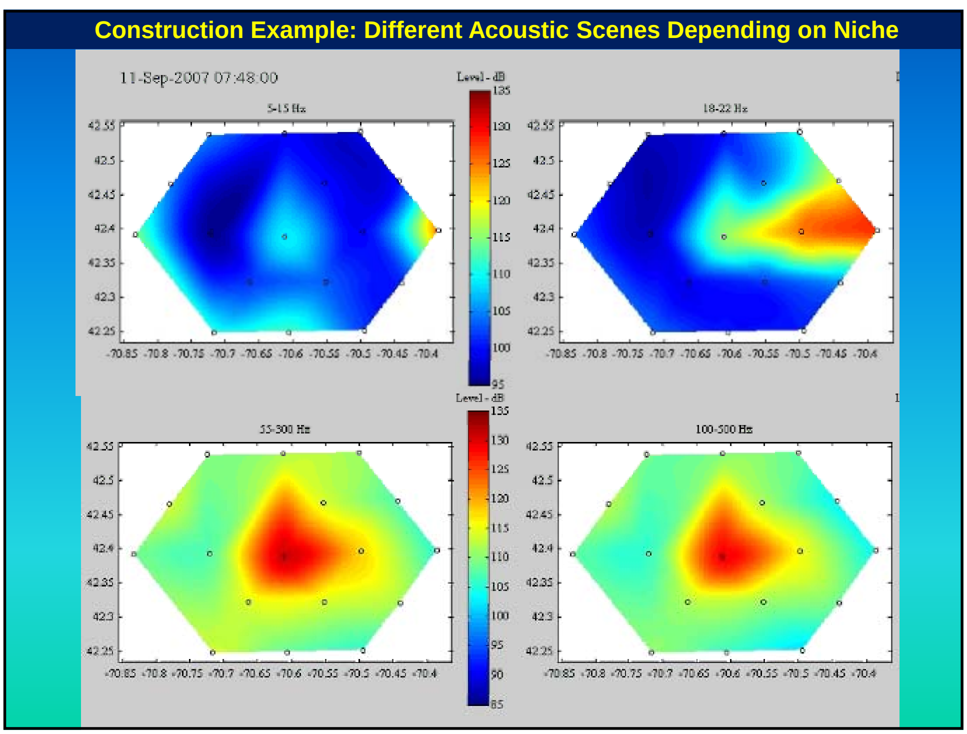

Bioacoustic Feature Space for Marine Mammals
CPA2_c
CPA1_c
CPA3_c

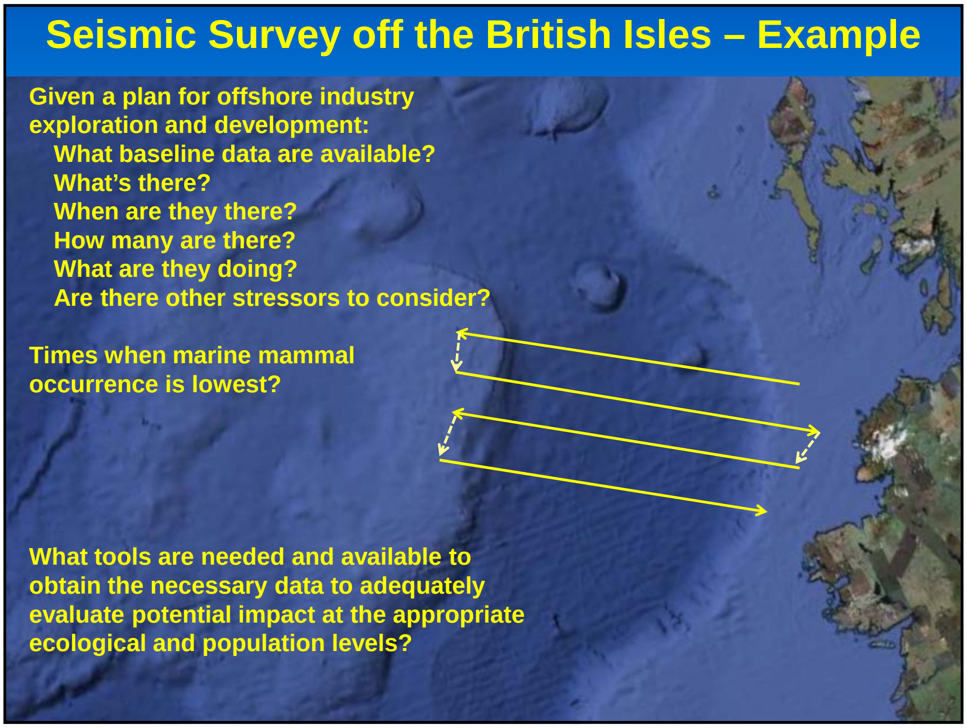

Biological Frequency Ranges:
VLF = Very-low-frequency < 100Hz
LF = Low-frequency < 1000Hz
MF-1 = Mid-frequency > 1khz, < 10kHz
MF-2 = Mid-frequency > 10khz, < 20kHz
HF = High-frequency > 20kHz
HF
MF-2
MF-1
LF
VLF
Log(range)
Log(frequency)
0
1
2
3
4
5
6
7

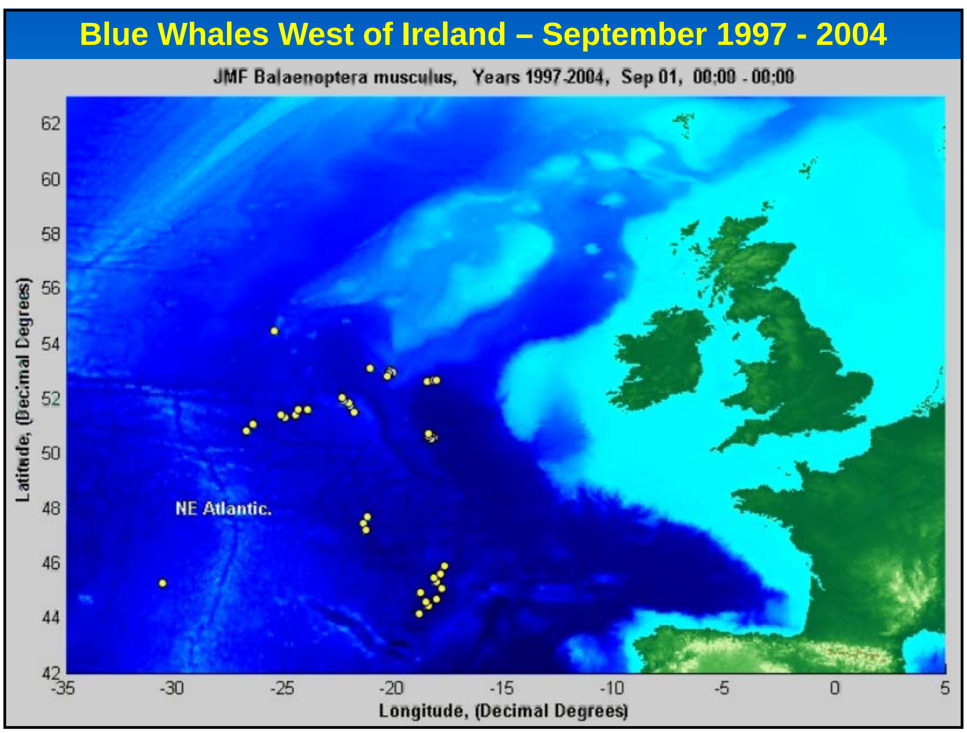

Acoustic Ecologies of different Marine Mammal Groups that occupy different spatial-temporal-frequency niches
Log(range)
Log(frequency)
Log(time)
HF
MF-2
MF-1
LF
VLF

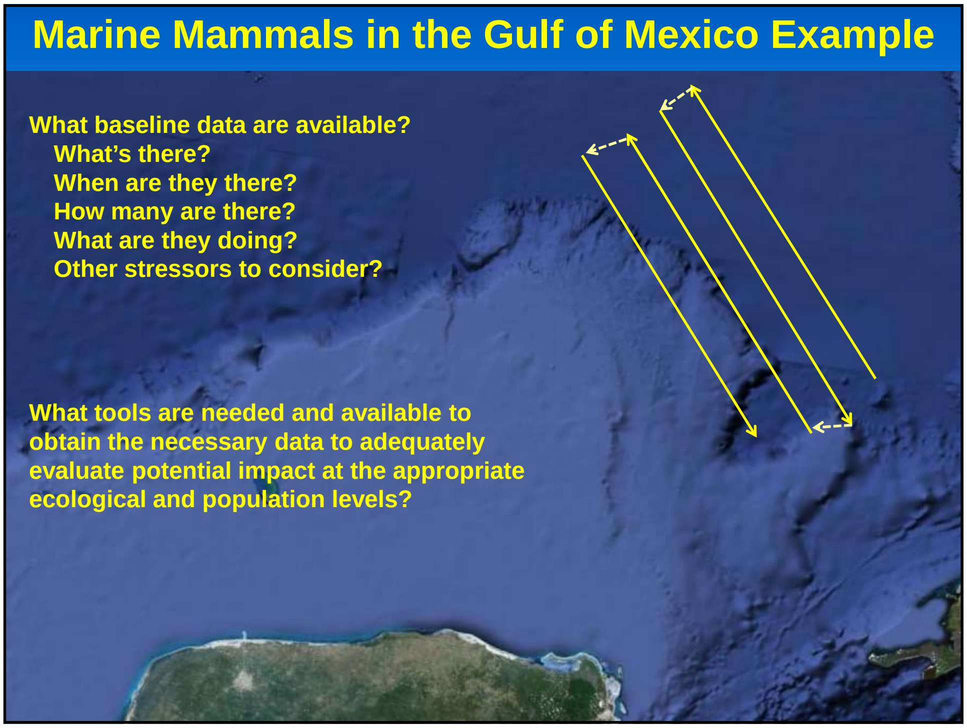

Seismic Exploration – Example of acoustic intrusion into VLF and LF niches
30 miles
300 miles

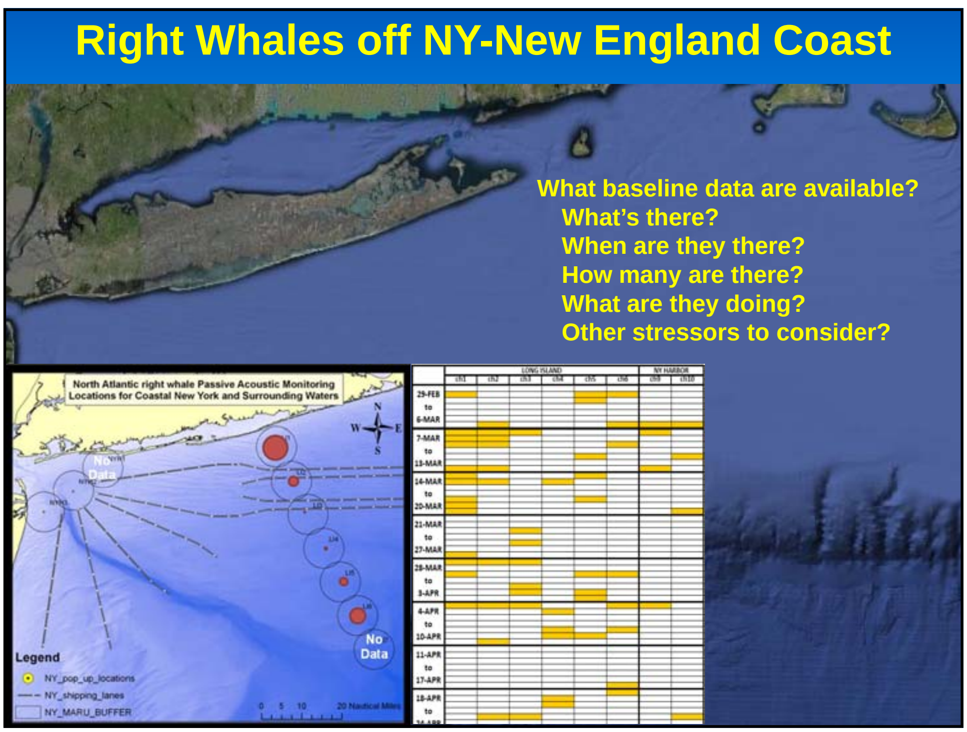

The Influence of Seismic Exploration on VLF Niche
95
90
85
80
75
70
65
60
26
27
28
29
30
31
32


Construction Example: Different Acoustic Scenes Depending on Niche
11-Sep-2007 07:48:00
5-15 Hz
18-22 Hz
55-300 Hz
100-500 Hz
Level - dB


Seismic Survey off the British Isles – Example
Given a plan for offshore industry exploration and development:
What baseline data are available?
What's there?
When are they there?
How many are there?
What are they doing?
Are there other stressors to consider?
Times when marine mammal occurrence is lowest?
What tools are needed and available to obtain the necessary data to adequately evaluate potential impact at the appropriate ecological and population levels?


Blue Whales West of Ireland – September 1997 - 2004
JMF Balaenoptera musculus, Years 1997-2004, Sep 01, 00:00 - 00:00
NE Atlantic.
Latitude, (Decimal Degrees)
Longitude, (Decimal Degrees)
62
60
58
56
54
52
50
48
46
44
42
-35
-30
-25
-20
-15
-10
-5
0
5


Marine Mammals in the Gulf of Mexico Example
What baseline data are available?
What's there?
When are they there?
How many are there?
What are they doing?
Other stressors to consider?
What tools are needed and available to obtain the necessary data to adequately evaluate potential impact at the appropriate ecological and population levels?


Right Whales off NY-New England Coast
What baseline data are available?
What's there?
When are they there?
How many are there?
What are they doing?
Other stressors to consider?
North Atlantic right whale Passive Acoustic Monitoring Locations for Coastal New York and Surrounding Waters
No Data
No Data
Legend
NY_pop_up_locations
NY_shipping_lanes
NY_MARU_BUFFER
0 5 10 20 Nautical Miles
LONG ISLAND
NY HARBOR
29-FEB to 6-MAR
7-MAR to 13-MAR
14-MAR to 20-MAR
21-MAR to 27-MAR
28-MAR to 3-APR
4-APR to 10-APR
11-APR to 17-APR
18-APR to

Some Basic Questions

How do the space-time-frequency dimensions of an offshore industry activity overlap with and intersect the acoustic behaviors and habitats of the different animals?

What spatial and temporal "monitoring" specs are necessary and sufficient to determine the level of any biological impact from an offshore industry activity?

What mitigation and monitoring tools are necessary, available and capable of providing those spatial and temporal resolutions at the agreed upon standards?

A Review of Fixed Passive Acoustic Monitoring Systems

Renata Sousa-Lima - Cornell University Bioacoustic Research Program

Tom Norris - Bio-Waves Inc.

Julie Oswald - Oceanwide Science Institute

MMS Workshop on the Status and Applications of Acoustic Mitigation and Monitoring Systems for Marine Mammals, Boston 17-19 Nov. 2009

Bio·Waves

Bioacoustics Research Program

OCEANWIDE SCIENCE INSTITUTE

Talk Outline

- Review for JIP
- Types of fixed PAM systems
- A little history and a few current examples
  - Autonomous recorders
  - Radio-linked hydrophones
  - Fixed cabled hydrophones
- Comparisons among fixed PAM systems
- The future of fixed PAM

JIP Fixed PAM Review GOALS

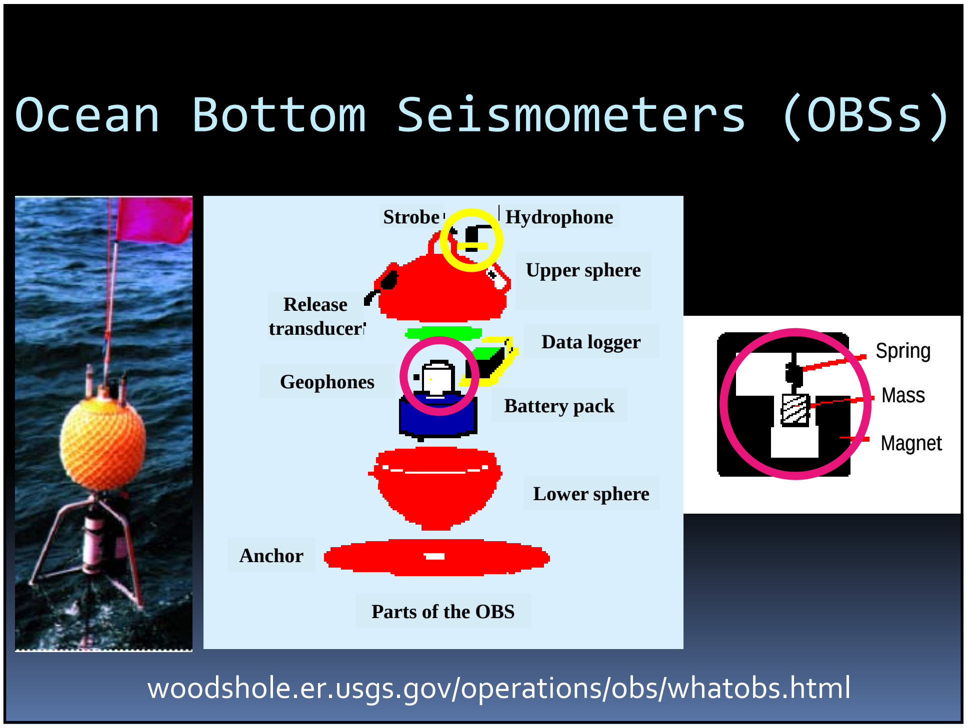
- To review and inventory fixed cabled, radio-linked, and autonomous passive acoustic monitoring (PAM) systems
- To review automated detection, classification, and localization techniques
- To provide recommendations for areas of future research and technological development

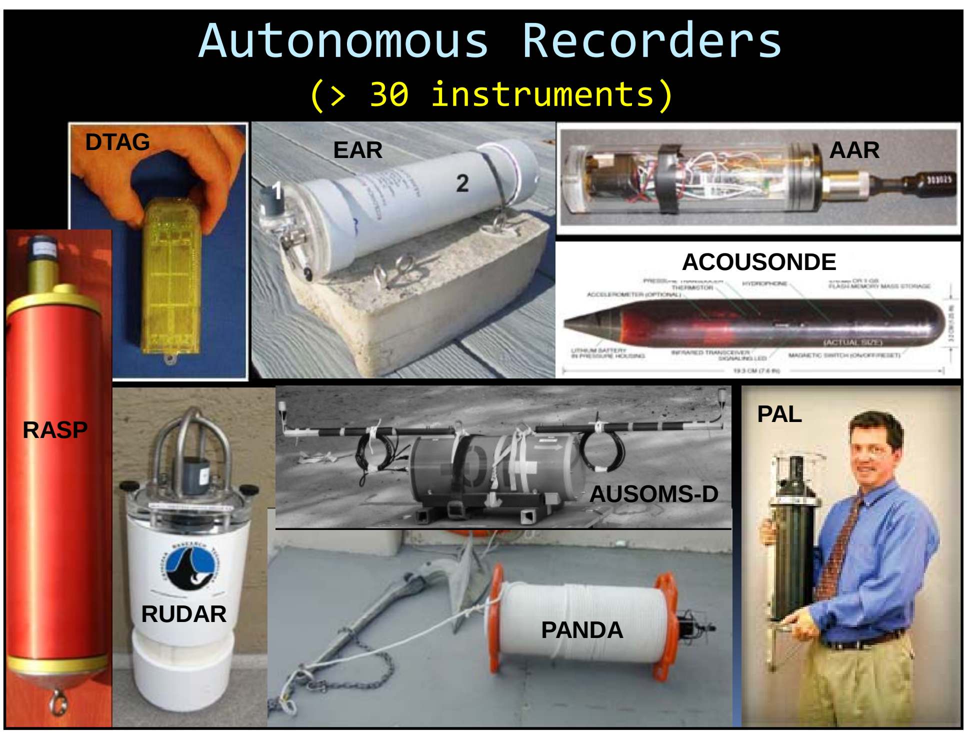
Types of fixed PAM

- Autonomous recorders (ARs)
- Radio-Linked Hydrophones (RLHs)
- Fixed cabled hydrophones (FCHs)

Autonomous recorders (ARs)

- Archival data
- Semi-permanent deployment underwater
- Retrieval required to download data
- Self-contained power supply & data storage
- Mooring (with or without surface expression)


Ocean Bottom Seismometers (OBSs)
Strobe
Hydrophone
Upper sphere
Release transducer
Data logger
Geophones
Battery pack
Lower sphere
Anchor
Parts of the OBS
Spring
Mass
Magnet
woodshole.er.usgs.gov/operations/obs/whatobs.html


Autonomous Recorders
(> 30 instruments)
DTAG
EAR
1
2
AAR
ACOUSONDE
RASP
RUDAR
AUSOMS-D
PANDA
PAL

Autonomous Recorders

HARP (High-frequency Acoustic Recording Package) – Scripps Institution of Oceanography (SIO)

Maximum Sampling frequency	200kHz
# of channels	1 (standard configuration)
Dynamic Range	96dB
Data acquisition mode	Continuous recording or Sampling schemes
Recording capacity	**16 x 2.5" HDs: up to ~ 2 TB FLASH coming soon**
Duration	55 days @ 200 kHz (soon 110 days) 1 year @ 30 kHz
Pressure case	31" OD pressure case with variable lengths
Weight	400 kg in air
Flotation	Syntactic foam
Maximum depth of deployment	**~ 6500m (standard 1300m)**

'Pop-Up' recorders

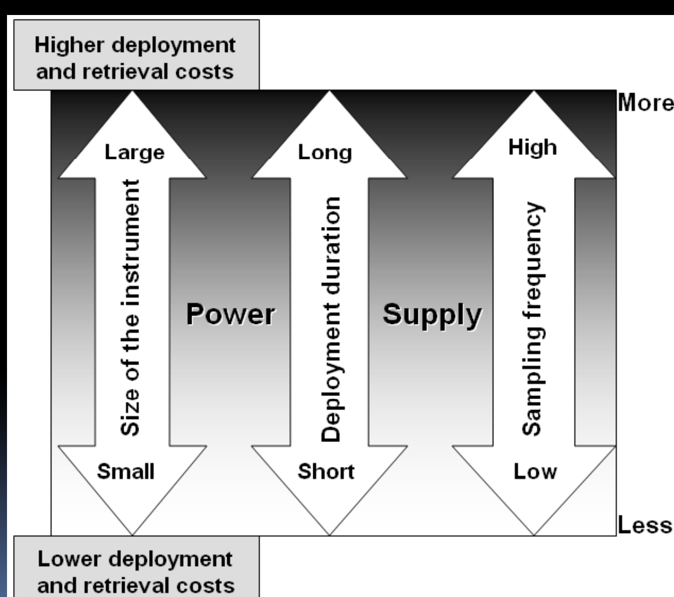
Cornell – Bioacoustics Research Program (BRP)

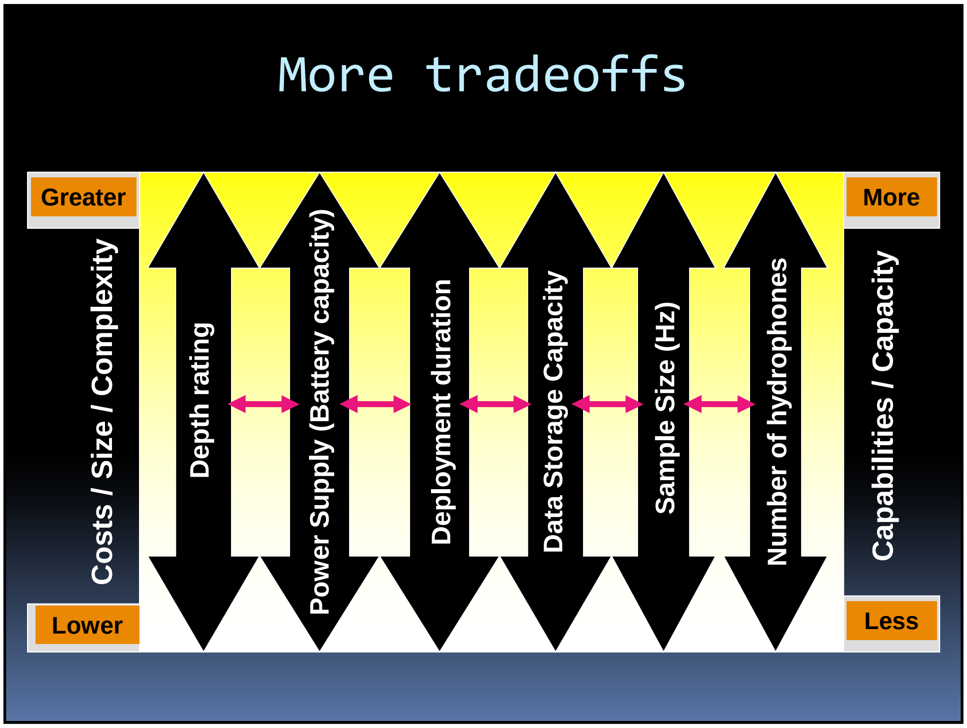
Maximum sampling frequency	**64 kHz**
# of channels	1
Dynamic Range	68 dB
Data acquisition mode	Continuous recording or Sampling schemes
Recording capacity	**~ single HD 120 GB FLASH coming soon**
Duration	90 days continuous @ 2 kHz (more depending on sampling scheme)
Pressure case	Glass sphere with plastic case
Weight	~50 kg in air
Flotation	12" glass spheres
Maximum depth of deployment	**~ 6000m**

Other AR capabilities

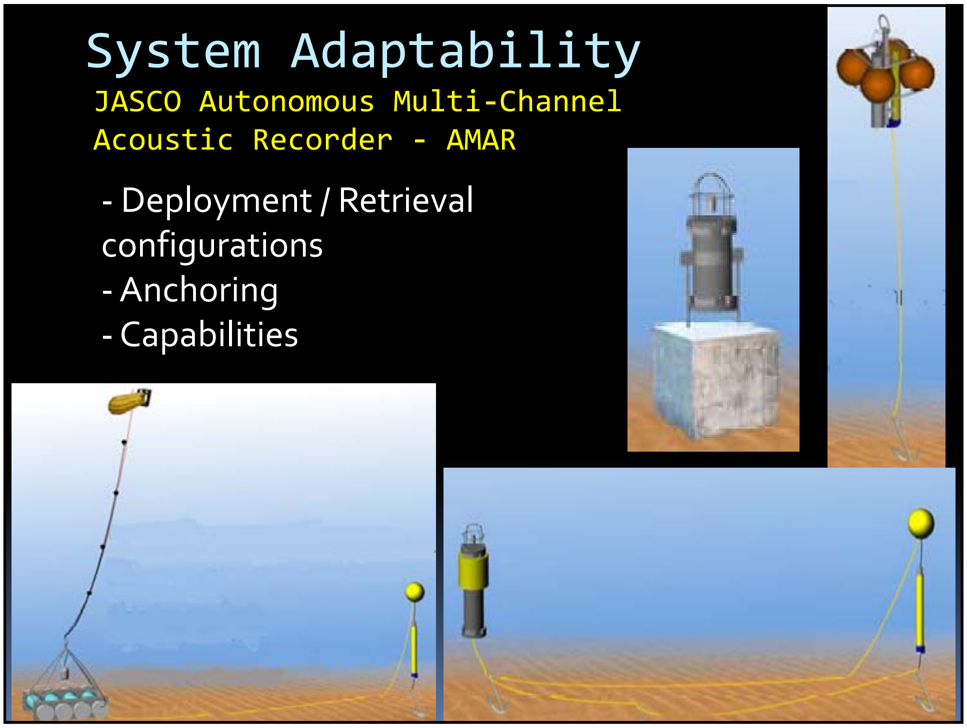
- Continuous recording vs. sampling schemes
- Automatic detection / classification / location of sounds
- Collection of non-acoustic oceanographic data

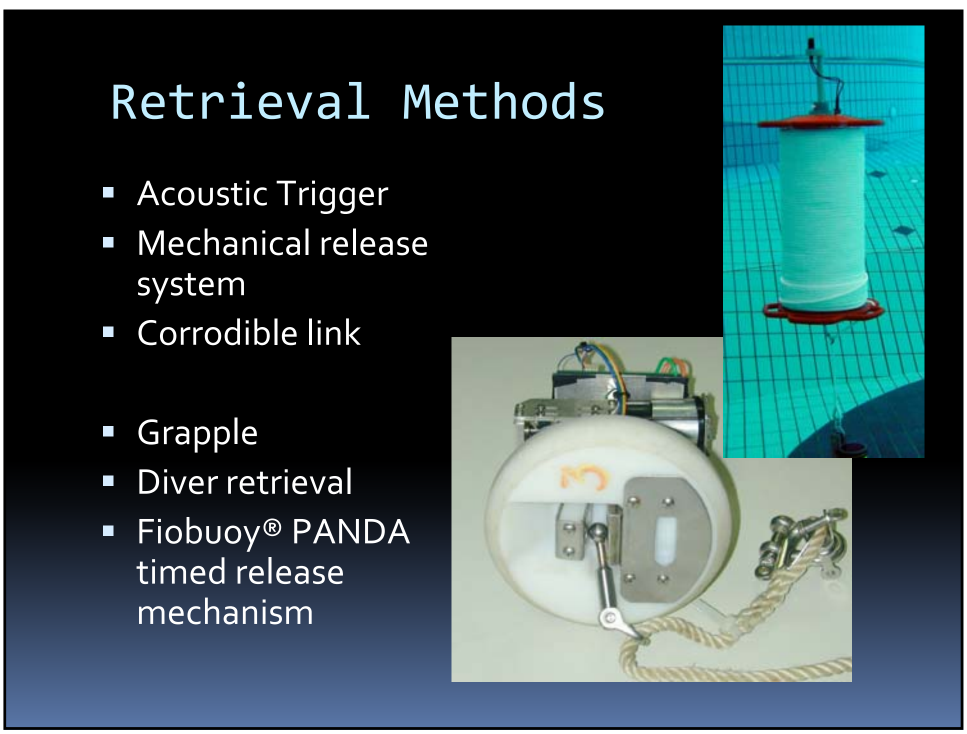
Tradeoffs




More tradeoffs
Greater
Costs / Size / Complexity
Lower
Depth rating
Power Supply (Battery capacity)
Deployment duration
Data Storage Capacity
Sample Size (Hz)
Number of hydrophones
More
Capabilities / Capacity
Less


Deployment Methods
ASL WCP
RDI ADCP
main buoy 380 kg
wire fixing frame
SBE CTD
Acoustic Recording Package
titanium swivel
25 m polyester rope
14mm (for recovery)
10 m floating polypropylene rope
40mm
45 m polyester rope
12 mm (Marlow braid)
acoustic release
railway wheels ~900 kg


System Adaptability
JASCO Autonomous Multi-Channel
Acoustic Recorder - AMAR
- Deployment / Retrieval
configurations
- Anchoring
- Capabilities

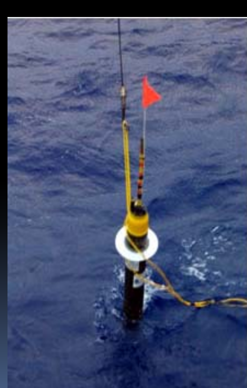

Retrieval Methods
Acoustic Trigger
Mechanical release
system
Corrodible link
Grapple
Diver retrieval
Fiobuoy® PANDA
timed release
mechanism

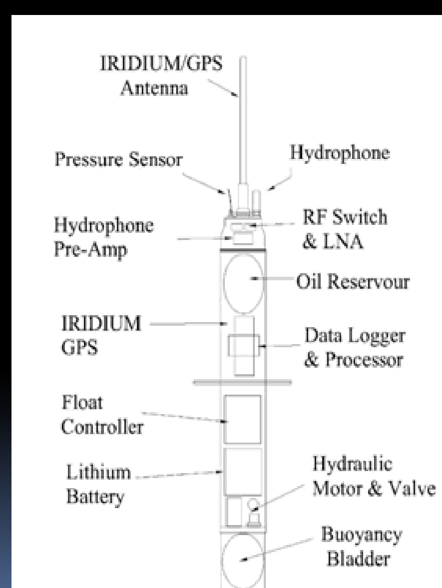
Radio-linked Hydrophones (RLHs)

- Real time or near real-time data aquisition
- Surface expression
- Limited data bandwidth
- Limited range of data transmission
- Self-contained power supply
- Maintenance issues

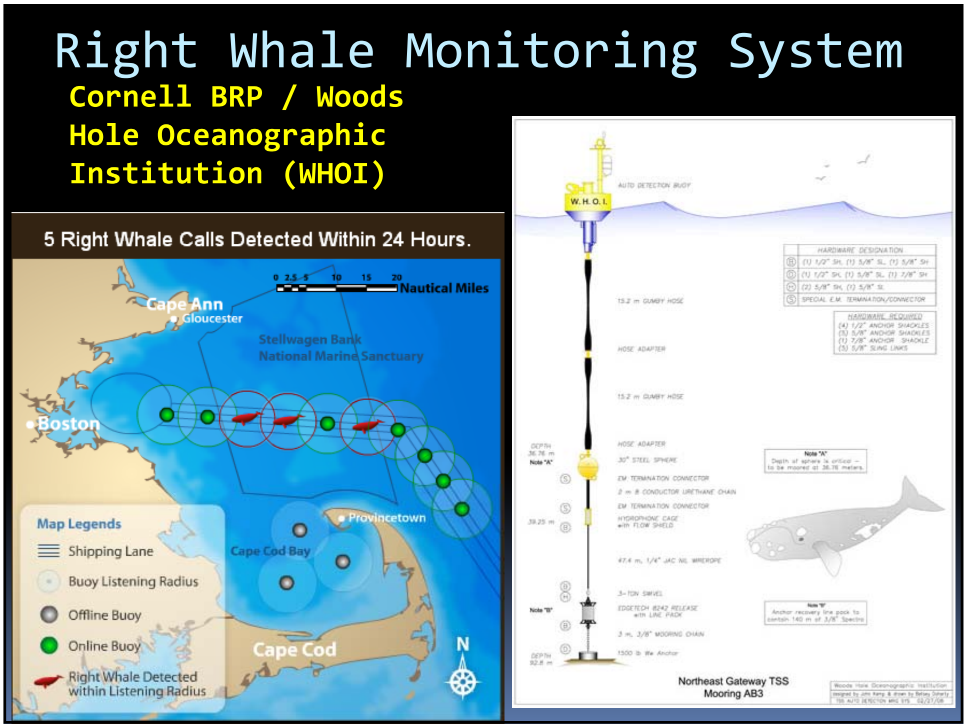
Radio-linked Hydrophones

QUE-Phone – NOAA's Pacific Marine Environmental Laboratory (PMEL)





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

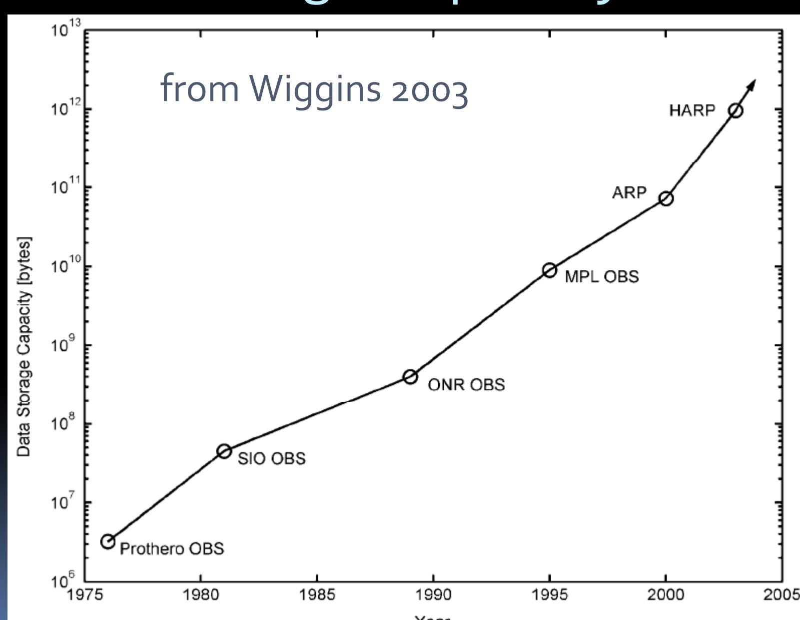

Right Whale Monitoring System
Cornell BRP / Woods Hole Oceanographic Institution (WHOI)
5 Right Whale Calls Detected Within 24 Hours.
0 2.5 5 10 15 20
Nautical Miles
Cape Ann
Gloucester
Stellwagen Bank National Marine Sanctuary
Boston
Provincetown
Cape Cod Bay
Cape Cod
N
Map Legends
Shipping Lane
Buoy Listening Radius
Offline Buoy
Online Buoy
Right Whale Detected within Listening Radius
W. H. O. I.
Northeast Gateway TSS
Mooring AB3


Whale Detection Buoys
WHOI
WHOI
WHOI

The Future

- Development of low power electronics
- Increase in data storage (ARs) and data transmission (RLHs) capacities

Data storage capacity



The Future

- Development of low power electronics
- Increase in Increase in data storage (ARs) and data transmission (RLHs) capacities
- Reduction in power consumption
- Reduction in size
- Reduction in self-noise
- Increase data pre-processing efficiency and automation
- Increase data post-processing speed and automation
- Information Networks and Integration

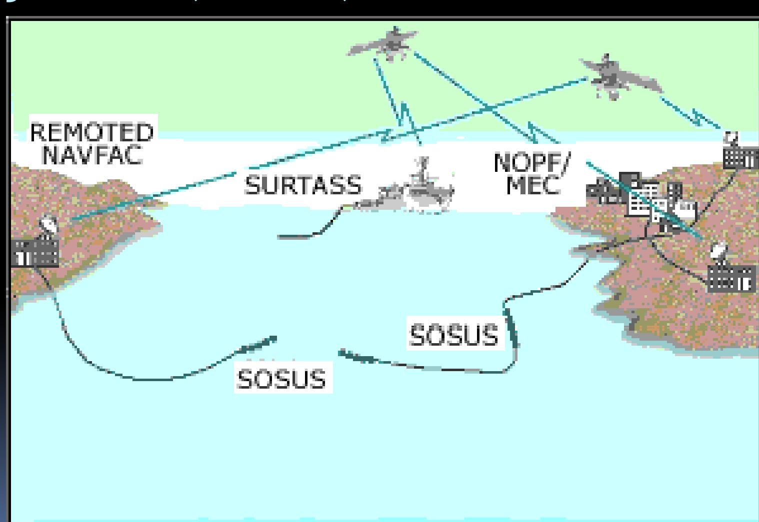
Fixed Cabled Hydrophones (FCHs)

- No surface expression
- External power supply (on land or sea facility)
- Near Real- to Real-Time data

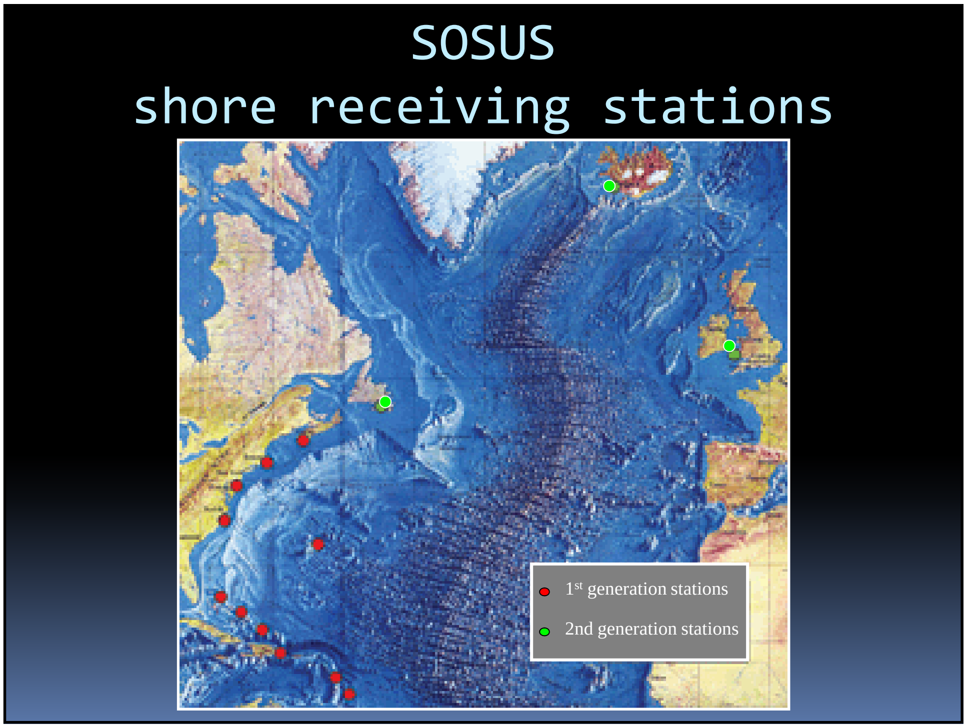
Fixed Cabled Hydrophones

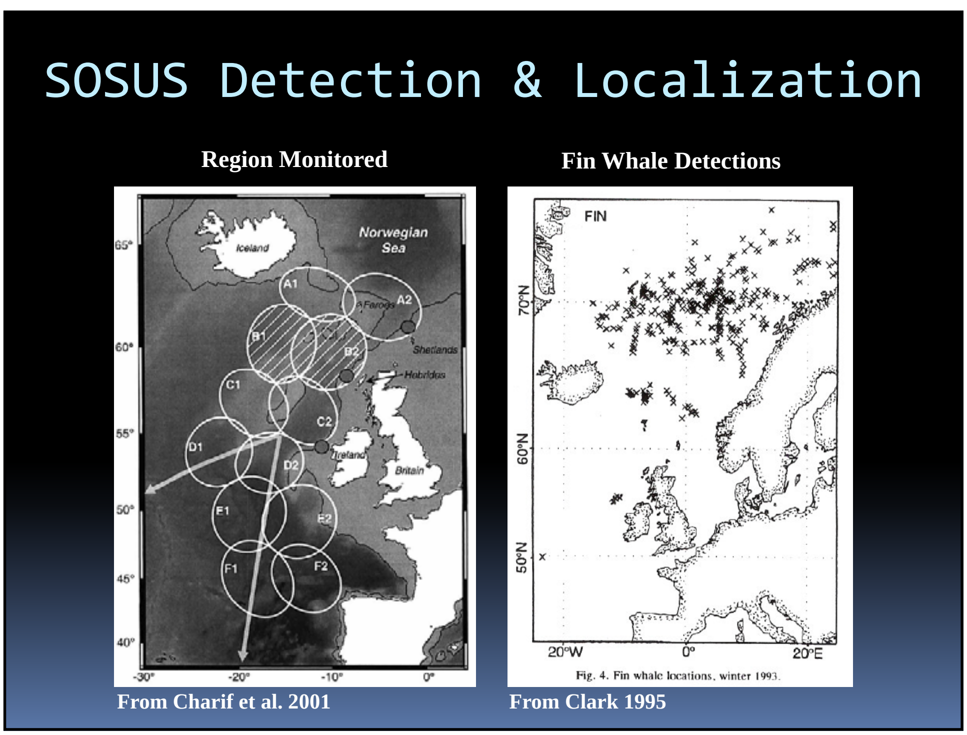
- US Navy Systems
  - SOSUS
  - Test Ranges
- Ocean Observatories
- Small scale systems for marine mammal research (not reviewed here)

US Navy Sound Surveillance System (SOSUS)



From NOAA/ PMEL website


SOSUS
shore receiving stations
1st generation stations
2nd generation stations

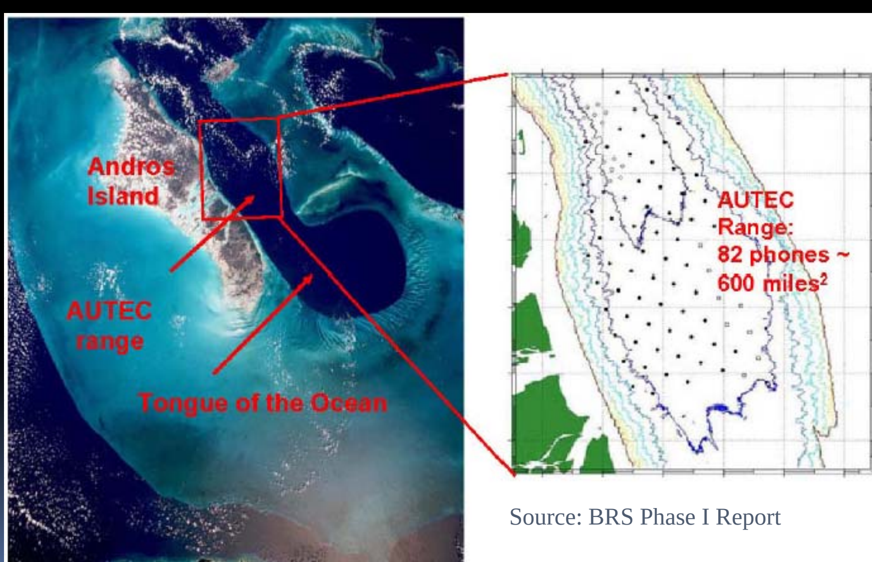

SOSUS Detection & Localization
Region Monitored
Fin Whale Detections
Iceland
Norwegian Sea
A1
A2
Faroes
B1
B2
Shetlands
Hebrides
C1
C2
D1
D2
Ireland
Britain
E2
F1
F2
65°
60°
55°
50°
45°
40°
-30°
-20°
-10°
0°
FIN
70°N
60°N
50°N
20°W
0°
20°E
Fig. 4. Fin whale locations, winter 1993.
From Charif et al. 2001
From Clark 1995

Navy Undersea Acoustic Test Ranges

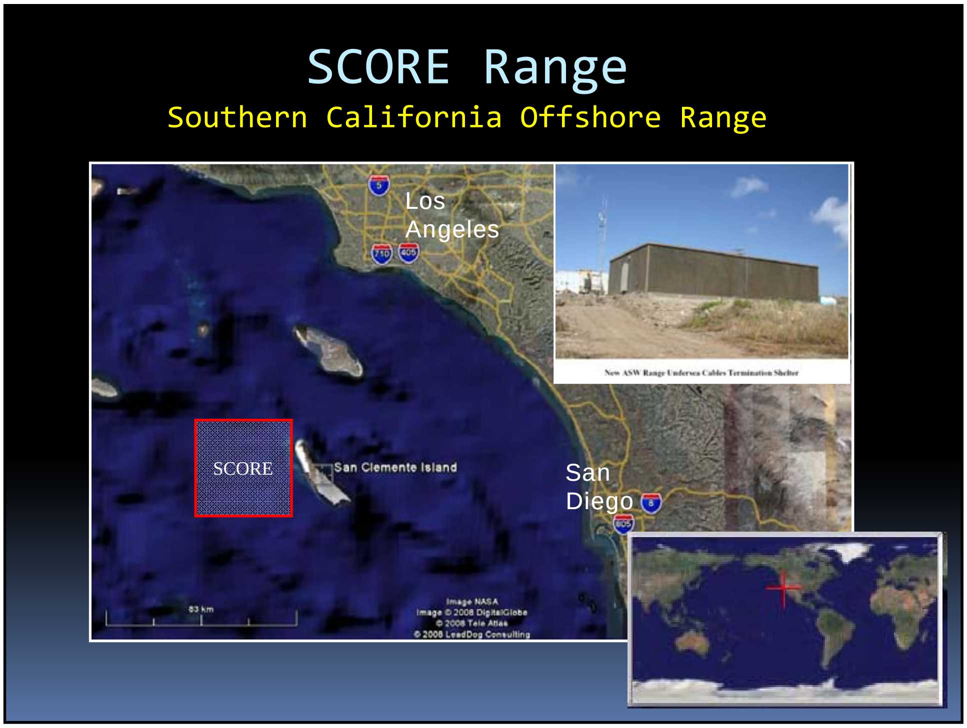
- AUTEC – The Bahamas
- SCORE/SOAR – California
- PMRF - Hawaii

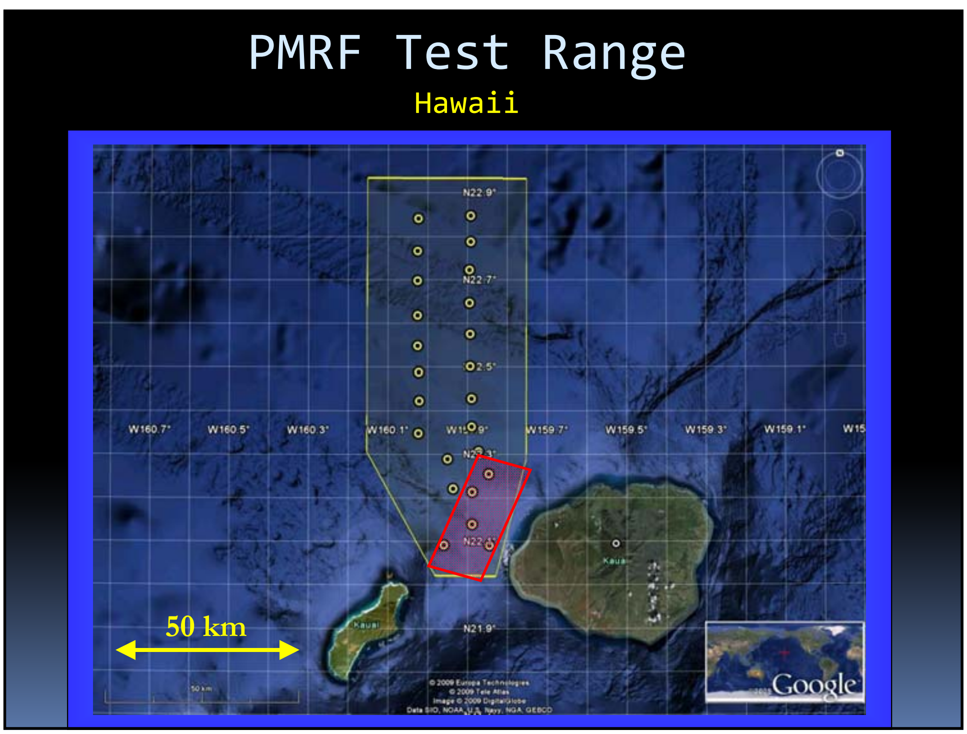
AUTEC Range

Bahamas



Source: BRS Phase I Report

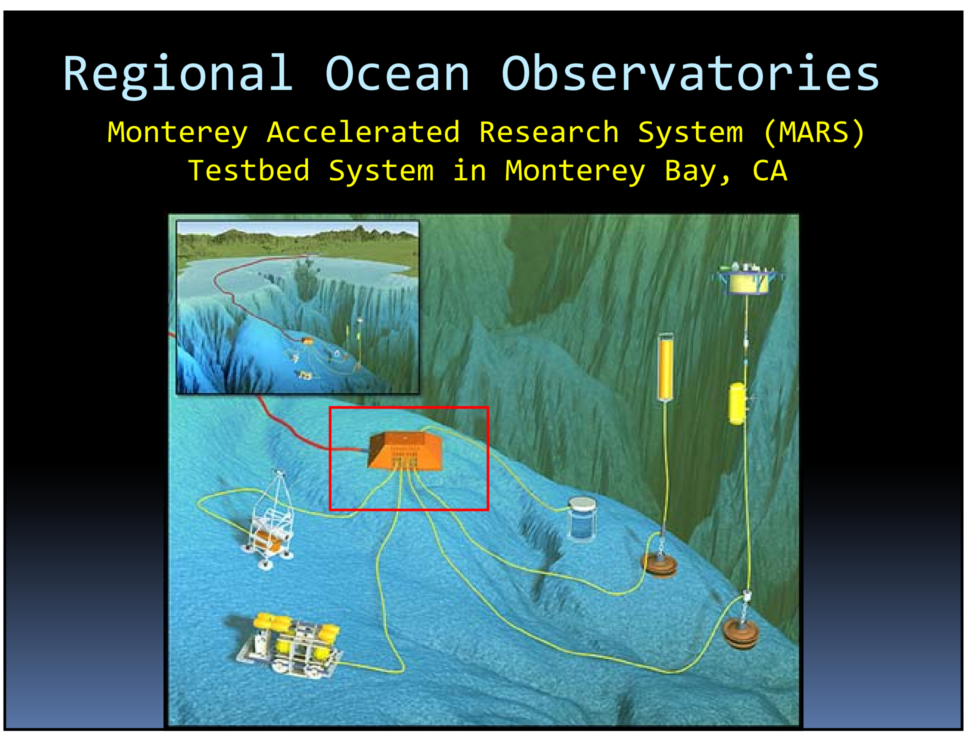

SCORE Range
Southern California Offshore Range
Los
Angeles
SCORE
San Clemente Island
San
Diego
New ASW Range Undersea Cables Termination Shelter

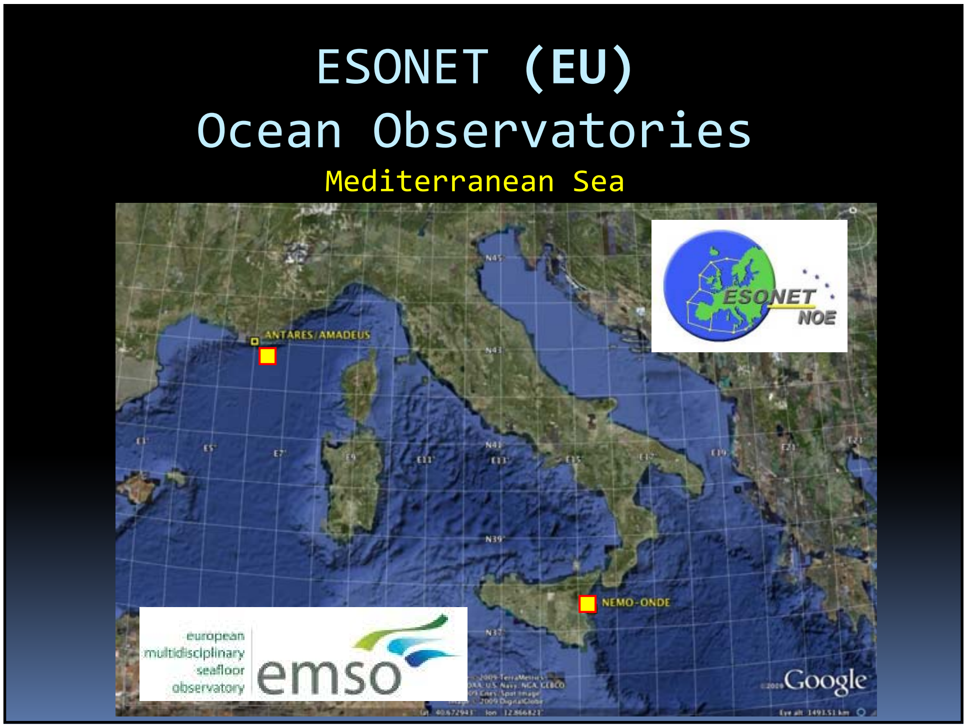

PMRF Test Range
Hawaii
50 km
Google

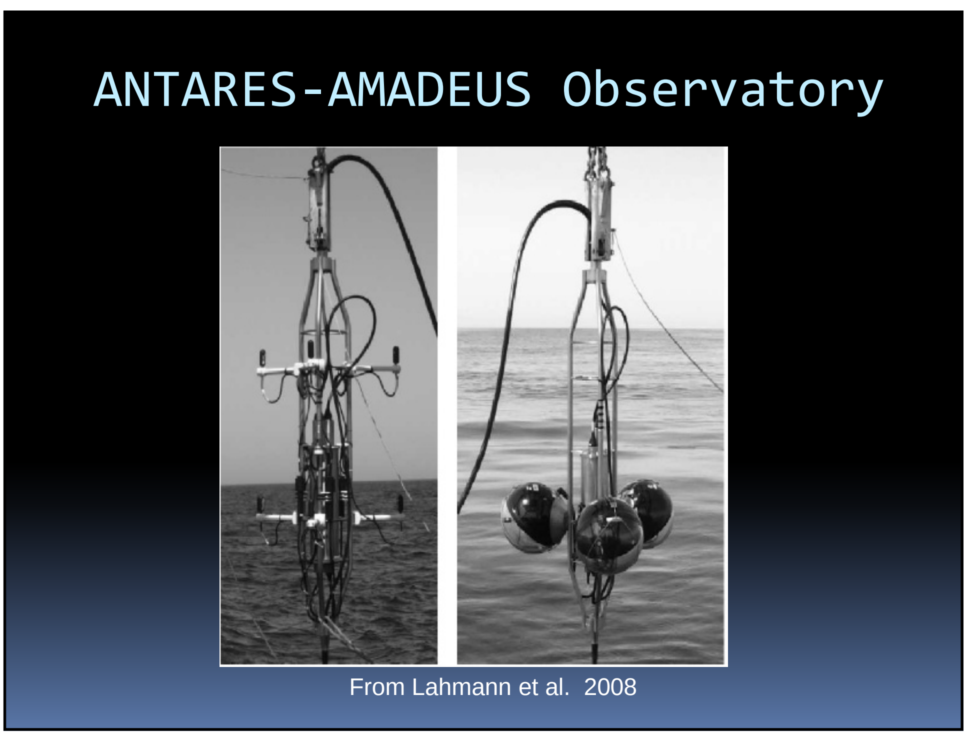

Ocean Observatories Initiative
The Ocean Observatories (OOI) will construct a networked infrastructure of science-driven sensor systems to measure the physical, chemical, geological and biological variables in the ocean and seafloor.
http://www.oceanleadership.org


Station Papa
Irminger Sea
Regional Scale Nodes
Endurance Array
Pioneer Array
Argentine Basin
Southern Ocean
Present & Planned Ocean Observatories
(in America)
http://www.oceanleadership.org


Regional Ocean Observatories
Project Neptune - now called Regional Scale Nodes (RSN) – Canada / USA
POWER NODE
EXPLORER PLATE
NEPTUNE Canada
Regional Scale Nodes - OOI
JUAN DE FUCA PLATE
NORTH AMERICAN PLATE
Victoria
Seattle
Portland
http://www.ooi.washington.edu/
http://www.oceanleadership.org


Regional Ocean Observatories
Monterey Accelerated Research System (MARS)
Testbed System in Monterey Bay, CA

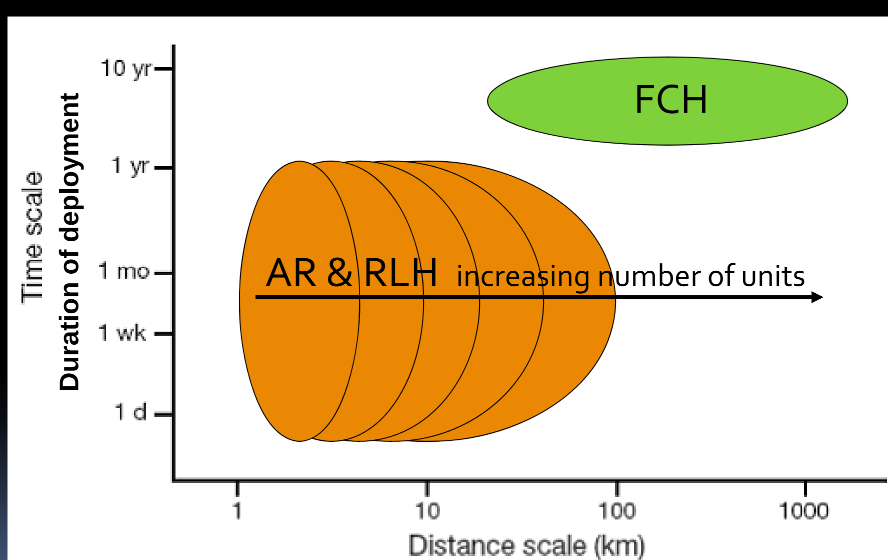

ESONET (EU)
Ocean Observatories
Mediterranean Sea
ANTARES/AMADEUS
NEMO-ONDE
ESONET
NOE
european
multidisciplinary
seafloor
observatory
emso
Google


ANTARES-AMADEUS Observatory
From Lahmann et al. 2008

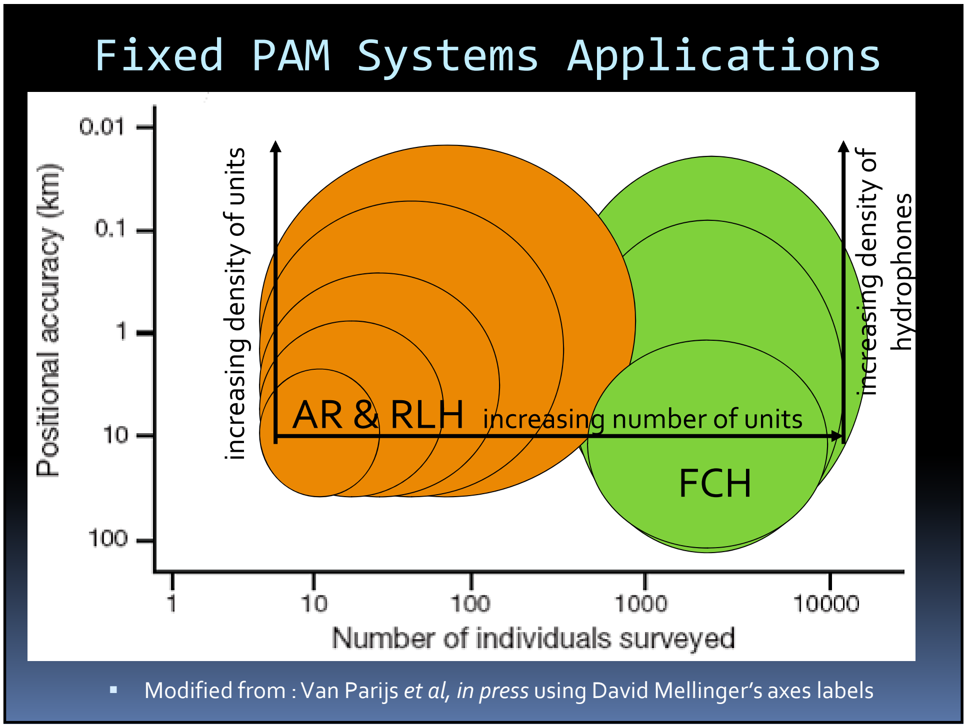
Fixed PAM Comparison

Type	Time scale	Spatial range	Spectral range	Initial Cost / unit	Data	Flexi-ble	Maintenance (no damage / damage)
AR	hour – year	# units	varies	low	archival	yes	low / medium
RLH	day – year	# units	varies	medium – high	real-time or near	yes	medium / high
FCH	> day – > year	large	Poten-tially broad	high	real-time or near	no	very low / very high

Fixed PAM Systems Applications



- Modified from : Van Parijs *et al*, *in press* using David Mellinger's axes labels



Biological Applications
Additional dimensions:

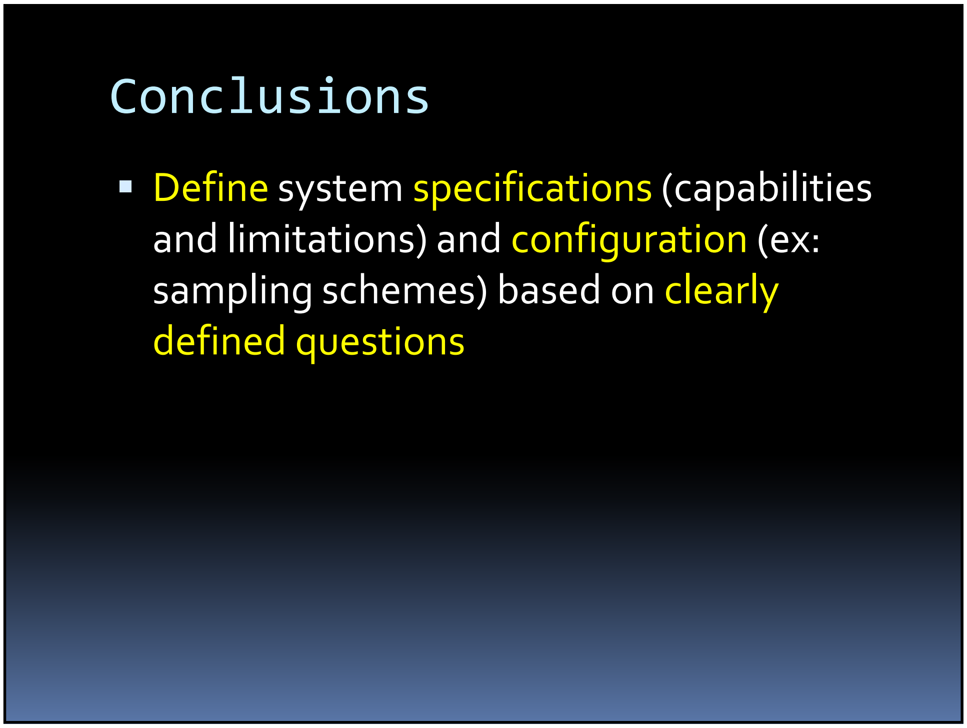
- Temporal (period of deployment; duty cycle)
- Spatial (effective acoustic range; sensor density)
- Acoustic (sampling frequency; dynamic range; detection / classification algorithms)
- Localization and tracking

Differences among fixed PAM

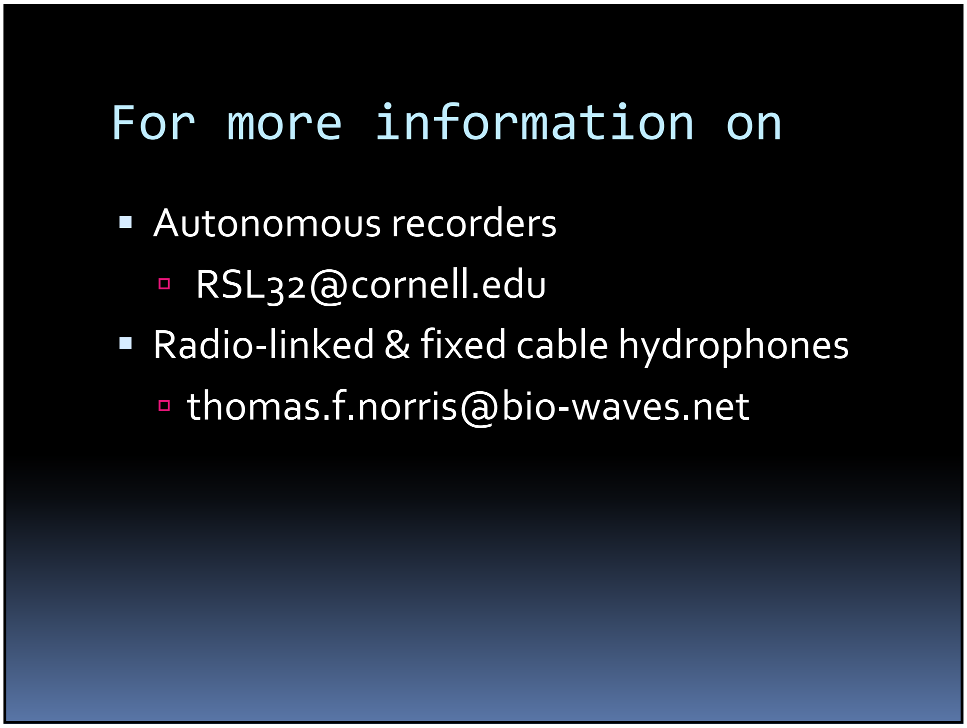
- Optimal temporal, spatial and biological applications
- Costs
- Maintenance
- Data availability (archival or real-time)
- Deployment longevity (FCHs are permanent)
- Flexibility / adaptability
- Surface expression

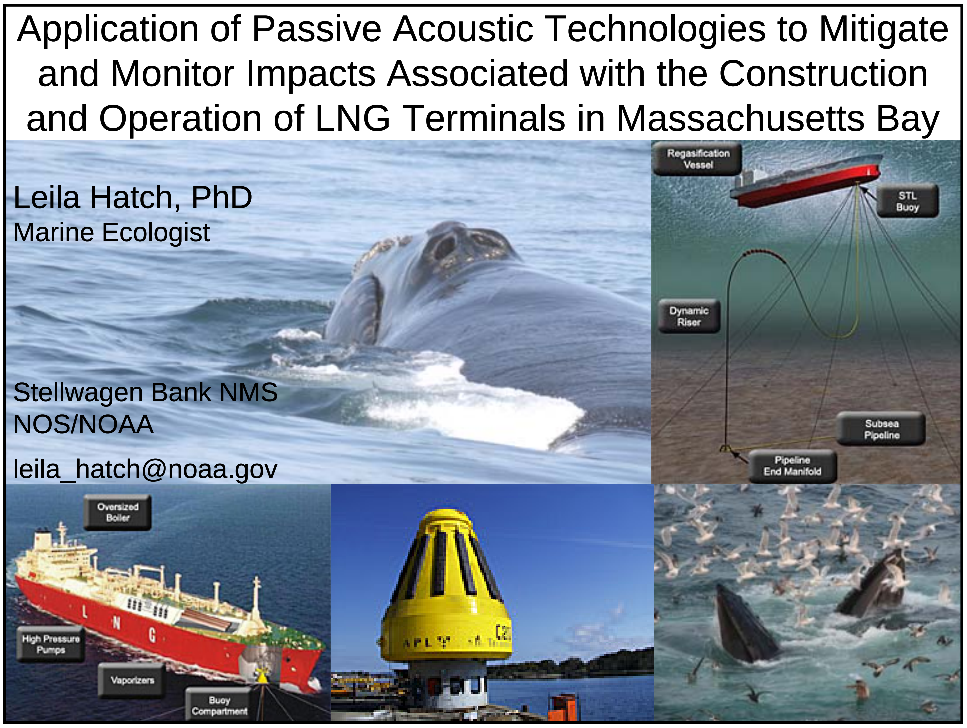
Conclusions

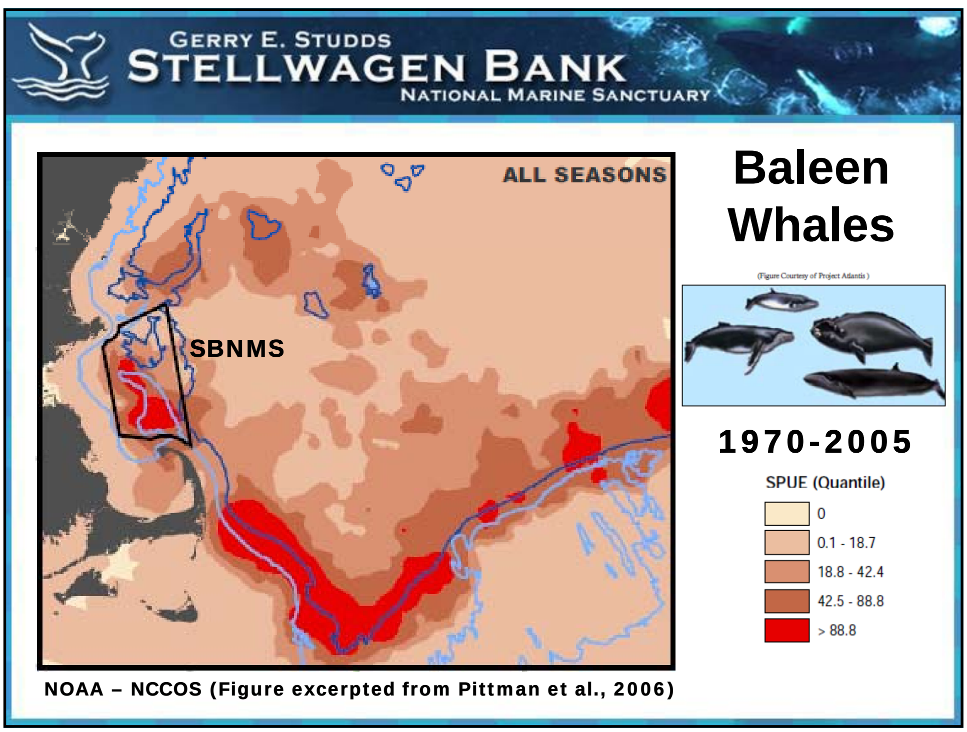
- There is no right answer
- Consider total costs (instrument + deployment + retrieval + data processing)
- Consider the biology of the species of interest, physical characteristics of the deployment area (bathymetry, currents, human activities)

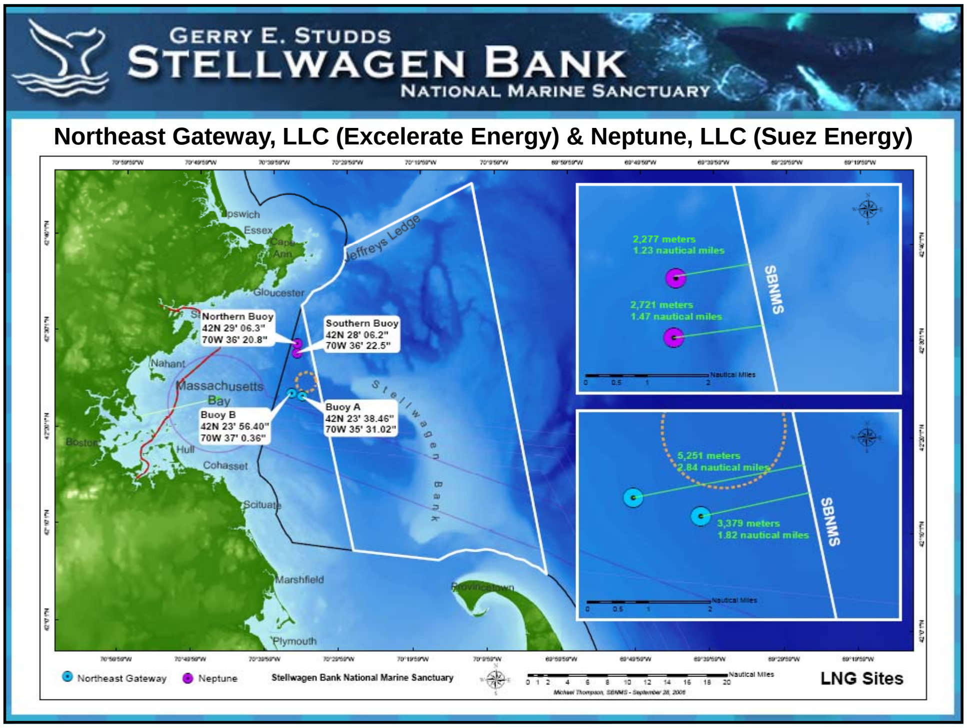

Conclusions
Define system specifications (capabilities and limitations) and configuration (ex: sampling schemes) based on clearly defined questions


Acknowledgements
Minerals Management Service
International Association of Oil and Gas Producers (OGP) Exploration & Production "Sound and Marine Life Joint Industry Programme" (JIP)
User and developers of fixed installation PAM technologies
RESOLVE


For more information on
Autonomous recorders
RSL32@cornell.edu
Radio-linked & fixed cable hydrophones
thomas.f.norris@bio-waves.net


Application of Passive Acoustic Technologies to Mitigate and Monitor Impacts Associated with the Construction and Operation of LNG Terminals in Massachusetts Bay
Leila Hatch, PhD
Marine Ecologist
Stellwagen Bank NMS
NOS/NOAA
leila_hatch@noaa.gov
Regasification Vessel
STL Buoy
Dynamic Riser
Subsea Pipeline
Pipeline End Manifold
Oversized Boiler
High Pressure Pumps
Vaporizers
Buoy Compartment


Gerry E. Studds
Stellwagen Bank
National Marine Sanctuary
ALL SEASONS
SBNMS
Baleen Whales
(Figure Courtesy of Project Atlantis)
1970-2005
SPUE (Quantile)
0
0.1 - 18.7
18.8 - 42.4
42.5 - 88.8
> 88.8
NOAA – NCCOS (Figure excerpted from Pittman et al., 2006)



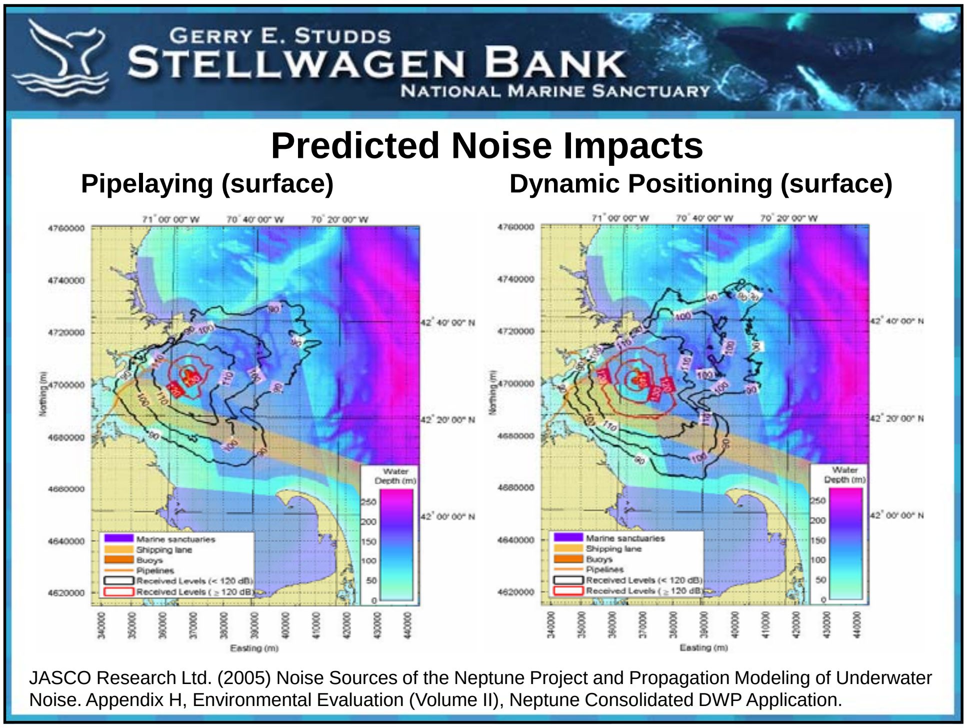
Gerry E. Studds
Stellwagen Bank
National Marine Sanctuary

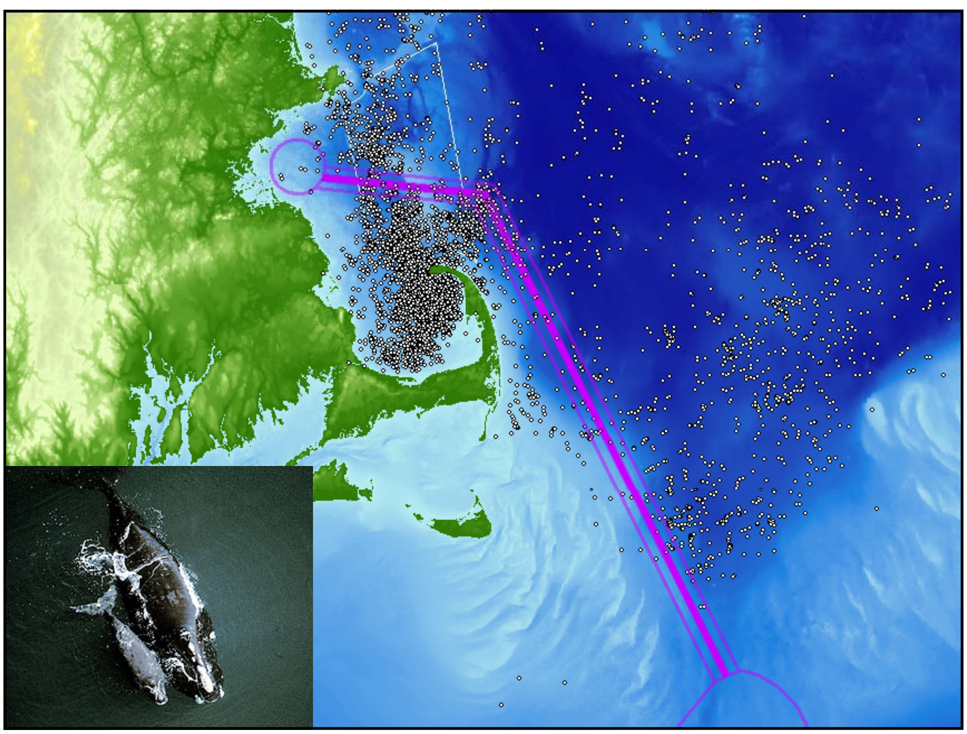
U.S. NATIONAL MARINE SANCTUARIES ACT*

MANDATE:

"…Identify and mitigate activities that are likely to destroy, cause the loss of, or injure a sanctuary resource".

**The 1992 reauthorization of the Marine Protection, Research, and Sanctuaries Act (33 U.S.C. § 1401 et seq.) renamed title III as the National Marine Sanctuaries Act (16 U.S.C. § 1431 et seq.).*


GERRY E. STUDDS
STELLWAGEN BANK
NATIONAL MARINE SANCTUARY
Predicted Noise Impacts
Pipelaying (surface)
Dynamic Positioning (surface)
Marine sanctuaries
Shipping lane
Buoys
Pipelines
Water Depth (m)
Northing (m)
Easting (m)
JASCO Research Ltd. (2005) Noise Sources of the Neptune Project and Propagation Modeling of Underwater Noise. Appendix H, Environmental Evaluation (Volume II), Neptune Consolidated DWP Application.



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NATIONAL MARINE SANCTUARY

Passive Acoustic Mitigation and Monitoring for Offshore LNG Terminals

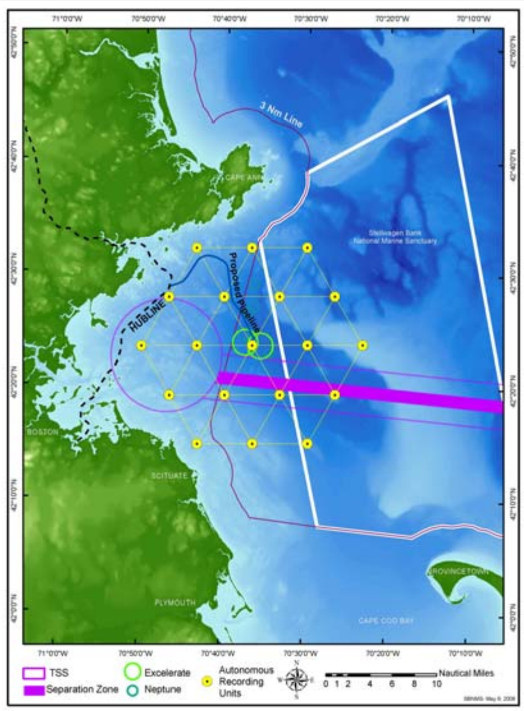
1. Design

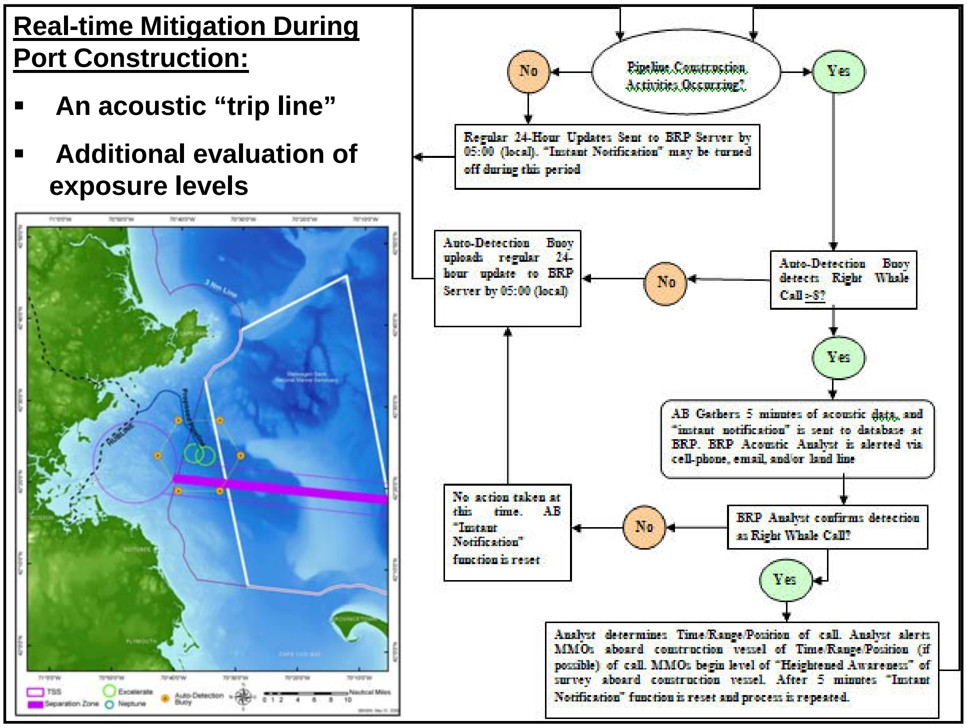
2. Implementation and Results

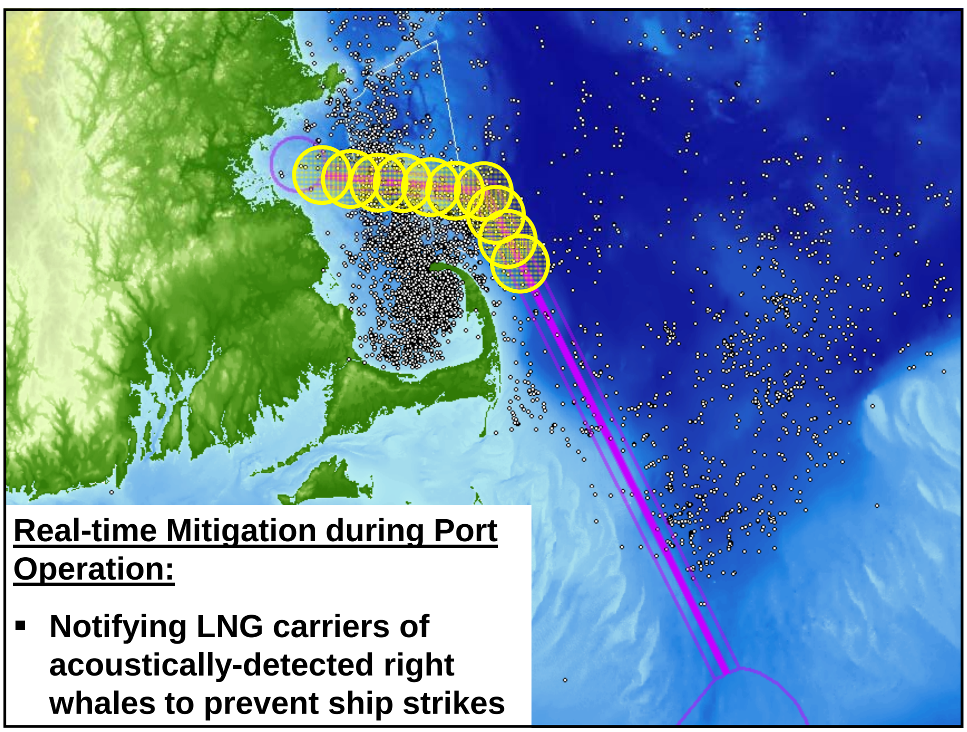
3. Future Directions

Pre-construction, Construction and Operational Monitoring:

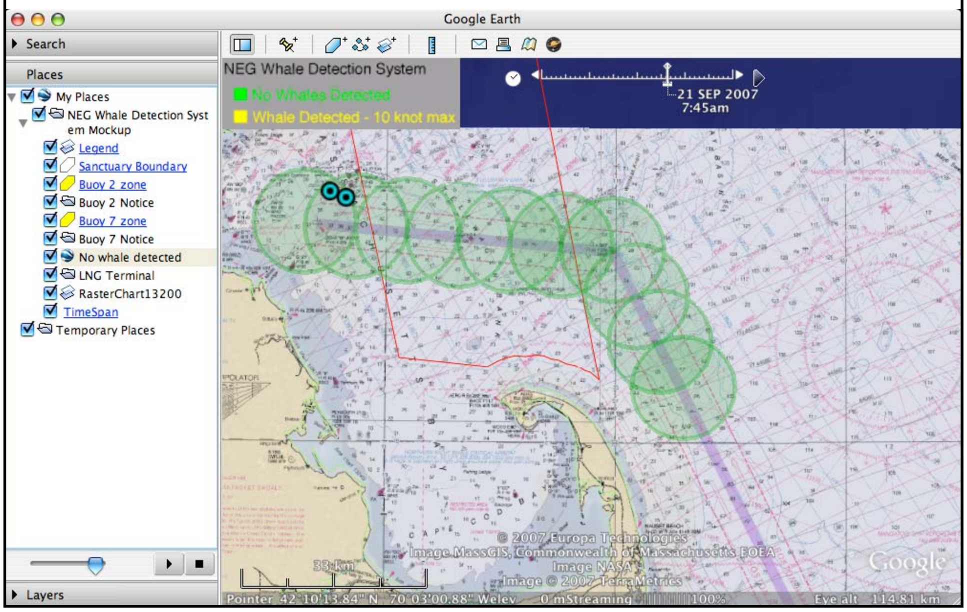
- **Characterizing the acoustic footprints of port activities**
- **Monitoring the distributions and behaviors of three endangered whale species**
    - **Estimating levels of exposure**
    - **Estimating changes in acoustic habitat**



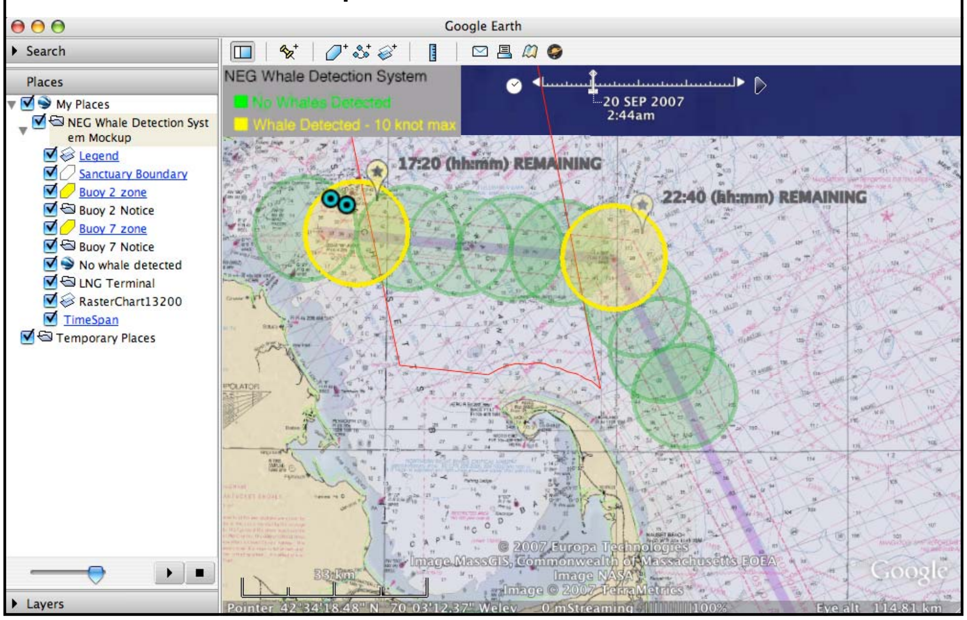

Real-time Mitigation During Port Construction:
▪ An acoustic “trip line”
▪ Additional evaluation of exposure levels
TSS
Separation Zone
Excelerate
Neptune
Auto-Detection Buoy
Nautical Miles
Pipeline Construction Activities Occurring?
No
Yes
Regular 24-Hour Updates Sent to BRP Server by 05:00 (local). "Instant Notification" may be turned off during this period
Auto-Detection Buoy detects Right Whale Call ≥8?
No
Auto-Detection Buoy uploads regular 24-hour update to BRP Server by 05:00 (local)
Yes
AB Gathers 5 minutes of acoustic data, and "instant notification" is sent to database at BRP. BRP Acoustic Analyst is alerted via cell-phone, email, and/or land line
BRP Analyst confirms detection as Right Whale Call?
No
No action taken at this time. AB "Instant Notification" function is reset
Yes
Analyst determines Time/Range/Position of call. Analyst alerts MMOs aboard construction vessel of Time/Range/Position (if possible) of call. MMOs begin level of "Heightened Awareness" of survey aboard construction vessel. After 5 minutes "Instant Notification" function is reset and process is repeated.

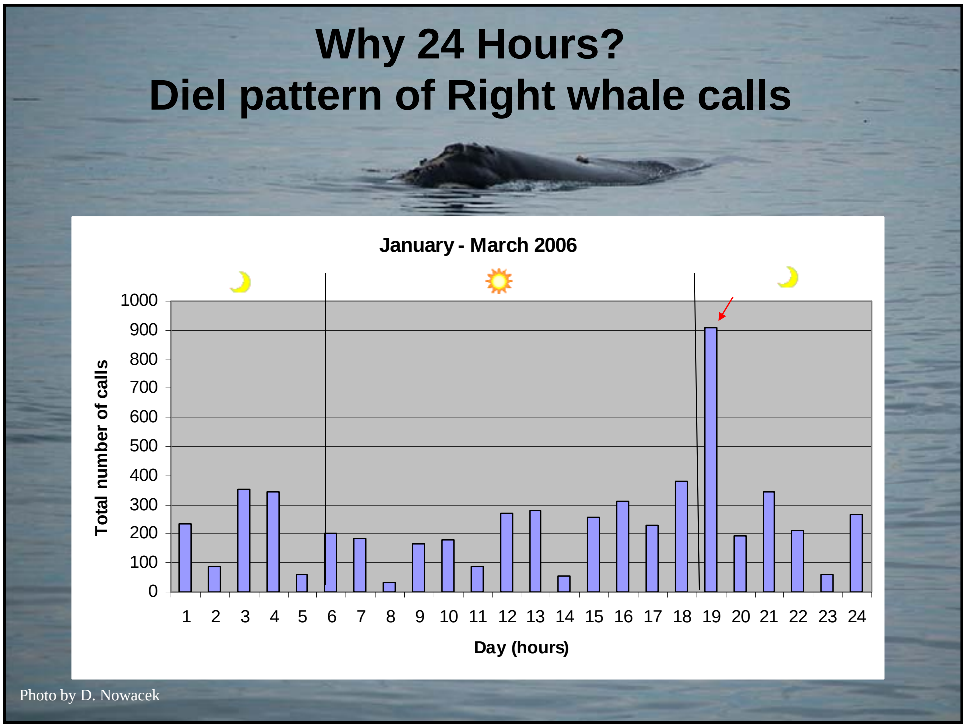

Real-time Mitigation during Port Operation:
▪ Notifying LNG carriers of acoustically-detected right whales to prevent ship strikes

All green - no right whales detected



2 yellow "active" detection areas
10 knot max speed & increased awareness





GERRY E. STUDDS STELLWAGEN BANK NATIONAL MARINE SANCTUARY

Passive Acoustic Mitigation and Monitoring for Offshore LNG Terminals

1. Design

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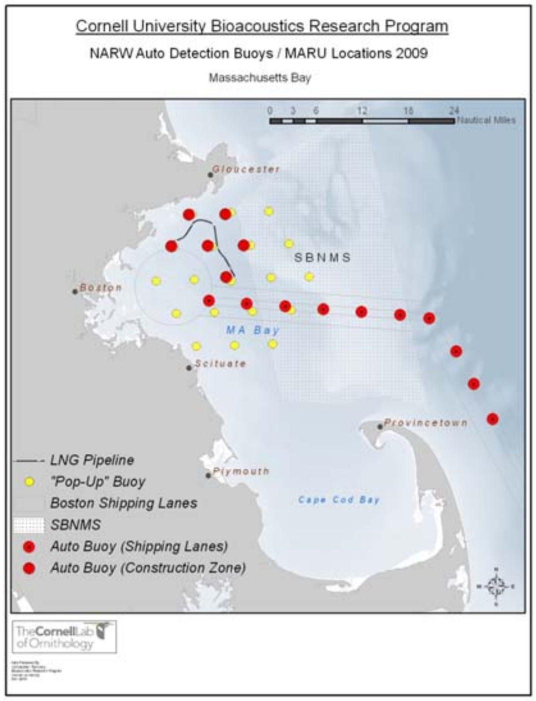
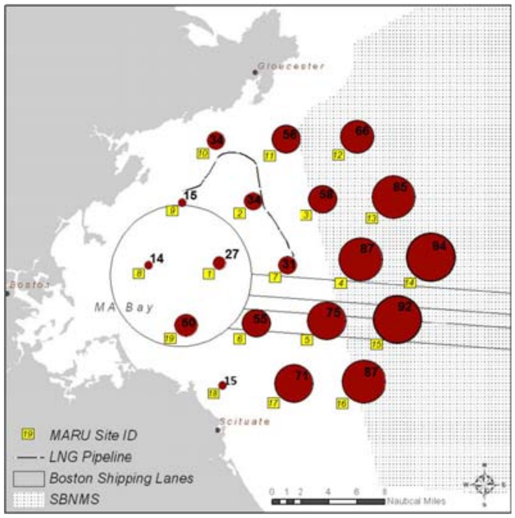


Marine Acoustic Recording Units

- **Cornell University's Bioacoustics Research Program**
- **Anchored temporarily with sandbags**
- **Rotated every 3 months**
- **Continuously recording low frequency sound**
  - **5-10 nautical mile listening area around each unit**

Figure 1. Marine Autonomous Recording Units (MARUs).

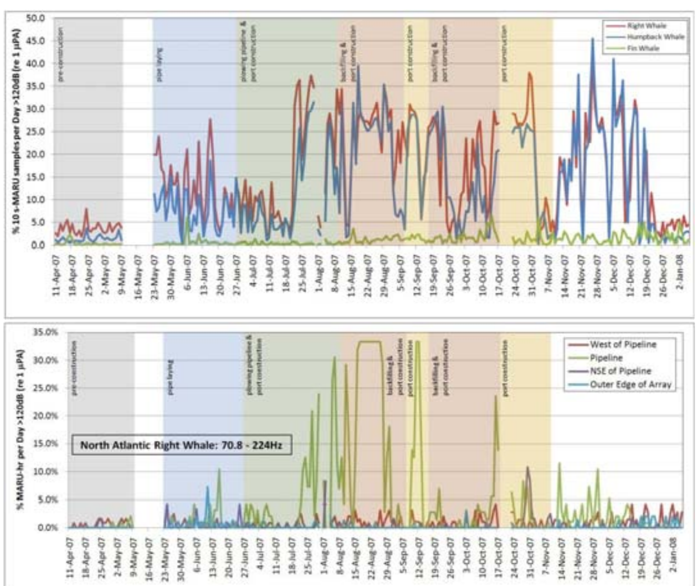
LNG Construction Acoustic Monitoring



days during construction with humpback whale calls

Figure: Cornell University Bioacoustics Research Program & Northeast Gateway, LLC

LNG Construction Acoustic Monitoring



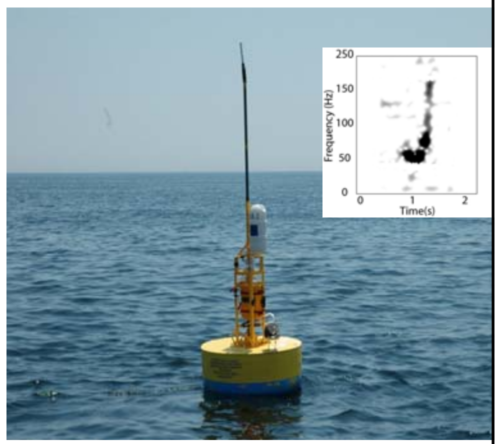
Noise in frequencies used by humpback and right whales

Noise highly localized to pipeline route

Figures: Cornell University Bioacoustics Research Program & Northeast Gateway, LLC

Auto-Detection Buoys

- Moored buoys (Cornell BRP & WHOI)
- Hydrophones to detect specific right whale call
- Computer software to identify specific call
- Satellite transmitter to immediately send data to land base for confirmation & communication



LNG Construction Acoustic Mitigation

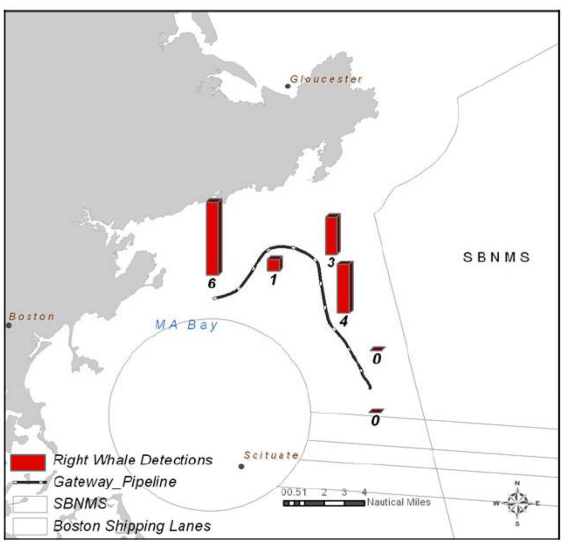


Figure 7. Numbers of right whale detections collected per AB during construction period.

Figure: Cornell University Bioacoustics Research Program & Northeast Gateway, LLC

LNG Operation Acoustic Mitigation

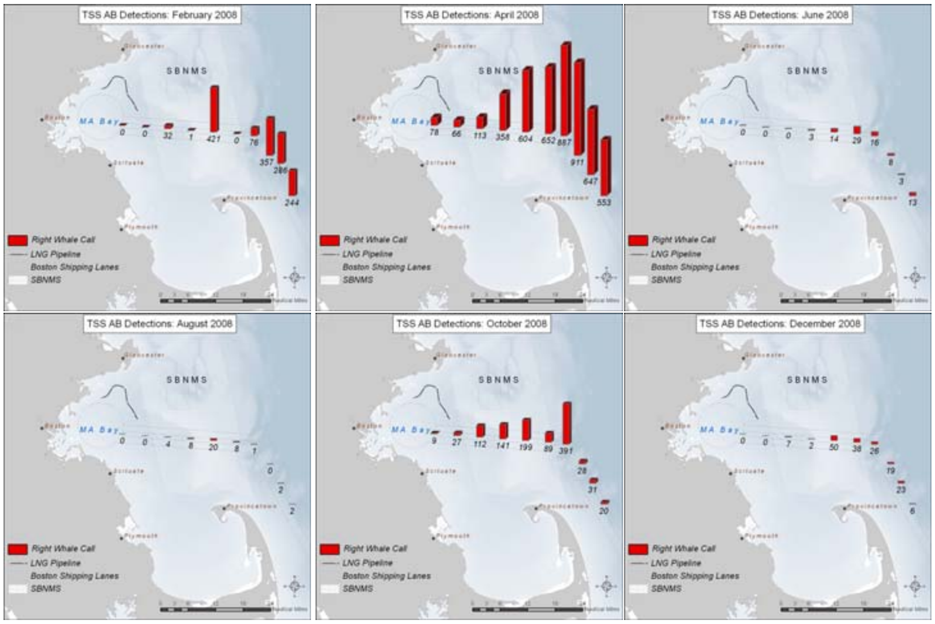
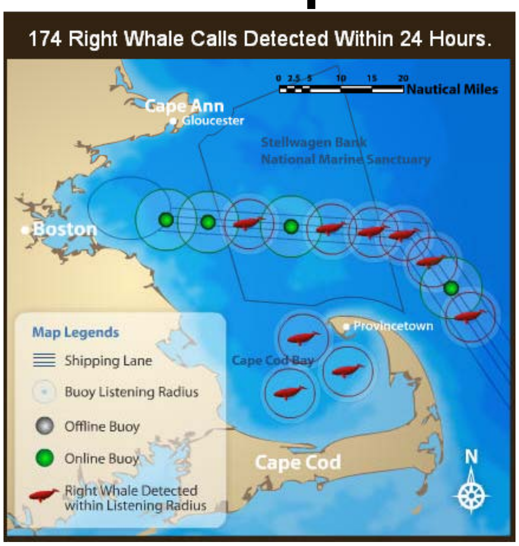


Figure: Cornell University Bioacoustics Research Program & Northeast Gateway, LLC

LNG Port Operation



Cornell University Bioacoustics Research Program
www.listenforwhales.org

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Passive Acoustic Mitigation and Monitoring for Offshore LNG Terminals

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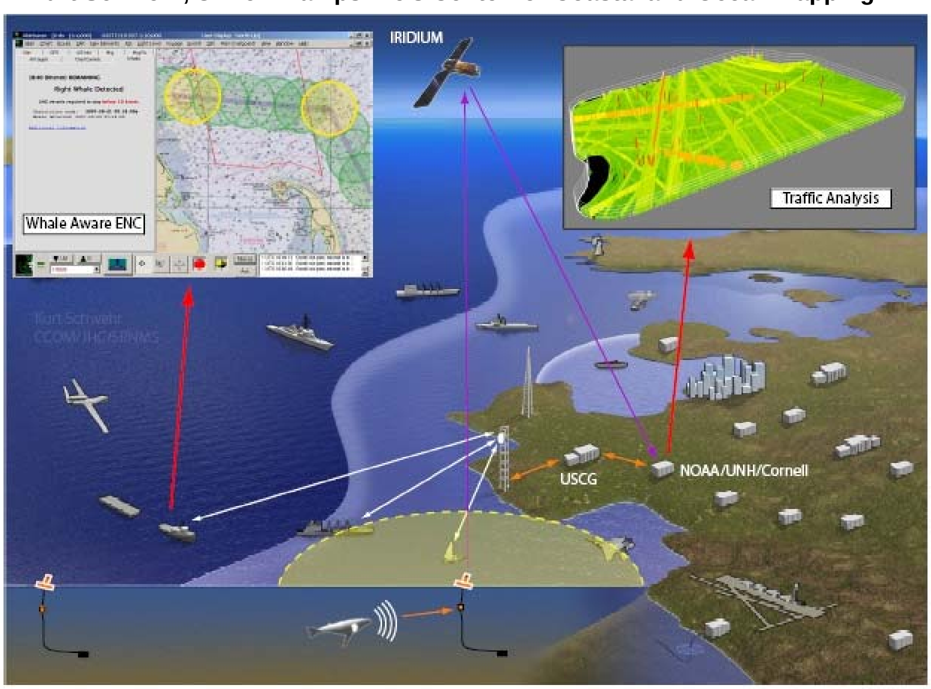
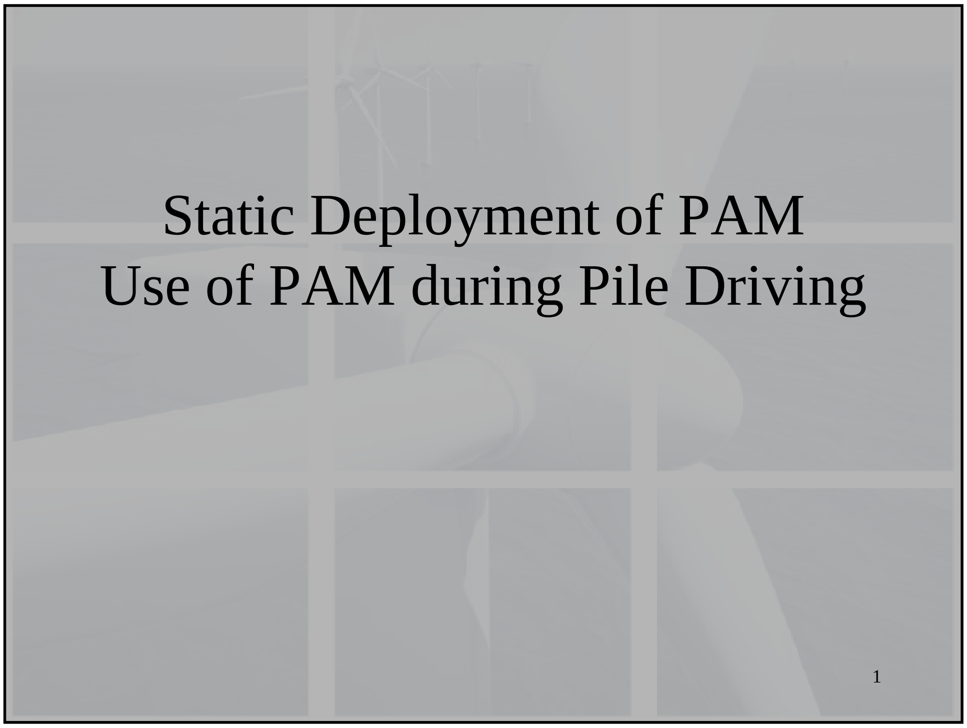
Kurt Schwehr, U. New Hampshire's Center for Coastal and Ocean Mapping

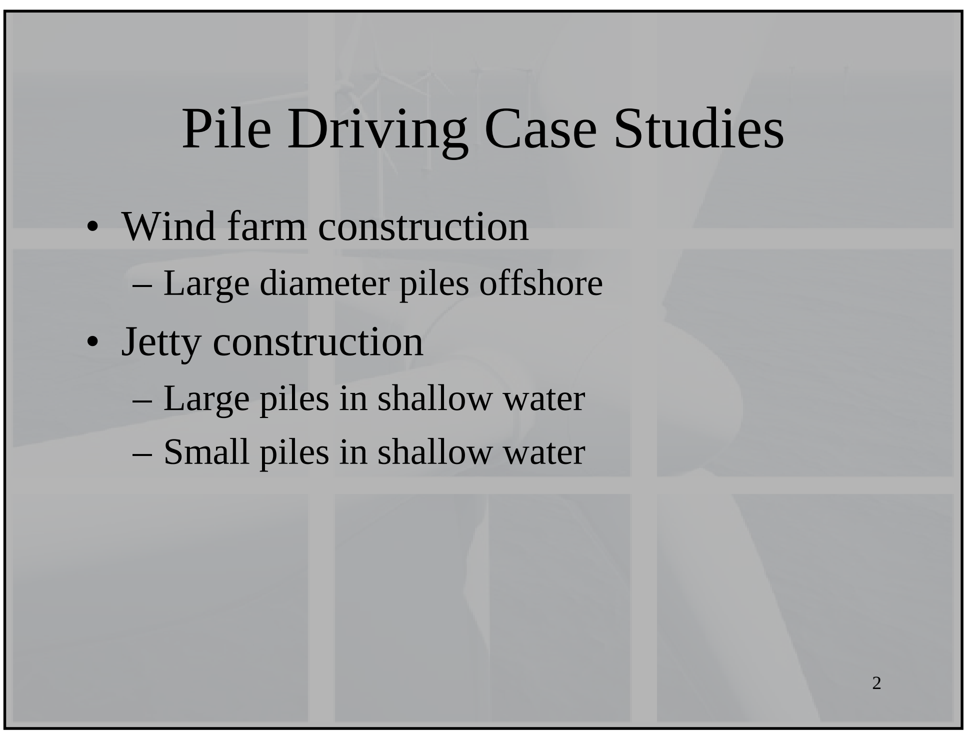


NOAA Guidelines for the Use of Passive Acoustic Listening Systems for Monitoring in Mitigation Programs

- Finalized and distributed October 2008 by
  - NOS Office of National Marine Sanctuaries
  - NMFS Office of Protected Resources
- Standardizing criteria for effective passive acoustic systems associated with NOAA consultations/permitting under
  - National Marine Sanctuaries Act
  - Endangered Species Act
  - Marine Mammal Protection Act
  - Coastal Zone Management Act

Bill Streever's presentation "Fixed Passive Acoustic Monitoring using DASARs at BP's Northstar Production Facility in the Alaskan Beaufort Sea" is not available.


Static Deployment of PAM
Use of PAM during Pile Driving
1


Pile Driving Case Studies
• Wind farm construction
– Large diameter piles offshore
• Jetty construction
– Large piles in shallow water
– Small piles in shallow water
2

Use of Passive Acoustic Monitoring during construction of a wind farm demonstrator

3

Wind Farm Demonstrator

- Installation of two wind turbines
- 24 km outside a SAC
  - Special Area of Conservation (SAC)
  - Important habitat for bottle nosed dolphin
- Environmental Protection Plan (EPP)
  - Considered impact on marine mammals
  - Visual observation
  - Acoustic monitoring

4

Marine Mammals

- Common species in area
  - Bottlenose dolphin
  - Harbour porpoise
  - Grey and common seal
  - Minke whales
- Piling taking place during peak of seasonal activity
- High encounter rates expected

5

Construction

- 22 km off the NE cost of Scotland
- 2 wind turbines of 5MW capacity
- Each turbine needed 4 piles
  - 72 inch diameter steel piles 44m long
  - Hydraulic impact pile driver weighing 25 tons
  - Maximum force 500 kN
  - Strike rate at max energy 45 bpm
- Water depth 45m

6

Barge “Rambiz”

8

Hydraulic Pile Driver “IHC S-500 Hydrohammer”

9

Mitigation Policy

- Precautionary approach taken
  - Based on Temporary Threshold Shift (TTS) levels

Exclusion zone calculated to be a 1 km radius

- Area to be free of visual or acoustic detections for 30 mins before commencement of piling
- Any visual or acoustic detection to delay or cease the piling operation
- All pile driving to be carried out during day
- Soft start procedure used

10

Challenges

- Acoustic monitoring in a noisy environment
  - Vessel noise
  - Rig noise
  - Pile driving noise
- Wide bandwidth to be monitored
  - Harbour porpoises 150kHz plus
- Limited Resources
  - 1 buoy
  - 2 observers
- Large area to be surveyed

11

Soft Start Procedure

– Minimum energy single blow	wait 5 minutes
– Second single blow	wait 3 minutes
– Third single blow	wait 2 minutes
– Fourth blow single blow	wait 1 minute
– Fifth single blow	

– Piling continues at min energy for 20 mins

– Full soft start if piling stopped for 10 mins +

12

Mitigation

- Two MMO observers
- One of the observers also operated the Passive Acoustic Monitoring system
- Observers based on a fishing boat
- Remote PAM system deployed
  - Operational 30 mins before piling start up

13

Visual Mitigation

- MMO’s based on fishing vessel
- 20 km transects made twice a day
  - Weather permitting
- Visual survey of mitigation area
  - Pre piling
  - During piling

14

Acoustic Mitigation

- Remotely Operated Buoy
  - Two vertical arrays, 4 hydrophones
    - Gives bearing to detection
  - Band width 20 Hz to 175 kHz
  - Remote on/off
  - Telemetry of acoustic data to fishing vessel
  - Started monitoring typically 1hr before piling
    - min of 30mins

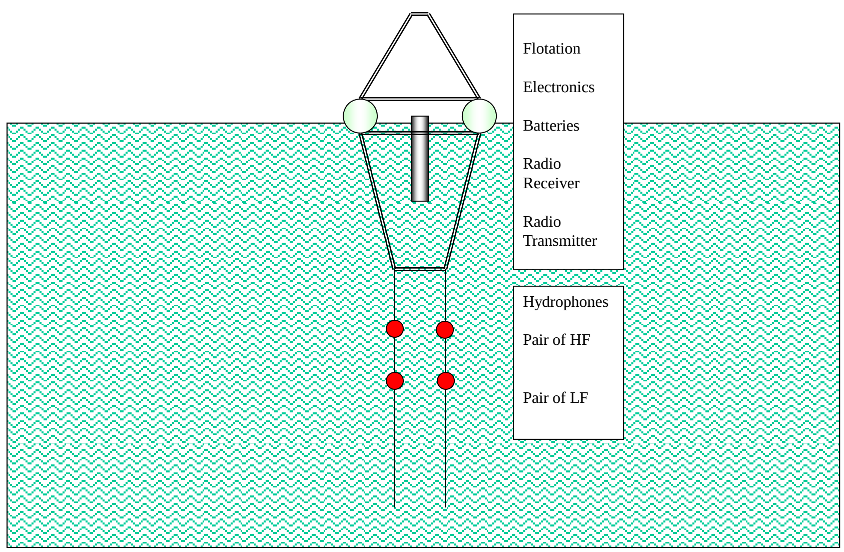
15

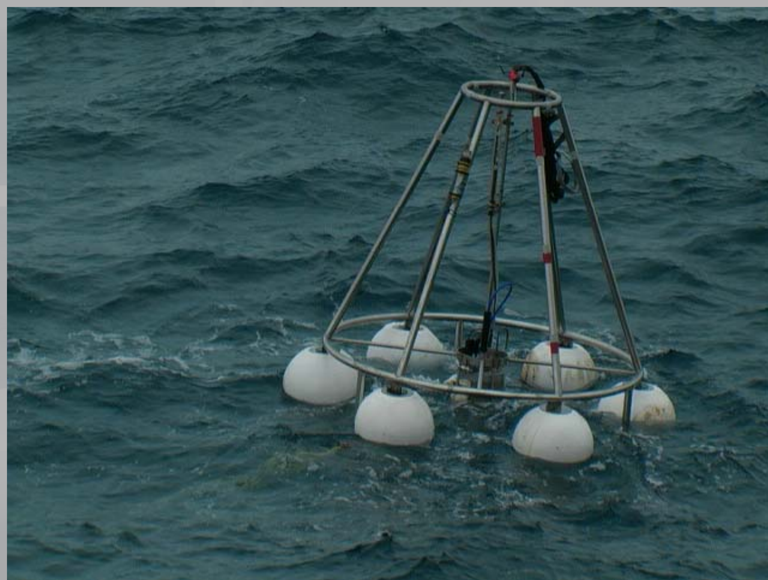
Acoustic Mitigation

- Buoy deployed 100m from pile site
  - Monitoring vessel moved away from deployment site
- PAM operator & MMO on fishing vessel
- Buoy deployed early am on days of piling
- Retrieved when piling finished for day
  - Batteries recharged overnight

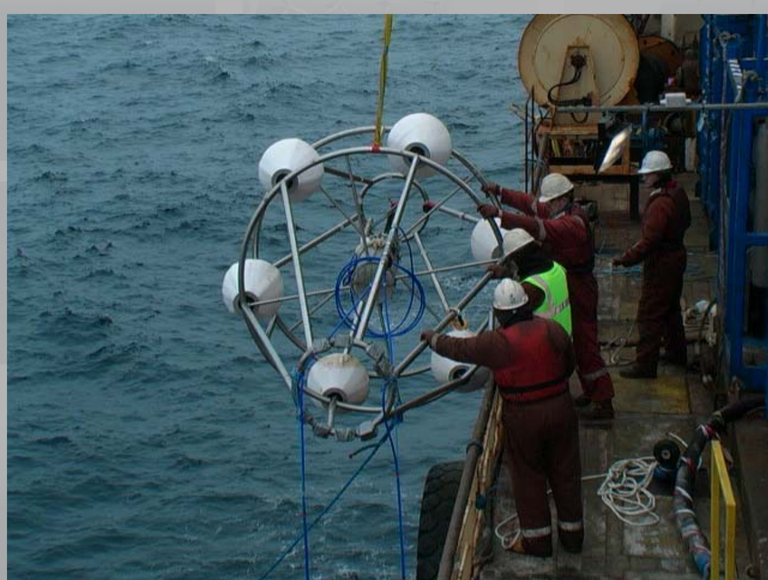
16

Fishing Vessel “Prowess”





19



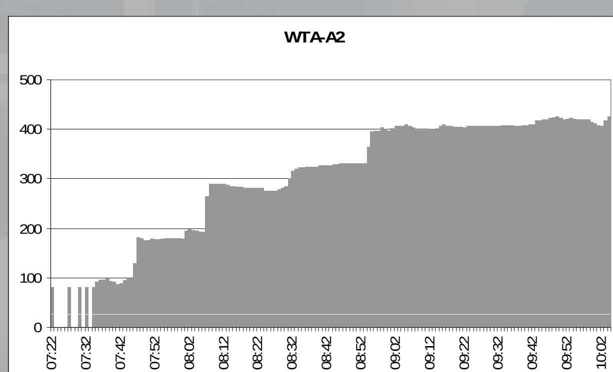
20

Acoustic Monitoring Software

- The IFAW set of software was used
- Standard software package for marine mammal monitoring
  - Porpoise detector
  - Rainbow click
  - Whistle detector
  - Spectrographic display – Ishmael
  - Audio monitoring by operator

23

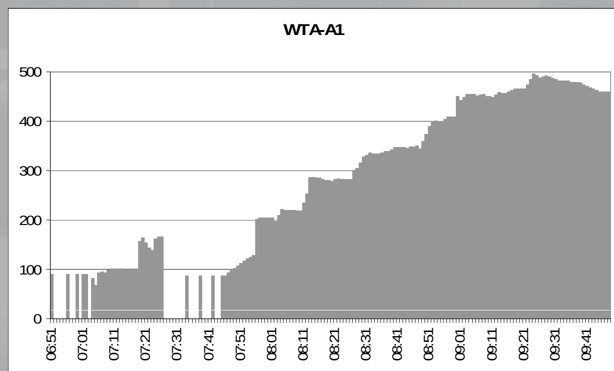
Pile Driving Energy Level



Mean force (kJ) applied per strike in a one minute period

24

Pile Driving Energy Level



Mean force (kJ) applied per strike in a one minute period

25

Sightings & Detections

- No sightings made within the 1km exclusion zone
- No Acoustic detections
- Possibility that area was avoided by marine mammals due to high levels of activity
- Sightings were made on transects from shore and on local platforms
  - Closest sightings were 5km away

26

General Data

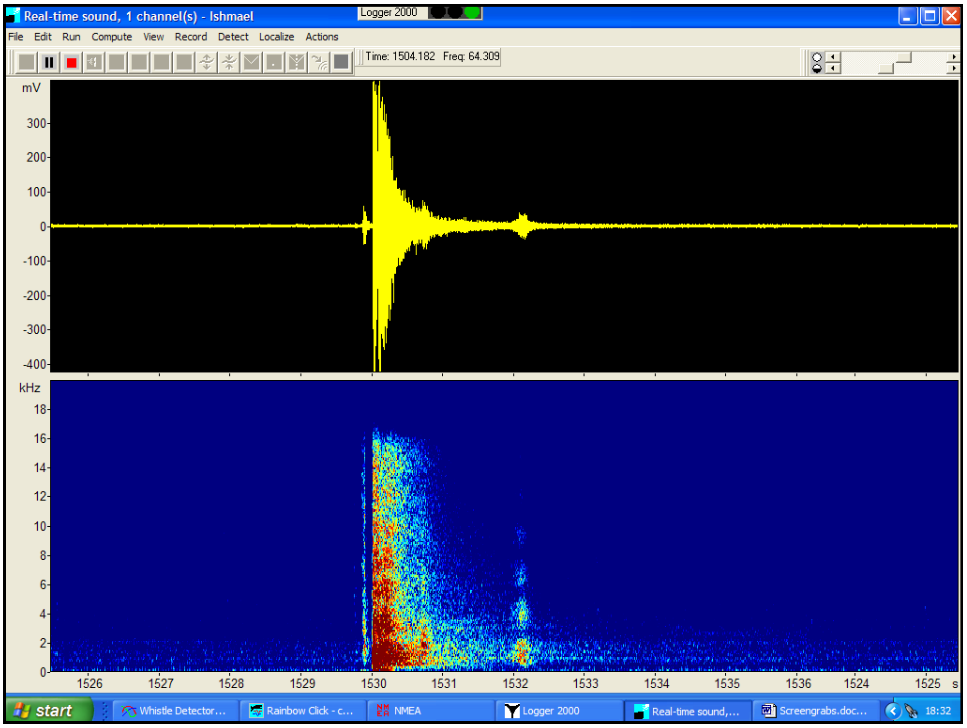
- Time to drive piles
  - 1hr 48mins quickest
  - 2hrs 37mins longest
- Total visual observation time - 90 hrs
- Total acoustic monitoring time – 29 hrs
- Soft starts for first turbine – 6
- 6000 to 7000 strikes to drive a pile

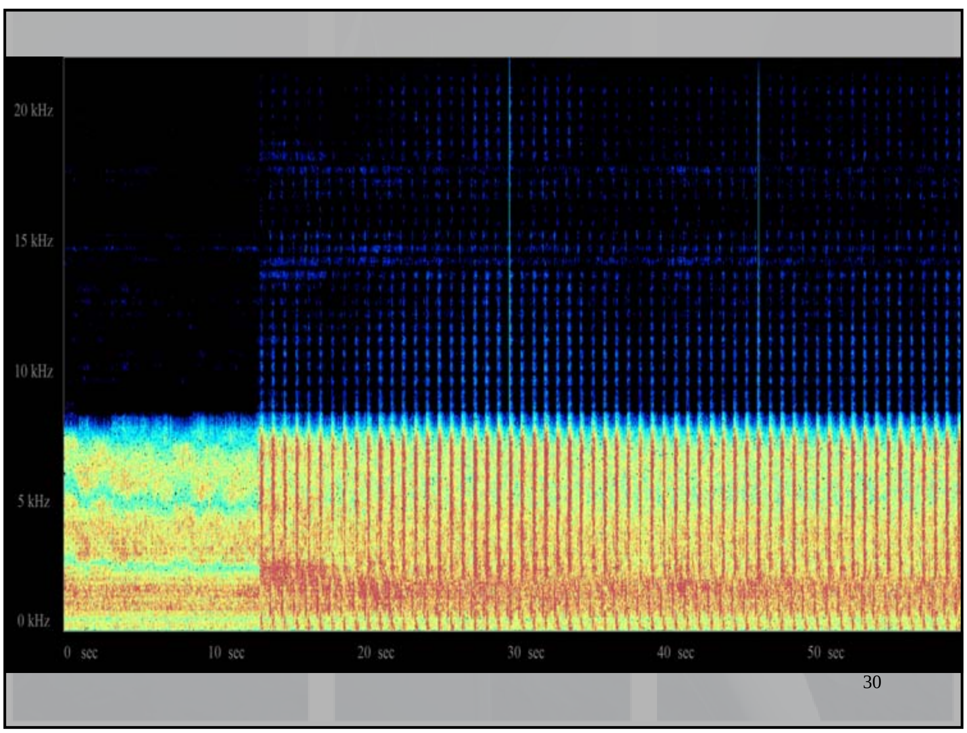
27

Acoustic Monitoring

- In addition to mitigation the PAM system monitored the pile driving noise
  - Time series
  - Spectrographic information
- Vessel movements during PAM operation limited effectiveness (a few times)
- Closeness of PAM system to pile driving limited ability to carry out detections during piling

28


Real-time sound, 1 channel(s) - Ishmael
Logger 2000
File Edit Run Compute View Record Detect Localize Actions
Time: 1504.182 Freq: 64.309
mV
300
200
100
0
-100
-200
-300
-400
kHz
18
16
14
12
10
8
6
4
2
0
1526 1527 1528 1529 1530 1531 1532 1533 1534 1535 1536 1524 1525 s
start
Whistle Detector...
Rainbow Click - c...
NMEA
Logger 2000
Real-time sound,...
Screengrabs.doc...
18:32


20 kHz
15 kHz
10 kHz
5 kHz
0 kHz
0 sec
10 sec
20 sec
30 sec
40 sec
50 sec
30

Acoustic Measurements

- Level Measured at 100m
  - SPL 200dB re 1μPa
- Calculated source level
  - SPL 235 to 240dB re 1μPa (based on spherical spreading)
- Based on measurements mitigation zone should have been 2km
  - Measurement data processed after event

31

Lessons Learned

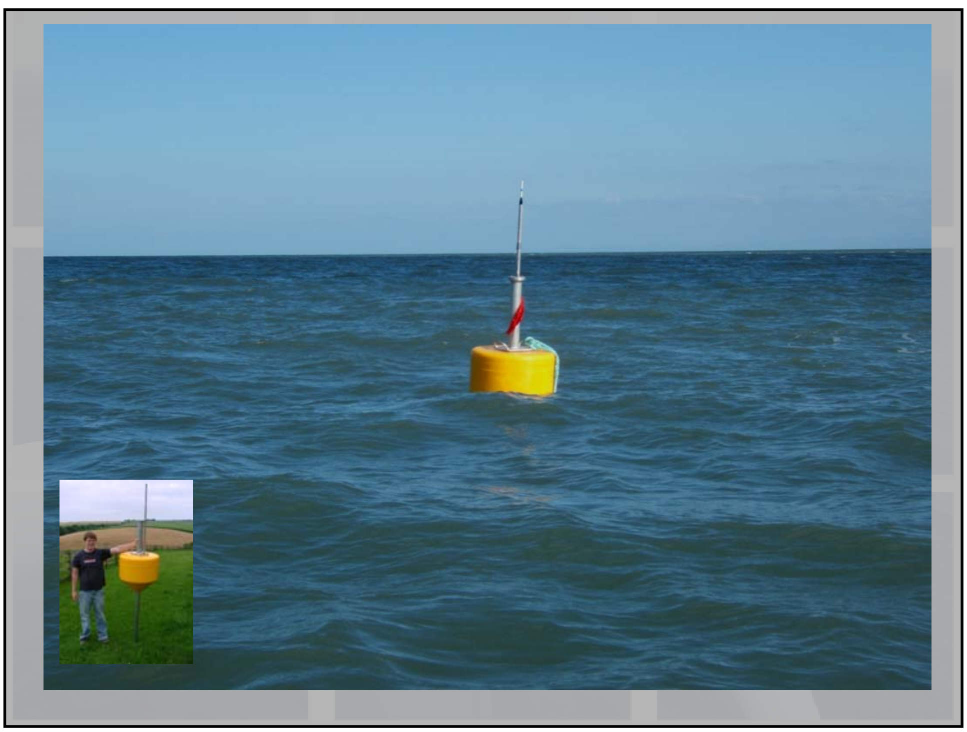
- Visual observations limited by position of monitoring vessel
- Acoustic monitoring limited by
  - Pile driving noise – too close to pile driver
  - Presence of other vessels
- Gradual ramp up did not occur
  - A series of abrupt changes not ideal
- Acoustic levels higher than predicted

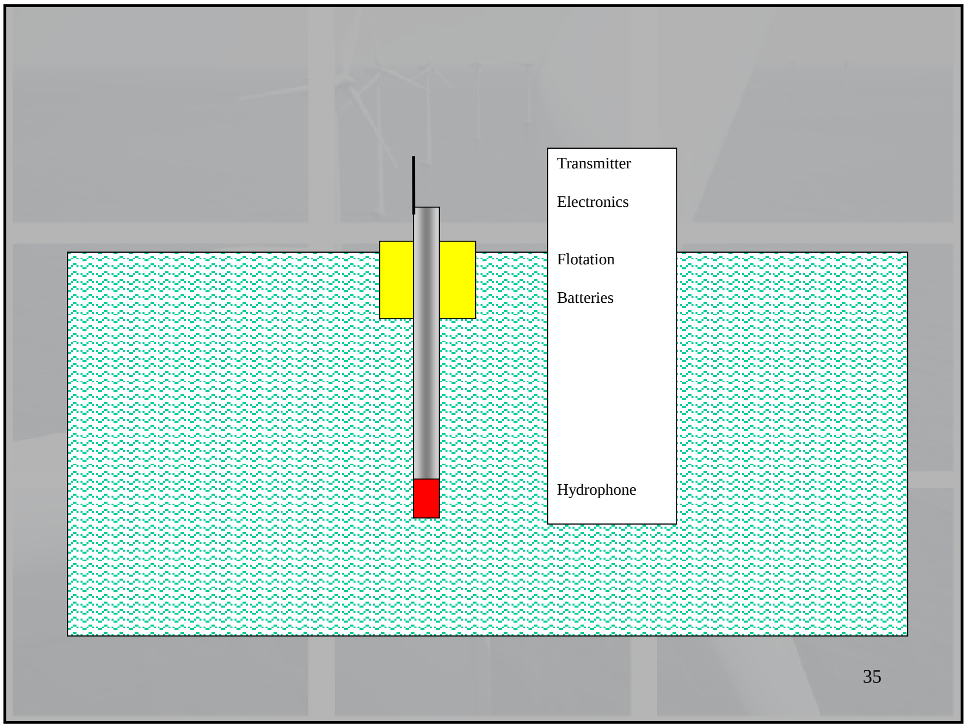
32

Updates

- New buoy and telemetry technology
  - Smaller
  - Easy deployment
  - Long range telemetry
- New Software
  - PAMGUARD
    - Now proven and can be fully utilized

33




Transmitter
Electronics
Flotation
Batteries
Hydrophone
35


Pile Driving in Milford Haven
36

Milford Haven

- Welsh coast of the UK
- Within European Marine Special Area of Conservation
- One of the largest oil and gas ports in Europe
- 2 new LNG terminals constructed
  - South Hook LNG
  - Dragon LNG

37

South Hook Jetty Construction

- Impact Pile driving over a 18 month period
- SPL measurements during test pile driving
- Exclusion zone of 500m defined
  - Visual Observation
    - Based on Jetty
  - PAM for use at night or poor visibility
    - Deployed from jetty when required
    - Operator was a trained MMO
- Noisy site

38

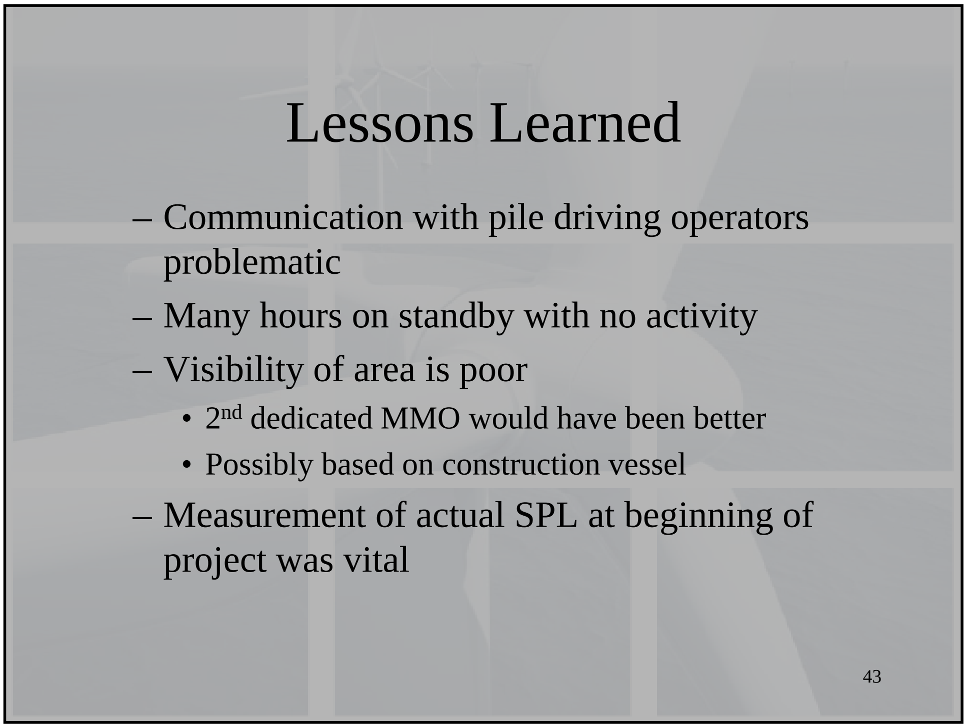

39

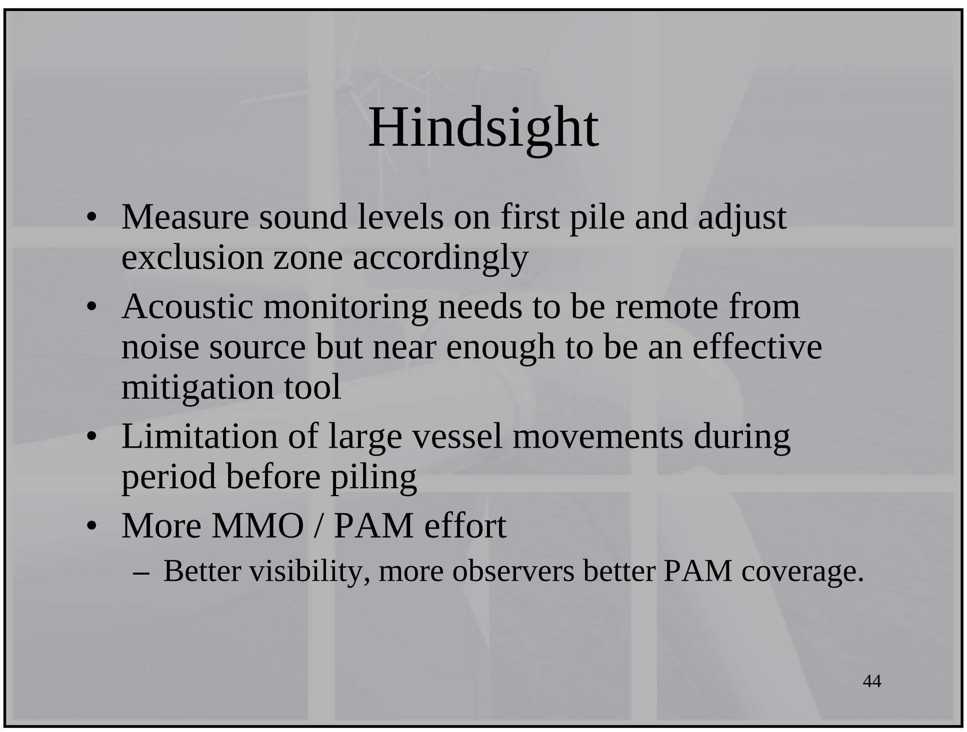

40

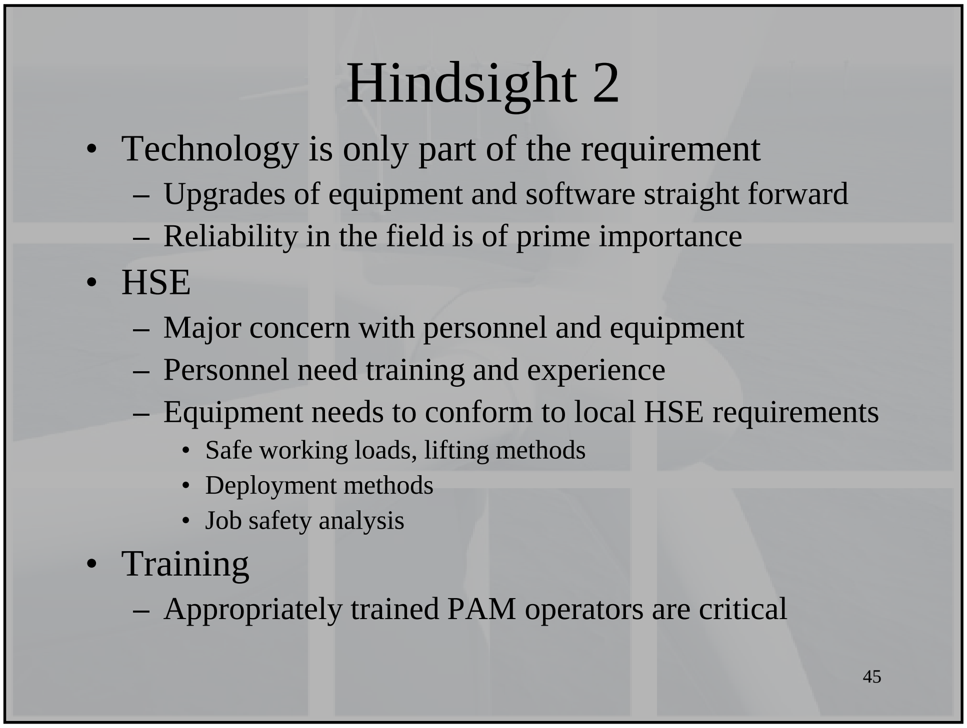
Dragon Jetty Construction

- Vibration driving of small piles
- SPL measured during driving of test pile
- Exclusion zone calculated at 10m
- Visual MMO only
- No pile driving at night
- PAM not required

41


Lessons Learned
– Communication with pile driving operators problematic
– Many hours on standby with no activity
– Visibility of area is poor
• 2nd dedicated MMO would have been better
• Possibly based on construction vessel
– Measurement of actual SPL at beginning of project was vital
43


Hindsight
• Measure sound levels on first pile and adjust exclusion zone accordingly
• Acoustic monitoring needs to be remote from noise source but near enough to be an effective mitigation tool
• Limitation of large vessel movements during period before piling
• More MMO / PAM effort
– Better visibility, more observers better PAM coverage.
44


Hindsight 2
• Technology is only part of the requirement
– Upgrades of equipment and software straight forward
– Reliability in the field is of prime importance
• HSE
– Major concern with personnel and equipment
– Personnel need training and experience
– Equipment needs to conform to local HSE requirements
• Safe working loads, lifting methods
• Deployment methods
• Job safety analysis
• Training
– Appropriately trained PAM operators are critical
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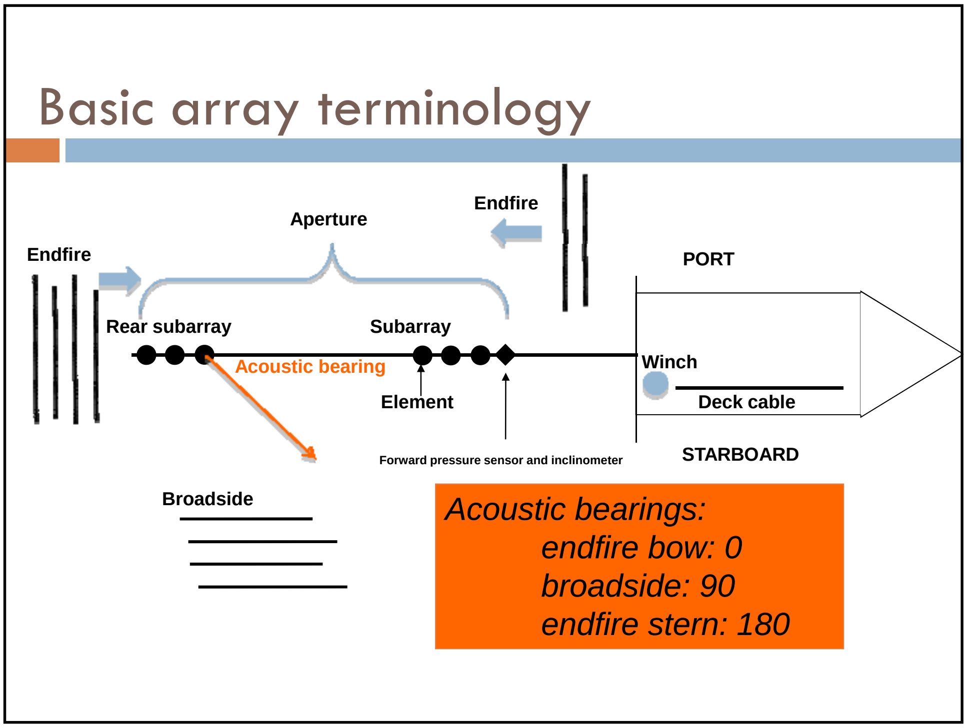
OVERVIEW OF PAM TOWED ARRAY SYSTEMS

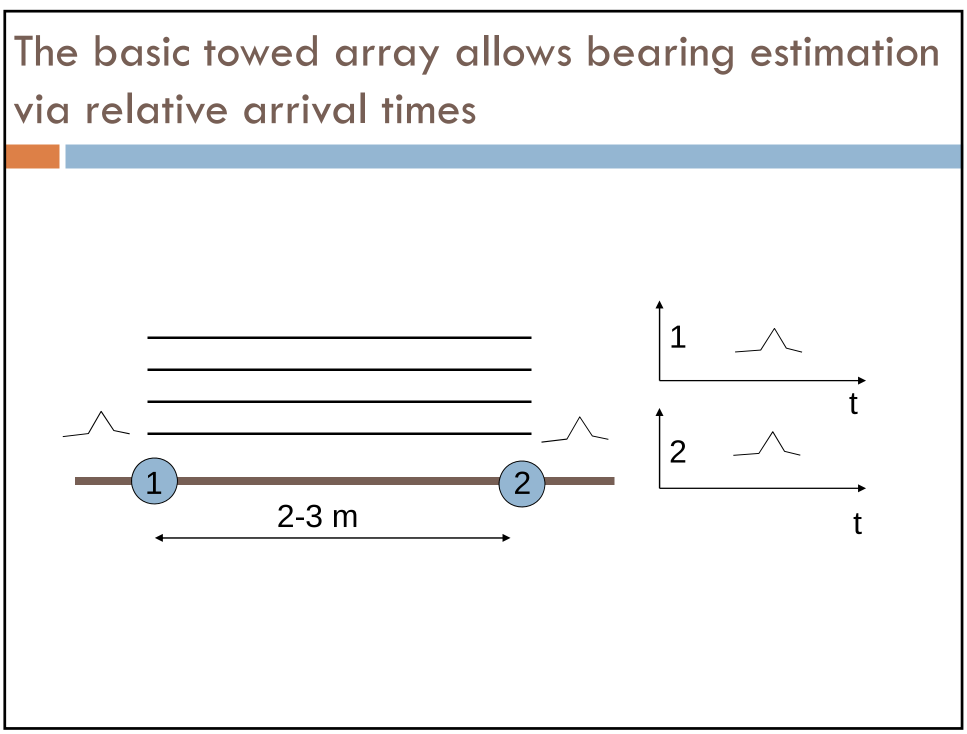
Aaron Thode
Scripps Institution of Oceanography
University of California, San Diego

MMS OGP PAMGUARD (Doug Gillespie)

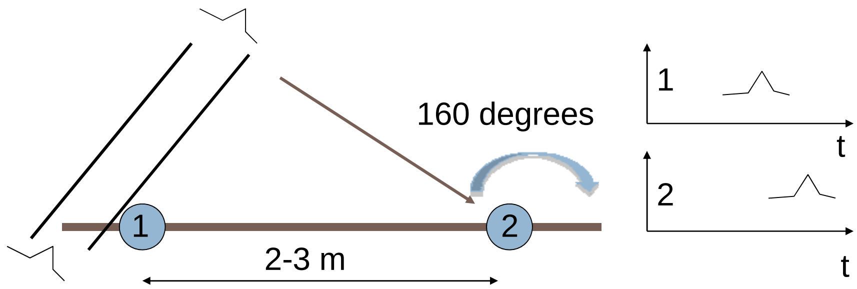
Towed array systems one of the oldest PAM configurations

- Overview of terminology
- Review of "standard" techniques
  - Acoustic bearing estimation
  - Range estimation via time-motion analysis
- Advantages/Disadvantages of towed systems
  - What is intrinsic, what can be solved with additional development?
- Research into extending towed PAM capabilities
  - 3-D tracking
  - Solving the ambiguity problem with vector sensors

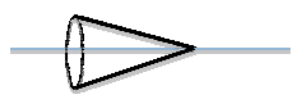

Basic array terminology
Endfire
Aperture
Endfire
PORT
Rear subarray
Subarray
Acoustic bearing
Winch
Element
Deck cable
Forward pressure sensor and inclinometer
STARBOARD
Broadside
Acoustic bearings:
endfire bow: 0
broadside: 90
endfire stern: 180


The basic towed array allows bearing estimation via relative arrival times
1
t
2
t
1
2
2-3 m

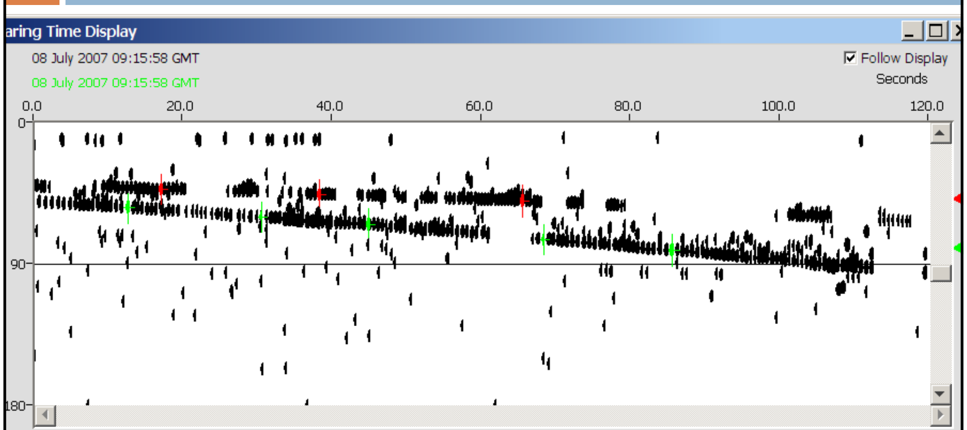
Bearing estimation for a near "endfire" signal



The acoustic bearing is actually a "cone" with axis aligned along the cable.



Typical computer display



Passing two animals

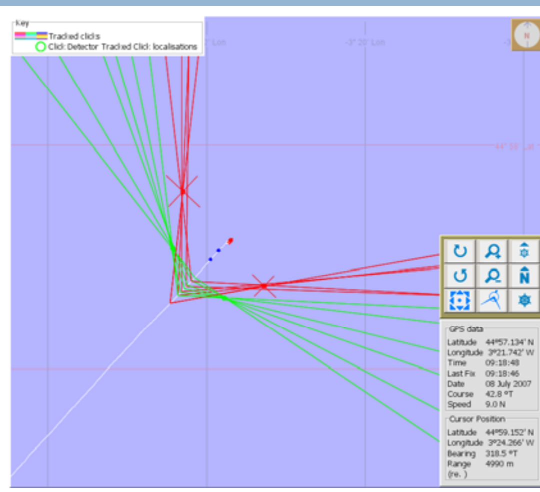
Credit: Doug Gillespie, SMRU

The “rules” of bearing estimation

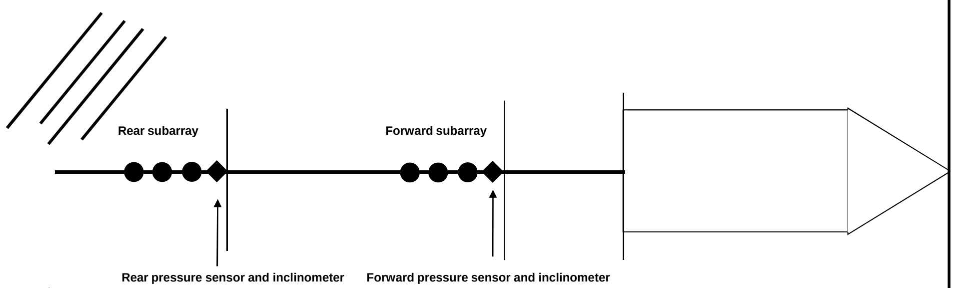
- The wider the hydrophones, the more precise the bearing.
- More precise “broadside” than “endfire”.
- Can’t tell “left” from “right”, “up” from “down”.
- Incorporated into PAMGUARD, Ishmael, Rainbowclick, and numerous proprietary programs.

A sequence of bearings can provide a spatial fix, given assumptions

Assumptions:
(1) Ship is faster than whale (fixed whale)
(2) source is shallow/close to surface
(3) Sound sequence is from same animal/group of animals.



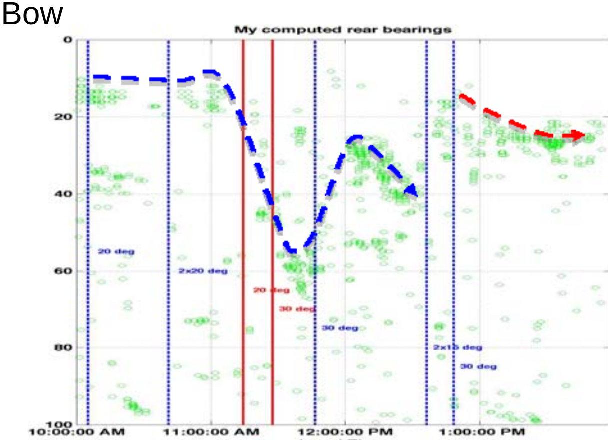
Single linear array cannot distinguish port/starboard



- Decision which way to turn during survey important
- Current options:
  - Turn (not practical, requires continuous calls)
  - Second lateral array

Example of how to establish "handedness" of a sequence of bearings

Bow



Broadside

- Animal on port side:
  - Starts on bow.
  - Ship turns starboard (red vertical lines).
  - Bearings shift toward broadside.
  - Ship turns port
  - Bearings shift back to bow.
  - Ship turns port some more.
  - Animal shifts to starboard side

Advantage: Large spatial coverage with minimum equipment

- Mobile: can remain close a moving source of concern
  - Close-range mitigation of mobile activities
  - Tracking a focal group of animals
- Real-time high-bandwidth monitoring
- No power or memory limitations
- Easily incorporated into visual mitigation and monitoring protocols, survey procedure and theory
  - Preferred approach for surveying
- Covers large spatial scales with minimum equipment

Intrinsic disadvantage: limited time coverage

- Limited to ship availability
  - Limited time
  - Limited conditions
- Vulnerability to at-sea damage
  - Deployment
  - Water hazard
- Restricted maneuverability

Intrinsic disadvantage(?): detection range

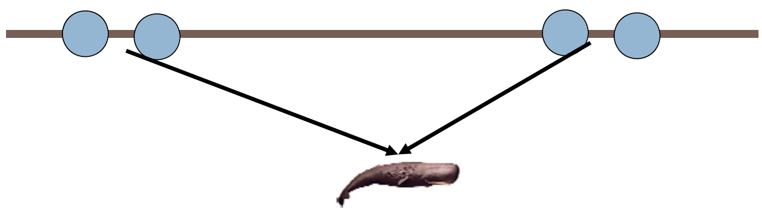
- Subject to many sources of noise
  - Tow platform noise, esp. if "opportunistic vessel"
  - Flow noise
  - Mitigation source noise
  - "Listening for birds next to a waterfall"
- Difficult to detect in front of survey platform
  - Precisely region of interest for mobile mitigation
- Some technological improvements possible
  - Array gain from additional hydrophones (need >=8)
  - Vector sensors
  - Bow deployment?
    - Mounted hull deployments a "mixed bag"

Disadvantage: limited localization ability-may not be intrinsic

- Typically 1-D localization via TOA
  - Frequency dependent
  - Low resolution toward endfire
  - Acoustic "bearing" cannot separate range from depth.
  - 2-D estimates via time-motion analysis require many assumptions and many vocalizations
- Port/starboard ambiguity
  - Moving the vessel undesirable (and long time lag anyway)
- Rest of talk: technological solutions to localization ability

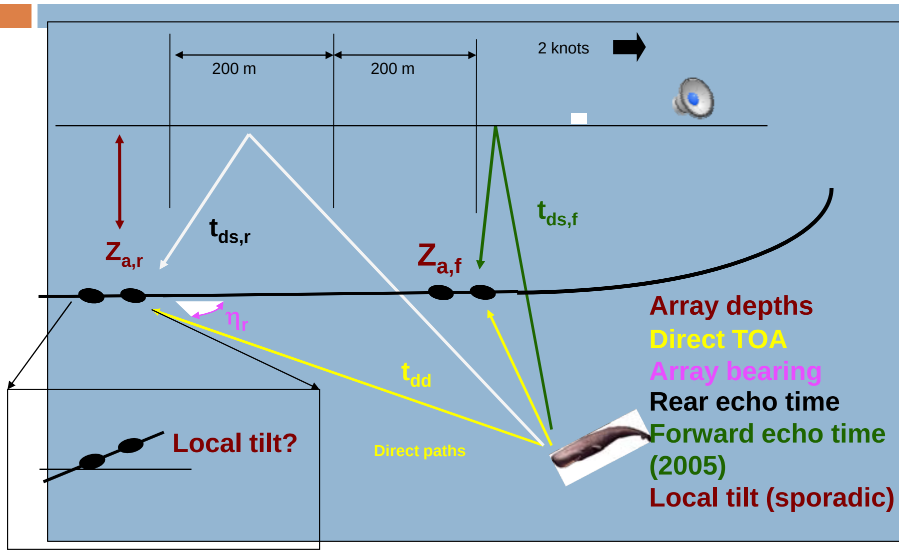
Bearings to distances 2: crossing simultaneous bearings

- Assumes wavefront is "curved"
  - Source is within 5x array aperture
- Oldest localization method (Euclid, 300 BC)
- Requires more hydrophones, longer array, or two arrays on same or separate vessels
- Incorporated into various software packages, including Ishmael and PAMGUARD.

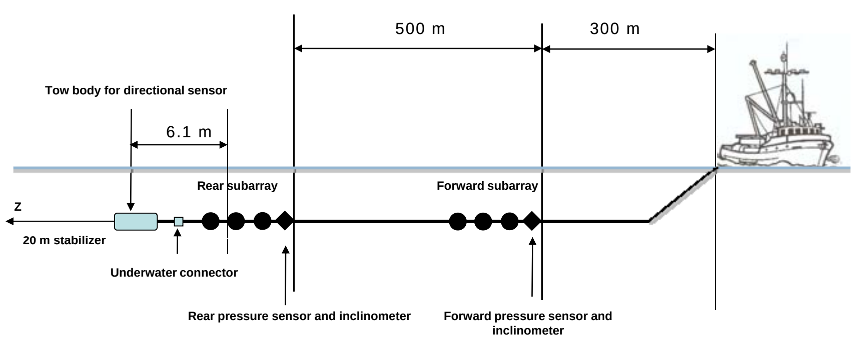


Detection range = cable length

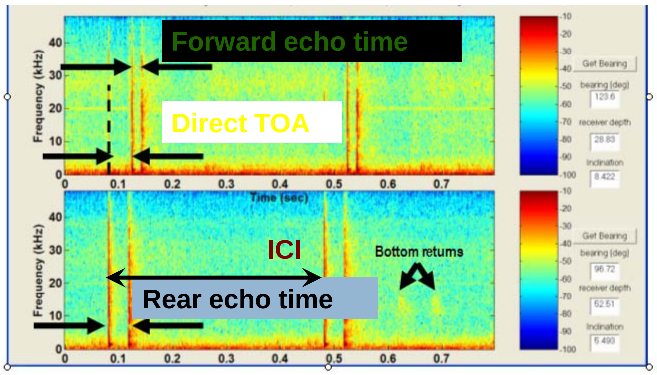
3-D tracking with a towed array exploits "echos" from ocean surface



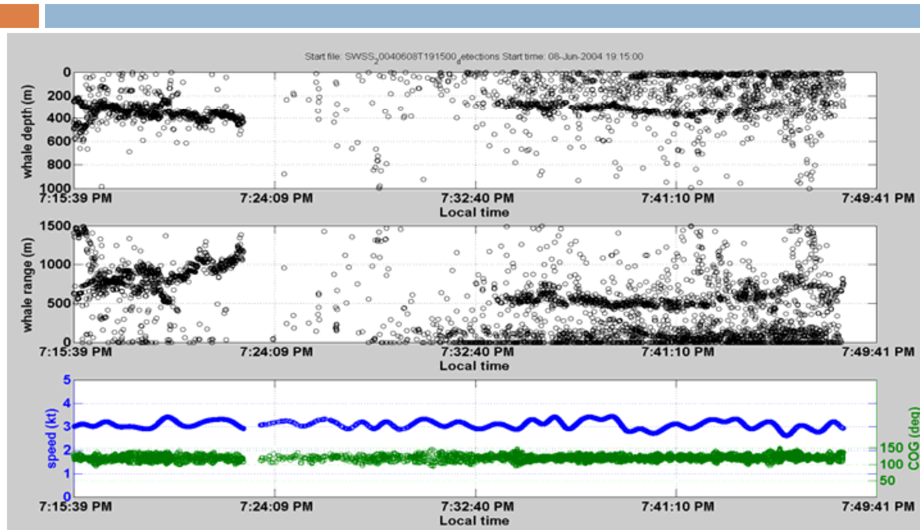
Configuration for short-range 3-D tracking



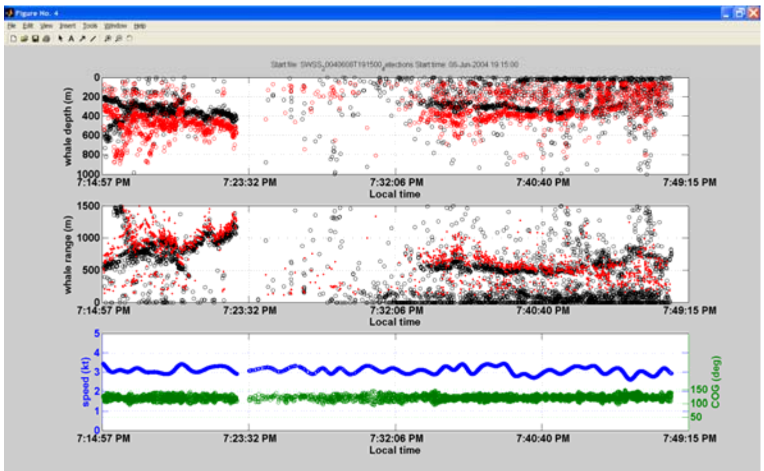
Visual representation of localization parameters



Tracking results for a ship on a steady course

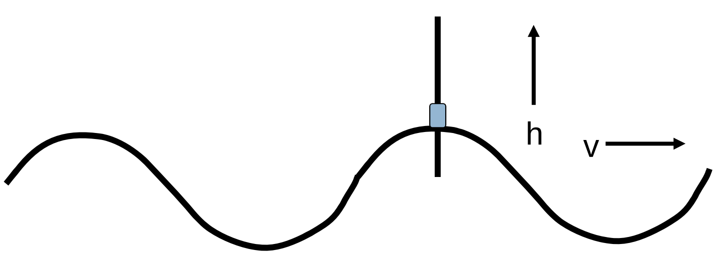


Effect of realistic sound speed profile



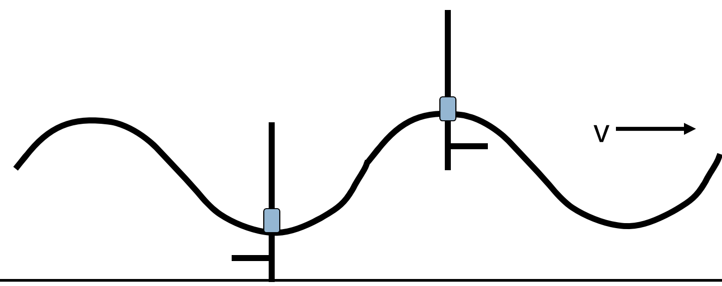
An acoustic wave has both velocity and pressure

- Molecules in a wave have a directional motion.
- Water wave analogy-measuring pressure is like measuring height of a wave: can't measure direction of travel



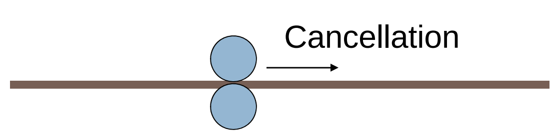
Measuring pressure and velocity gives a unique direction

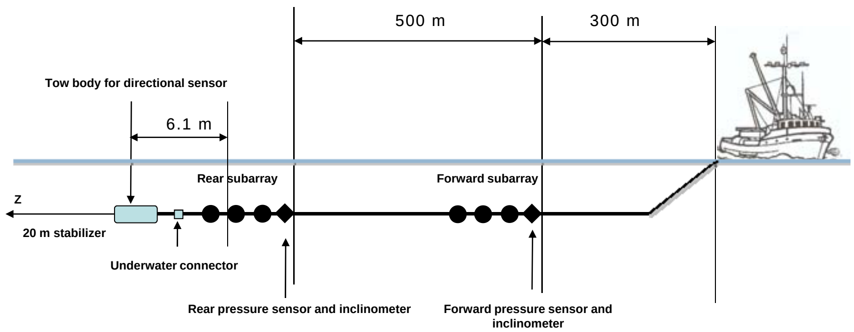
- Analogy-a piece of string "blows" left in trough of right-traveling wave , "blows" right at crest.
- Velocity alone can't distinguish left from right, but measuring both gives direction.
- "Hearing specialist" fish figured this out long ago.



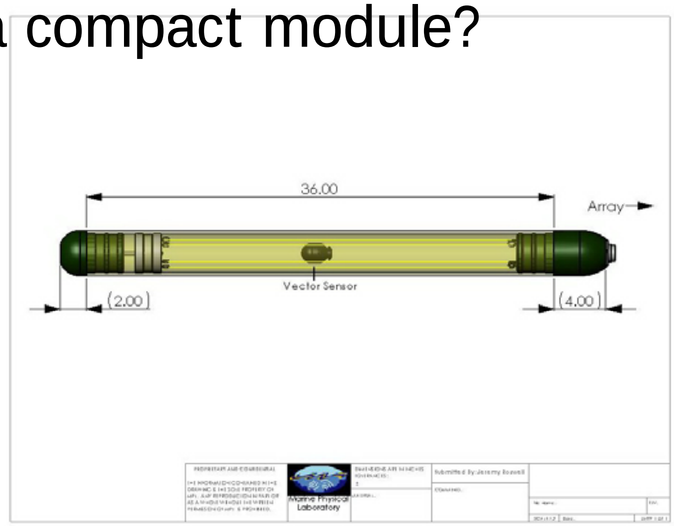
A vector sensor can either be a small array or a "geophone"

- In acoustics, velocity can be measured indirectly by measuring "gradient" of wave.
- Closely spaced hydrophones in a ring around a cable one option
  - Bulky, need precise calibration
- Geophones, accelerometers
  - Vibration sensitive

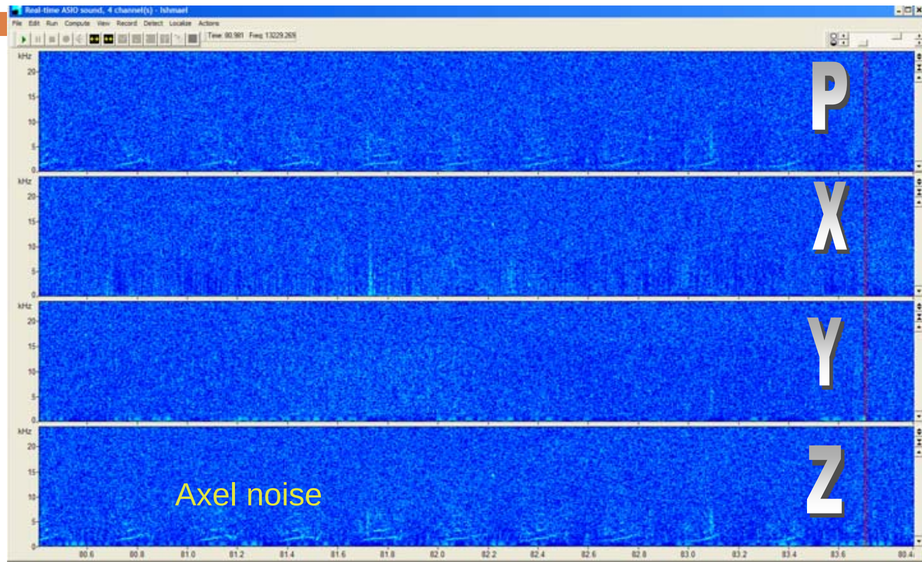


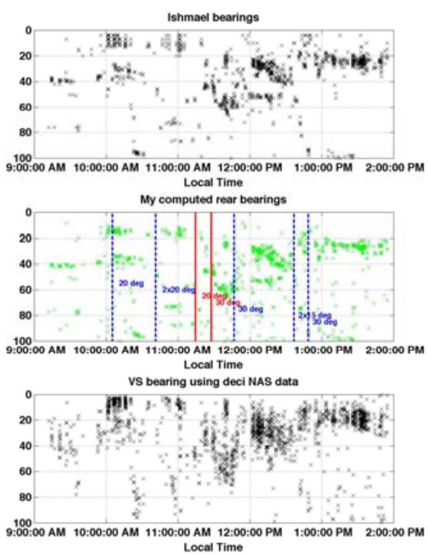


Key uncertainty: reducing mechanical vibration and flow noise in a compact module?



Can confirm noise rejection from tow vessel



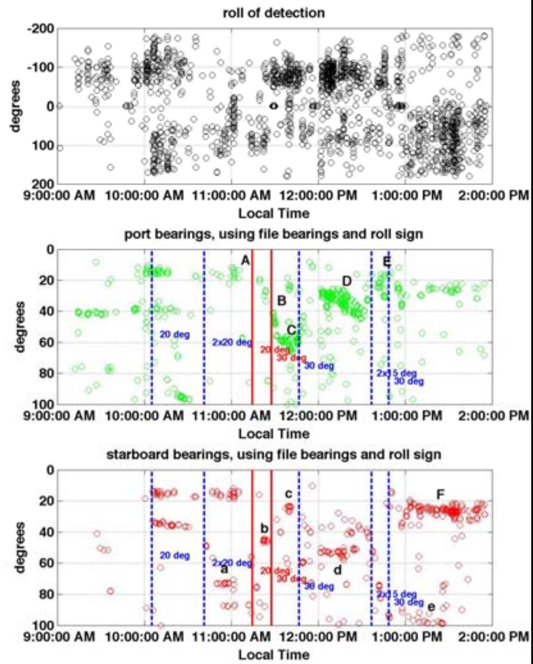


Vector sensor can measure angles from a single point

-Vector sensor allows two whales to be separated, one port, one starboard.

-Vertical lines represent port(blue) or starboard(red) turns.

-Note whale shifting from port to starboard from “D” to “F”.



Summary

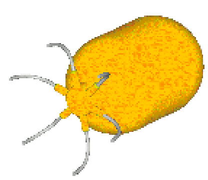
- Towed PAM one of the most “mature” technologies, used extensively for surveys and close-range mitigation of mobile activities.
- Advantages: large spatial coverage, mobility
- Disadvantages: short time coverage, detection range
  - How does one guarantee a minimum detection range for a towed array?
  - Can additional hydrophones overcome detection range issues?
  - Can arrays be “towed” from the bow of a vessel?
- Localization ability limited, but technological fixes may be possible.
  - 3-D tracking possible using large aperture, surface reflection.
  - Vector sensors break ambiguity, some noise rejection.
  - Incorporating sensors into standard seismic streamers.

Case studies

- Claudio Fossati, CIBRA-practical, logistical issues in PAM deployments in the field
- Mary Jo Barkasi-towed PAM in the Gulf of Mexico
- Bruce Martin, JASCO- extending localization capabilities of towed PAM, removing port/starboard ambiguity

Wilcoxon Research

VS-205 Vector Sensor



Features
- Preamplifer and differential output
- Pitch and roll
- Heading
- Health check
- Micro-controller (RS-485 com port)

Dynamic

Output sensitivity:	
Accelerometer	3.5 V/g
Hydrophone	-158 dB re 1.0V/uPa
Full scale input range:	
Accelerometer	2.0 g peak-peak
Hydrophone	400 Pa peak-peak
Resonance frequency	13.5 kHz
Frequency response	3 Hz - 5 kHz
Transverse sensitivity	<5%

5 kHz

Electrical

Power requirement: voltage	6.5 - 9 Vdc
current	< 55 mA
Accelerometer noise intersection with Knudsen SS0	420 Hz
Output type	differential
Output impedance	<100 Ohm

Environmental

Pressurse range:	
Operational	0 - 1500 psi
Survival	2500 psi
Operating temperature	-40°C to 60°C

Physical

Diameter	1.60 inches
Length	2.80 inches
Neutral buoyancy in water	-31%
Mass (w/o cables)	76 grams

Hardware export classification: USML XI(c)

MEGGITT
smart engineering for extreme environments
98932 Rev.A 08/06

This marketing information is exempt from U.S. export controls

BHP Billiton Multi-Vessel Survey

A case study for the commercial application of Passive Acoustic Monitoring (PAM) for regulatory compliance in the Gulf of Mexico, USA

By Mary Jo Barkasi, M.S.
Vice President, Protected Species Compliance Programs, RPSGeocet

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Acknowledgments

- BHP Billiton – Full support and commitment to the project and scope
- Minerals Management Service Gulf of Mexico Region – Carol Roden, Deborah Epperson, & Ron Brinkman
- WesternGeco
- Seiche Measurements

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Regulatory Background

RPS

- Since 2003, Notice To Lessees (NTL) regulations have included an Experimental Passive Acoustic Monitoring (PAM) Option
- The MMS strongly encourages operators to participate in an experimental program by including passive acoustic monitoring as part of the protected species observer program.
- Monitoring with a passive acoustic array by an observer proficient in its use will allow ramp-up and the subsequent start of a seismic survey during times of reduced visibility (darkness, fog, rain, etc.) when such ramp-up otherwise would not be permitted using only visual observers.
- NTL provides for the alternative to implement a separate constant source for continued firing between lines during non-visual conditions

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Project History with PAM in the Gulf of Mexico

RPS

- Borehole seismic and blasting operations have used PAM successfully throughout the GOM since 2003
- BHP Billiton project was the first fully commercial use of towed PAM in the GOM for a conventional marine seismic survey
- Survey was also multi-vessel making it one of the few, possibly only, commercial PAM applications in such a setting

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Project Objectives

RPS

1. Zero Harm
2. **Safe operations**
   a. Ensure 100% compliance with regulatory requirements
   b. Improve marine mammal protection
      - Provide 24hr monitoring for marine mammals
      - Reduce noise footprint
3. **Test PAM technology under normal operations**
   a. Identify deficiencies to allow further development
4. **Engagement of all key stakeholders in project planning**
   a. Regulatory Agencies - MMS, NMFS
   b. PAM developers and operators
   c. WesternGeco
   d. BHPB Partners

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Equipment and Software

RPS

- 4-hydrophone cable from *Seiche Measurements* with IFAW and Pamguard
- GOM is unique with Odontocete species prevalent and only one common baleen species (Brydes)
- Odontocetes were primary species with Sperm Whales being focus of detection
- Selection of system and design was driven by expectation of species and prevailing regulatory requirements

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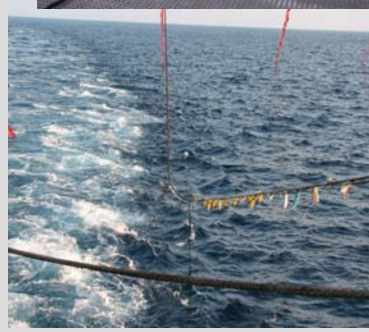
Deployment



- Deployment was off the stern of the vessels using standard equipment.
- Towing arrangement along with deployment and recovery was conducted by the WesternGeco personnel with PAM operator in an oversight capacity.

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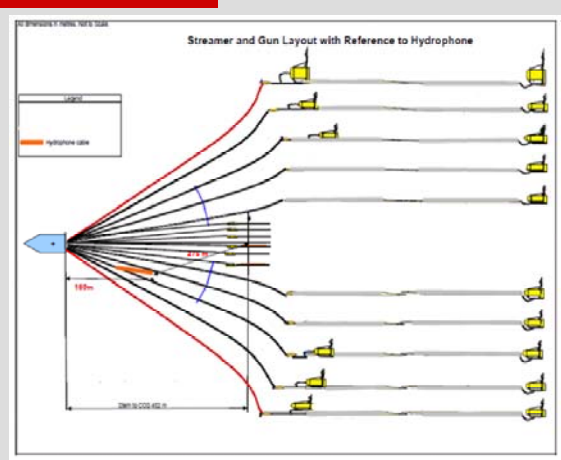
Deployment Schematic

RPS

- Deployed in front of airguns
- Towing depth was 10 – 13 m
- IFAW Software – used for compliance
- Pamguard – used for opportunistic testing



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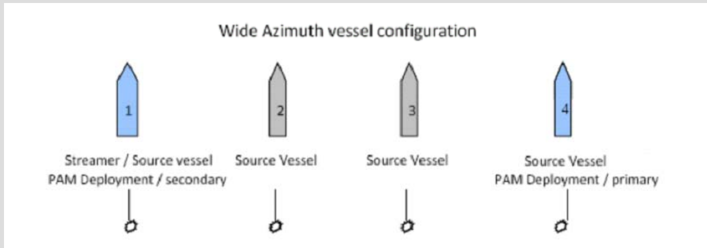
Multi-vessel configuration



- Two vessels utilizing PAM (along with testing of telemetry system)
- Two vessels with sources only, no streamers or PAM.
- Multi-vessel surveys result in utilization of additional sources. Shot intervals are typically similar to conventional 3D surveys but the sources occupy a larger footprint.

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Monitoring Protocols

- All vessels used three visual Marine Mammal Observers (MMOs)
- There was one fully dedicated PAM technician/operator in the field
- There was were 2 PAM-trained MMOs on the two PAM equipped vessels for support
- Dedicated PAM technician goal was nighttime monitoring for compliance.
- Survey design incorporated shooting during line changes and allowed the sources to be shut down while the crew reconfigured the recording systems for the next line in under 20 minutes.
- The NTL allows 20 minutes of silence thus enables return to full power at Start of Line if constant monitoring is conducted.

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PAM Data Summary

RPS

- July 18th – September 8th 2008
- Total hours of visual monitoring: 2580 hours with 133 protected species sighting records (4 vessels)
- Total hours of PAM monitoring: 653 hours with 42 detections (2 vessels)
- Some overlap in visual and acoustic monitoring totaling approximately 76 hours with some acoustic – visual correlations (~10)

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Protected Species Detections

RPS

Species	Observation Record	Number of Records	Ave Duration of Record	Records per hour of monitoring
Sperm Whale	Visual	25	0:15:02	0.019
	Acoustic	22	1:10:00	0.033
Delphinids	Visual	42	0:19:11	0.032
	Acoustic	20	0:15:18	0.030
Other Whales	Visual	3	0:09:40	0.002
	Acoustic	0	0:00:00	0.00
Turtles	Visual	21	0:02:40	0.015
	Acoustic	0	0:00:00	0.00

- **Data only from the two PAM-equipped vessels**
- **Visual records/hour based on 2 MMOs as a single unit of effort**
- **Observations normalized to duration of observation and observations per monitoring hour**

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Protected Species Detection Summary

- Results of detections were within expected ranges
- Sperm whales : higher detection frequency and longer duration of observations.
- Frequency of dolphin detections per monitoring hour were very similar for acoustic and visual detections
- Other Whales : Lower detection frequency (system design-bandwidth, prevalence, behaviour)
- The signal to noise ratio for a commercial operation is likely to have an effect on detection ranges
- Turtles do not vocalize

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Operational savings on project afforded by PAM use

Start Date of Record	End Date of Record	Guns Off	Guns On	Hours of night time gun silence prior to requiring PAM (silence optimized)	Hours of night time gun operations allowed by PAM	Affected Vessels	Reason for PAM monitoring	Alternate mitigation	Amount of time saved within fleet	Amount of individual boat down time saved
		Time (CST)	Time (CST)	Hrs : Min : Sec	Hrs : Min : Sec					
22-Jul	23-Jul	11:58	22:13	3:13:00	9:17:00	Snapper	Ramp up - Guns down waiting for return of KW	Yes, Snapper could have run mitigation gun		
22-Jul	23-Jul	8:53	22:10	3:10:00	9:20:00	KW	Ramp up - Return to prospect for weather	No, arrived on prospect after dark	9:20:00	
29-Jul	31-Jul	6:29	5:18	24:18:00	1:34:00	Snapper	Ramp up - Extensive maintenance	Possible - may have able to run mitigation gun but time would have been extensive		1:34:00
22-Jul	23-Jul	18:57	5:15	Intermittent throughout period, most under 20 minutes	13:22:00	Neptune, Snapper	Ramp up for Snapper, Neptune required intermittent maintenance all under 20 minutes, need for continuous monitoring	No, would not have allowed silence at night	13:22:00	
9-Aug	10-Aug	23:21	0:41	0:50:00	1:20:00	Snapper	Ramp up - Gun maintenance	Yes, Snapper could have run mitigation gun		
5-Aug	12-Aug	1:10		0:30:00	0:30:00	Neptune	Silent turn less than 20 minutes	No, if mitigation source was used it would have resulted in an additional 20 min ramp up		1:30:00
12-Aug	14-Aug	16:19	3:13	36:57:00	2:47:00	Snapper, Neptune	Ramp up - Return from weather	No, all vessels would have to wait until dawn	2:47:00	
16 Aug	29 Aug	n/a		n/a	3:16:00	Neptune	Silent turn less than 20 minutes	No, if mitigation source was used it would have resulted in an additional 20 min ramp up		7:15:00
25-Aug	26-Aug	19:08	19:44:00	0:00:00	10:15:00	Snapper	Ramp up - Sperm whale visual shutdown just before dark	No, vessel would have been shut down for close to 12 hours due to los of visual contact		12:22:00
3-Sep	3-Sep	19:05	3:00	0:00:00	7:55:00	entire fleet	Ramp up - Return to prospect after hurricane	No, all vessels would have to wait until dawn; Neptune did not ramp up but their silent period was less than 20 minutes	7:55:00	

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Project savings

- Saved approximately 33 hours of fleet-wide down time in production directly due to the implementation of PAM.
- Saved 22 hours of individual vessel time which would not have resulted in lost production but would have reduced data quality.

Reduction in noise footprint

- 61.5 hours of silence (when no sources were fired during line changes)
- Noise footprint could have been further reduced with better communications

Mitigation actions during project

RPS

- Non-PAM equipped vessels:
  - No delays or shutdowns
- PAM equipped vessels:
  - VISUAL
    - 3 delays for dolphins prior to ramp up
    - 3 shutdowns for sperm whales
  - ACOUSTIC
    - No delays or shutdowns for protected species
    - 10 PAM-assisted ramp ups

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Evaluation

- Lowlights
- Highlights
- Mitigation tool

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Lowlights

1. Range and Bearing issues - Pre-installation information and coordination could have been better with particular attention to the GPS link and data string to maximize the use of logger program and provide less subjectivity to some compliance decisions
2. Software issues – PamGuard stability. Basic operating parameters and real time support for both PG and IFAW were lacking

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Lowlights (continued)

3. Communications concerning noise reduction objectives did not filter through multiple crew changes. While the goal was achieved, an opportunity was missed to increase the overall effectiveness of the initiative
4. Late in the project a concern was raised over the noise levels and duration of exposure of operators wearing headphones that should have been communicated early in the project

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Highlights

RPS

1. Safety was priority and all work was achieved using safe practices
2. Achieved 100% compliance
3. Reduced noise footprint by 61.5 hours
4. Saved 33 hours of production time and enhanced data quality by allowing all sources to fire for an additional 22 hours
5. Achieved objective of 24 hour monitoring for marine mammal mitigation

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Highlights (continued)

RPS

6. Achieved excellent working collaboration between MMS, BHPB, RPS, and WesternGeco
7. Successful, rigorous trial of PAM hardware and IFAW software including parallel use of Pamguard
8. Demonstrated confidence in species detection with comparable detection rates for Sperm Whales and dolphins

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Highlights (continued)

9. Achieved some acoustic – visual correlations in a working environment
10. Achieved first commercial application of towed PAM array in the GOM
11. BHPB accepted BOTH the benefits and the risks of PAM utilization

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Key Lessons Learned

- Planning
- Communications
- Operators
- PAM as a monitoring tool
- PAM as a mitigation tool

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Planning and Mobilization

RPS

- Safety
- Staffing on board and on shore
- Spares requirements and logistics
- Equipment installation
- Technical support system
- Ideal conditions versus working solutions
- WesternGeco

Keeping compliance as top priority

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Planning Lessons

RPS

- Planning for PAM should be identified and incorporated into the early stages of project planning and individual vessels
- Effectiveness and quality of project will be directly associated with the planning detail
- Expand scope of the JSA from the back deck operations to include all aspects of PAM operations: communications, installation, and utilization of electronics. Some will be standard, others will be project-specific.
- A full assessment of technical risks and suitable spare levels should be established.

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Communication Lessons

RPS

- Revision to operating procedures brought about by use of PAM require constant communication throughout the project. Inclusion of geophysical contractor, company reps, and MMOs are key to achieving objectives
- Field-based MMO should be designated as a “survey manager” for PAM data management and coordination of PAM and visual monitoring
- Shore based PAM technical support available near real time

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PAM Operator Lessons

RPS

- Gap between PAM “user” and PAM “technician” that can only be filled with field based experience
- Documentation and training on software and troubleshooting needs to be improved overall and in particular for wide spread Pamguard application
- Resolve safety issue with headphones to enable visual and acoustic correlations
- Additional training and experience is required as this technology develops

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PAM as a monitoring tool

RPS

- Equipment and software issues were anticipated and encountered
- Nevertheless, PAM was tested rigorously during a commercial operation and performed well as a monitoring tool

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PAM as a compliance tool

RPS

- PAM compliments visual observation
- PAM requires further development
  - Functionality of the hardware and software to accurately locate marine mammals (range and bearing) requires improvement
  - This issue is exaggerated by noisy environments (which vary considerably by vessel) and currently requires frequent operator adjustments to software settings

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Where do we go from here?

RPS

- Further encourage the industry to engage this technology to its fullest extent on commercial operations
- Foster understanding of both risks and benefits from all stakeholders' perspectives
- Development of PAM for compliance should be driven by industry to ensure that commercial viability and functionality are prioritized
- Without Seismic Industry involvement, PAM development and future requirements *may* be driven by regulation and/or non-commercial research without practical input

November 2009 | RPS - BHPB Commercial PAM Case Study | 31

CIBRA
Centro Interdisciplinare di Bioacustica e Ricerche ambientali
Università di Pavia

Towed arrays and PAM:

10 years of field application

Claudio Fossati, Giovanni Caltavuturo, Gianni Pavan

Status and Applications of Acoustic Mitigation and Monitoring Systems for Marine Mammals
November 17-19, 2009 -- Boston Park Plaza Hotel & Towers, Boston, MA

Status and Applications of Acoustic Mitigation and Monitoring Systems for Marine Mammals
November 17-19, 2009 -- Boston Park Plaza Hotel & Towers, Boston, MA

CIBRA & RIGHT WAVES background

CIBRA – Centre for Bioacoustics, University of Pavia, IT was established in 1989. Main interest was underwater communication in Marine Mammals

We designed our first array in 1993. Since then we developed and made all our hardware and software, gaining a unique experience.

Since 10 years we provide services and equipment for Acoustic Mitigation (NATO Undersea Research Centre & LDEO – Columbia Univ, NY)

CIBRA team opened RIGHT WAVES to provide its services

Right Waves

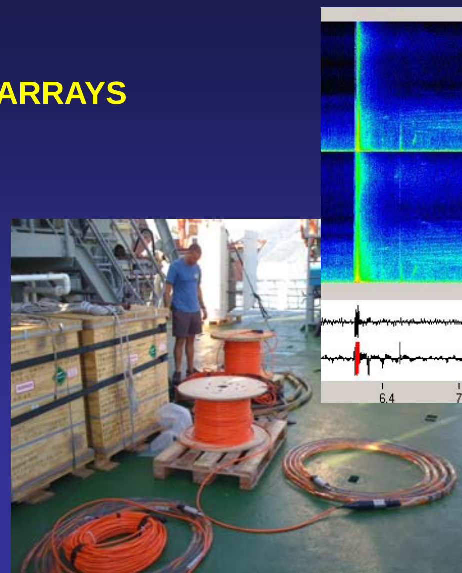
Status and Applications of Acoustic Mitigation and Monitoring Systems for Marine Mammals
November 17-19, 2009 -- Boston Park Plaza Hotel & Towers, Boston, MA

CIBRA

TOWED ARRAYS

Pros

- most practical and suited solution for moving sources (seismic surveys, Navy exercises) or wide area monitoring
- 24h ops for continuous monitoring of Marine Mammals and Sound sources
- less affected by weather than visual
- can be used from a wide variety of vessels
- if properly designed and operated offer a great detection capability
- great possibility for improvements



Right Waves

Status and Applications of Acoustic Mitigation and Monitoring Systems for Marine Mammals
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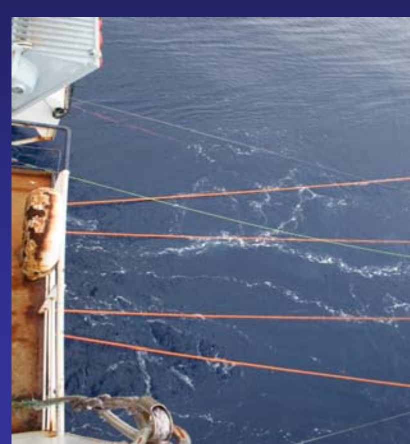
CIBRA

TOWED ARRAYS

Cons

- must be operated close to the source vessel for Mitigation purposes
- every “first installation” must be designed and planned by skilled personnel
- if deployed from the source vessel, it may “interact” with seismic gear



Status and Applications of Acoustic Mitigation and Monitoring Systems for Marine Mammals
November 17-19, 2009 -- Boston Park Plaza Hotel & Towers, Boston, MA

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK
Lamont-Doherty Earth Observatory
COLUMBIA UNIVERSITY | EARTH INSTITUTE

Case study: the RV Langseth

Objective: Acoustic Risk Mitigation during seismic activity worldwide

Equipment:

- 2 dipole towed arrays (1 as a backup), 48kHz bandwidth, low self noise, manufactured at CIBRA-RW labs, based on our 15-years long experience.

- SeaPro software PAM suite, designed and written at CIBRA, concentrates all our experience in data collecting, recording, analysis and display and can run on a single good laptop.

It is a user friendly, light, reliable, flexible software that assists the operator in data entry and concentrates all our experience in the field.

Status and Applications of Acoustic Mitigation and Monitoring Systems for Marine Mammals
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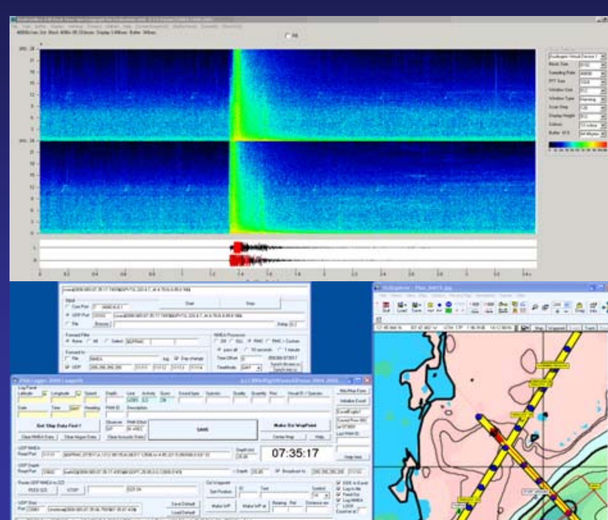
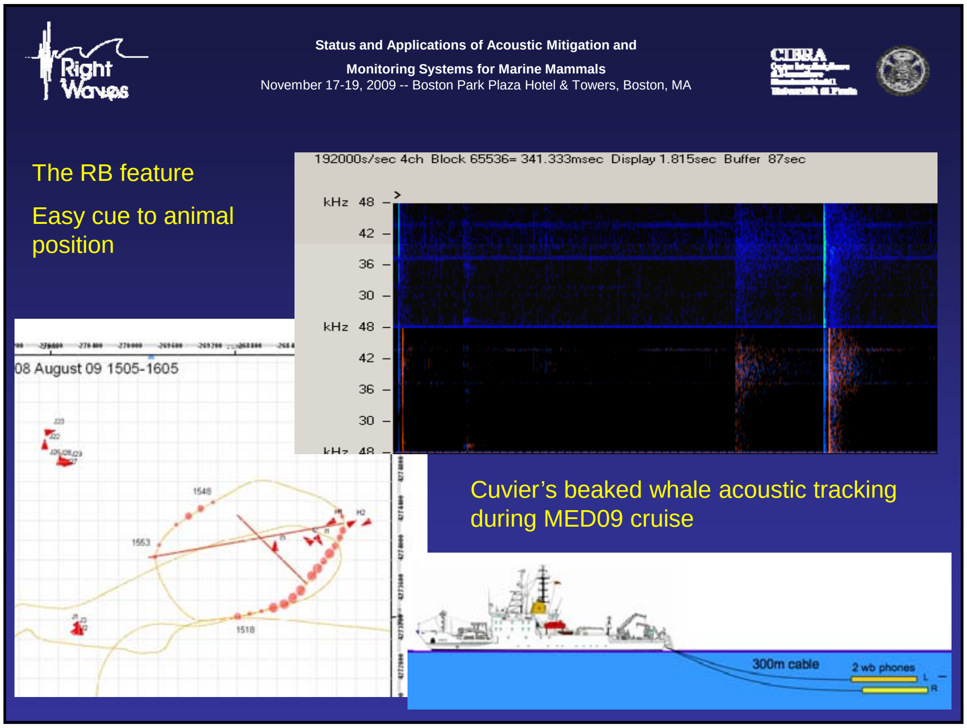
PAM station in the main lab

SeaPro display
NMEA Manager
PAMLogger
OziExplorer




Status and Applications of Acoustic Mitigation and
Monitoring Systems for Marine Mammals
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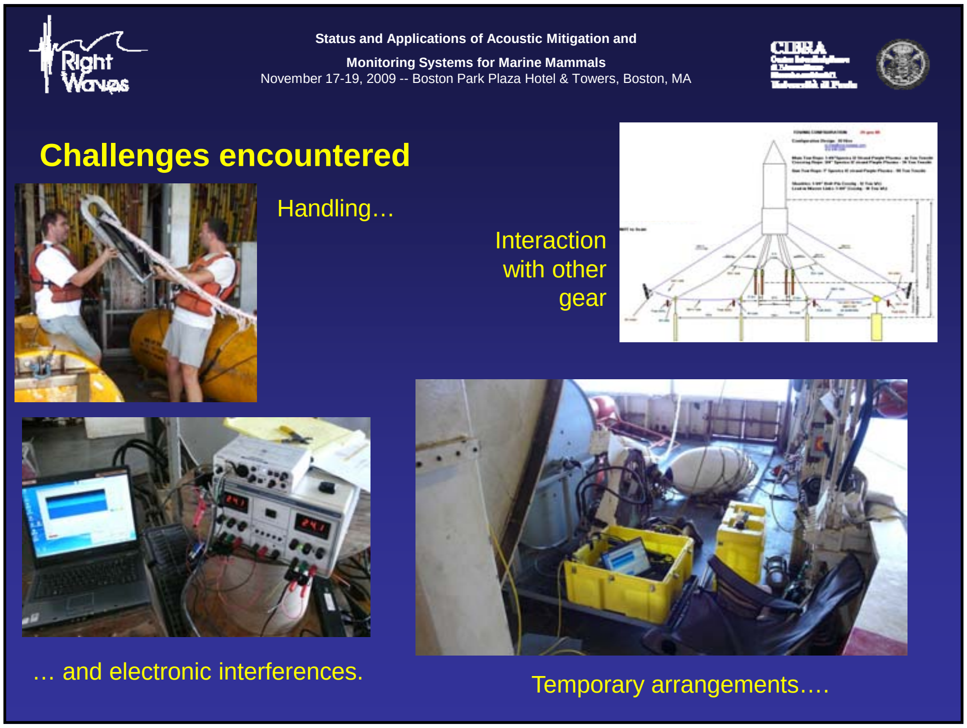
Right Waves
CIBRA
The RB feature
Easy cue to animal position
192000s/sec 4ch Block 65536= 341.333msec Display 1.815sec Buffer 87sec
kHz 48
42
36
30
08 August 09 1505-1605
1548
1553
1518
Cuvier's beaked whale acoustic tracking during MED09 cruise
300m cable
2 wb phones


Status and Applications of Acoustic Mitigation and
Monitoring Systems for Marine Mammals
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Right Waves
CIBRA
Challenges encountered
Handling…
Interaction with other gear
… and electronic interferences.
Temporary arrangements….

Right Waves

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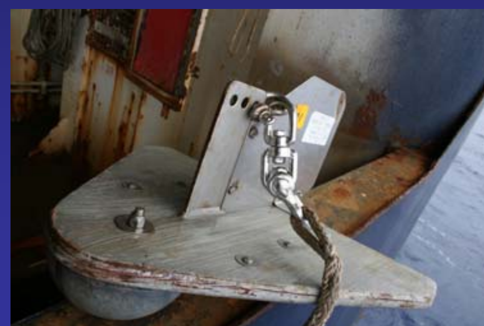
Solutions

Compact lightweight array, 2 sensors, wideband and low noise, differential output, pressure gauge, 15mt long active section, towing cable 100-400 m

Still room for improvements

"High tech" depth controller



Right Waves

Status and Applications of Acoustic Mitigation and Monitoring Systems for Marine Mammals
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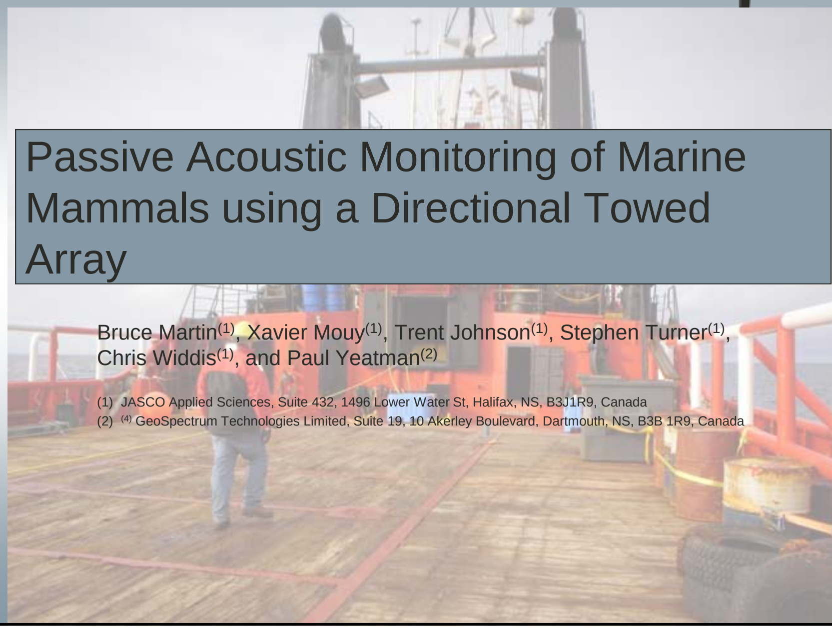
Final considerations

Towed arrays are optimal solutions for PAM. When proper setup is possible (eg on the MED09 cruise: quiet and stable platform), exceptional results may be achieved, like diving beaked whales' acoustic tracking.

Unfortunately on non dedicated cruises (seismic, military), it can be hard to find the best solution underway. The system has to be operative as you leave the dock. Actual setup on the Langseth is a mix of work done between each cruise and solutions arranged on the fly during experiments. The recent number and quality of acoustic detections (> than visuals) confirms that the overall level is matching our expectations.

We do stress the fact that to achieve good results like the ones we now have on the Langseth, a proper amount of time and resources must be dedicated to the design, test and tuning of the whole acoustic system.

Key-points: wideband; low noise; depth; spectrographic display;
SKILLED OPERATOR



Passive Acoustic Monitoring of Marine Mammals using a Directional Towed Array

Bruce Martin[1], Xavier Mouy[1], Trent Johnson[1], Stephen Turner[1], Chris Widdis[1], and Paul Yeatman[2]

(1) JASCO Applied Sciences, Suite 432, 1496 Lower Water St, Halifax, NS, B3J1R9, Canada
(2) [4] GeoSpectrum Technologies Limited, Suite 19, 10 Akerley Boulevard, Dartmouth, NS, B3B 1R9, Canada

Objectives

- Demonstrate that directional sensor technology can improve PAM performance by providing a localization for each detected vocalization.
- Believe that this capability will significantly improve PAM information – fewer false shutdowns and easier tracking
- Primary interest is with Beaufort / Chukchi species in the ice-free months.
  - Bowheads
  - Belugas
  - Walrus
  - Also ice seals, narwhal, orca, gray.

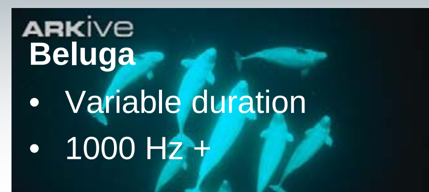
Acoustic Signatures

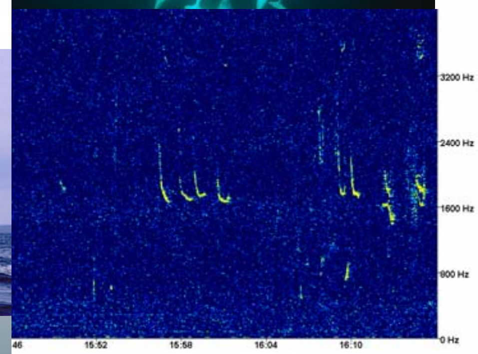
Bowhead

- Low frequency calls – sweeps, undulations
- 250 – 500 Hz; 160 dB

Beluga

- Variable duration
- 1000 Hz +





Participants

- System Integration: JASCO
- System Operation: JASCO
- Sensor Development, Towed Array Assembly: GeoSpectrum Technologies Inc.

Field Trials

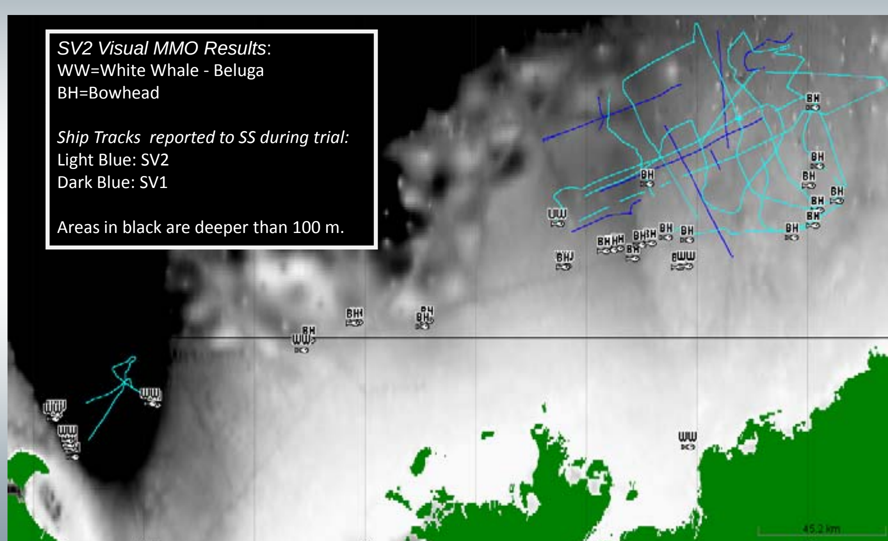
PAM Field Trial Project

- 30 – 50 m water; Canadian Beaufort
- Opportunistic field trial
- Three vessel flotilla: seismic source (SS), and two support vessels, SV1 and SV2.
- PAM deployed from SV2
- Operated during 2-D seismic survey
- SS and SV1 were used as targets.

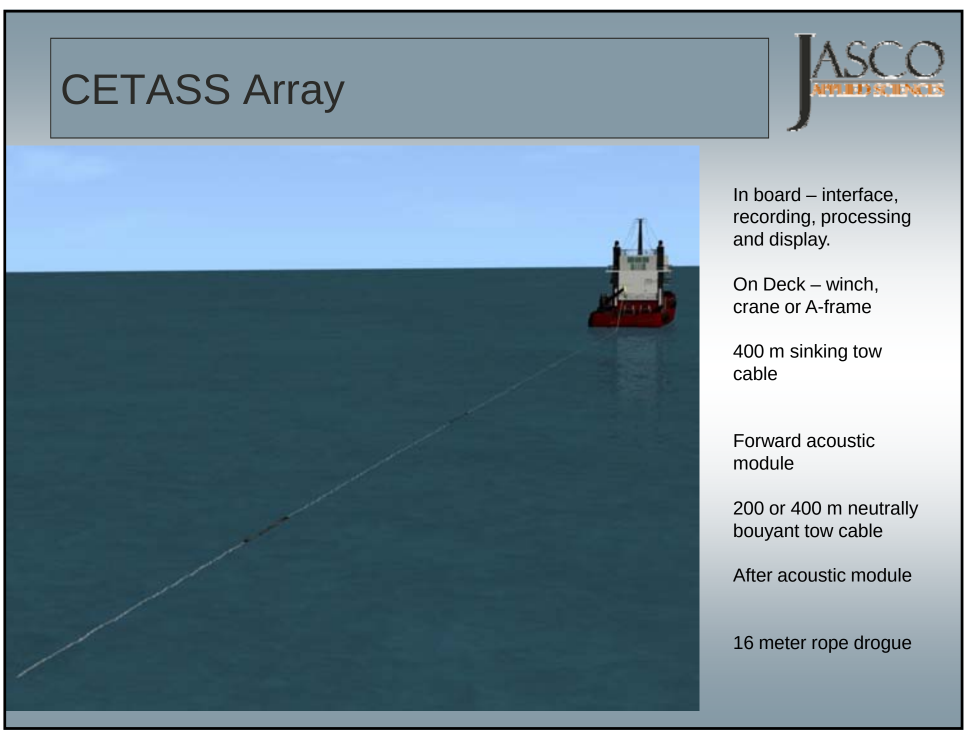
Deployments

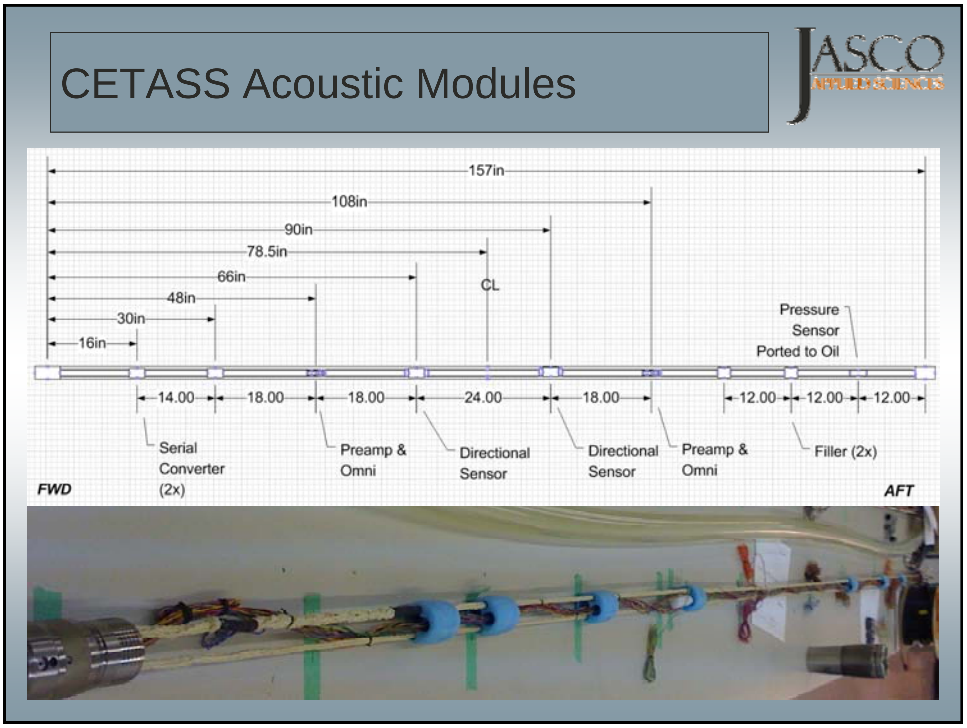
Start Time	End Time	Duration
14/Aug 6:25:58	14/Aug 12:55:09	6:29:11
17/Aug 2:50:17	17/Aug 4:18:27	1:28:10
17/Aug 4:48:10	17/Aug 14:48:44	10:00:34
17/Aug 18:06:40	17/Aug 18:27:28	0:20:48
17/Aug 19:06:18	17/Aug 19:58:52	0:52:34
17/Aug 20:30:31	17/Aug 21:33:12	1:02:41
17/Aug 22:30:31	18/Aug 17:59:44	19:29:13
21/Aug 18:42:32	22/Aug 4:43:39	10:01:07
22/Aug 23:54:40	23/Aug 19:37:36	19:42:56
23/Aug 22:28:42	24/Aug 3:51:41	5:22:59
24/Aug 4:59:38	24/Aug 12:15:09	7:15:31
24/Aug 19:06:20	24/Aug 23:20:51	4:14:31

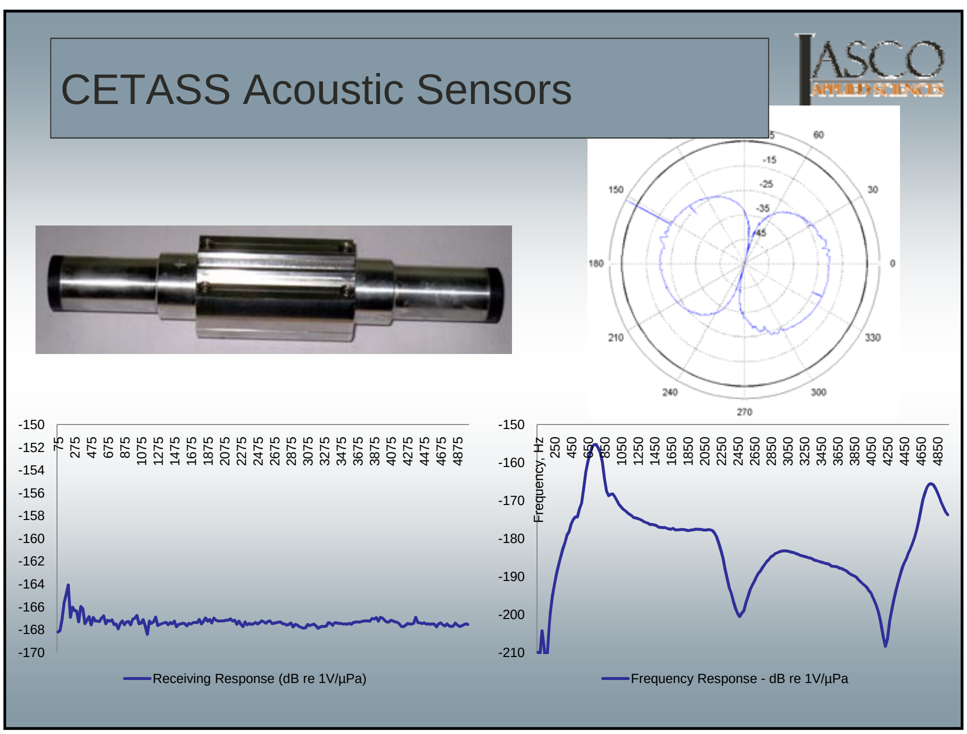
Trial Locations – 13 – 25 Aug 2009



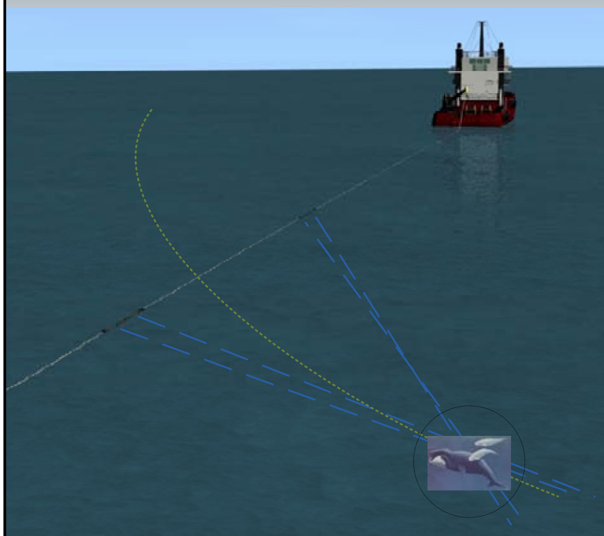

JASCO
CETASS – Cetacean Towed Array Sonar System Trials
EQUIPMENT


CETASS Array
JASCO
In board – interface, recording, processing and display.
On Deck – winch, crane or A-frame
400 m sinking tow cable
Forward acoustic module
200 or 400 m neutrally bouyant tow cable
After acoustic module
16 meter rope drogue


CETASS Acoustic Modules
JASCO
APPLIED SCIENCES
157in
108in
90in
78.5in
66in
CL
48in
30in
16in
Pressure
Sensor
Ported to Oil
14.00
18.00
18.00
24.00
18.00
12.00
12.00
12.00
Serial
Converter
(2x)
Preamp &
Omni
Directional
Sensor
Directional
Sensor
Preamp &
Omni
Filler (2x)
FWD
AFT

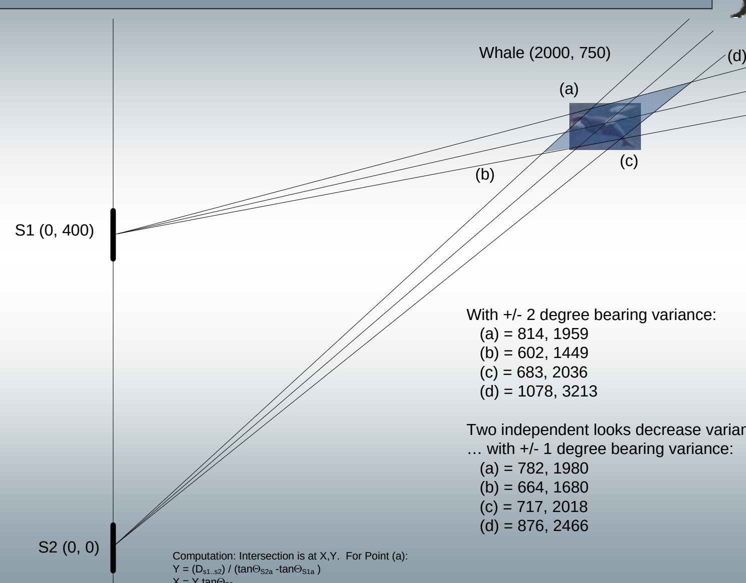

CETASS Acoustic Sensors
JASCO
APPLIED SCIENCES
60
-15
-25
-35
45
150
30
180
0
210
330
240
300
270
-150
-152
-154
-156
-158
-160
-162
-164
-166
-168
-170
Receiving Response (dB re 1V/µPa)
-150
-160
-170
-180
-190
-200
-210
Frequency, Hz
Frequency Response - dB re 1V/µPa

Localization



- Two bearing estimates from each module
- 4 time delay estimates between modules
- Difficult to localize in range fore-aft

Accuracy – Cross Fix Only

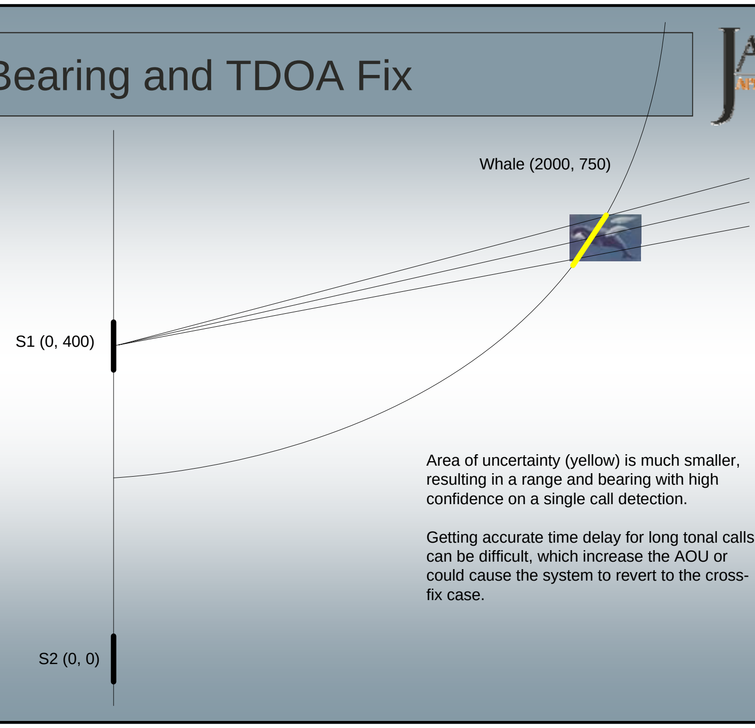


With +/- 2 degree bearing variance:
(a) = 814, 1959
(b) = 602, 1449
(c) = 683, 2036
(d) = 1078, 3213

Two independent looks decrease variance by 2
… with +/- 1 degree bearing variance:
(a) = 782, 1980
(b) = 664, 1680
(c) = 717, 2018
(d) = 876, 2466

Computation: Intersection is at X,Y. For Point (a):
$Y = (D_{s1..s2}) / (\tan\Theta_{S2a} - \tan\Theta_{S1a})$
$X = Y \tan\Theta_{S2a}$

Bearing and TDOA Fix



Area of uncertainty (yellow) is much smaller, resulting in a range and bearing with high confidence on a single call detection.

Getting accurate time delay for long tonal calls can be difficult, which increase the AOU or could cause the system to revert to the cross-fix case.

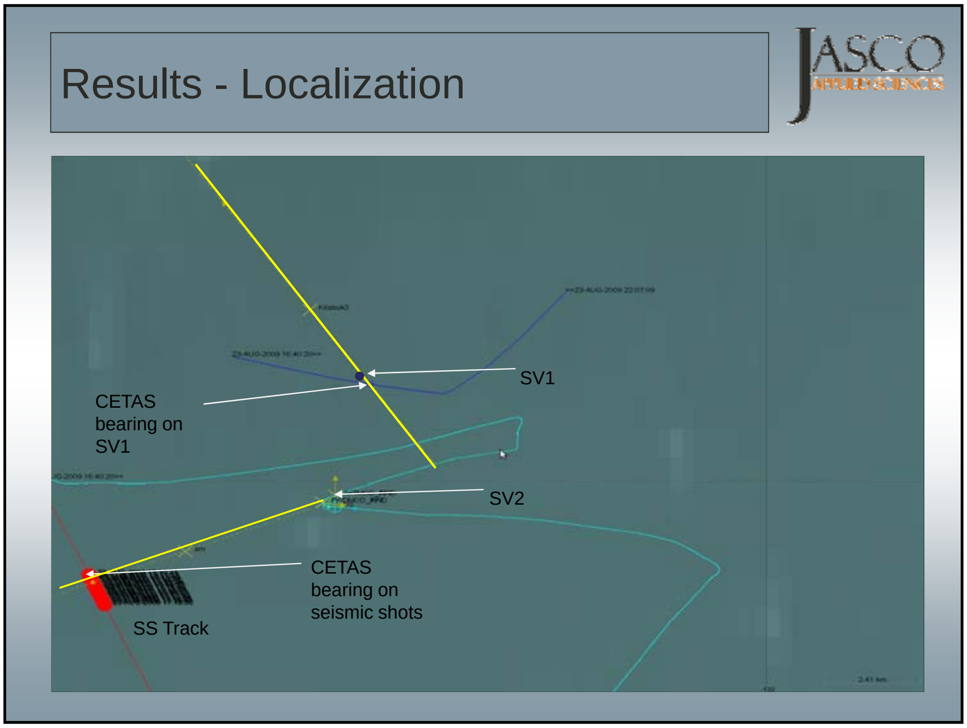
Processing and Display Software

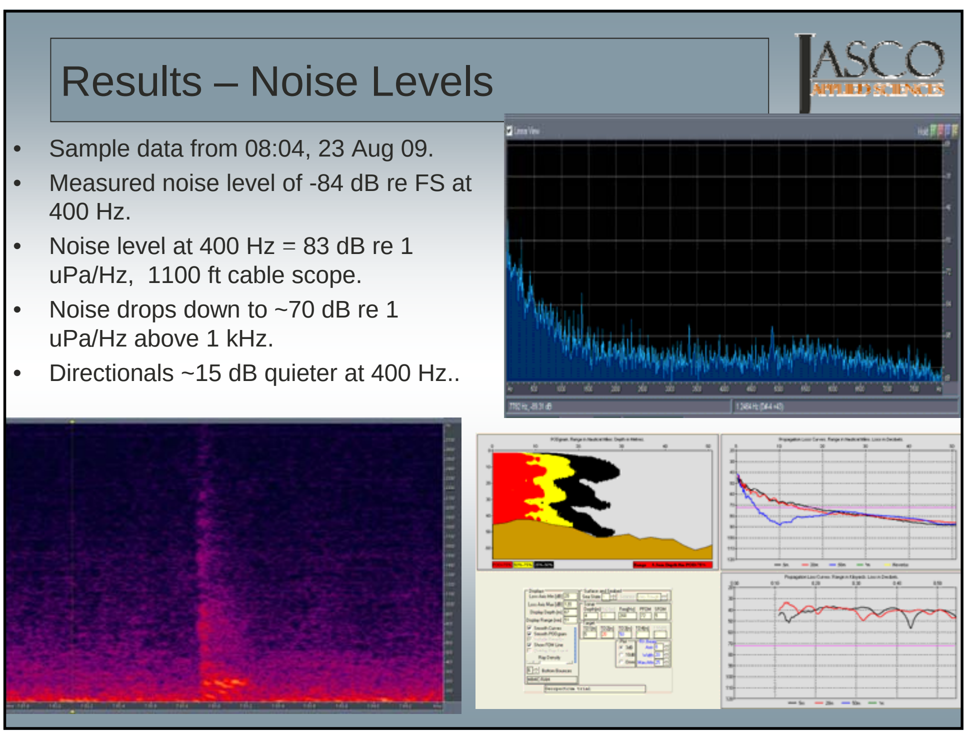
- Main processing and display was in the System Test Bed (STB), a tactical detection software package used by JASCO for previous sonar projects.
- Most customizations were performed in OpenMap, which can be incorporated into PamGuard in the future.
- Wrote a new socket interface to PamGuard which was used for the omni-only channels (spectrograms and BLED detection)
- Added a record and replay capability on the socket interface as well

RESULTS AND DISCUSSION

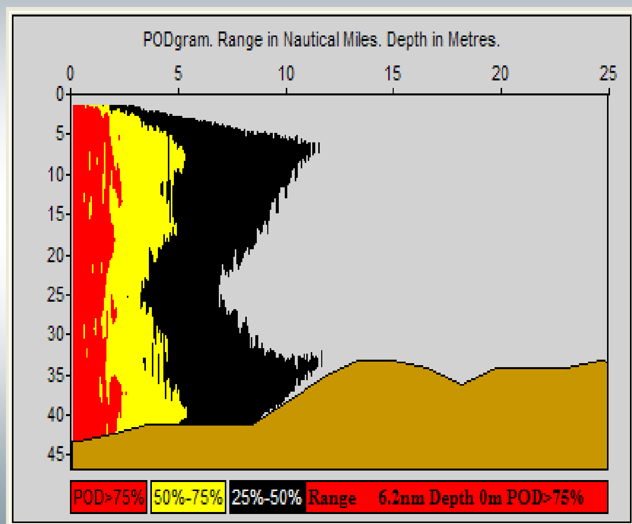
Results – Mammal Detection

- No marine mammal detections during opportunistic monitoring.
- During post analysis we found that there were only 32 minutes of the 87 hours of recordings that had a sighted bowhead within the high probability detection range of the array.
- It is probable that the mammals were not vocalizing during the period that they were close to the array


Results - Localization
JASCO
APPLIED SCIENCES
SV1
CETAS
bearing on
SV1
SV2
CETAS
bearing on
seismic shots
SS Track


Results – Noise Levels
JASCO
APPLIED SCIENCES
• Sample data from 08:04, 23 Aug 09.
• Measured noise level of -84 dB re FS at 400 Hz.
• Noise level at 400 Hz = 83 dB re 1 uPa/Hz, 1100 ft cable scope.
• Noise drops down to ~70 dB re 1 uPa/Hz above 1 kHz.
• Directionals ~15 dB quieter at 400 Hz..

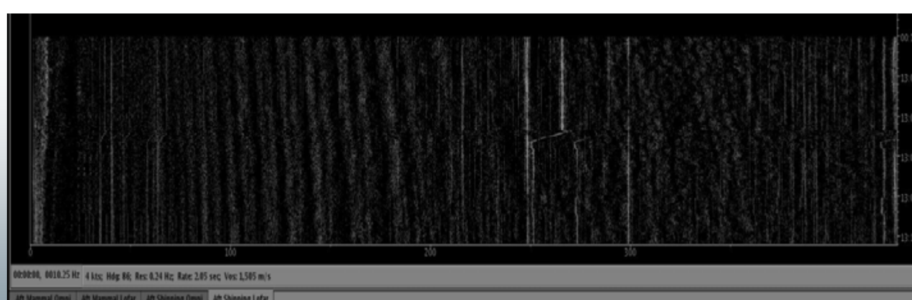
Bowhead Whale Probability of Detection



- Median level call, 153 dB SPL.
- -6 dB processing gain
- Measured noise from SV2 (100 dB re 1 uPa / Hz at 300 Hz)
- 200 – 250 Hz sweep, .5 sec duration

Results - Shipping

- Shipping processing uses narrowband normalization, higher resolution and lots of averages.
- Able to extract and identify SV1 at ranges > 9 nm.
  - Modeled and actual predictions match
- *Confirms towed directional sensor effectiveness*.



CONCLUSIONS

Was the Trial a Success?

- Objective - Demonstrate that directional sensor technology can improve PAM performance by providing a localization for each detected vocalization.
  - ☑ Bearing results excellent – directional sensors are effective for transient and tonal sources
  - ☑ Directional sensors provided left-right ambiguity resolution.
  - ☑ Directional sensors were 15 dB quieter than omni sensors.
  - ☒ Without data on aft sensors we could not localize.

Was the trial a success?

- Objective – provide evidence of good performance detecting bowhead, beluga and walrus, plus orca, narwhal, seals if opportunity arose.
  - ☑ Real world tow vessel noise from the SV2 used in performance modeling that indicates we should be able to detect median level Bowhead vocalizations at least 5 nm with 50% POD.
  - ☒ No vocalizations detected in data; likely not operating in presence of vocalizing mammals – additional structured trials required

Applicability of Technology

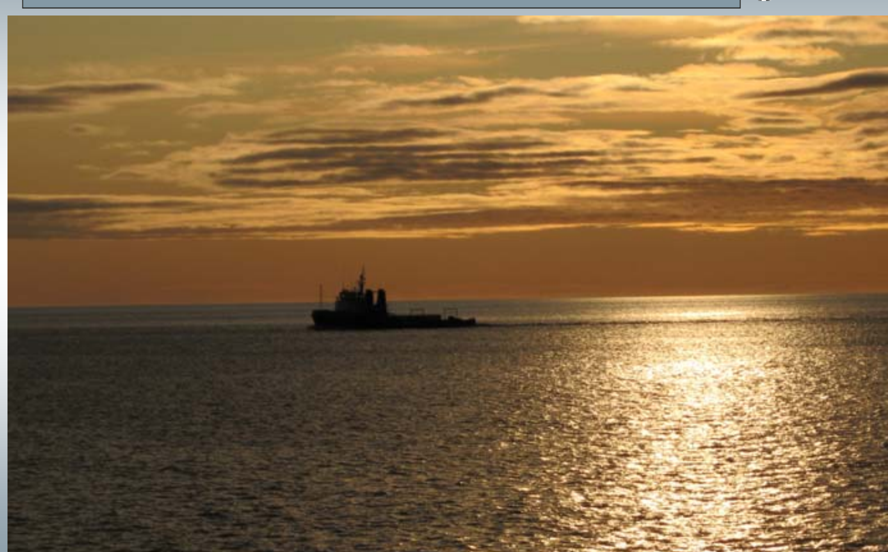
- Measured noise levels and modeling indicate it should be effective at providing single call localizations for low frequency mammals, even from noisy tow platforms.
- Bearing results indicate that these sensors can significantly improve speed and accuracy of mammal localizations.
- Further trials will provide additional evidence of it's effectiveness.
- Integration with PamGuard should get easier as new JAVA technology and faster processors come on line. For the present the STB provides a reliable trial package.

Acknowledgements

The support of the following people is acknowledged and appreciated:

- Eugene Fitzgerald, Dale Bruce, Ryan Wright & Darrin Collins from the SV2 for their professional and enthusiastic support on deck.
- MMO's Melanie Vaughan and Vernon Amos from Kavik Axys.
- JASCO's sea crew – Eric Lumsden and Chris Widdis.

Questions?



DEFENCE R&D DÉFENSE

Active Detection of Marine Mammals

James A. Theriault[1], L. Gilroy[1], J. Hood[2], B. Maranda[1], and E. MacNeil[1]

[1]DRDC Atlantic [2]Akoostix

Defence Research and Development Canada   Recherche et développement pour la défense Canada

Canada

Acknowledgement

This work was funded by

International Association of Oil and Gas Producers

- Joint Industry Programme:
  E&P Sound and Marine Life Programme
- www.soundandmarinelife.org

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3

Outline

- Will it work?
- Performance Factors
  - Sonar Equation
  - Beyond the Sonar Equation
- E&P Operations Context
- Closing Summary

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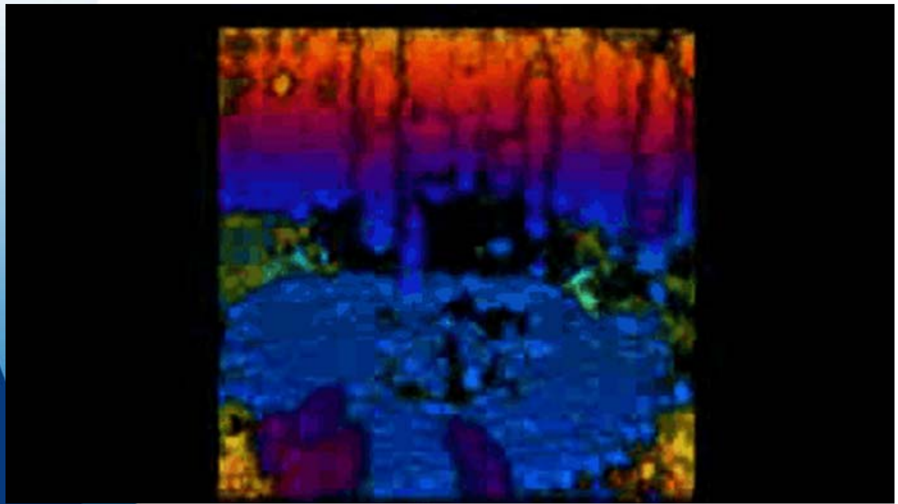
4

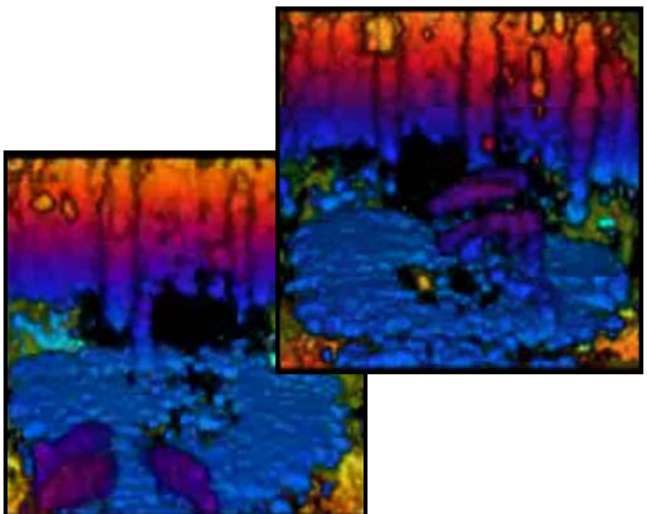
Will it work?



Credit: CodaOctopus/Youtube

5

Will it work?



Credit: CodaOctopus/Youtube

6

Outline

- Will it work?
- **Performance Factors**
  - Sonar Equation
  - Beyond the Sonar Equation
- E&P Operations Context
- Closing Summary

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7

Sonar Performance
Simplified Sonar Equation

$$SE = SL + T - 2PL - NL \oplus RL + TS - DT - S_{loss}$$

- SE Signal Excess
- SL Source Level
- T Pulse Length (dB)
- PL Propagation Loss
- NL Noise Level
- RL Reverberation Level
- TS Target Strength
- DT Detection Threshold
- S_{loss} System Loss

$\oplus$ Linear addition (vice log addition)

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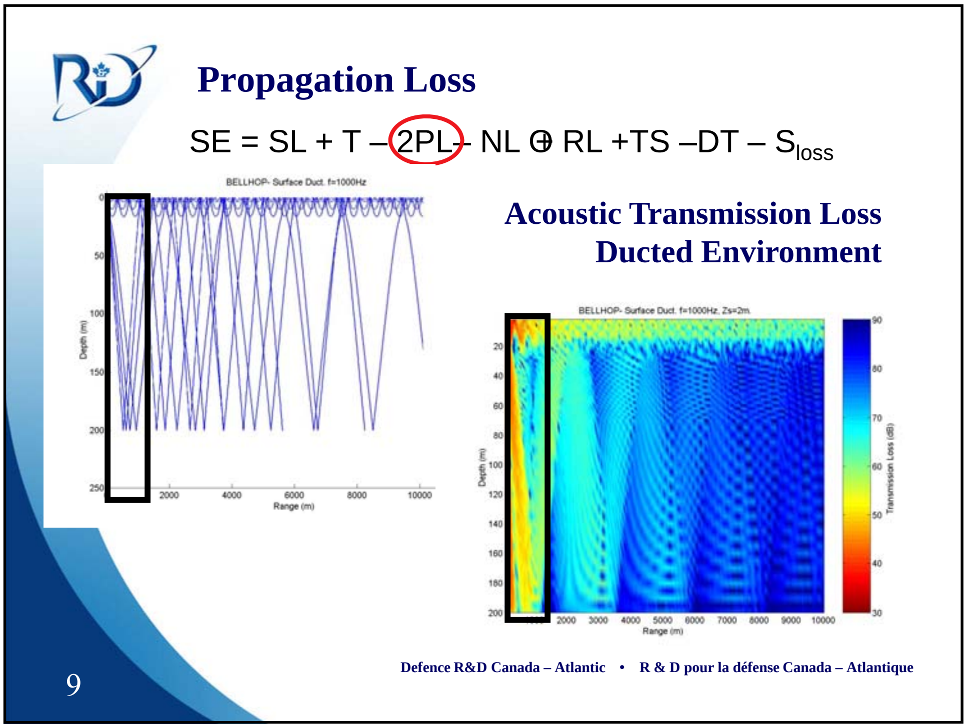
8


Propagation Loss
SE = SL + T – 2PL – NL ⊕ RL +TS –DT – S$_{loss}$
BELLHOP- Surface Duct, f=1000Hz
Depth (m)
Range (m)
Acoustic Transmission Loss
Ducted Environment
BELLHOP- Surface Duct, f=1000Hz, Zs=2m.
Transmission Loss (dB)
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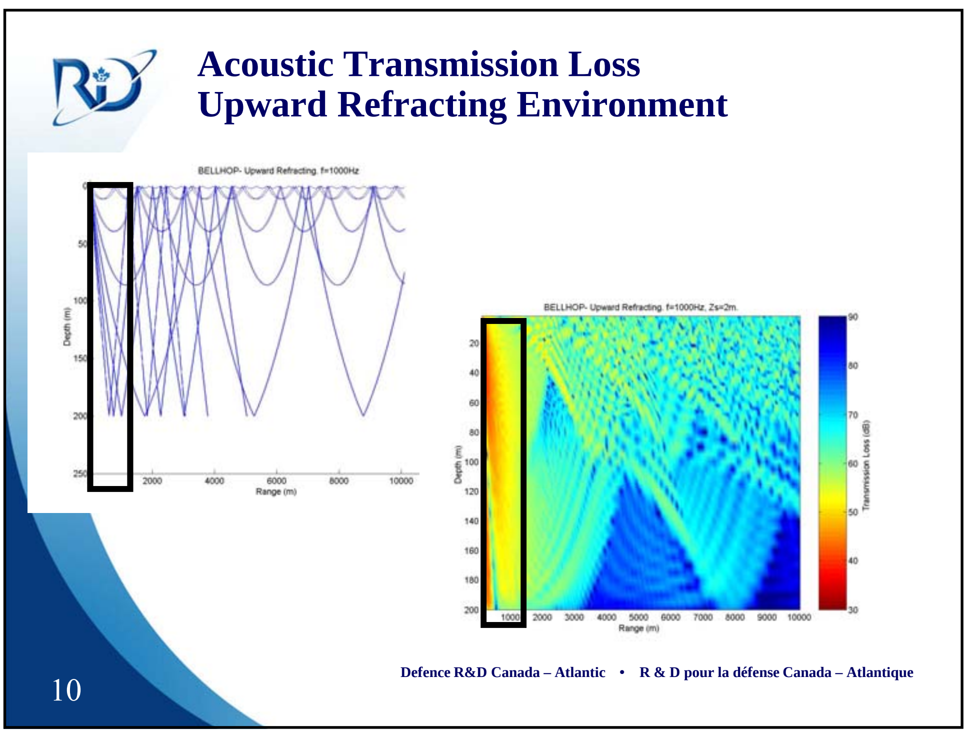
9


Acoustic Transmission Loss
Upward Refracting Environment
BELLHOP- Upward Refracting, f=1000Hz
Depth (m)
Range (m)
BELLHOP- Upward Refracting, f=1000Hz, Zs=2m.
Transmission Loss (dB)
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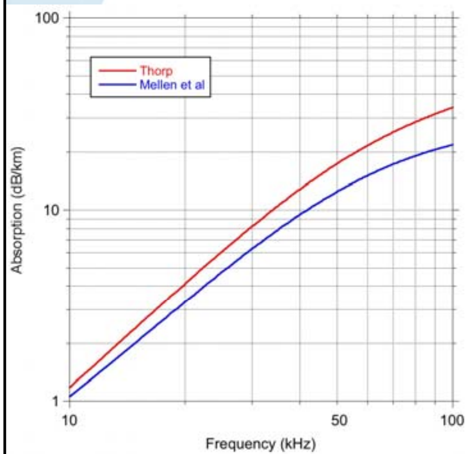
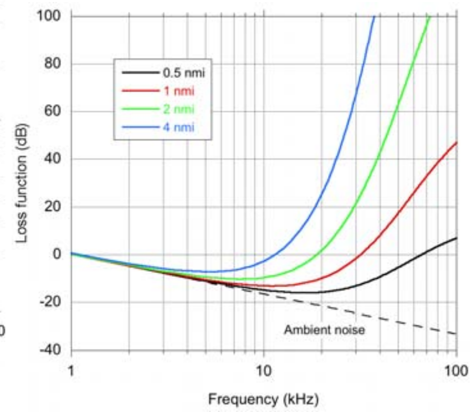
10

Frequency Impact: Two-way absorption loss above ambient-noise background

$$SE = SL + T - 2PL - NL \oplus RL + TS - DT - S_{loss}$$





11

Target Strength Estimates

$$SE = SL + T - 2PL - NL \oplus RL + TS - DT - S_{loss}$$

- Sample measurements in literature for broadside whale TS for dolphin, humpback, gray, and sperm.

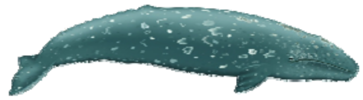
Species	Frequency	Measurement
Dolphin	23 kHz	-11 dB
Humpback	10 kHz	2 dB
Humpback	20 kHz	7 dB
Gray	23 kHz	8.7 dB
Sperm	1 kHz	0 to +10 dB

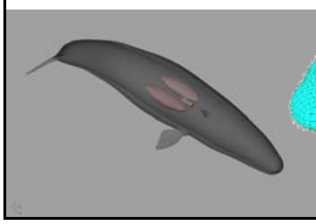
- **Hypothesis: Lung collapse decreases Target Strength?**

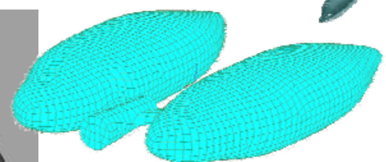
12

Hypothesis: Lung collapse decreases Target Strength?

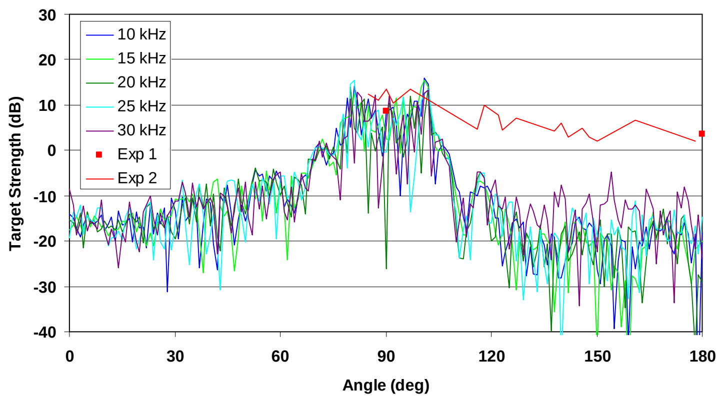
- Limited measurements available in literature for broadside TS for dolphins and humpback, gray, and sperm whales.
- Little overall sampling with respect to frequency.
- Selected 14m gray whale for modelling.
- Investigated directivity, frequency and range dependence, and comparison to experimental data.
- Created model of whale lungs to compare.

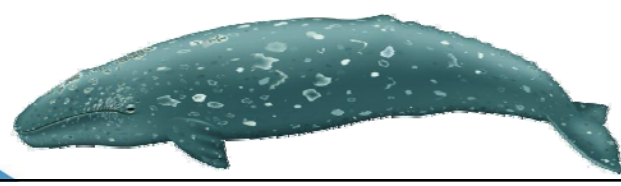






Results – Outer Shape

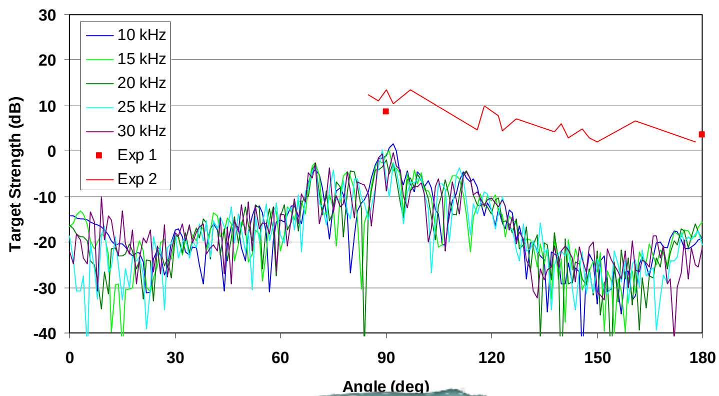


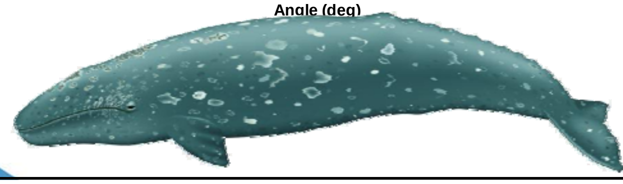


17

Results – Lung Model

- Assumes rest of body is acoustically transparent.





18

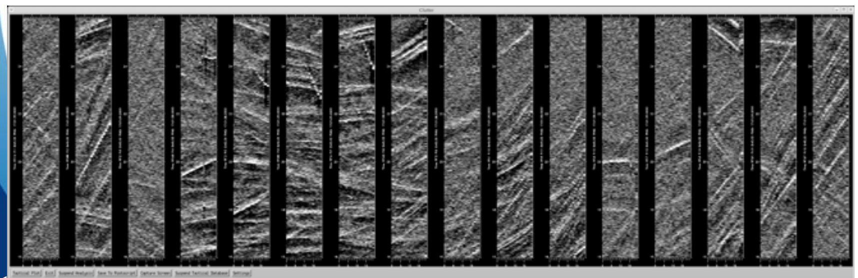
Hypothesis: Lung collapse decreases Target Strength?

- Modelling does not support Hypothesis
- However,
  – Minimal Data available
  – Multiple Species would need to be considered
    - Only one species considered
  – Detailed Physical Models could indicate other dominant effects

Sonar Performance
Beyond the Simplified Sonar Equation

$SE = SL + T - 2PL - NL \oplus RL + TS - DT - S_{loss}$

- Data Fusion
- Human – Machine Interface
- Training
- Track before Detect
- Echo Splitting
- Clutter (False Targets)
- Variable Depth Capability
- Interfering Sources
- Cost



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Outline

- Will it work?
- Performance Factors
  - Sonar Equation
  - Beyond the Sonar Equation
- **E&P Operations Context**
- Closing Summary

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Active sonar Detection of Marine Mammals
E&P Context: Activities

Platform Type		Noise Type	
Moving	**Non-Moving or Fixed Location**	**Impulsive**	**Continuous**
• air guns • explosives used in exploration activities • vessel operations	• impact pile driving • explosives used in construction activities	• air guns • explosives • impact pile driving	• vessel operations

Active sonar Detection of Marine Mammals
Summary of Concepts of Use for AAM Systems in E&P Activities

Concept of Use	Description	Example
1	AAM system is used during an E&P activity that is conducted from a moving platform and which generates impulsive underwater noise.	Seismic survey using air guns.
2	AAM system is used during an E&P activity that is conducted from a moving platform and which generates continuous underwater noise.	Vessel operations: tankers, supply or support vessels, pipelay vessels, icebreakers.
3	AAM system is used during an E&P activity that is conducted from a non-moving or fixed location platform and which generates impulsive underwater noise.	Construction activities using impact pile driving or explosives.

E&P Context: Environments

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E&P Context: Target Species

Family	Species	Common Name(s)	Size (m)	Diving Behaviour	IUCN Status	P 1	P 2	P 3	P 4	P 5	P 6
Balaenidae		**Right whales**									
	Eubalaena glacialis	▪North Atlantic right whale ▪Black right whale ▪Northern right whale ▪Right whale	14-18	Shallow	EN			•			
	Eubalaena australis	▪Southern right whale ▪Chile-Peru right whale	11-17	Shallow	LC (CR)						
	Eubalaena japonica	▪North Pacific right whale ▪Northeast Pacific right whale	14-18	Shallow	EN (CR)						
	Balaena mysticetus	▪Bowhead whale ▪Bowhead ▪Greenland right whale	12-20	Shallow	LC (LR, EN, CR)	•					

EX: Extinct, EW: Extinct in the Wild, CR: Critically Endangered, EN: Endangered, VU: Vulnerable, NT: Near Threatened, LC: LR: Lower risk, Least Concern, DD: Data Deficient, NE: Not Evaluated. Designations in parenthesis relate to specific sub-populations.

E&P Context: Target Species

Size Grouping	Marine Mammals
Small	Small Odontocetes (toothed whales)
Medium	Large Odontocetes (toothed whales)
Large	Mysticetes (baleen whales)

Technology Survey

- On Line Survey
  - By invitation only
    - 24 (26) companies
  - Responses
    - 11 systems
- Approximately 85 questions

Technology Evaluation

- E&P Concept of Use (General Applicability)
- E&P Platform Type
- Marine Mammal Size
- Marine Mammal Diving Characteristics

System		Ranking with respect to E&P Platform Type		
		Ship Based	Fixed Platform	Autonomous
1		g	g	g
2		y	g	r
3		g	y	y

Outline

- Will it work?
- Performance Factors
  - Sonar Equation
  - Beyond the Sonar Equation
- E&P Operations Context
- **Closing Summary**

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Closing Comments

- Active sonar detection of marine mammals possible
- Large uncertainty regarding marine mammal target strength
- Survey results indicate many desirable technologies
- Operational system requires high level design study
  - Concept of use
  - Environments
  - E&P Application
  - Depending on context, may require top down/bottom-up design

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Collaborators

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B. Maranda, and
L. Gilroy; Defence R&D Canada – Atlantic

J. Hood, G. Ryan; Akoostix, Inc.
R. Burke; Canadian Seabed Research, Ltd
P. Brodie; Balaena Dynamics, Ltd.

DEFENCE DÉFENSE

jim.theriault@drdc-rddc.gc.ca

SIMRAD
www.simrad.com

Using echosounders and sonars to detect marine mammals

Frank Reier Knudsen
Simrad, Kongsberg Maritime
Horten, Norway

TECHNOLOGY FOR SUSTAINABLE FISHERIES

KM SIMRAD, Horten, Norway

SIMRAD
www.simrad.com

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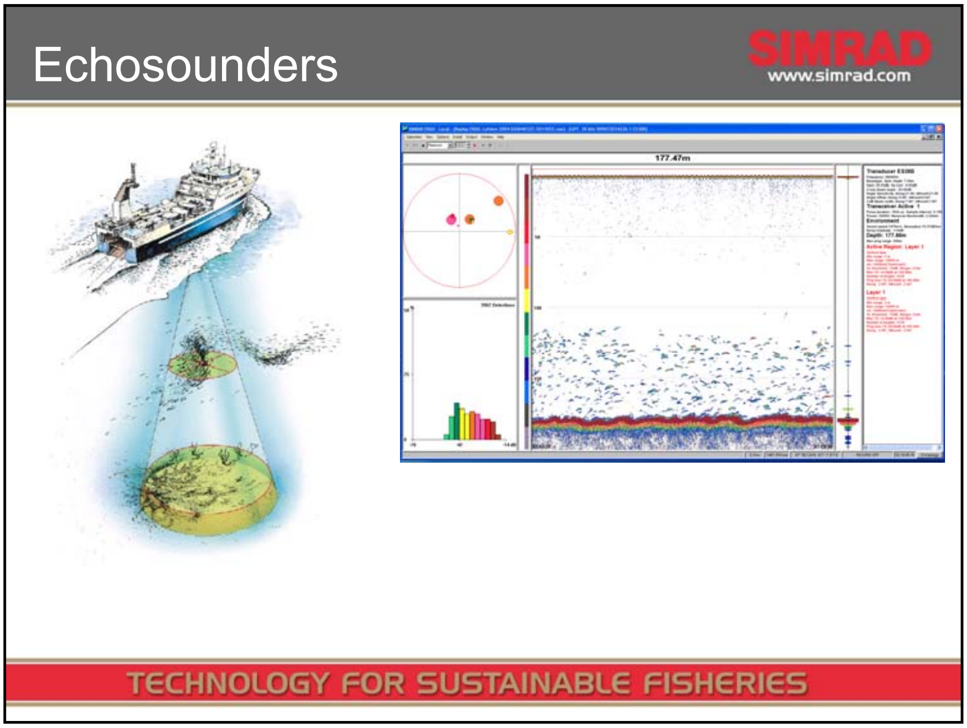
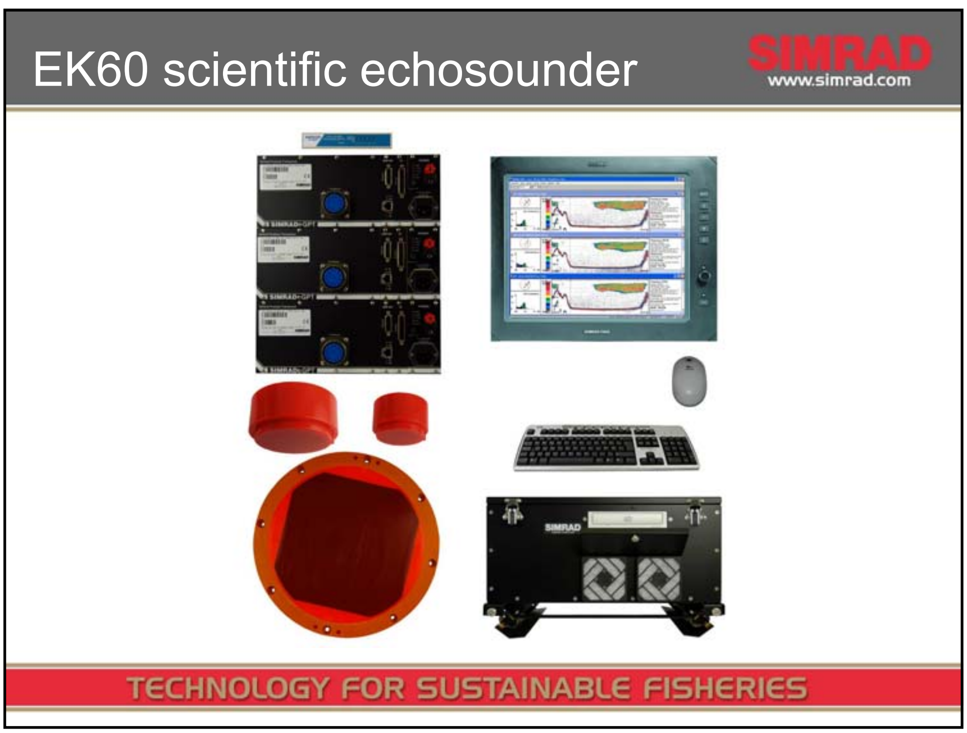

Echosounders
SIMRAD
www.simrad.com
177.47m
TECHNOLOGY FOR SUSTAINABLE FISHERIES


EK60 scientific echosounder
SIMRAD
www.simrad.com
SIMRAD
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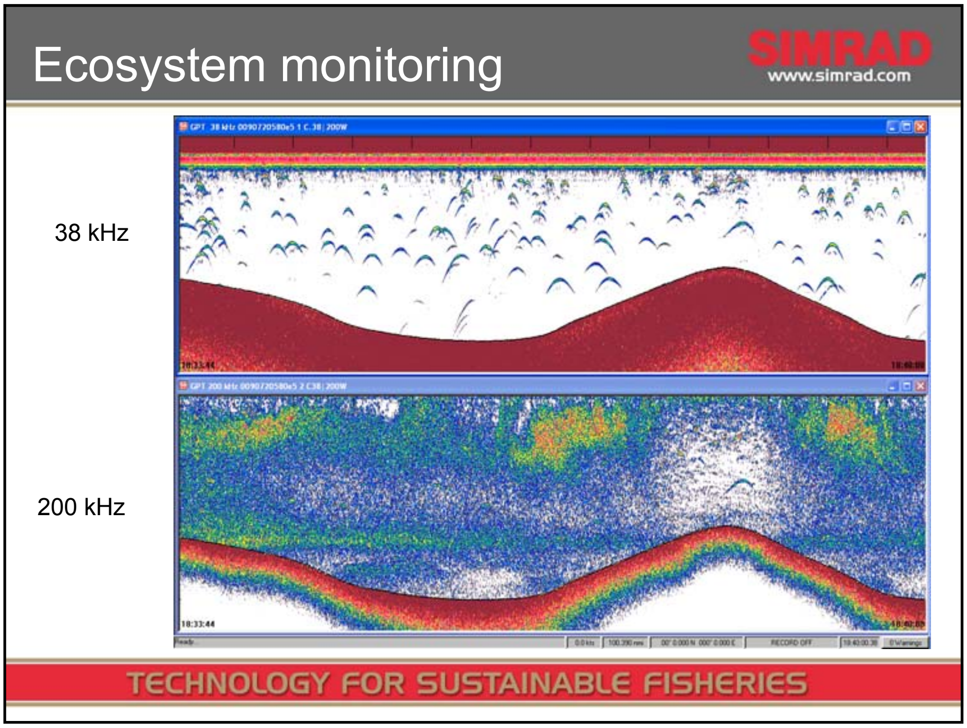
Ecosystem monitoring
SIMRAD
www.simrad.com
38 kHz
200 kHz
TECHNOLOGY FOR SUSTAINABLE FISHERIES


ES15
SIMRAD
www.simrad.com
12 V
32° beam angle
192 kHz
Ethernet
Raw data storage
ES15 PROTOTYPE SN 6
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Dams - fish passage

SIMRAD
www.simrad.com

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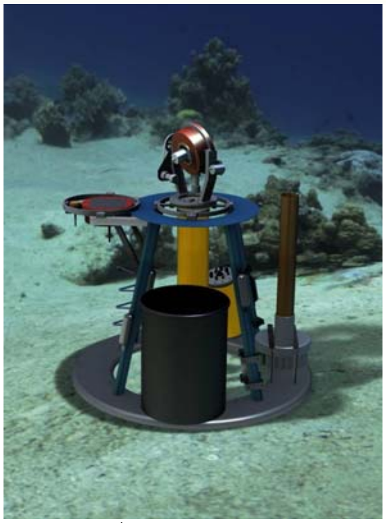
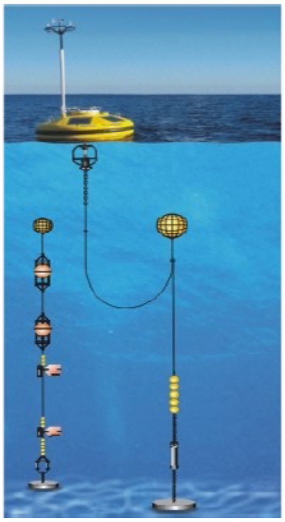
Landers and buoys

SIMRAD
www.simrad.com



www.metas.no



www.oceanor.no

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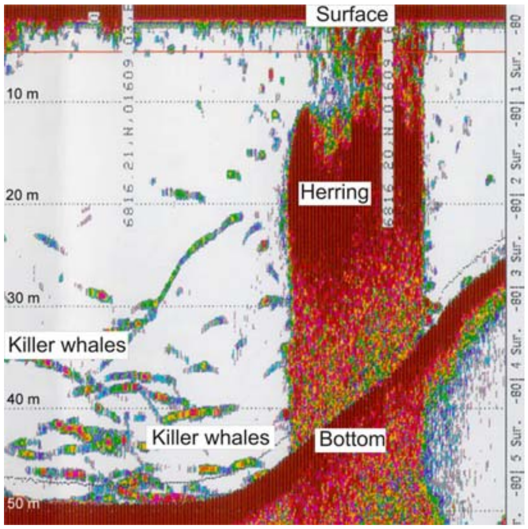
Herring and killer whales

SIMRAD
www.simrad.com



IMR, with permission

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SIMRAD
www.simrad.com

Evaluation of fisheries sonar for whale detection in relation to seismic survey operations

KM Simrad

Norwegian Defense Research Establishment

Institute of Marine Research

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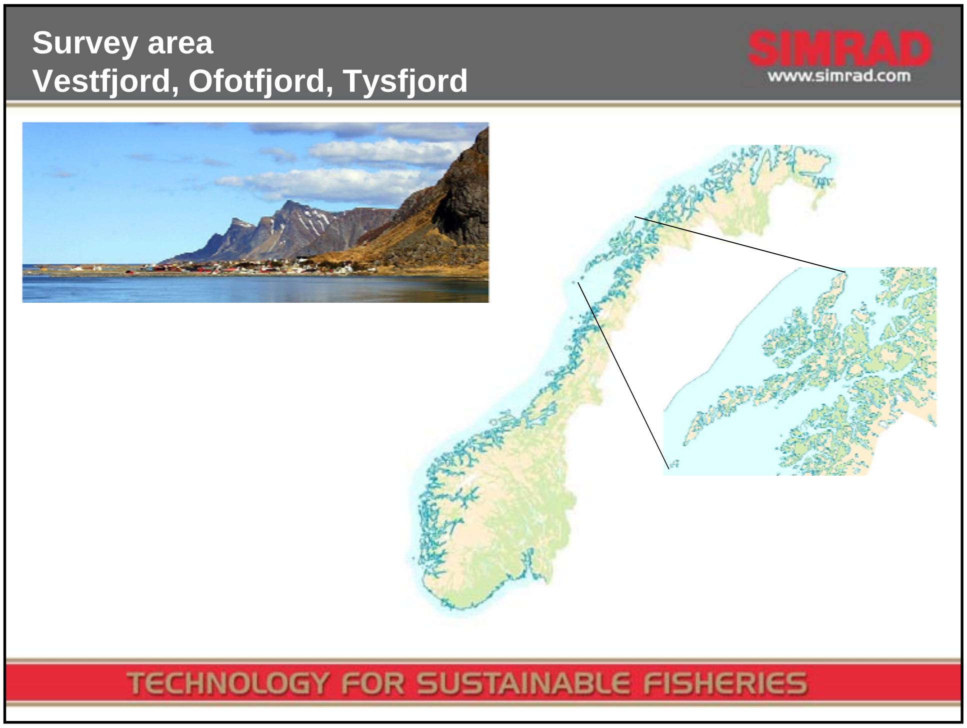
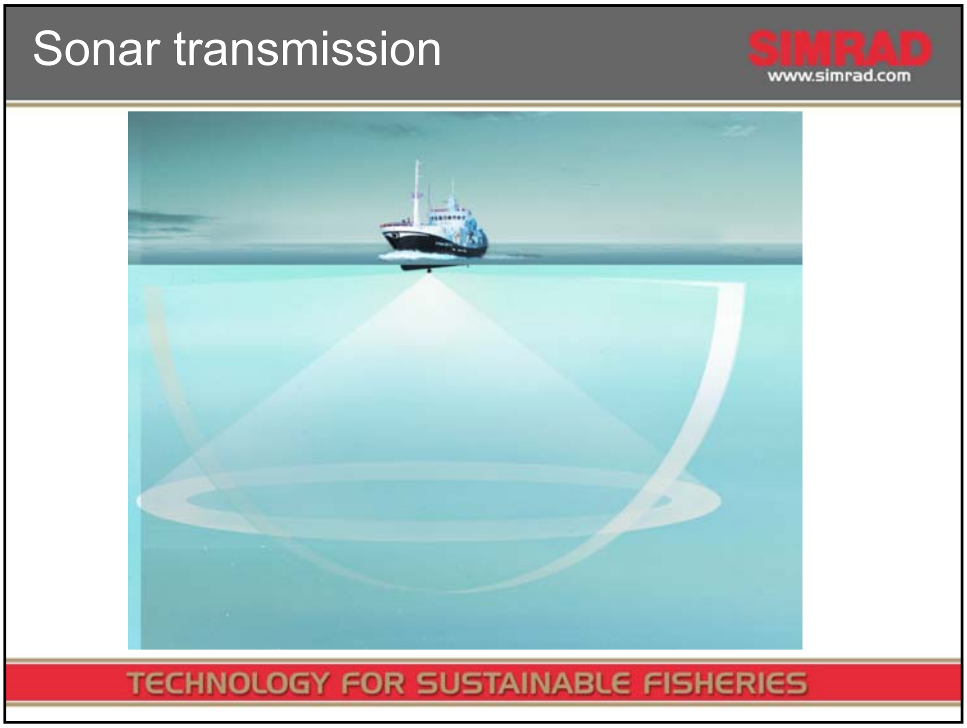
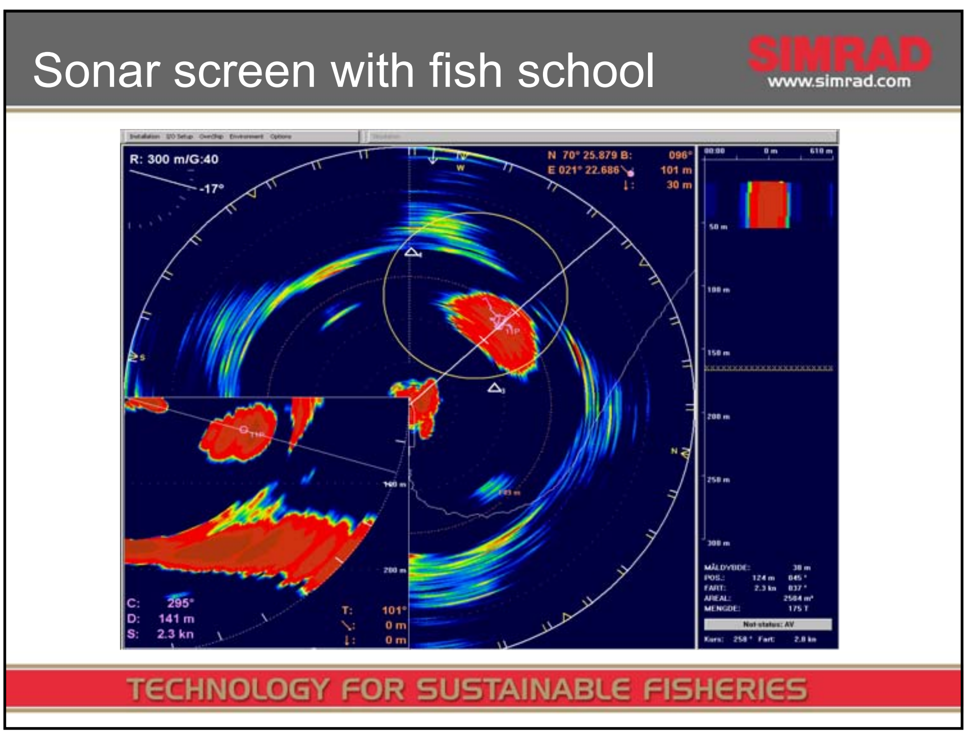

Survey area
Vestfjord, Ofotfjord, Tysfjord
SIMRAD
www.simrad.com
TECHNOLOGY FOR SUSTAINABLE FISHERIES


FV "Inger Hildur"
SIMRAD
www.simrad.com
TECHNOLOGY FOR SUSTAINABLE FISHERIES


Sonar transmission
SIMRAD
www.simrad.com
TECHNOLOGY FOR SUSTAINABLE FISHERIES


Sonar screen with fish school
SIMRAD
www.simrad.com
R: 300 m/G:40
-17°
N 70° 25.879 B:
096°
E 021° 22.686
101 m
30 m
C: 295°
D: 141 m
S: 2.3 kn
T: 101°
0 m
0 m
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Sonar specification

SIMRAD
www.simrad.com

SP90
Frequency: 20-30 kHz

Power:
- High 218 dB
- Medium 212 dB
- Low 206 dB

Pulse: Auto FM 16-64 ms, 1 kHz bandwith

Tilt: +10 to -60°

SH80
Frequency: 110-122 kHz

Power:
- Medium 211 dB

Pulse: Auto FM 13-26 ms, 5 kHz bandwith

Tilt: +10 to -60°

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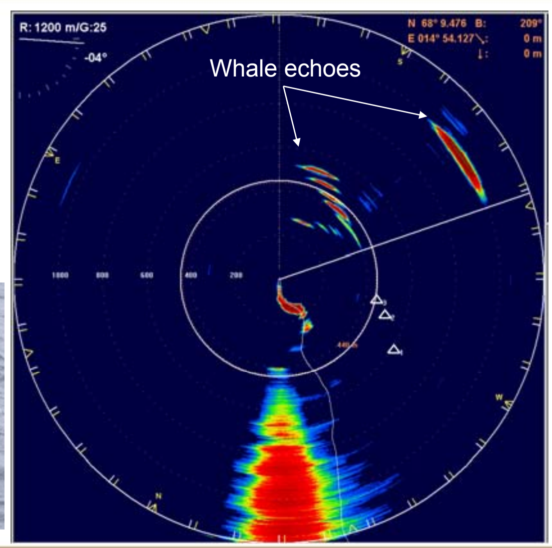
SP90 – 20 to 30 kHz

SIMRAD
www.simrad.com

Echoes from at least six killer whales



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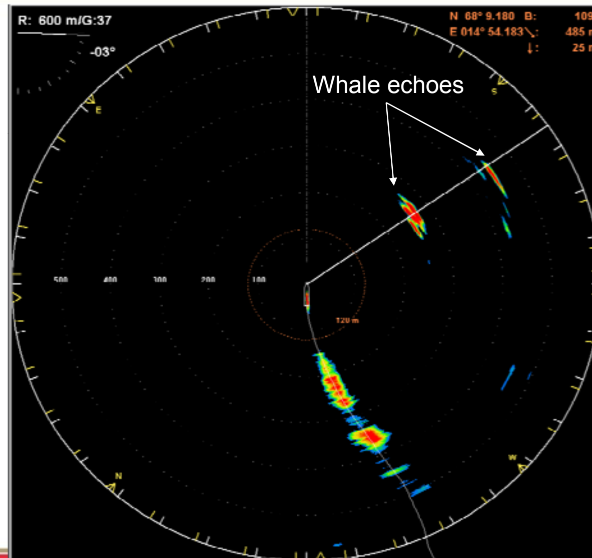
SH80 – 110 to 122 kHz

SIMRAD www.simrad.com

Echoes from four killer whales



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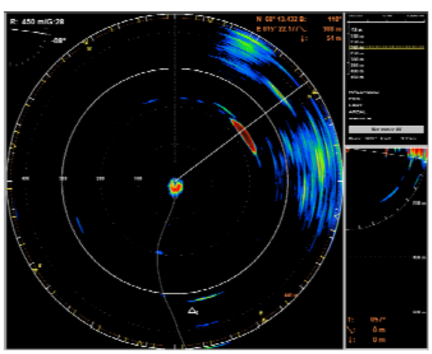
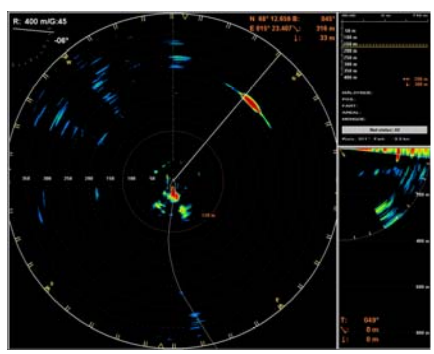
SP90 vs. SH80

SIMRAD www.simrad.com

SP90



SH80



Whale echo strength

SP90 > -5 dB re 1 μPa
SH80 > -10 dB re 1 μPa

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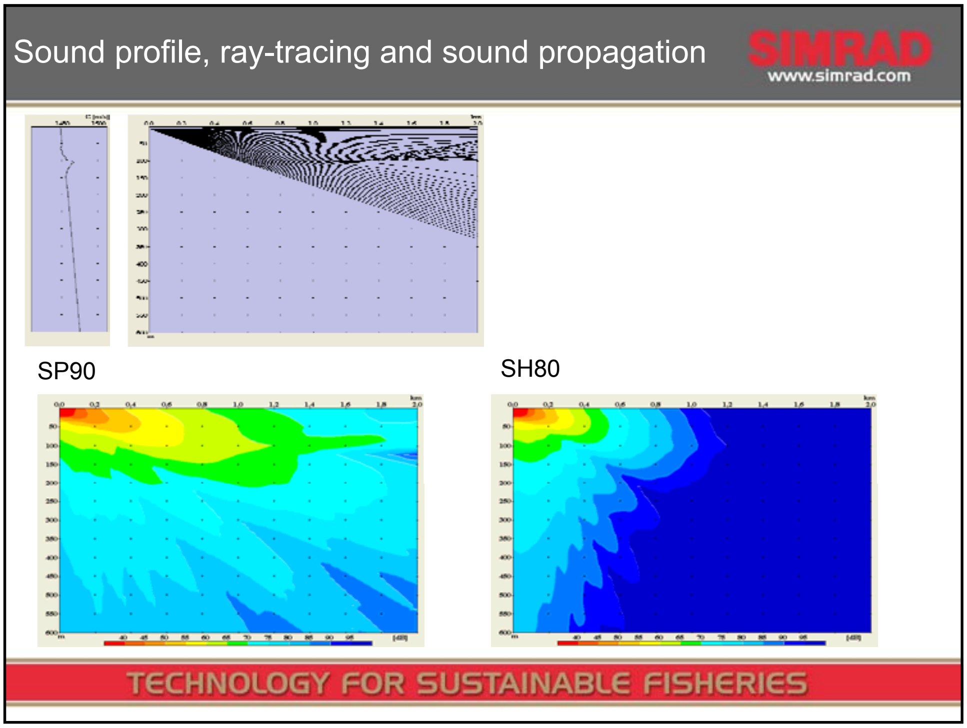
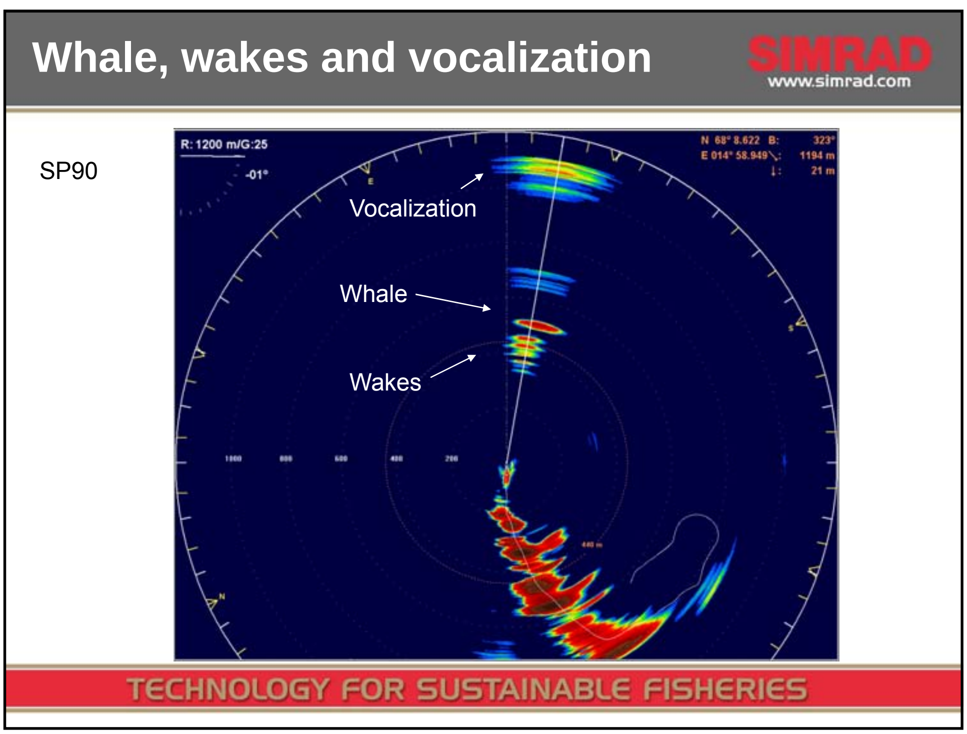
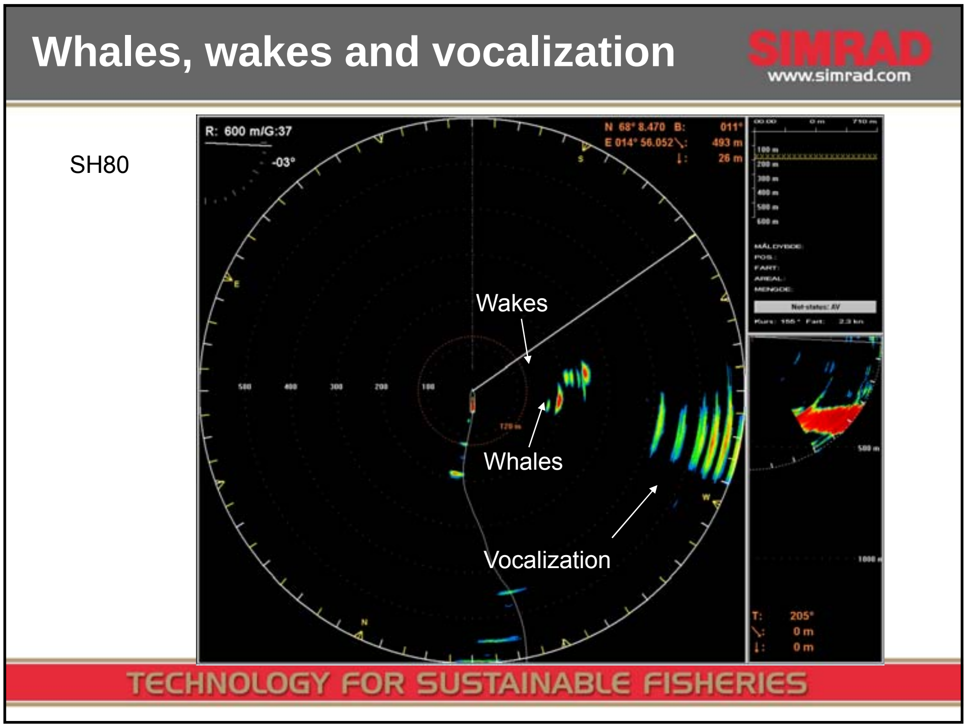
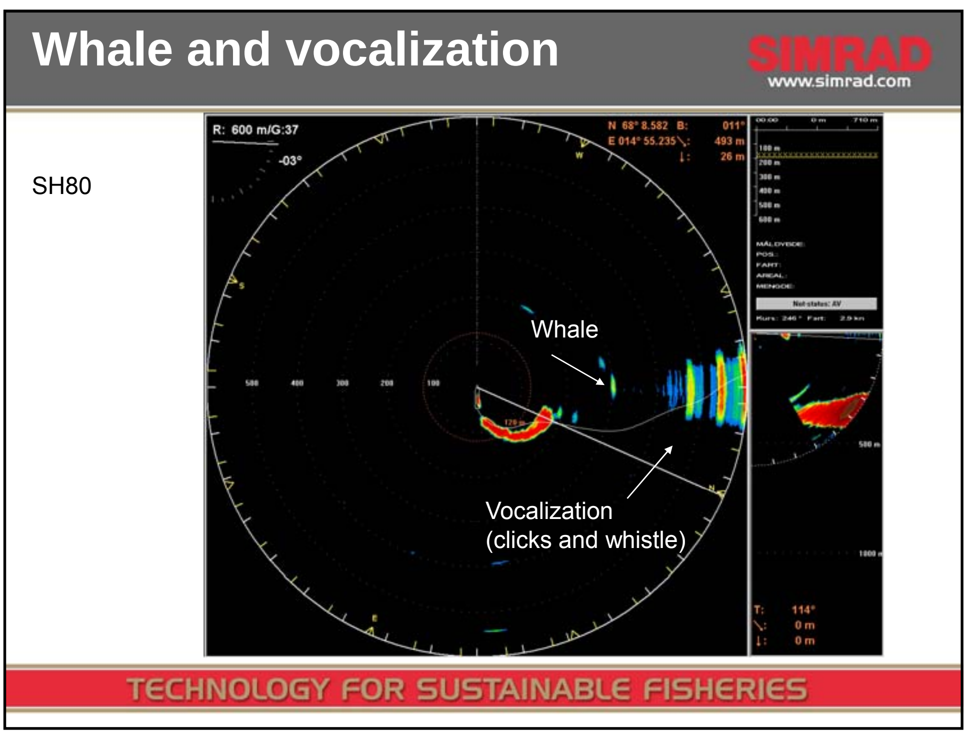
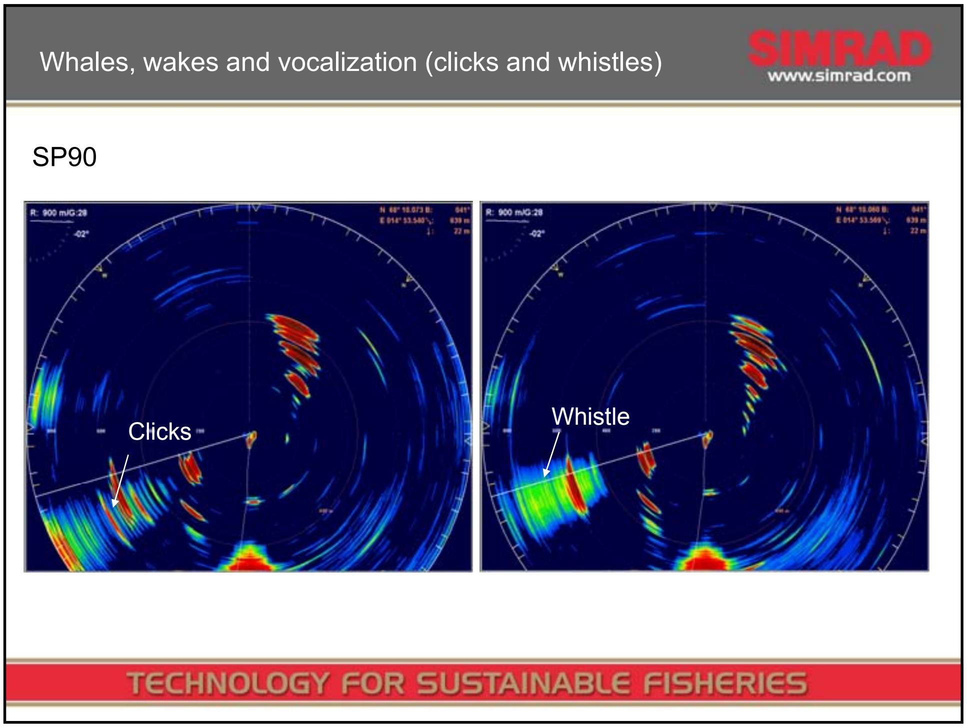
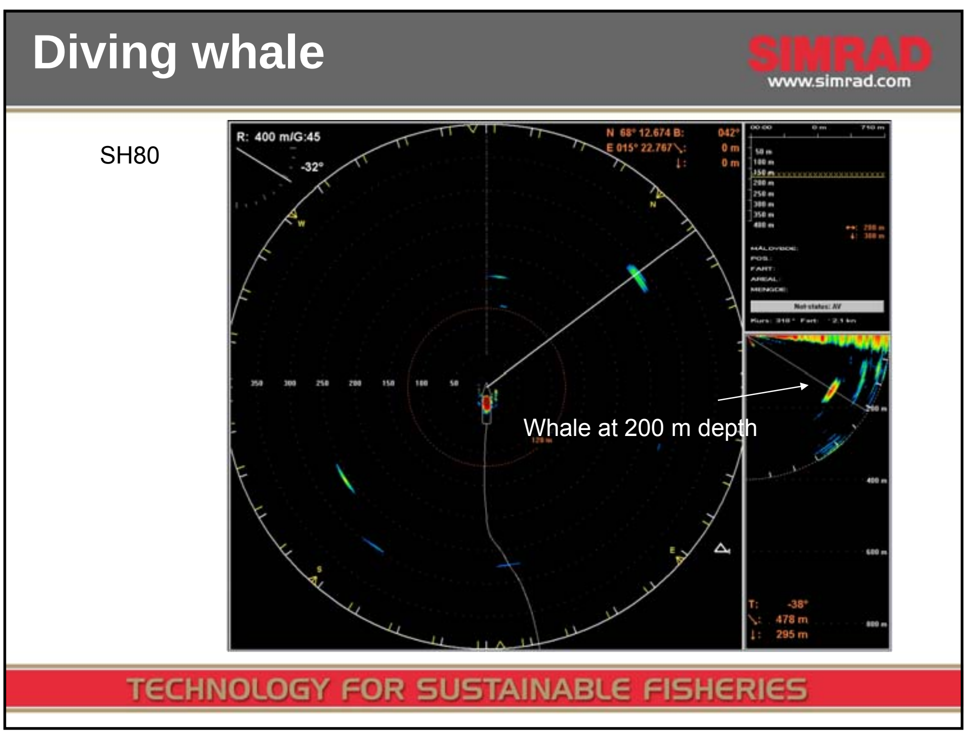

Sound profile, ray-tracing and sound propagation
SIMRAD
www.simrad.com
SP90
SH80
TECHNOLOGY FOR SUSTAINABLE FISHERIES

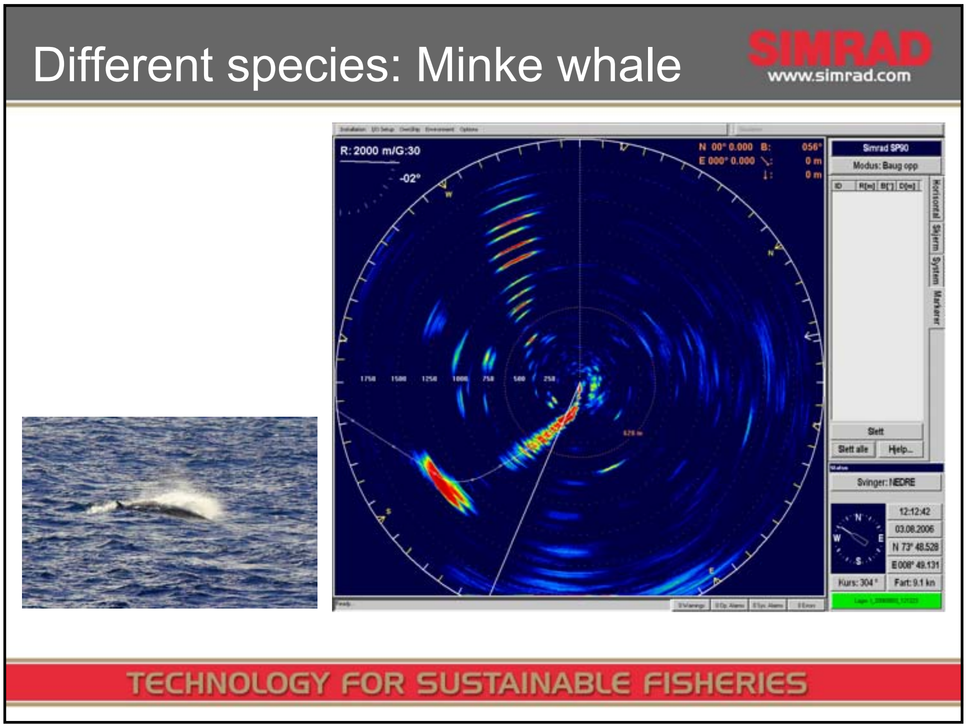

Whale, wakes and vocalization
SIMRAD
www.simrad.com
SP90
R: 1200 m/G:25
Vocalization
Whale
Wakes
TECHNOLOGY FOR SUSTAINABLE FISHERIES

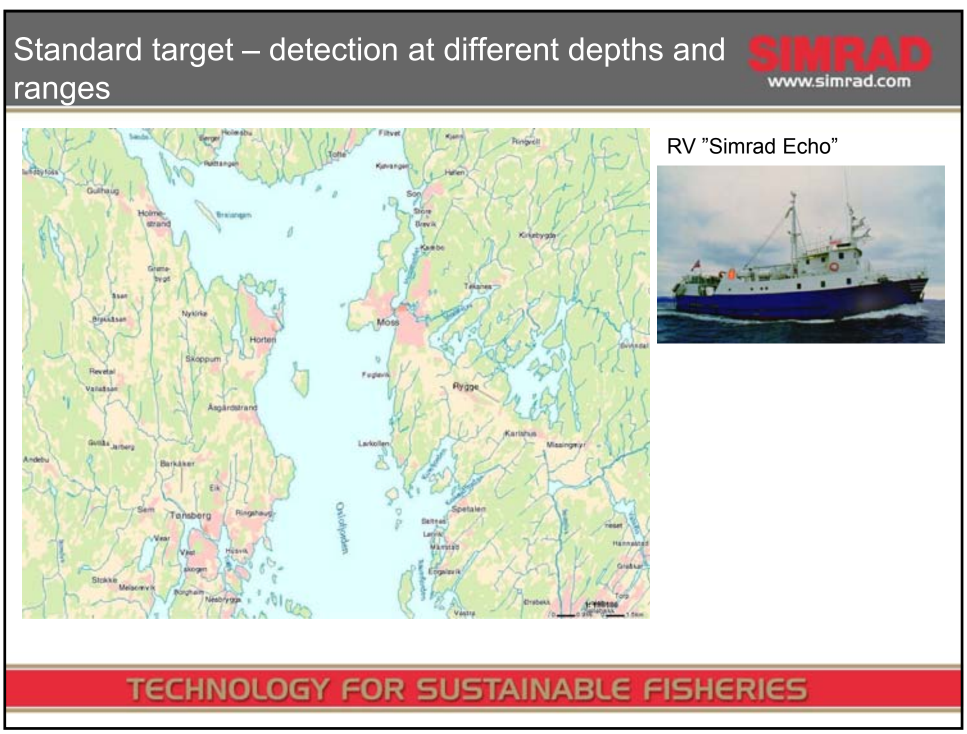

Whales, wakes and vocalization
SIMRAD
www.simrad.com
SH80
R: 600 m/G:37
-03°
Wakes
Whales
Vocalization
TECHNOLOGY FOR SUSTAINABLE FISHERIES

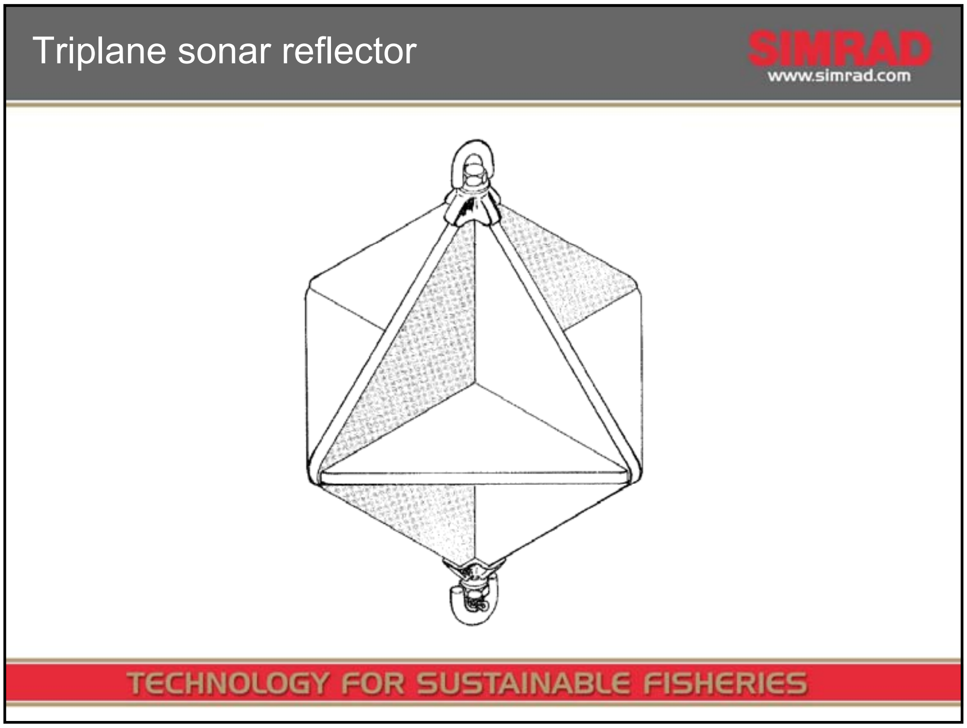

Whale and vocalization
SIMRAD
www.simrad.com
SH80
R: 600 m/G:37
-03°
Whale
Vocalization
(clicks and whistle)
TECHNOLOGY FOR SUSTAINABLE FISHERIES

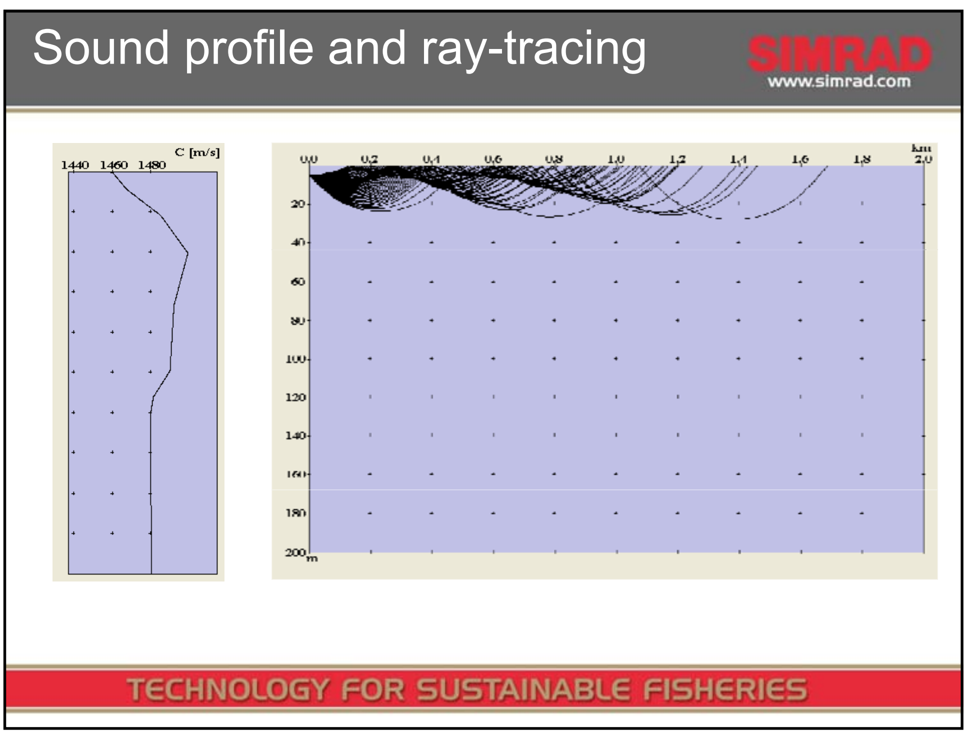

Whales, wakes and vocalization (clicks and whistles)
SIMRAD
www.simrad.com
SP90
Clicks
Whistle
TECHNOLOGY FOR SUSTAINABLE FISHERIES


Diving whale
SIMRAD
www.simrad.com
SH80
Whale at 200 m depth
TECHNOLOGY FOR SUSTAINABLE FISHERIES


Different species: Minke whale
SIMRAD
www.simrad.com
R: 2000 m/G:30
Simrad SP90
TECHNOLOGY FOR SUSTAINABLE FISHERIES


Standard target – detection at different depths and ranges
SIMRAD
www.simrad.com
RV ”Simrad Echo”
Moss
Horten
Rygge
TECHNOLOGY FOR SUSTAINABLE FISHERIES


Triplane sonar reflector
SIMRAD
www.simrad.com
TECHNOLOGY FOR SUSTAINABLE FISHERIES


Sound profile and ray-tracing
SIMRAD
www.simrad.com
C [m/s]
1440 1460 1480
0,0 0,2 0,4 0,6 0,8 1,0 1,2 1,4 1,6 1,8 2,0
km
20
40
60
80
100
120
140
160
180
200
m
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Conclusions

SIMRAD
www.simrad.com

- The SP90 sonar detected whales up to at least 1500 m range. The SH80 sonar did not give reliable detection at ranges > 400 m.
- Whale echo strength was higher at the SP90 sonar than at the SH80.
- In addition to the direct echo from the whale, both vocalization and wake echoes from swimming were seen on the sonar screen providing strong criteria for whale detection. Again, the SP90 had best performance.
- There was no indication that the echo of the whale was reduced with depth. Animals were clearly detected to 200 m water depth.
- The whales showed no apparent reaction to sonar transmissions, even near the vessel (<50 m).

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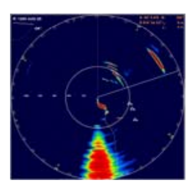
Follow up

SIMRAD
www.simrad.com

- More species
- Reaction to sonar transmission of different species under different conditions
- Echo strength during dives



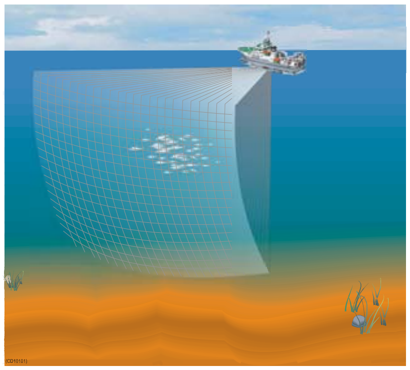



TECHNOLOGY FOR SUSTAINABLE FISHERIES

Main objectives MS70 Multibeam Sonar

SIMRAD www.simrad.com

Main objects for IMR, Bergen to start the project was to improve fish stock assessment estimation:



MS70

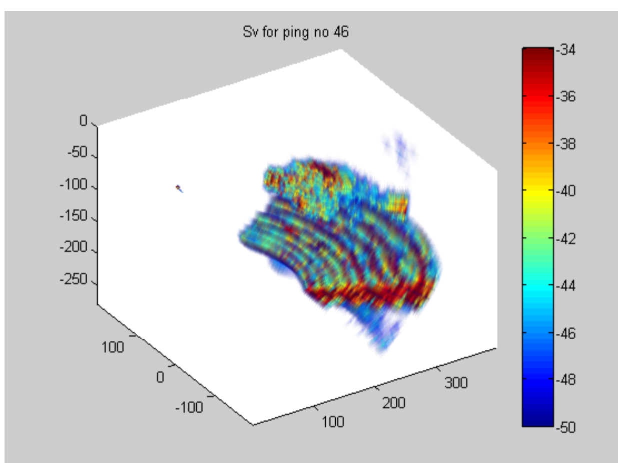
- Quantitative sonar system
- 3D data in one ping
  - School volume and structure
- 4D data in multiple pings
  - School behavior
- Near surface observation
- Easy to use and calibrate
- High dynamic range
- Low side lobes and cross talk
- Raw data logging and replay

TECHNOLOGY FOR SUSTAINABLE FISHERIES

MS70 – Data examples

SIMRAD www.simrad.com

Recordings with MS70 from R/V G.O. Sars outside Lofoten, Norway



Performed by Institute of Marine Research (IMR) in Bergen.

TECHNOLOGY FOR SUSTAINABLE FISHERIES

Two (three) Examples of Active Acoustic Sonar Systems for Marine Mammal Monitoring

Dr. Peter J. Stein
Scientific Solutions, Inc.

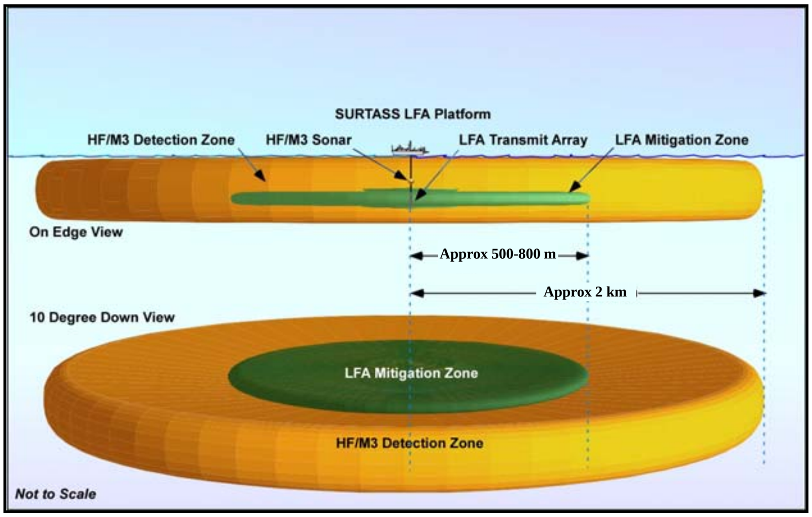
Status and Applications of Acoustic Mitigation and Monitoring Systems for Marine Mammals

Boston, Massachusetts, USA
November 17-19, 2009

System #1: HF/M3

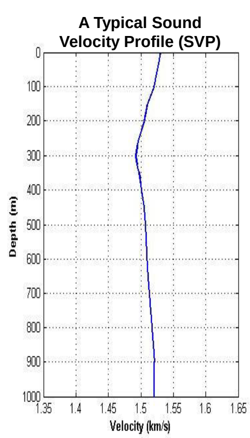
- High Frequency Marine Mammal Monitoring Sonar (HF/M3)
- Installed on U.S. Navy's Surveillance Towed Array Sensor System (SURTASS) Low Frequency Active (LFA) Sonar System
- HF/M3 must be operational during SURTASS LFA transmissions
  - Ramp up procedures are required for both HF/M3 and LFA transmissions
- Custom designed for the application
  - Deep water
  - Slow tow speeds
  - Existing stable tow platform for mounting sonar

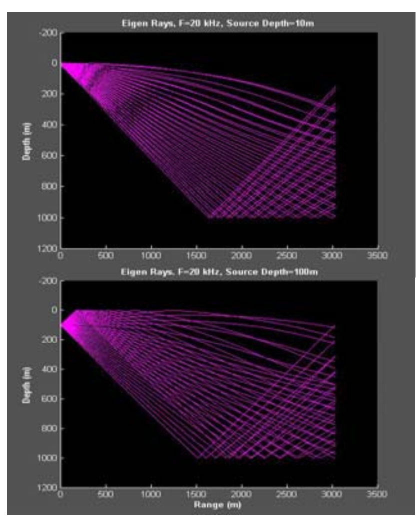
HF/M3 Requirement



Propagation Effects on HF/M3 Design

Monitoring sonar could not be hull mounted





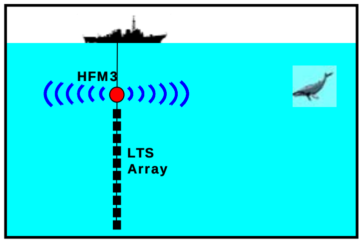
10 m depth

120 m depth

Peter Stein

Two (three) Examples of Active Acoustic Sonar Systems for Marine Mammal Monitoring

HF/M3: Mechanically steered focusing reflectors

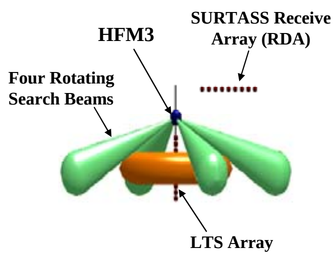


Only 4 transducers

No beamforming

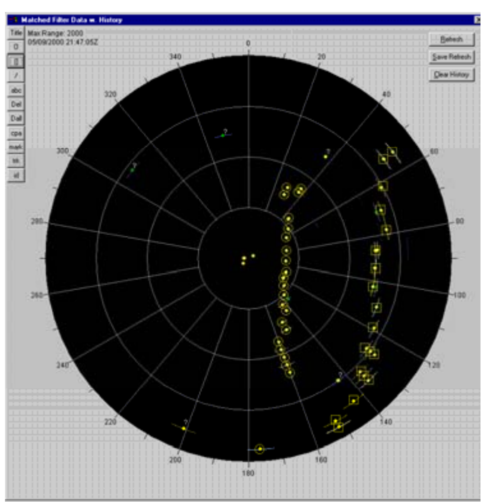
30-40 kHz

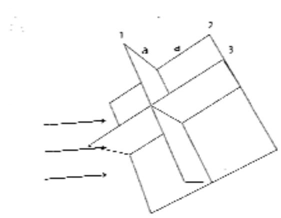
Up to 220 dB re μPa^2 @ 1m



SCIENTIFIC SOLUTIONS, INC.
INNOVATIVE RESEARCH AND ENGINEERING

HF/M3 Testing with Simulated Whale Target





TS = -3 to +7 dB re 1 m

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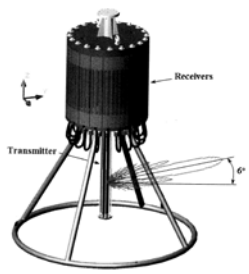
INNOVATIVE RESEARCH AND ENGINEERING

System #2: IMAPS Prototype Active Sonar

IMAPS = Integrated Marine Mammal Monitoring and Protection System

- 21-25 kHz
- Source level up to 215 dB re µPa @ 1m
- 60 Receivers, electronically steered
- Self-contained power amplifiers and receive electronics
- Vertical line array source



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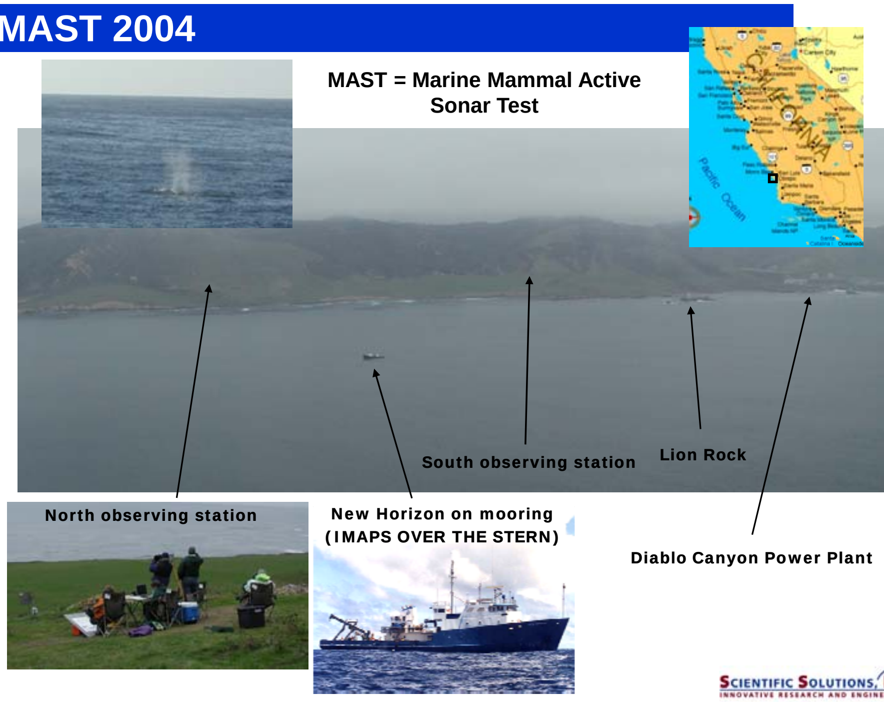
MAST 2004

MAST = Marine Mammal Active Sonar Test



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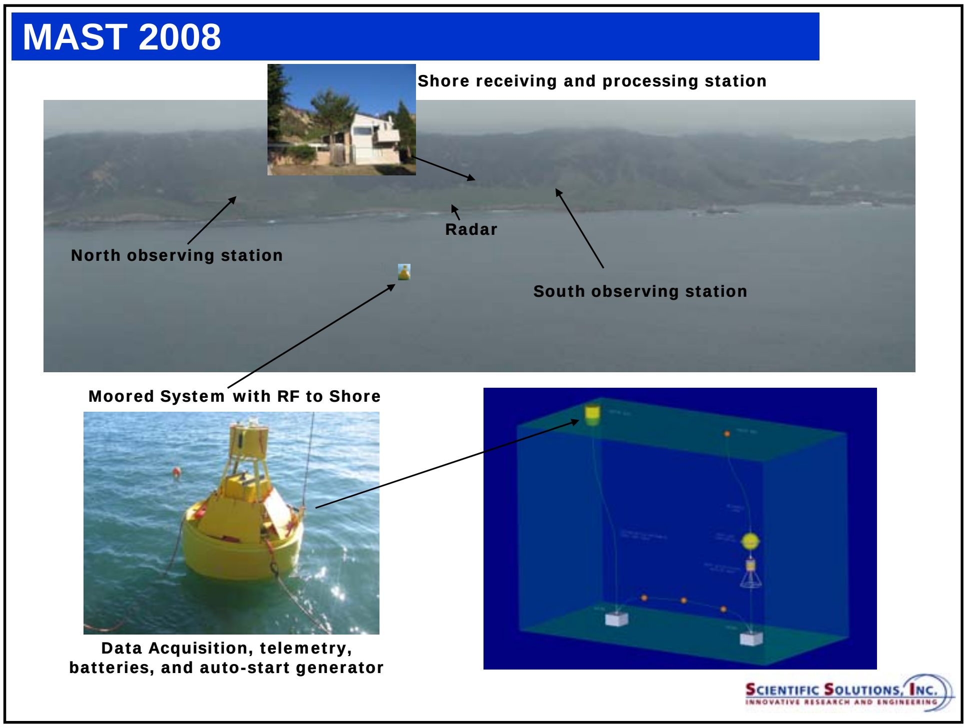
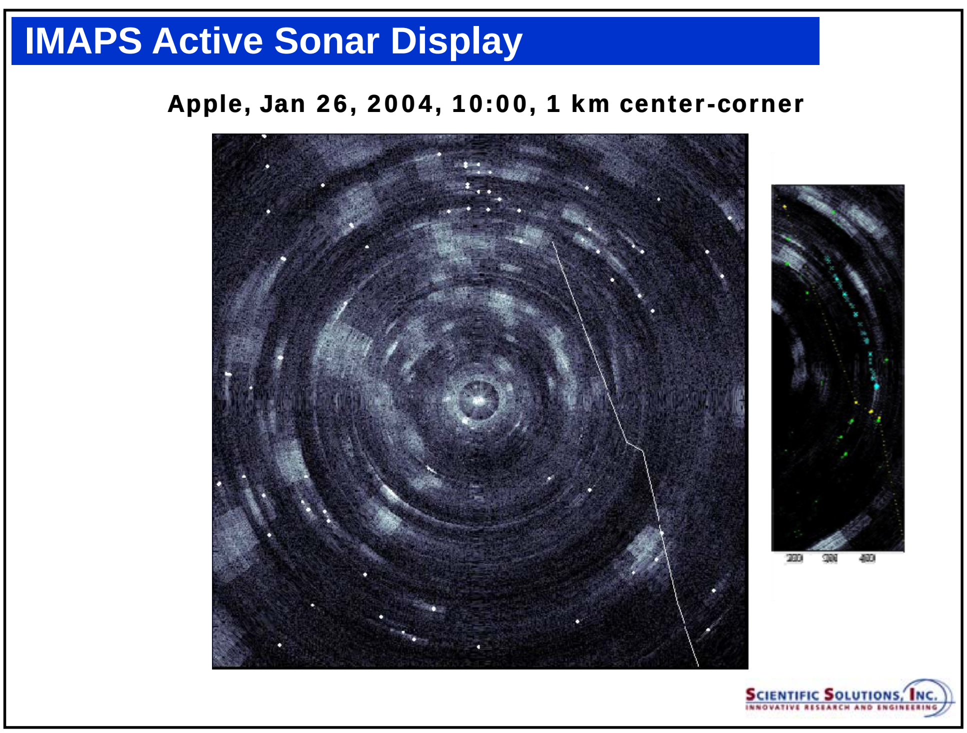
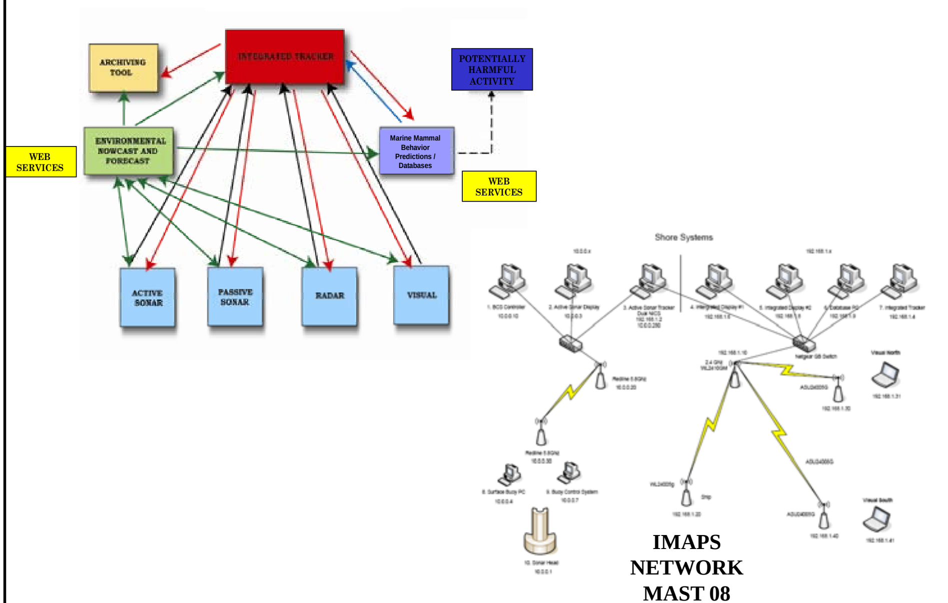

MAST 2008
Shore receiving and processing station
Radar
North observing station
South observing station
Moored System with RF to Shore
Data Acquisition, telemetry,
batteries, and auto-start generator
Scientific Solutions, Inc.
Innovative Research and Engineering


IMAPS Active Sonar Display
Apple, Jan 26, 2004, 10:00, 1 km center-corner
Scientific Solutions, Inc.
Innovative Research and Engineering

IMAPS Implementation



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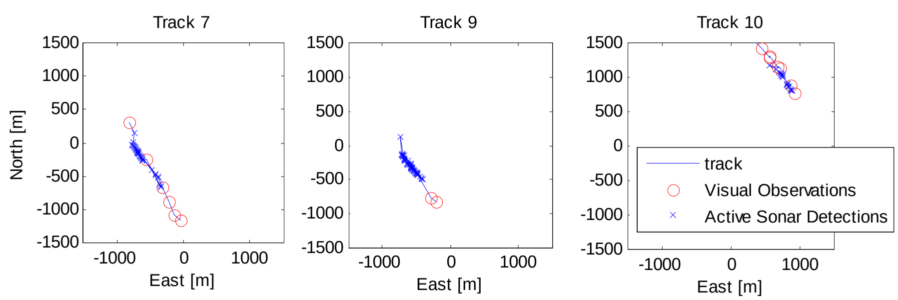
MAST 08 Integrated Tracks



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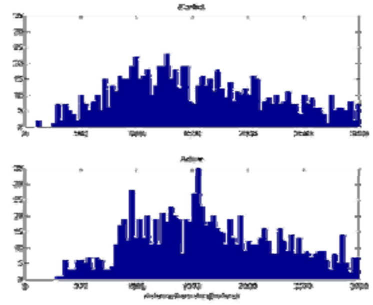
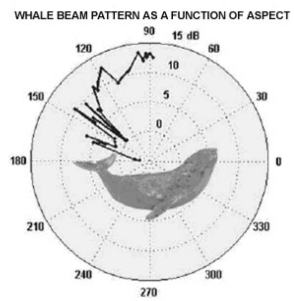
MAST 08 – Two other tidbits



Grey whales hear the sonar and some exhibited an avoidance reaction

Frankel, A.S. 2005. Gray whales hear and respond to signals 21 kHz and higher. Page 97 in Abstracts, Sixteenth Biennial Conference on the Biology of Marine Mammals, San Diego, California.



Grey whale target strength at 21-25 kHz varies from around -5 to + 13 dB re 1 m depending on aspect

I. Lucifredi and P.J. Stein, "Grey whale target Strength measurements and the analysis of the backscattered response," J. Acoust. Soc Am. 121(3) March 2007

P.J. Stein, I. Lucifredi, J.N. Lustig, G.S. Edelson, D.E. Egnor, and B. Ramawamy, "Integrated Marine Mammal Monitoring and Protection System," (Unclassified) JUA(USN) 59, 19-46 (2009) (Unclassified).

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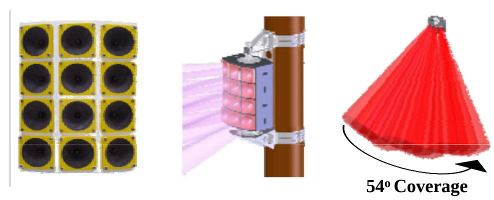
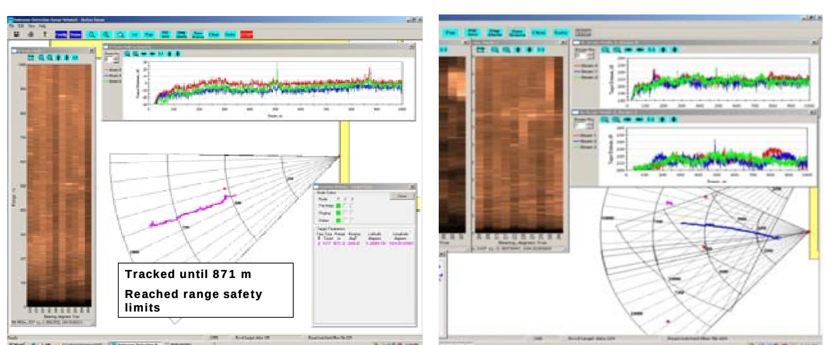
INNOVATIVE RESEARCH AND ENGINEERING

System #3: SDSN

SDSN = Swimmer Detection Sonar Network

- **45-75 kHz**
- **54º coverage per node**
- **Networkable**





SDSN U.S. Patent 7,457,198 B2

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INNOVATIVE RESEARCH AND ENGINEERING

Summary

- **Active acoustic can provide for very high probability of detection and accurate tracking at ranges out to around 2 km depending on conditions, animal size, and sonar design**
- **In general the sonar cannot be hull mounted**
- **Custom sonar implementations for particular applications are necessary**
- **The best solution will be achieved through integration of several "modalities" of monitoring**

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INNOVATIVE RESEARCH AND ENGINEERING

Ian Boyd
Movements of marine mammals around a marine renewable device

Movements of marine mammals around a marine renewable device: application of a high frequency imaging sonar

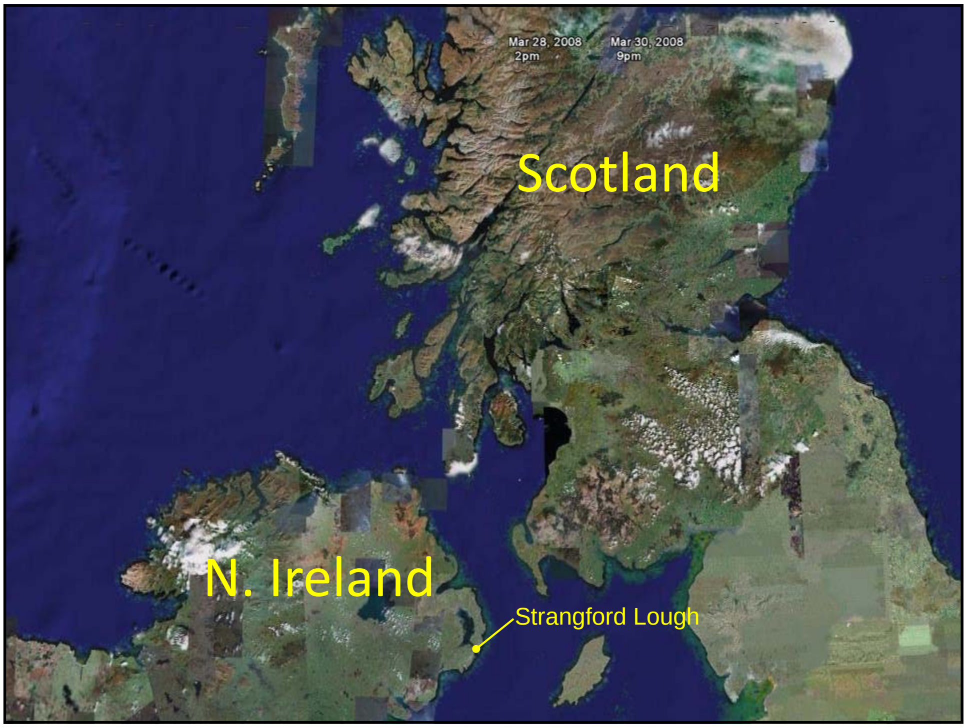
Gordon Hastie[1], Beth Mackey[1], Andrew Murray[1], Jennifer Snowball[2], and Ian Boyd[3]
[1] SMRU Ltd, Scottish Oceans Institute, St Andrews, Fife, UK. gdh@smru.co.uk;
[2] Royal Haskoning, 10 Bernard Street, Leith, Edinburgh, UK;
[3] Sea Mammal Research Unit, Scottish Oceans Institute, St Andrews, Fife, UK;

Background

SeaGen

- 1.2MW tidal energy convertor
- Installed in Strangford Lough in April 2008
- Twin 17m diameter rotors
- Maximum tip speed 12ms^{-1}

www.smru.co.uk


Mar 28, 2008
2pm
Mar 30, 2008
9pm
Scotland
N. Ireland
Strangford Lough


Turbine location
Image NASA
Image © 2008 DigitalGlobe
Image © 2008 The GeoInformation Group
Image © 2008 TerraMetrics
54°26'13.00" N
5°36'27.45" W
elev 0 m
Eye alt

Background

www.smru.co.uk

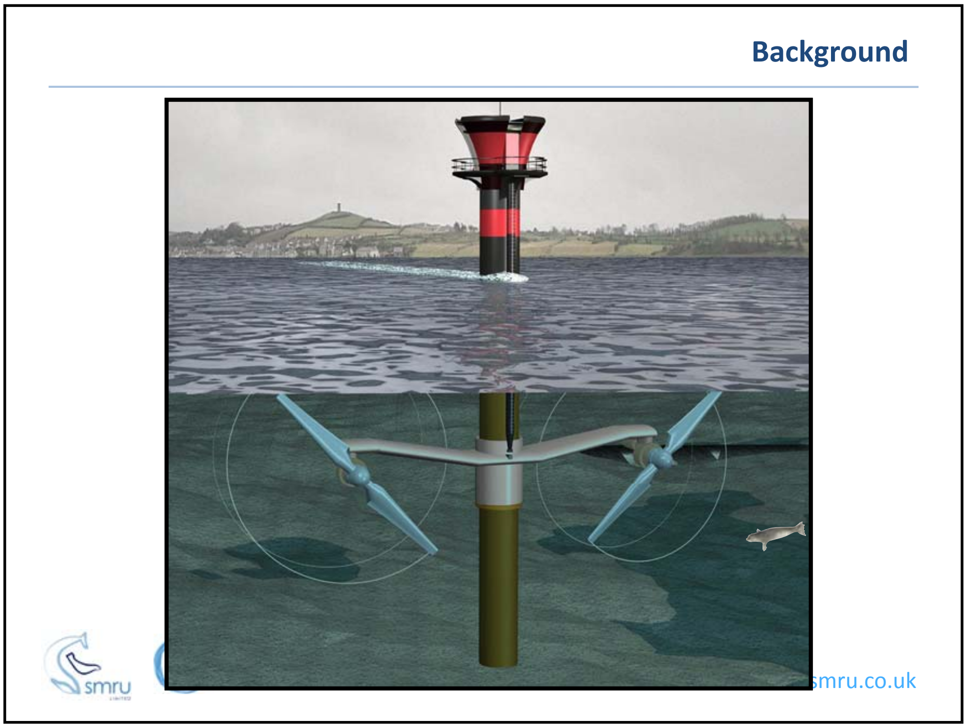
Background

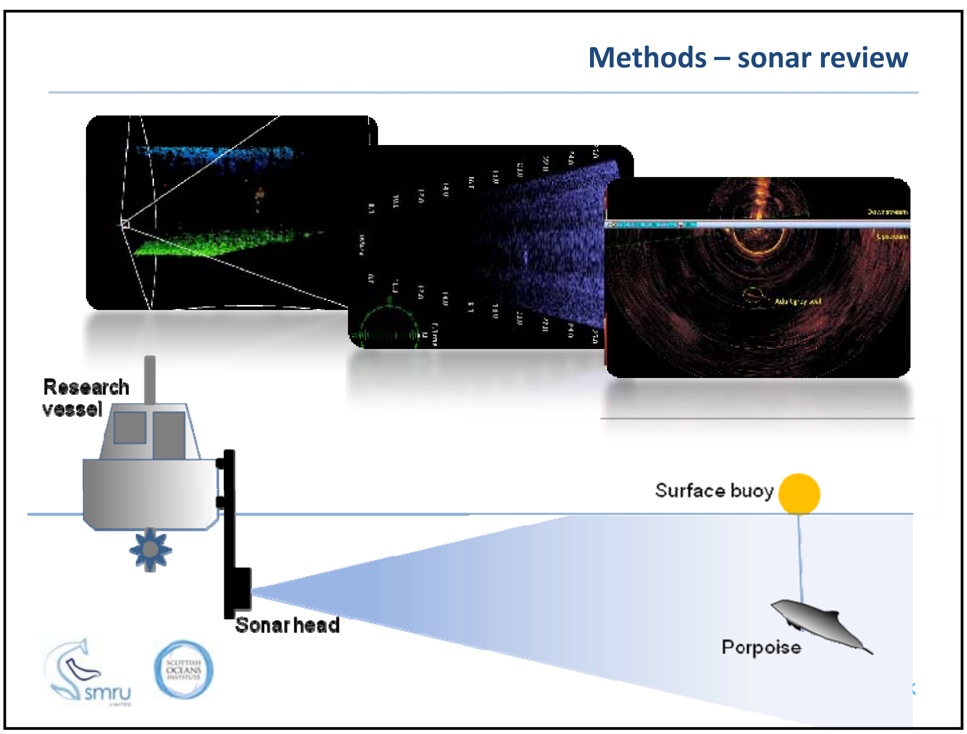
Interactions may include:

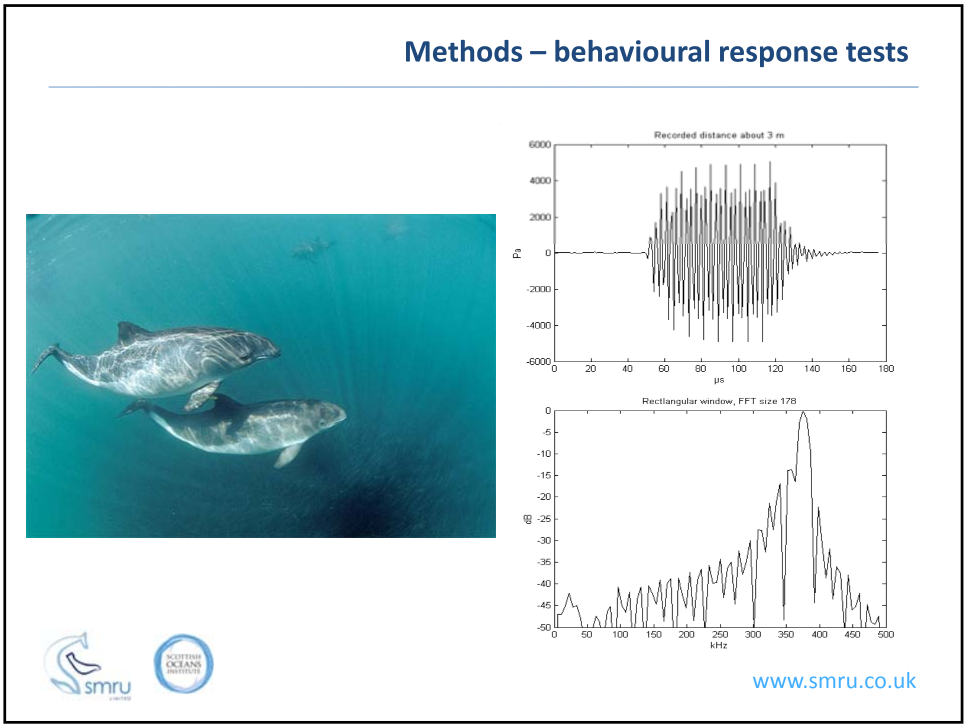
- Habitat exclusion,
- Attraction towards devices due to increased foraging opportunities,
- Direct physical interactions.

The aim of this study was to quantify close range interactions between marine mammals and the tidal device.

www.smru.co.uk


Background
smru
smru.co.uk


Methods – sonar review
Research vessel
Surface buoy
Sonar head
Porpoise
smru


Methods – behavioural response tests
Recorded distance about 3 m
Pa
µs
Rectlangular window, FFT size 178
dB
kHz
smru
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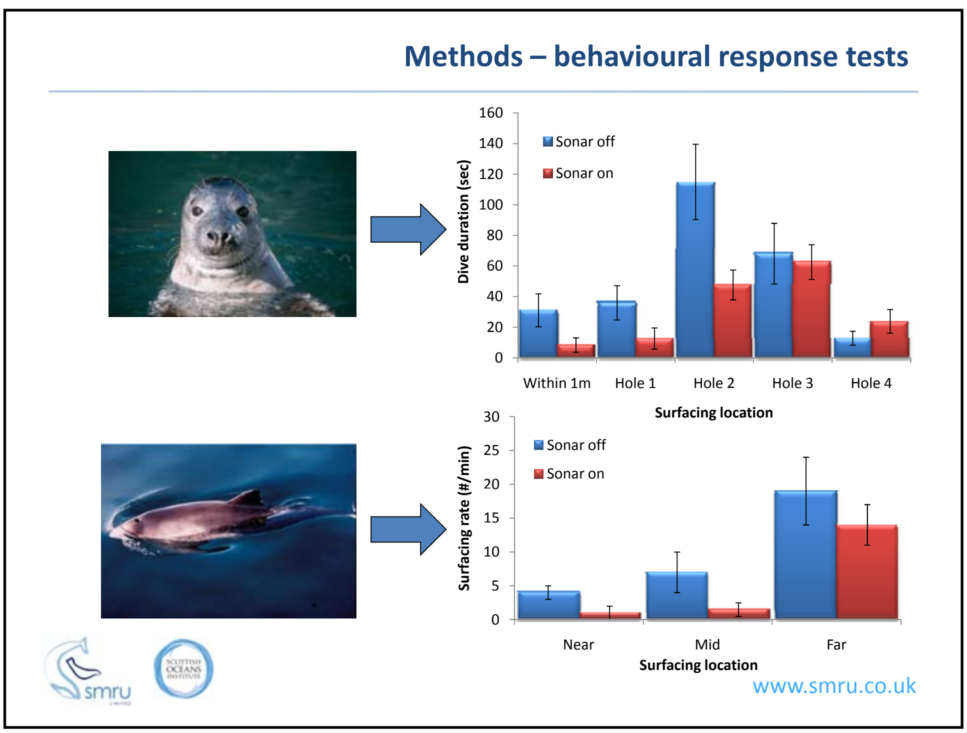
www.smru.co.uk


Methods – behavioural response tests
Sonar off
Sonar on
Dive duration (sec)
Within 1m
Hole 1
Hole 2
Hole 3
Hole 4
Surfacing location
Sonar off
Sonar on
Surfacing rate (#/min)
Near
Mid
Far
Surfacing location
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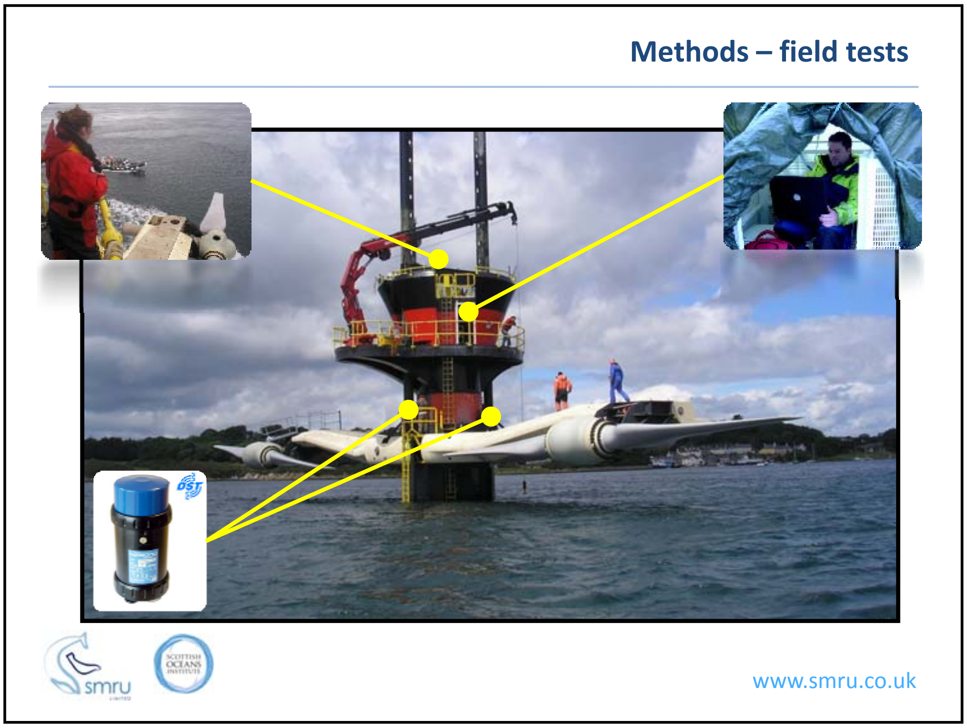
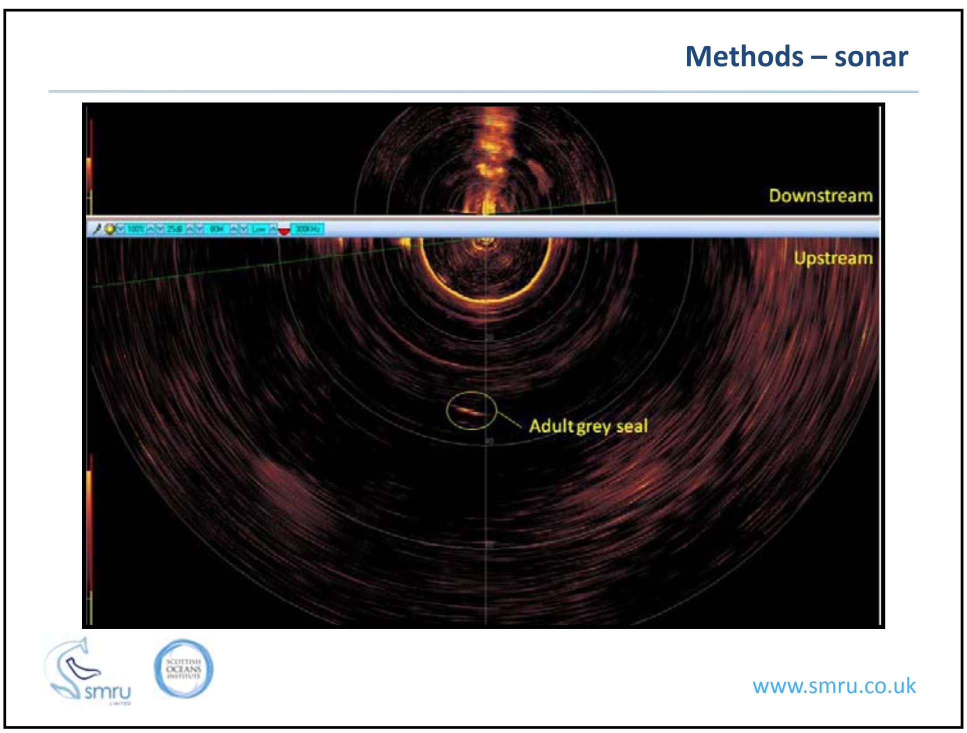

Methods – field tests
www.smru.co.uk

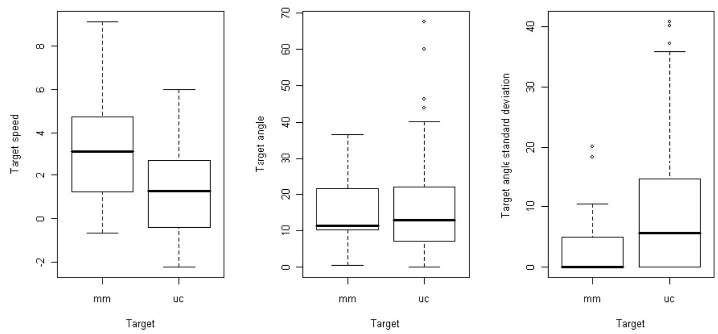

Methods – sonar
Downstream
Upstream
Adult grey seal
www.smru.co.uk

Results – sonar targets

❖Mobile targets could be detected and tracked using imaging sonar.

❖Comparison of sonar detections to sightings confirmed that approximately 16% of targets were marine mammals.

❖Within areas directly upstream of the turbine (up to 100m), the percentage of visual sightings that were detected using the sonar was around half (46.7%).



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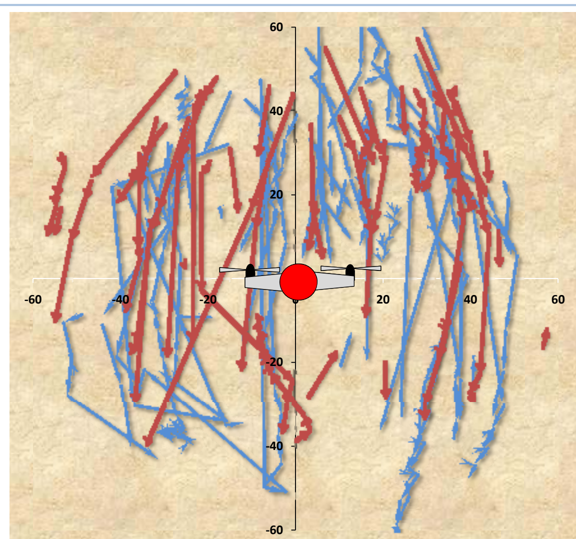
Results – XY tracks



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Conclusions - Strangford

- ❖Small mobile targets can be detected using HF imaging sonar;
- ❖Comparison of sonar detections to sightings 'confirmed' that a number of these (16% of all targets) were marine mammals;
- ❖The percentage of visual sightings that were detected using the sonar was around half (46.7%);
- ❖Results from the target tracks shows that marine mammals do move past the turbine in relatively close proximity;

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Conclusions – sonar as a monitoring tool

- ❖ Sonar can detect and track marine mammals around tidal turbines;
- ❖ Has the potential as a behavioural research tool;
- ❖ Factors such turbulence appear to have an impact on detection probability;
- ❖ Proportion of marine mammals detected may be variable – implications for monitoring and mitigation;
- ❖ Important to ensure that acoustic signals are not within auditory ranges of target animal;

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Future development – research collaboration
smru
LIMITED
EMEC ORKNEY
The European Marine Energy Centre Ltd
BioSonics®
www.smru.co.uk

Signal Processing and Analysis: Detection, Classification and Localization of Marine Mammal Sounds

David K. Mellinger
Oregon State University and National Oceanic and Atmospheric Administration

with help from

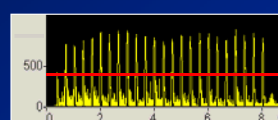
Doug Gillespie
University of St. Andrews

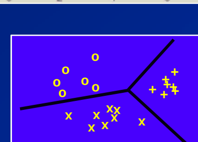
Christopher W. Clark
Cornell University

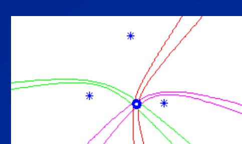
Aaron Thode
Scripps Institution of Oceanography

Overview: What this talk is

- The analysis chain
  - > primacy of the type of result
- Detection
  - > overview
  - > issues
- Classification
  - > overview
  - > issues
- Localization and tracking
  - > overview
  - > issues







Overview: What this talk is *not*

Not a list of techniques

Not a list of software packages

Overview

- The analysis chain
  - > primacy of the type of result
- Detection
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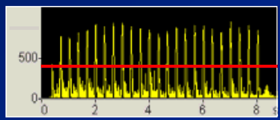
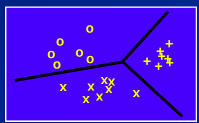
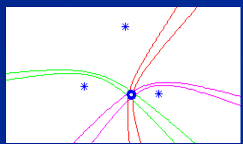
  - > issues
- Classification
  - > overview
  - > issues
- Localization and tracking
  - > overview
  - > issues



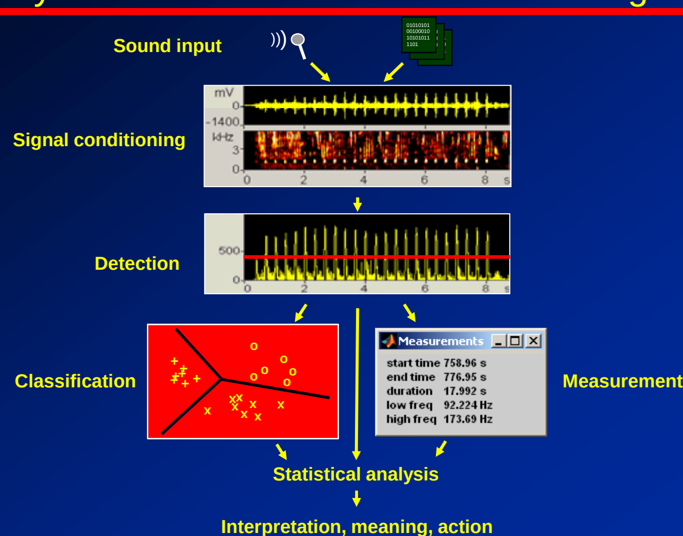




The Analysis Chain: From Sound to Knowledge

- Hydrophone
- Analog signal conditioning
  - electrical conditioning, anti-alias filtering etc.
- Data acquisition (to a computer)
  - data storage
- Signal processing and analysis
  - normalization, detection, classification, localization, measurement
- Data reduction
  - statistical methods
- Interpretation
- Results

The Analysis Chain: From Sound to Knowledge



Measuring Human Impacts on Marine Mammals

Processing depends on type of result desired

For instance, types of human impact:

- Hearing damage
  - need to measure received spectrum
    - instantaneous or over time
  - need to locate animals
    - vocal and non-vocal
    - locate in range, or 2-D position, or 3-D position
- Masking of important sounds
  - need to measure duty cycle, spectrum of received sound at the receiver
  - examine behavioral change due to signals not received
    - predators or prey not heard
    - breeding vocalizations (advertisement, courtship, etc.)

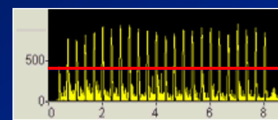
Measuring Human Impacts on Marine Mammals

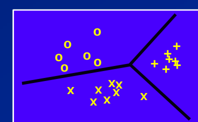
Types of impact (cont'd):

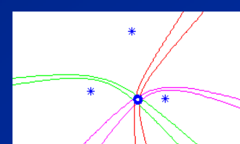
- Change in behavior
  - disruption of critical activities
    - foraging, breeding, etc.
  - displacement from important habitat
    - feeding, breeding, resting, etc.
  - displacement in movement
    - e.g., migration
  - disruption of communicative activities
    - socializing, breeding, coordinated movement

Overview

- The analysis chain
  - > primacy of the type of result
- Detection
  - > overview
  - > issues
- Classification
  - > overview
  - > issues
- Localization and tracking
  - > overview
  - > issues





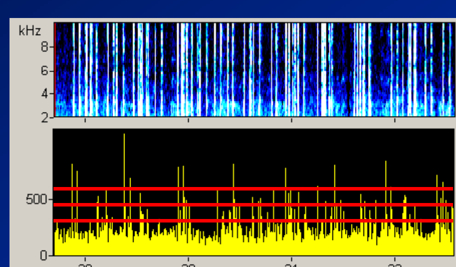


Detection and Classification

- Detection: deciding whether a sound of interest is present
  - normally a yes-or-no decision
  - > usually involves a decision criterion
    - e.g., a detection threshold
    - choice of criterion (threshold) is always a *tradeoff between false detections and missed calls*

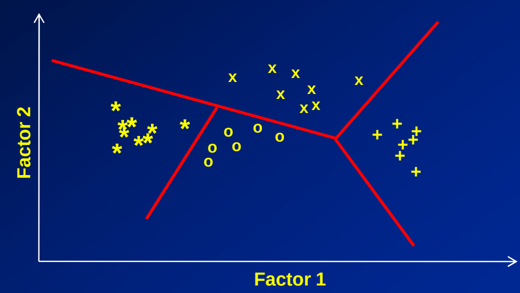
Spectrogram of sperm whale clicks

Detection function: measured likelihood that a click is present



Detection and Classification

- Classification:
  - identifying a sound: deciding on a category
  - usually a multi-way decision



- There is no rigid boundary between detection and classification
  - some methods, like template-matching techniques, do some of both

Detection and Classification: Issues

Degree of detection specificity required:

Does one need to detect…

…all marine organisms?

…all marine mammals?

…a certain taxon, such as beaked whales?

…a group defined acoustically, such as marine mammals that use low-frequency communication?

…all threatened/endangered species?

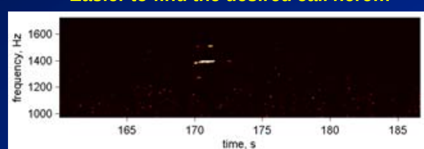
…a single species, such as bowhead whales?

…a single call type, as is often done for population estimation?

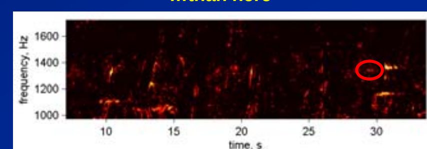
Detection and Classification: Issues

- Difficulty of detection depends on
  - how stereotyped the calls are
    - highly stereotyped calls are usually easier to detect and classify
    - highly stereotyped calls can use template-matching methods
  - type of sound
    - click, moan, burst pulse, whistle, etc.
  - frequency range
    - what other sounds are in the same frequency band?

Easier to find the desired call here…



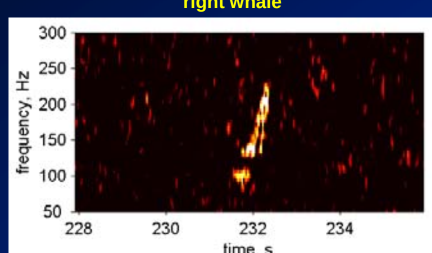
…than here



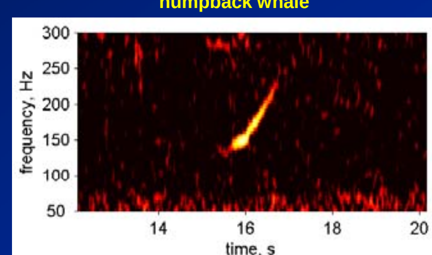
Detection and Classification: Issues

- Difficulty of detection and classification depends on
  - similarity to other species, other call types

right whale



humpback whale



Detection and Classification: Issues

How many calls must be detected?

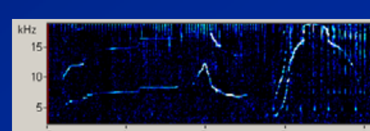
- > "all of them" is not an answer – there are always faint calls at the limit of detection or classification
- For detection, the answer affects how the decision criterion is used
- Rare species or calls:
  - > want to find as many as possible
  - > set detection threshold LOW, so as to detect fainter calls
- Common species or calls:
  - > to evaluate trends in calling rate (and perhaps population), set detection threshold HIGH, so as to get few false detections
  - > to count total calls, set detection threshold to an INTERMEDIATE value, so that false detections balance missed calls

Detection and Classification: Issues

How general a method is needed?

- More general methods
  - > e.g., detecting changes in the energy within a frequency band
  - > can detect more species/call types
  - > useful for detecting a wide variety of species
  - > useful for detecting species with highly variable vocalization, like humpbacks

- Highly specific methods
  - > e.g., template matching (matched filtering)
  - > aim is often to detect one call type of one species
  - > may miss some of the target call type if slightly different from the template

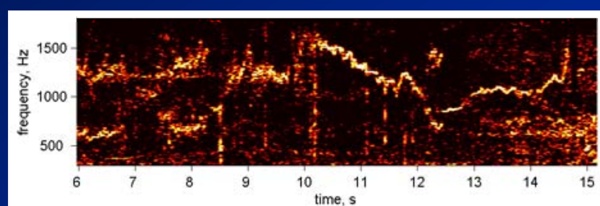


- Methods with intermediate specificity
  - > e.g., click detectors, whistle detectors
  - > capture a group call types, often defined by frequency – e.g., mid-frequency whistlers

Detection and Classification: Issues

Degree of automation: how involved are humans in the detection and classification process?

- Full automation:
  - signal processing method detects and classifies sounds with no checking
  - easy, quick
  - prone to error, particularly when the type of noise changes over time



Detection and Classification: Issues

Degree of automation: how involved are humans in the detection and classification process?

- No automation:
  - signal processing step just makes spectrogram for human(s) to view
  - human finds marine mammal calls and (optionally) classifies them
  - very labor-intensive, slow
  - (probably) most accurate method
    - useful when calls are highly variable

Detection and Classification: Issues

Degree of automation: how involved are humans in the detection and classification process?

- Automation with checking
  - detection/classification method(s) produce a set of putative calls
  - human(s) check each detection
  - somewhat labor-intensive
  - accurate for weeding out false detections
  - missed calls can be a problem
    - (sometimes) humans check periods of time with no calls to estimate the missed-call rate

Detection and Classification: Issues

Degree of automation: how involved are humans in the detection and classification process?

- Automation with partial checking
  - human(s) check a *sample* of the detections
    - estimate correct-detection rate
  - again, can also sample periods of time with no detections to estimate missed-call rate
  - *need to sample whenever the noise changes*
    - changes in human activity
    - physical sources: wind, storms, ice, flow noise, etc.
    - diel and seasonal changes in calling
      - of either target species or interfering species

Detection and Classification: Issues

Data for training and testing

- Automated detectors require some degree of training and testing
  - > need data set(s) for these
  - > data used for training *should not be used for testing*
  - > the greater the variety of training data, the more robust the detector
  - > variety can come from
    - recordings from different places, populations, times
    - recordings made in different noise conditions
      - physical, human, or non-target-species noise
    - different recording arrangements
      - towed vs. fixed hydrophones
      - different models of hydrophones, conditioning equipment

Detection and Classification: Issues

Data for training and testing

- Often a large data set is split into pieces, with some data used for testing and some for training

figure courtesy of M. Roch

Detection and Classification: Issues

- Detector/classifier performance evaluation
  - for characterizing how well a method works
  - description of performance should include signal-to-noise ratio (SNR) of detected/classified calls
    - clear (high SNR) calls are significantly easier to detect/classify than faint ones
  - no performance metric fully characterizes a method
    - changes in noise strongly affect performance
      - especially changes in non-target-species calls similar to target-species calls

Detection and Classification: Issues

Detector performance evaluation

- "Receiver Operating Characteristic" (ROC) curve:
  - shows rates of correctly detected calls (true detections) and false detections
  - "Detection Error Tradeoff" (DET) curve is nearly the same thing

Detection and Classification: Issues

Detector performance evaluation

- “False Alarm Rate”:
  - for a specific missed-call rate (e.g., 10%), provides the number of false alarms per unit time (e.g., per hour)
  - similar to a single point on the DET curve, but uses false alarms per hour

Detection and Classification: Issues

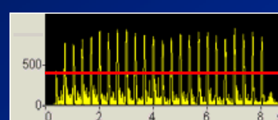
- Classifier performance evaluation
- “Confusion matrix”
  - says how often calls are classified into the correct and incorrect categories
  - entries on the diagonal represent correct answers

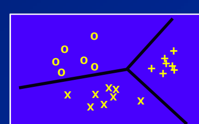
Detection and Classification: Issues

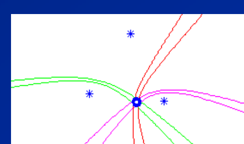
- Classifier performance evaluation:
  - Overall classification error rate

Overview

- The analysis chain
  - primacy of the type of result
- Detection
  - overview
  - issues
- Classification
  - overview
  - issues
- Localization and tracking
  - overview
  - issues

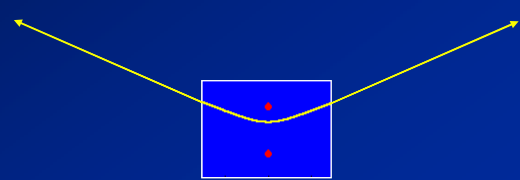






Localization

- *Localization*: Using a sound to estimate the location of a sound source, such as a calling marine mammal
- *Tracking*: Combining successive locations to estimate movement
- Both of these…
  - can be done in 1, 2, or 3 dimensions
  - are usually done using the differences in the times that a call arrives at several hydrophones
    - for example, with two closely-spaced hydrophones, a given time delay corresponds to a sound source at a certain bearing angle

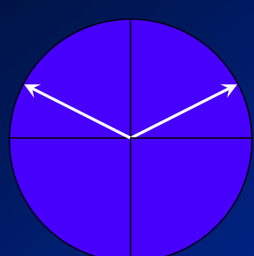


Localization

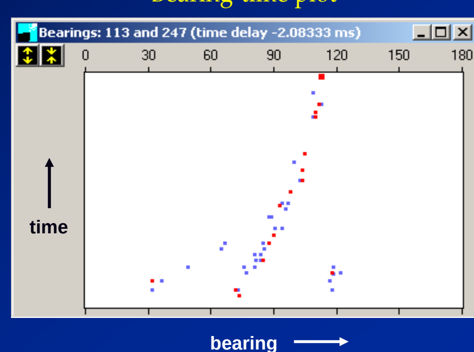
1-dimensional localization: estimating the bearing to the animal

- with 2 phones, there is left-right ambiguity

Direction indicator



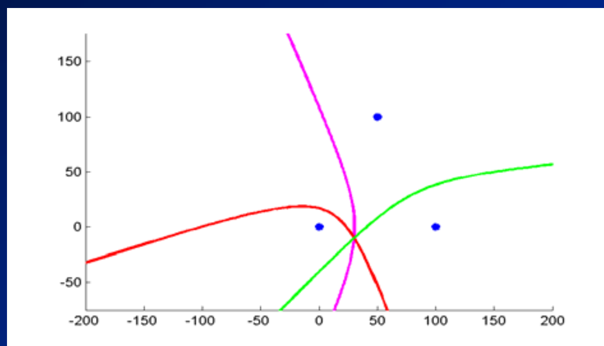
Bearing-time plot



Localization

2-dimensional localization: estimating the position of the animal

- often involves intersection of hyperbolas
- X-Y (horizontal) position
- range-depth position



Y

X

Localization

3-dimensional localization: estimating the position of the animal in 3 dimensions

> X-Y-Z

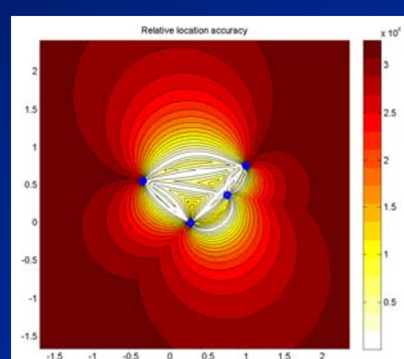
> range-depth-azimuth

Localization: issues

- Localization methods produce an *estimate* of position
  - there is always some uncertainty (variance) in this estimate
  - sometimes this uncertainty is shown as an error ellipse
- Ambiguity surface (ambiguity plot):
  an image showing the likelihood at each position that a calling animal is at that position

Localization: Issues

- Localization accuracy depends on
  - “time-bandwidth product” of the call type, i.e., the duration of the call times its bandwidth
  - signal-to-noise ratio of the received call, which depends on
    - animal-to-hydrophone distance
    - loudness of the animal
    - noise level in the frequency band of interest
  - geometry of the hydrophones
    - can model this →
  - for some methods, geometry of the environment



Localization: Issues

- Number of hydrophones
  - not just the number in use, but rather the number at which a given call is received clearly
- Multipath arrivals
  - clear bottom or surface bounces and be used for localization
    - unclear ones can simply make it difficult to locate animals
  - it's possible to localize in range and depth from just 1 hydrophone
    - need at least 3 arrivals
    - can even localize in 3 dimensions with the right bathymetry

Localization: Issues

Degree of automation: how involved are humans in the localization process?

- Similar factors apply as for automatic detection and classification
  - full automation vs. no automation vs. intermediate amount of automation

Summary of important points

- Overall:
  - the method to use depends on the type of result desired
  - crucial choice: the amount of human involvement in the process
- Detection:
  - there is always a tradeoff between wrong detections and missed calls
- Classification:
  - make sure training data is independent of testing data
- Localization:
  - localization methods produce an estimate, whose quality depends on the call that is localized and the array geometry

Detection and Localisation of Clicks Using Passive Acoustics

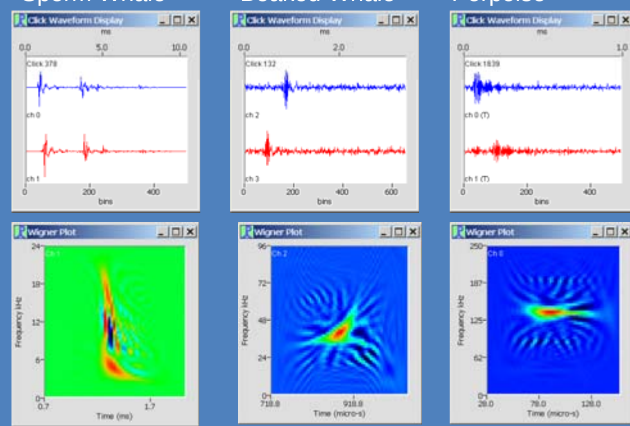
Doug Gillespie
Sea Mammal Research Unit
Scottish Oceans Institute

Which Species Click ?

- All odontocetes (toothed whales and dolphins) are believed to click
- Level of study varies
- Some seem to vocalise most of the time
- Others vocalise rarely
- Some species have never been recorded

Types of Sound

Sperm Whale | Beaked Whale | Porpoise

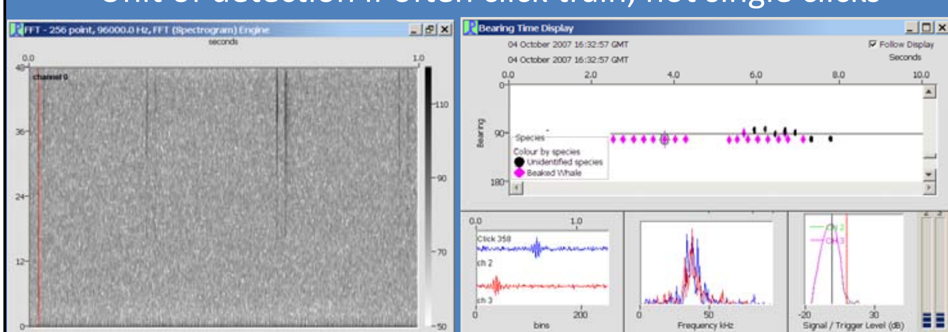


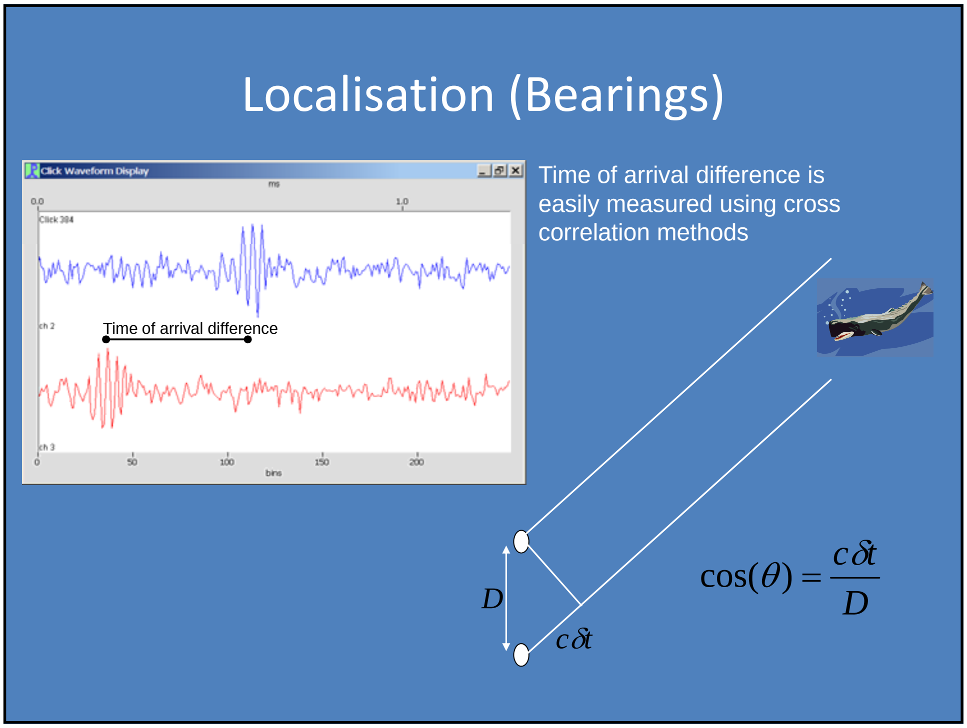
Clicks are highly directional

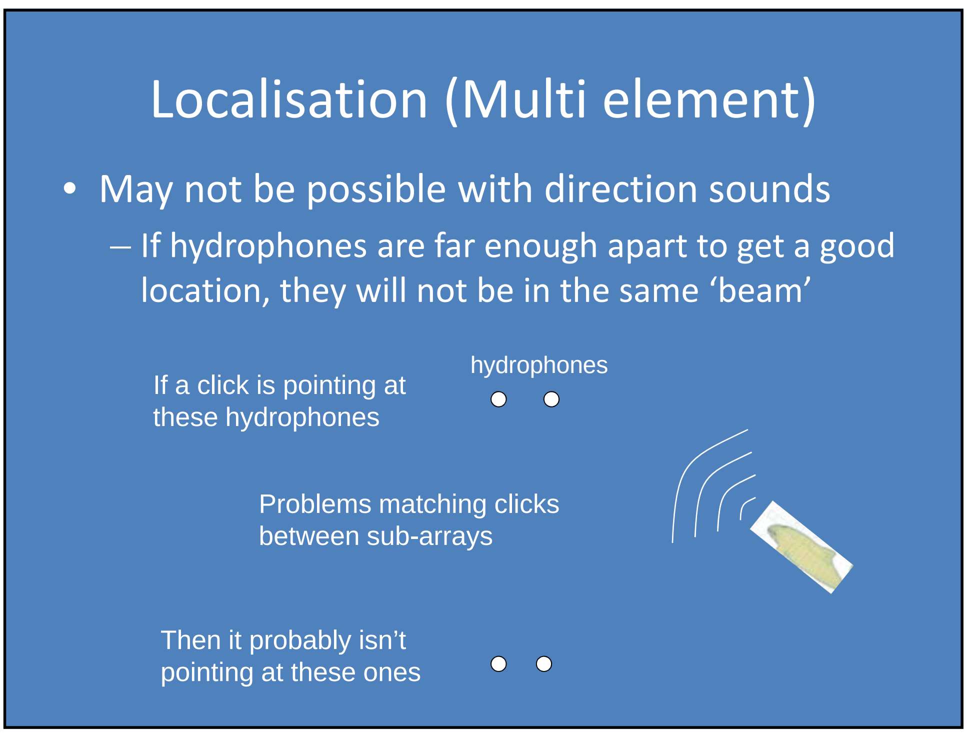
Many are ultrasonic

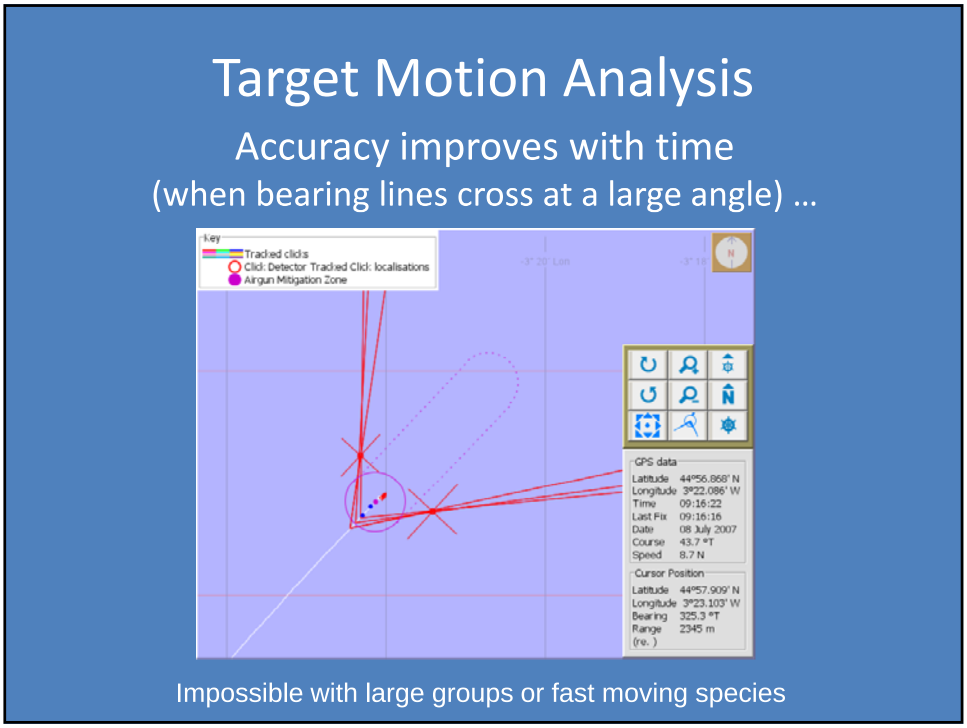
Detection

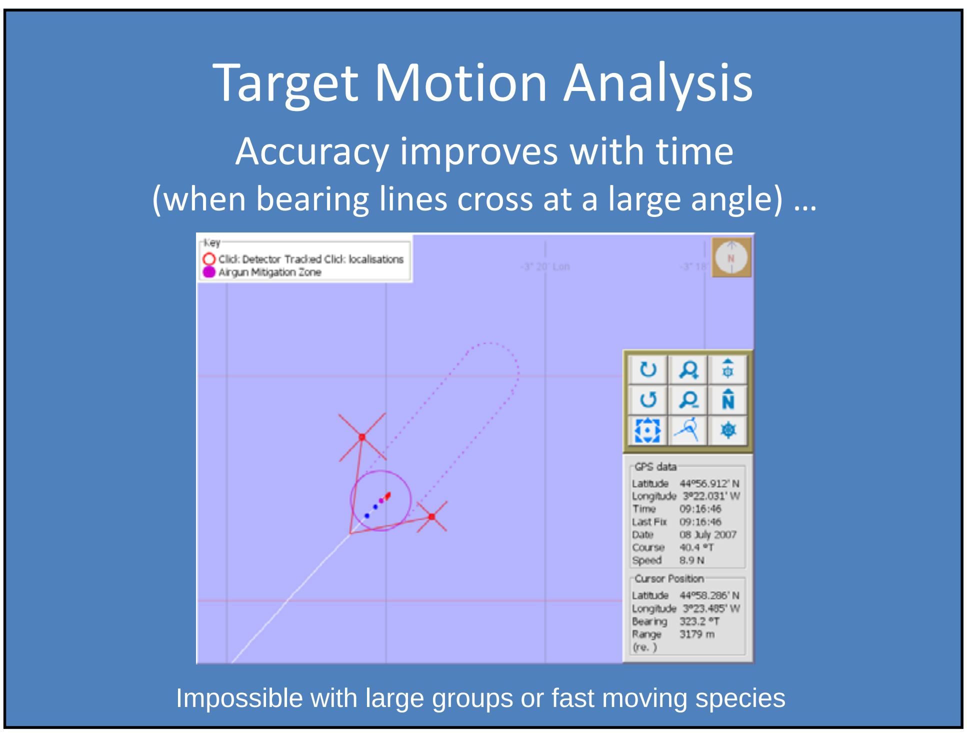
- Aural only possible if in human audio band
- Visual on spectrogram display
- Automatic on spectrogram
- Automatic on time series data
- Unit of detection if often click train, not single clicks

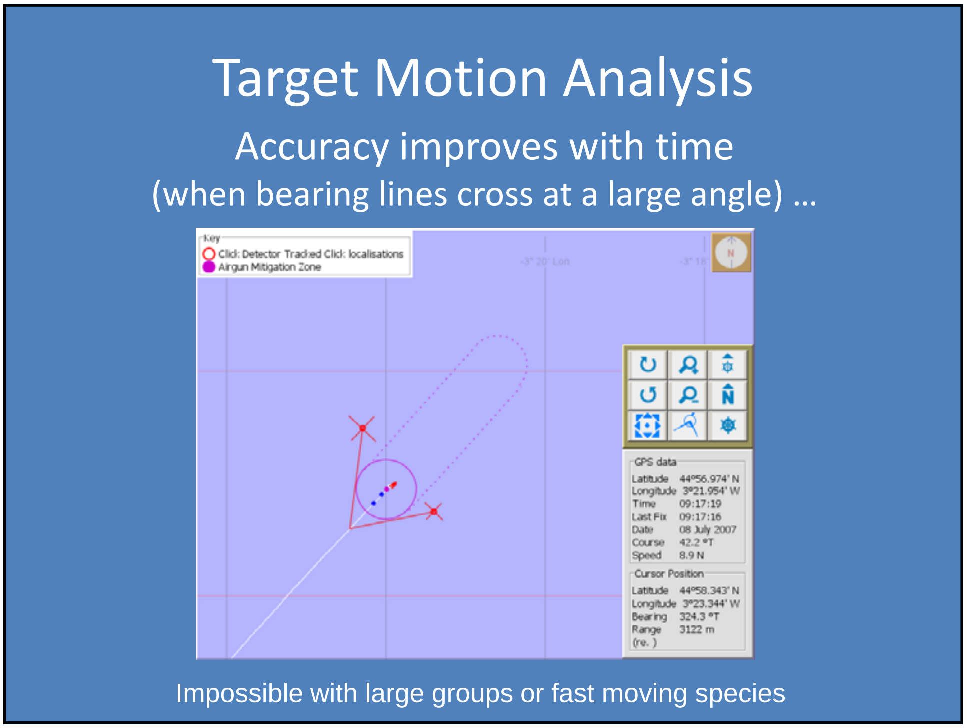


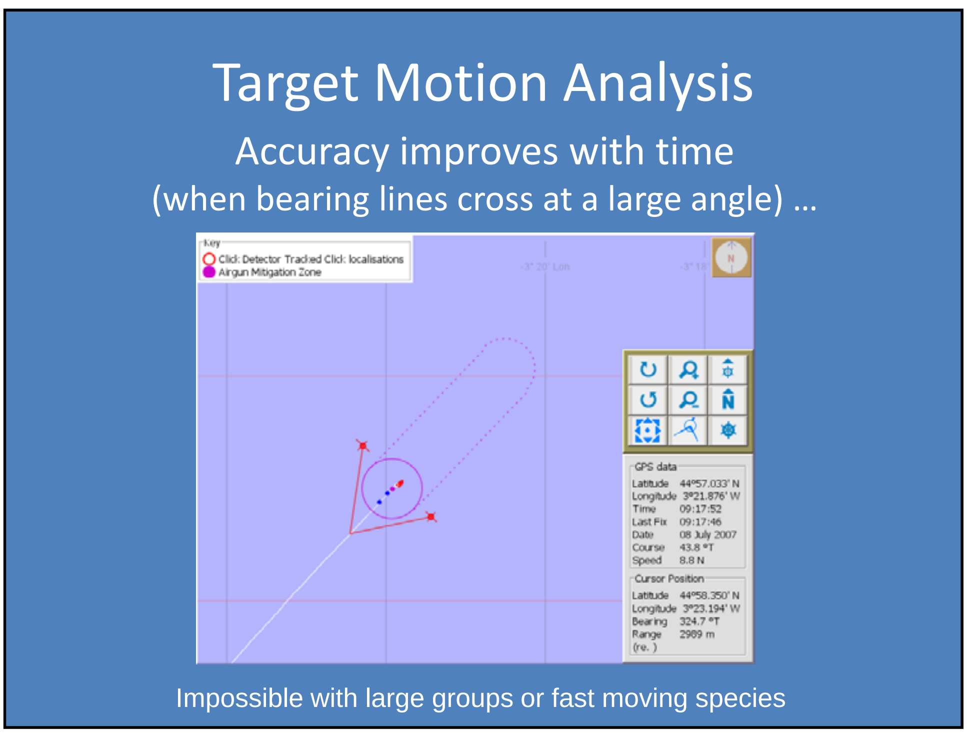

Localisation (Bearings)
Click Waveform Display
Time of arrival difference
Time of arrival difference is easily measured using cross correlation methods
D
cδt
$\cos(\theta) = \frac{c\delta t}{D}$

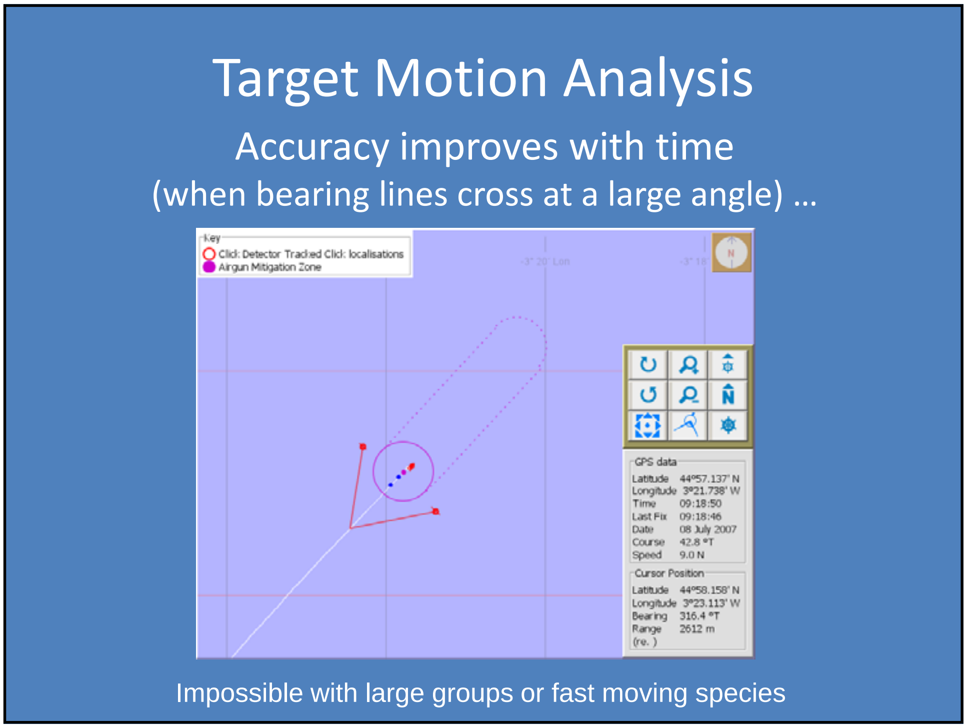

Localisation (Multi element)
• May not be possible with direction sounds
– If hydrophones are far enough apart to get a good location, they will not be in the same 'beam'
hydrophones
If a click is pointing at these hydrophones
Problems matching clicks between sub-arrays
Then it probably isn't pointing at these ones

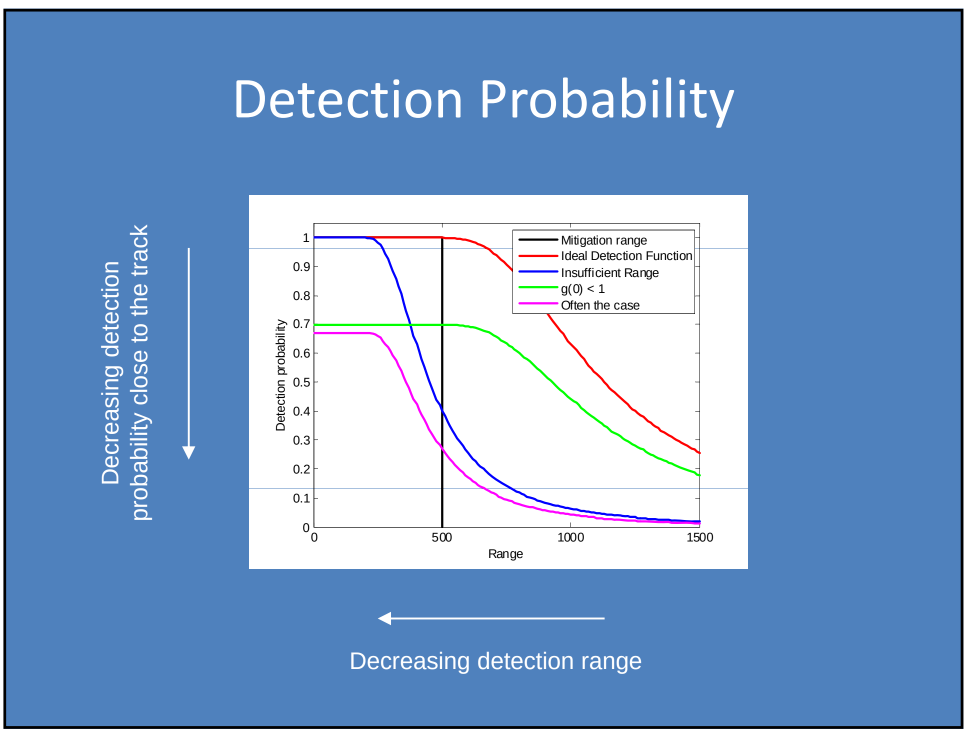

Target Motion Analysis
Accuracy improves with time
(when bearing lines cross at a large angle) …
Key
Tracked clicks
Click Detector Tracked Click localisations
Airgun Mitigation Zone
GPS data
Cursor Position
Impossible with large groups or fast moving species


Target Motion Analysis
Accuracy improves with time
(when bearing lines cross at a large angle) …
Key
Click Detector Tracked Click localisations
Airgun Mitigation Zone
GPS data
Cursor Position
Impossible with large groups or fast moving species


Target Motion Analysis
Accuracy improves with time
(when bearing lines cross at a large angle) …
Impossible with large groups or fast moving species


Target Motion Analysis
Accuracy improves with time
(when bearing lines cross at a large angle) …
Impossible with large groups or fast moving species


Target Motion Analysis
Accuracy improves with time
(when bearing lines cross at a large angle) …
Key
Click Detector Tracked Click localisations
Airgun Mitigation Zone
GPS data
Latitude 44°57.137' N
Longitude 3°21.738' W
Time 09:18:50
Last Fix 09:18:46
Date 08 July 2007
Course 42.8 °T
Speed 9.0 N
Cursor Position
Latitude 44°58.158' N
Longitude 3°23.113' W
Bearing 316.4 °T
Range 2612 m
(re.)
Impossible with large groups or fast moving species


Detection Probability
Decreasing detection probability close to the track
Mitigation range
Ideal Detection Function
Insufficient Range
g(0) < 1
Often the case
Detection probability
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
500
1000
1500
Range
Decreasing detection range

Detection Probability

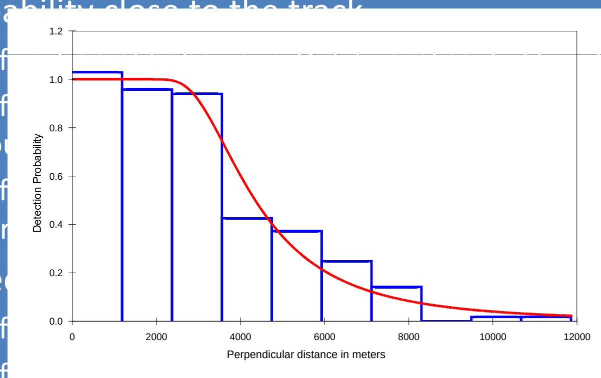
- Probability close to the track
  - A function of behaviour: Did it vocalise ?
  - A function of detector: Would we be sensitive to that sound ?
  - A function of luck: Is it’s beam of sound pointing at the array ?
- Detection range
  - A function of evolution: How loud is that species ?
  - A function of noise: At what range are sounds masked ?
  - A function of technology: How good is our equipment

Detection Probability Sperm Whales

- Probability close to the track
  - A function of behaviour: Did it vocalise ? Very Likely
  - A function of detector: Would we be sensitive to that sound ? Yes
  - A function of luck: Is it’s beam of sound pointing at the array ? Who cares
- Detection range
  - A function of evolution: How loud is that species ? Very
  - A function of noise: At what range are sounds masked ?
  - A function of technology: How good is our equipment

Detection Probability
Sperm Whales

- Proba…
  - A f… Likely
  - A f… that so…
  - A f… at the arr…
- Dete…
  - A f… ? Very
  - A f… sked ?
  - A function of technology: How good is our equipment

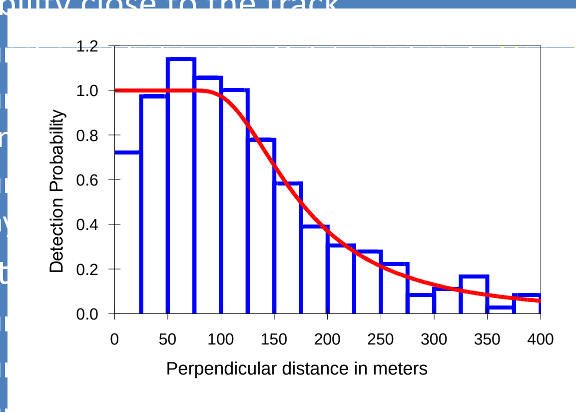


Detection Probability
Harbour Porpoise

- Probability close to the track
  - A function of behaviour: Did it vocalise ? Very Likely
  - A function of detector: Would we be sensitive to that sound ? Requires specialist equipment
  - A function of luck: Is it’s beam of sound pointing at the array ? Probably not (if it’s swimming away)
- Detection range
  - A function of evolution: How loud is that species ? Not very
  - A function of noise: At what range are sounds masked ? 200m
  - A function of technology: How good is our equipment

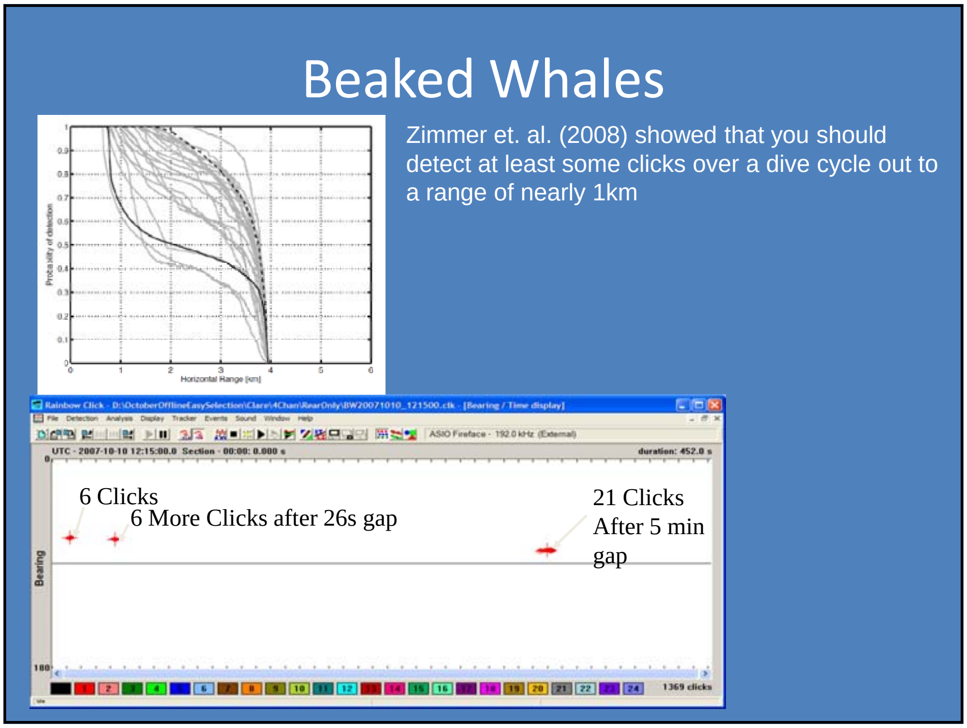
Detection Probability
Harbour Porpoise

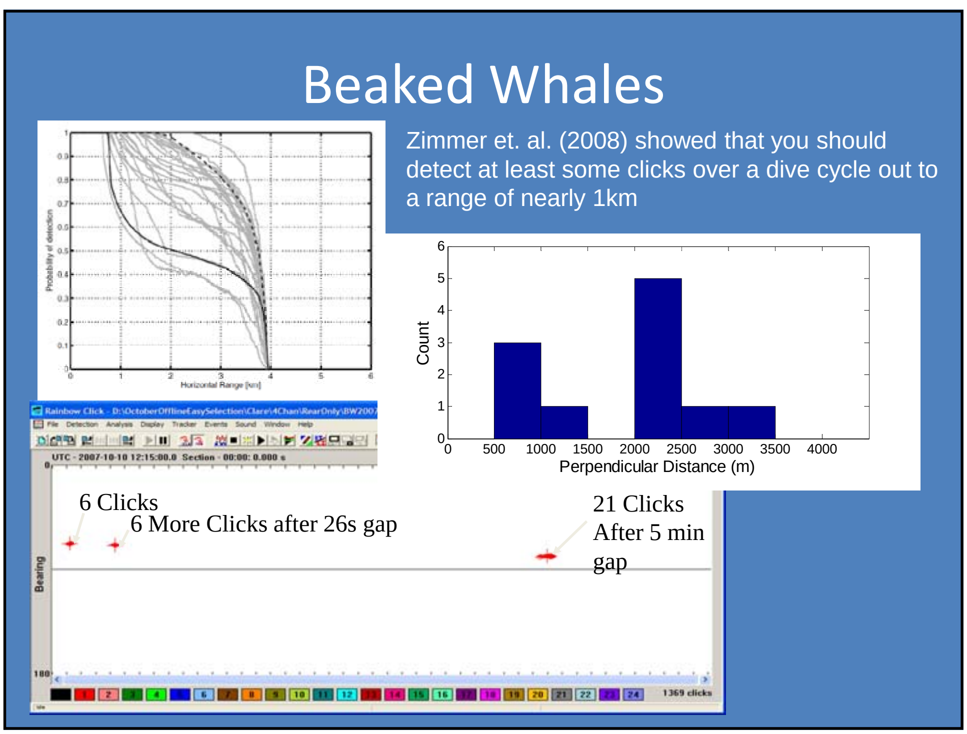
- Probability close to the track
  - A fu… Likely
  - A fu… that soun…
  - A fu… at the array
- Detect…
  - A fu… ? Not very
  - A fu… asked ? 200m
  - A function of technology: How good is our equipment



Detection Probability
Beaked Whales

- Probability close to the track
  - A function of behaviour: Did it vocalise ? Probably not
  - A function of detector: Would we be sensitive to that sound ? Requires specialist equipment
  - A function of luck: Is it's beam of sound pointing at the array ? Occasionally
- Detection range
  - A function of evolution: How loud is that species ?
  - A function of noise: At what range are sounds masked ?
  - A function of technology: How good is our equipment


Beaked Whales
Zimmer et. al. (2008) showed that you should detect at least some clicks over a dive cycle out to a range of nearly 1km
Horizontal Range [km]
6 Clicks
6 More Clicks after 26s gap
21 Clicks
After 5 min
gap
Bearing
1369 clicks


Beaked Whales
Zimmer et. al. (2008) showed that you should detect at least some clicks over a dive cycle out to a range of nearly 1km
Horizontal Range [km]
Count
Perpendicular Distance (m)
0
500
1000
1500
2000
2500
3000
3500
4000
6 Clicks
6 More Clicks after 26s gap
21 Clicks
After 5 min
gap
Bearing
1369 clicks

Summary

- Clicks from odontocetes can be easily detected
- Some are indistinct from other background noises in which case the 'click train' is a better unit of detection
- Bearings are easily calculated
- Some species may be tracked using target motion analysis
- Detection probability varies by species
  - Need to consider detection range
  - Need to consider detection probability at short distance

Detection and Localisation of Whistles Using Passive Acoustics

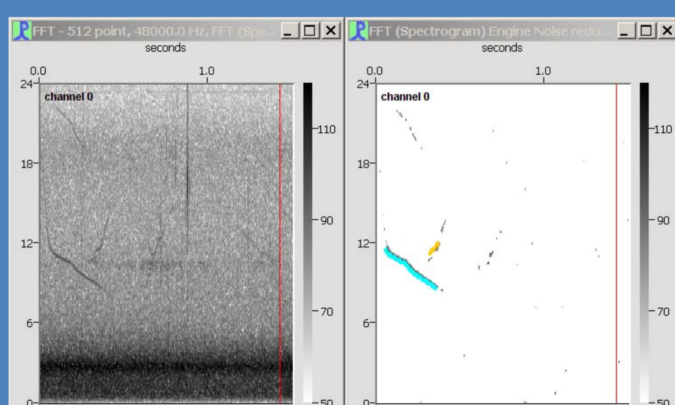
Doug Gillespie
Sea Mammal Research Unit
Scottish Oceans Institute

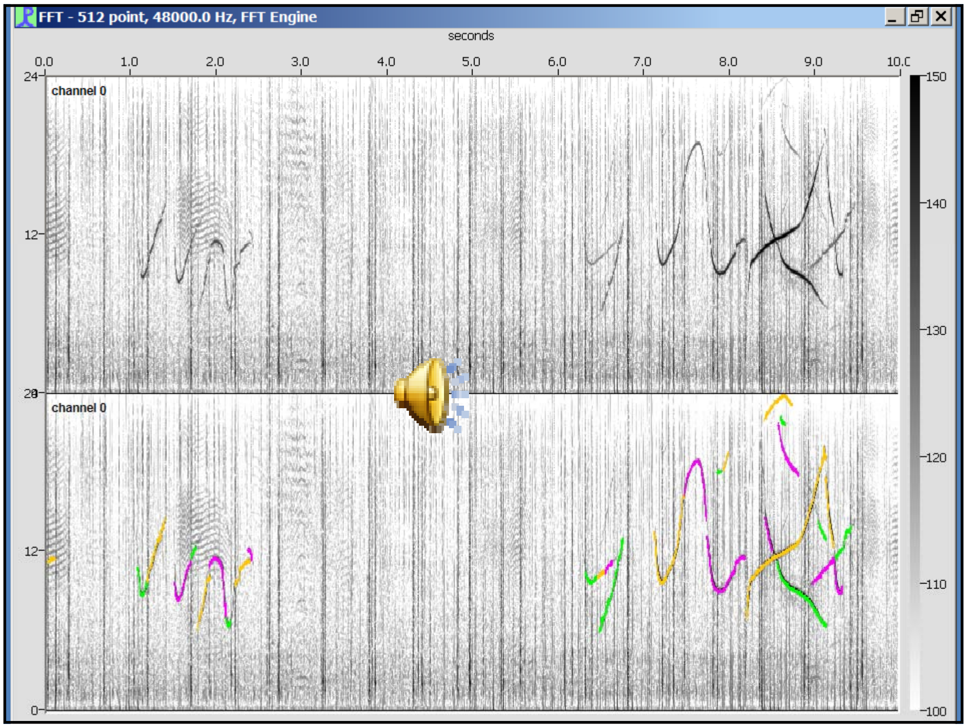
Which Species Whistle ?

- Not all odontocetes (toothed whales and dolphins) whistle
  - Dolphins, Killer Whales, Pilot whales, etc. do.
  - Sperm whales, porpoises, beaked whales don't
- Social sound dependent on behavioural state
- Some seem to vocalise most of the time
- Others vocalise rarely

Detection

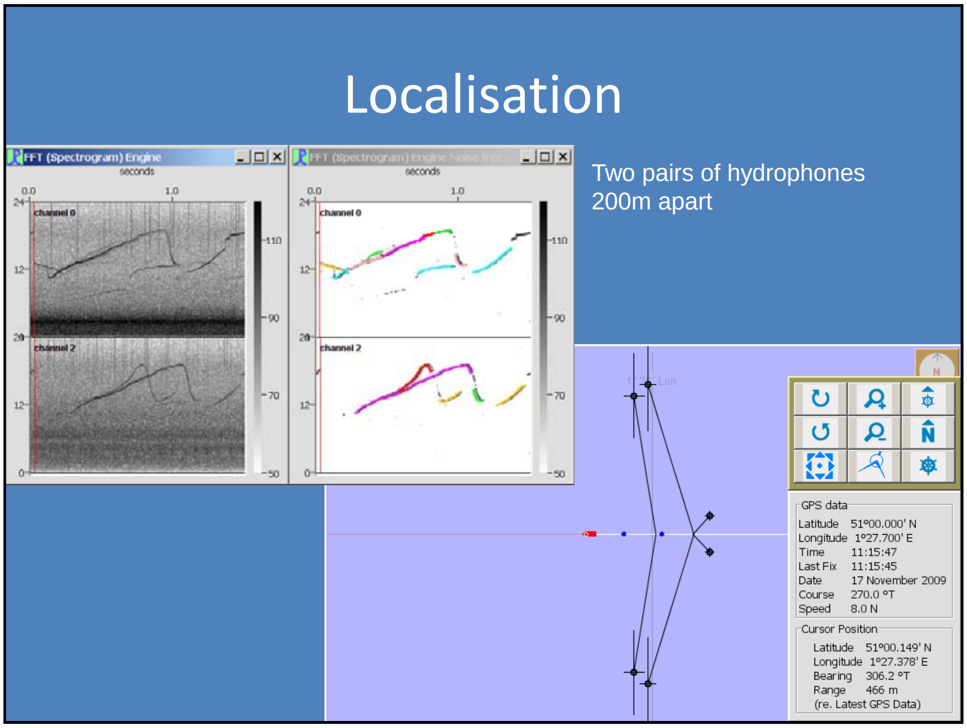
- Generally some kind of noise removal and contour tracing on a spectrogram





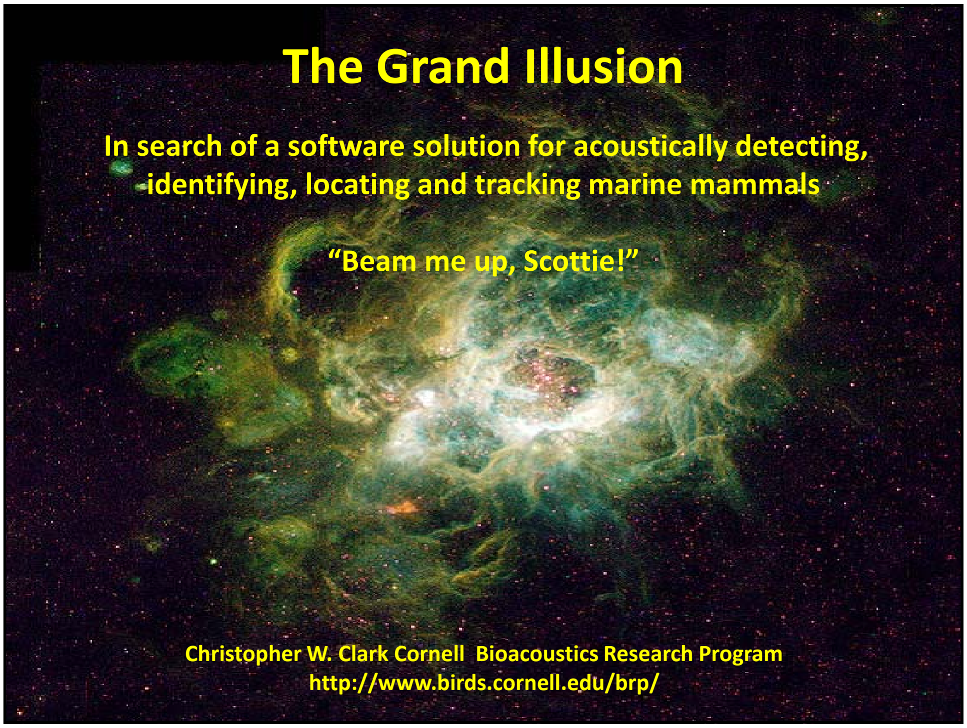
Localisation

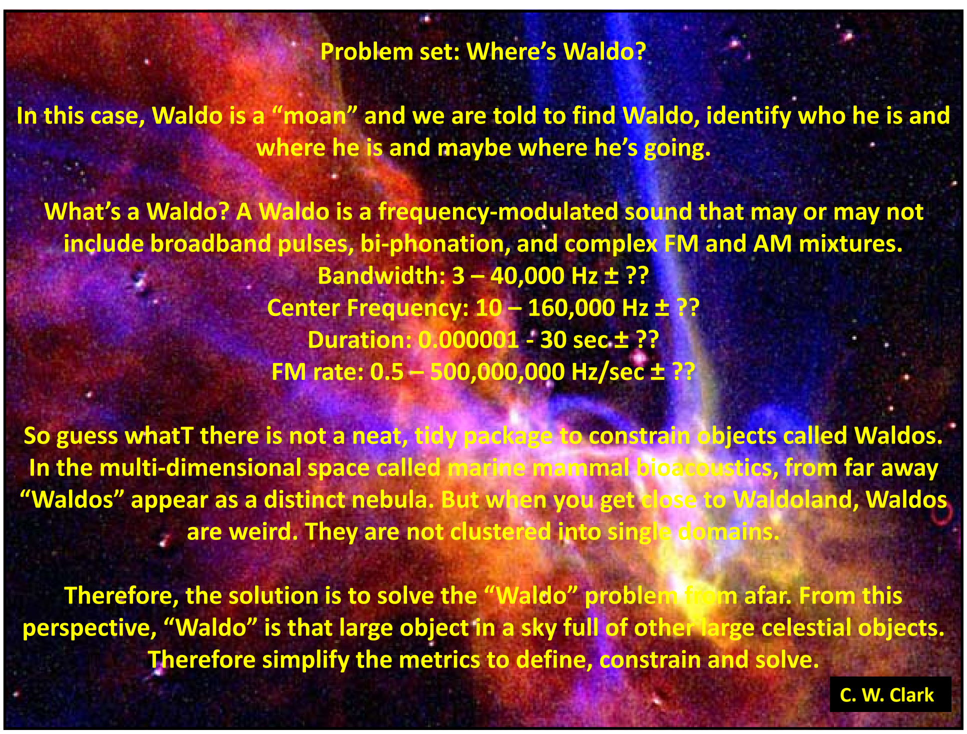
- Bearings from closely spaced hydrophones relatively straight forward.
- Localisation using target motion not possible
  - Often several animals are present
  - Too much animal movement
- Localisation using multiple elements possible if the sounds can be reliably matched

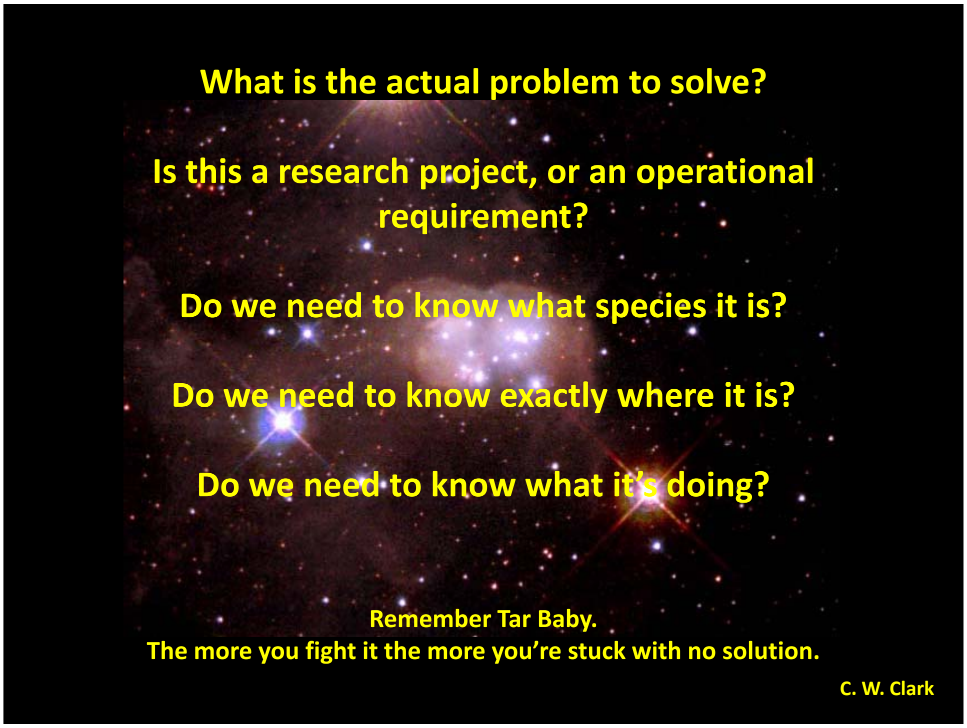


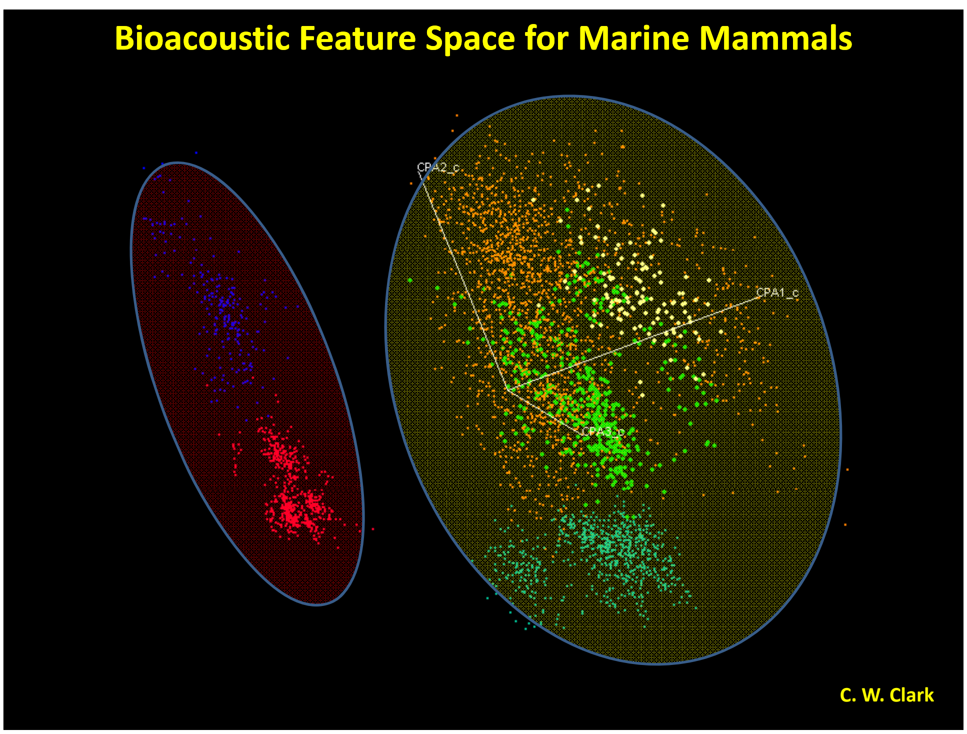
Summary

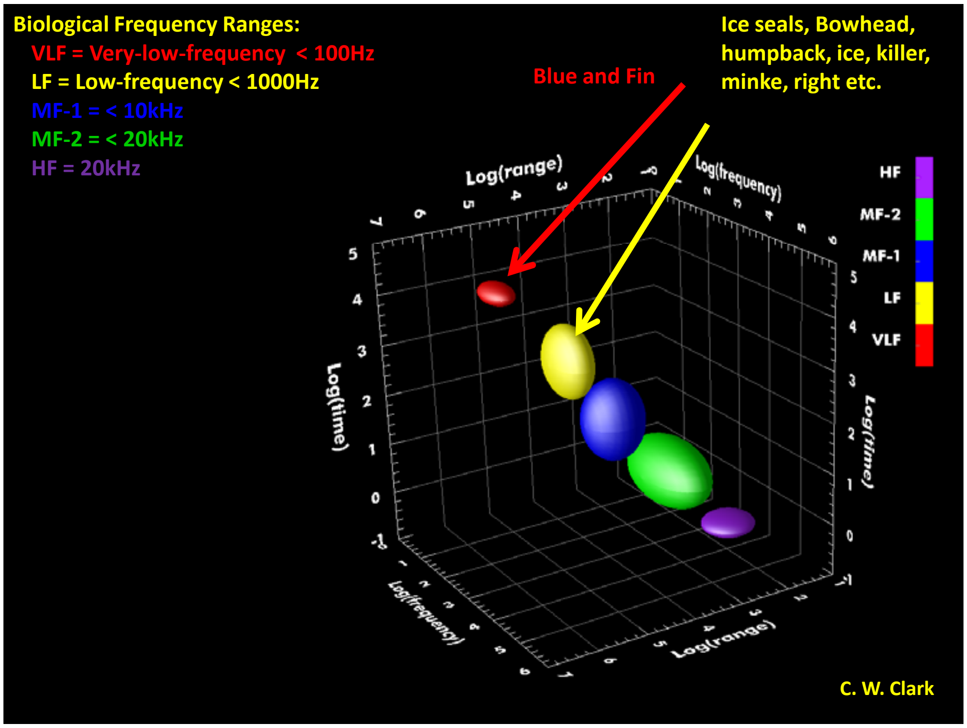
- Distinctive sounds which are easily detected
- Detection Probability a function of behaviour
- Localisation requires multiple hydrophones
- More information on detection range required

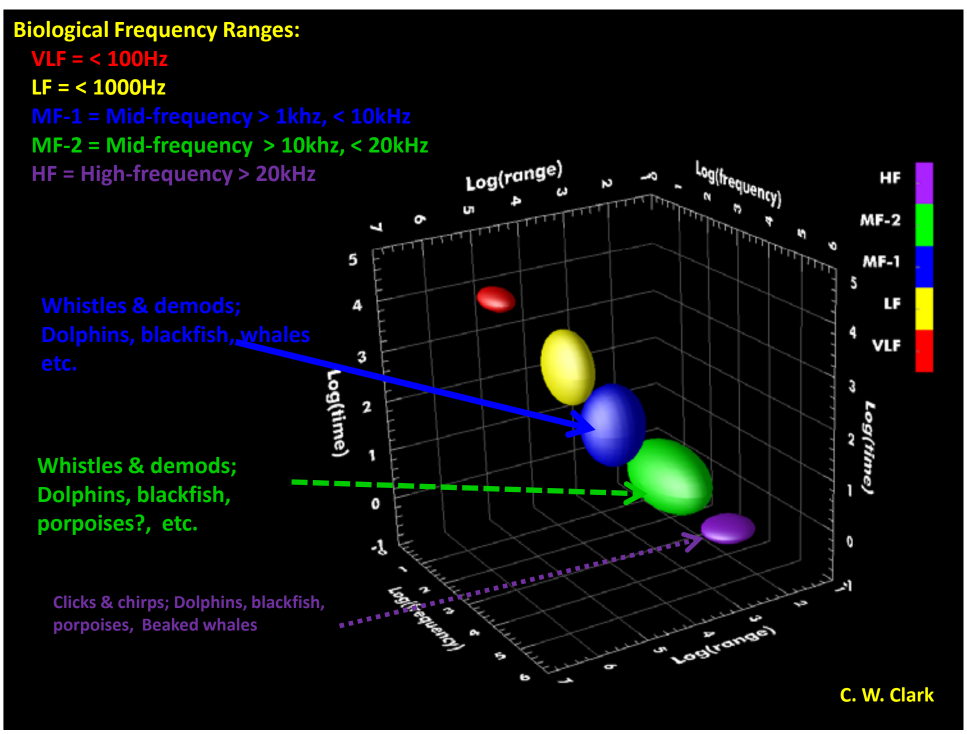

The Grand Illusion
In search of a software solution for acoustically detecting, identifying, locating and tracking marine mammals
"Beam me up, Scottie!"
Christopher W. Clark Cornell Bioacoustics Research Program
http://www.birds.cornell.edu/brp/

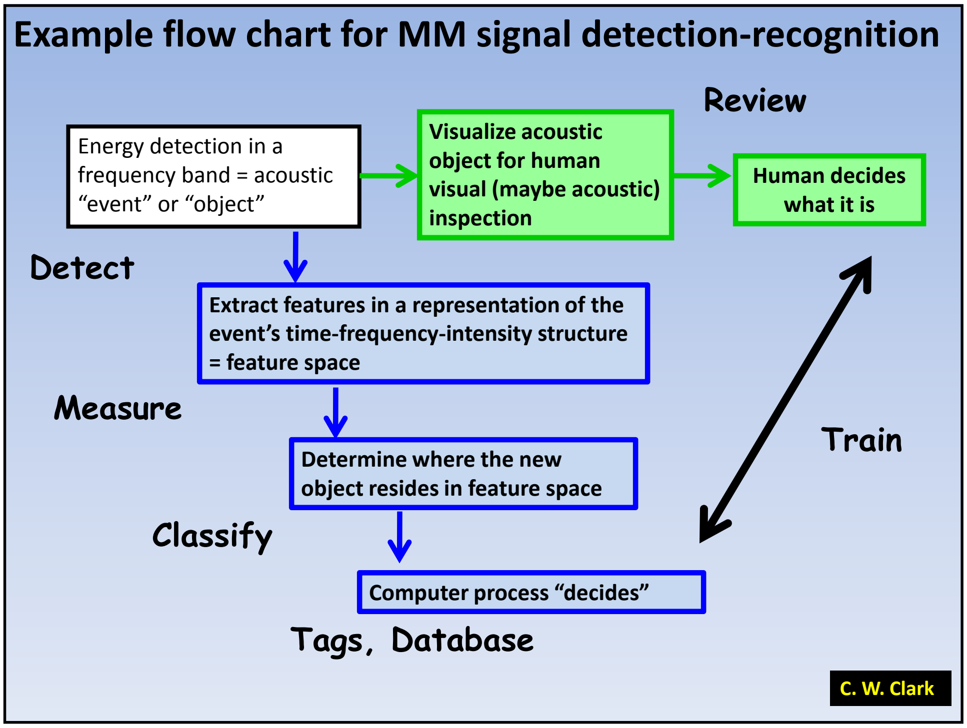

Problem set: Where's Waldo?
In this case, Waldo is a "moan" and we are told to find Waldo, identify who he is and where he is and maybe where he's going.
What's a Waldo? A Waldo is a frequency-modulated sound that may or may not include broadband pulses, bi-phonation, and complex FM and AM mixtures.
Bandwidth: 3 – 40,000 Hz ± ??
Center Frequency: 10 – 160,000 Hz ± ??
Duration: 0.000001 - 30 sec ± ??
FM rate: 0.5 – 500,000,000 Hz/sec ± ??
So guess whatT there is not a neat, tidy package to constrain objects called Waldos. In the multi-dimensional space called marine mammal bioacoustics, from far away "Waldos" appear as a distinct nebula. But when you get close to Waldoland, Waldos are weird. They are not clustered into single domains.
Therefore, the solution is to solve the "Waldo" problem from afar. From this perspective, "Waldo" is that large object in a sky full of other large celestial objects. Therefore simplify the metrics to define, constrain and solve.
C. W. Clark

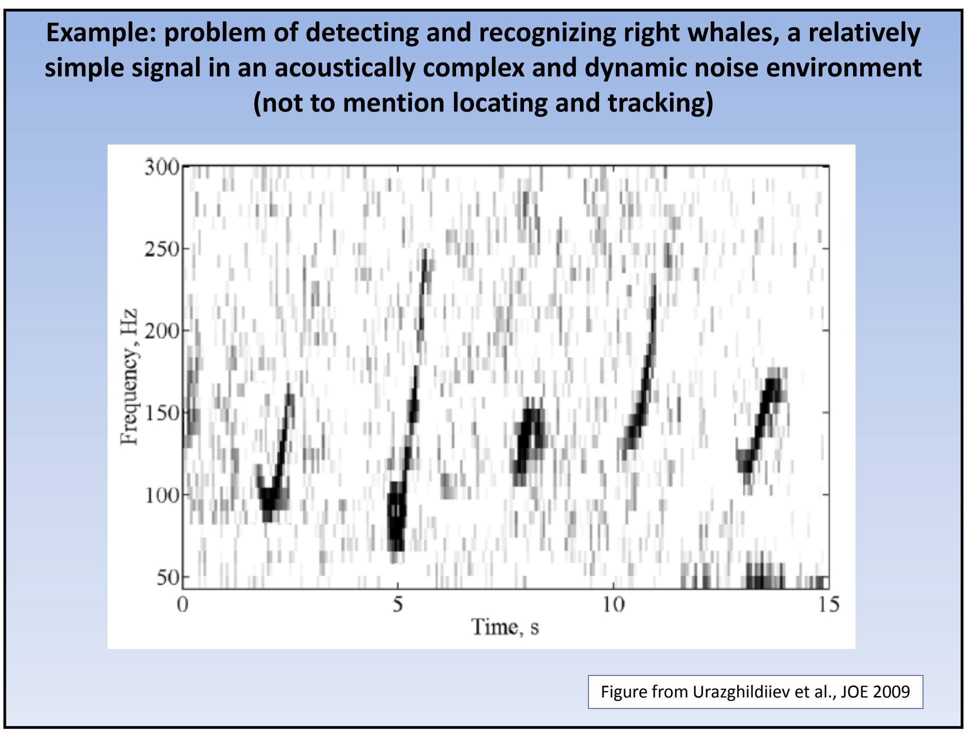

What is the actual problem to solve?
Is this a research project, or an operational requirement?
Do we need to know what species it is?
Do we need to know exactly where it is?
Do we need to know what it's doing?
Remember Tar Baby.
The more you fight it the more you're stuck with no solution.
C. W. Clark

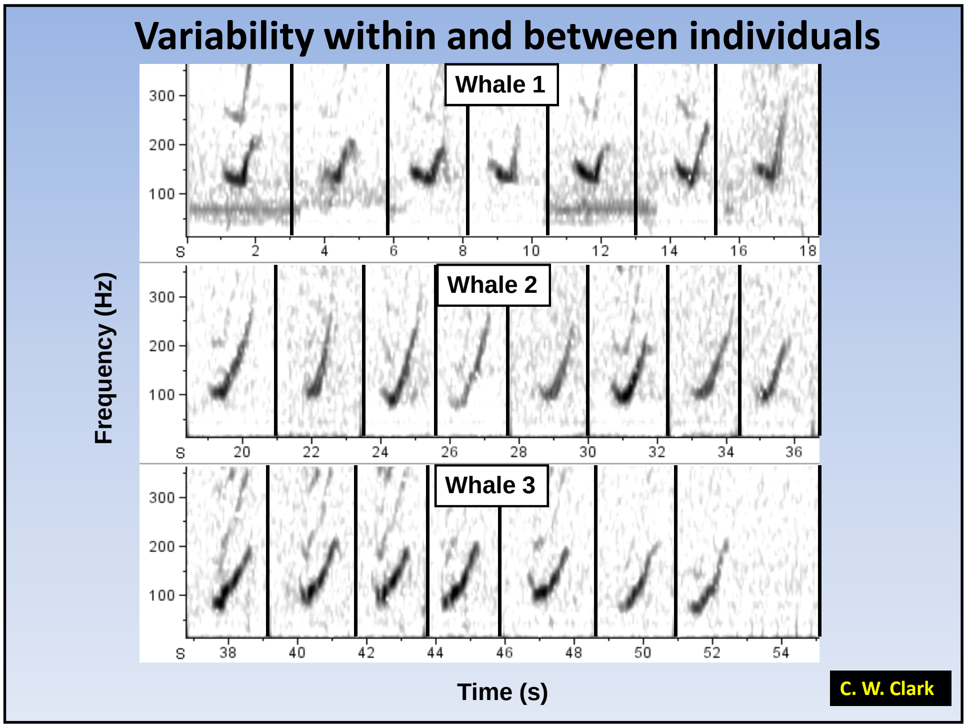

Bioacoustic Feature Space for Marine Mammals
CPA2_c
CPA1_c
C. W. Clark

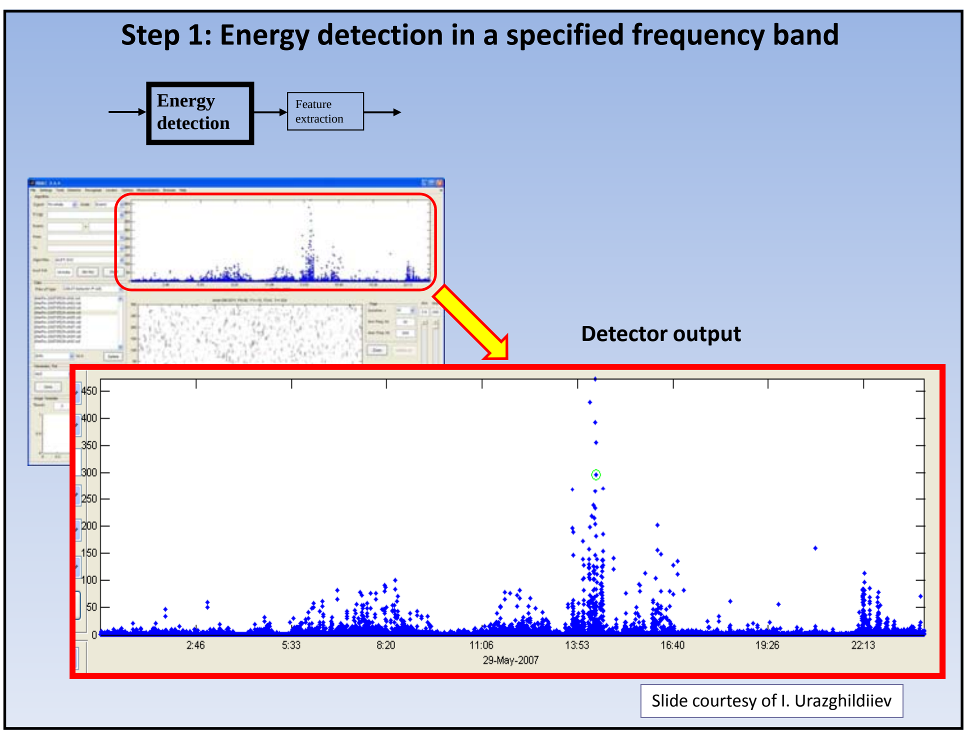

Biological Frequency Ranges:
VLF = Very-low-frequency < 100Hz
LF = Low-frequency < 1000Hz
MF-1 = < 10kHz
MF-2 = < 20kHz
HF = 20kHz
Blue and Fin
Ice seals, Bowhead, humpback, ice, killer, minke, right etc.
Log(range)
Log(frequency)
Log(time)
HF
MF-2
MF-1
LF
VLF
C. W. Clark

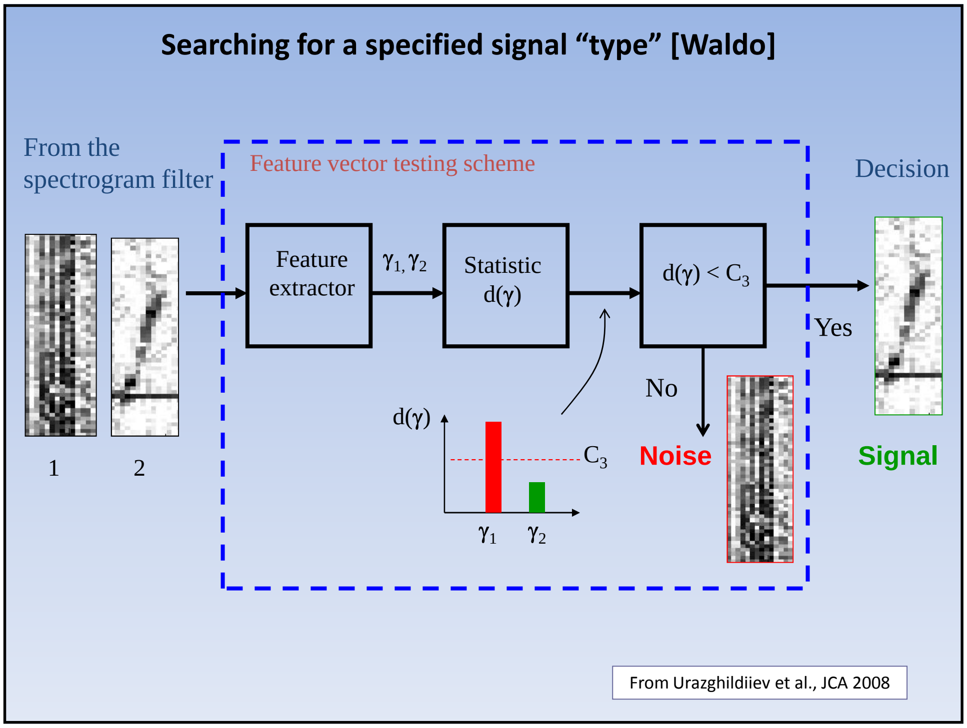

Biological Frequency Ranges:
VLF = < 100Hz
LF = < 1000Hz
MF-1 = Mid-frequency > 1khz, < 10kHz
MF-2 = Mid-frequency > 10khz, < 20kHz
HF = High-frequency > 20kHz
Whistles & demods; Dolphins, blackfish, whales etc.
Whistles & demods; Dolphins, blackfish, porpoises?, etc.
Clicks & chirps; Dolphins, blackfish, porpoises, Beaked whales
Log(range)
Log(frequency)
Log(time)
HF
MF-2
MF-1
LF
VLF
C. W. Clark

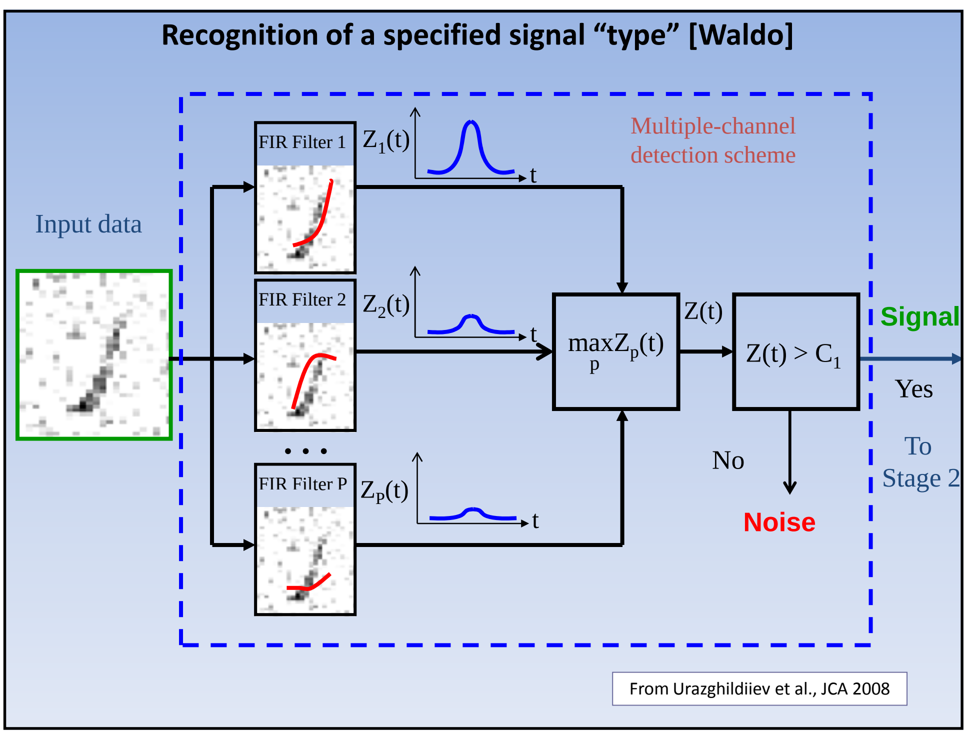

Example flow chart for MM signal detection-recognition
Review
Energy detection in a frequency band = acoustic "event" or "object"
Visualize acoustic object for human visual (maybe acoustic) inspection
Human decides what it is
Detect
Extract features in a representation of the event's time-frequency-intensity structure = feature space
Measure
Train
Determine where the new object resides in feature space
Classify
Computer process "decides"
Tags, Database
C. W. Clark

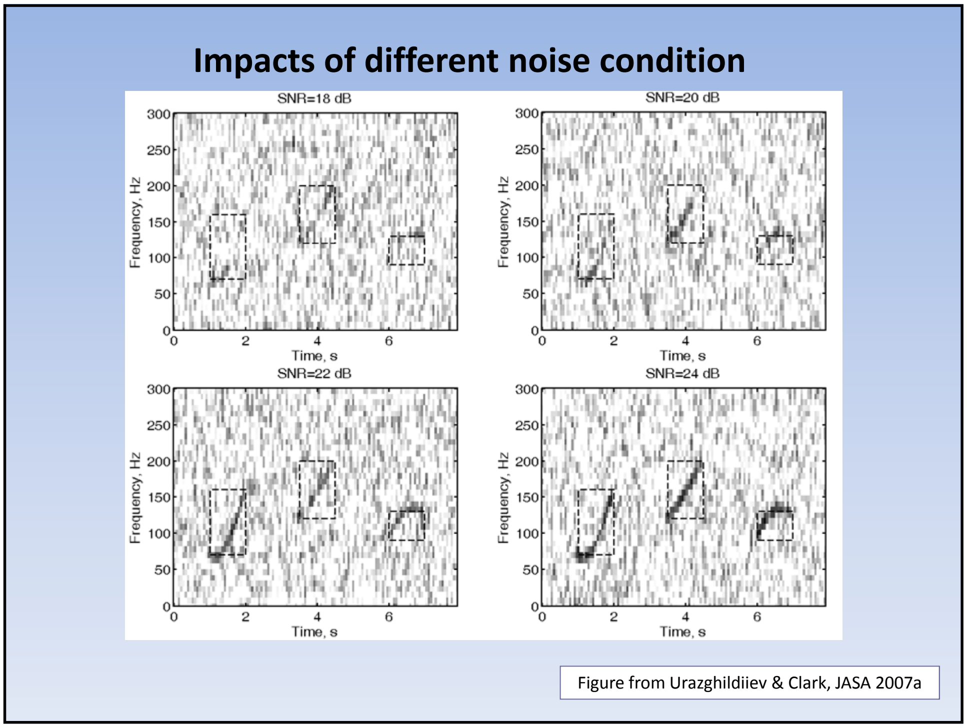

Example: problem of detecting and recognizing right whales, a relatively simple signal in an acoustically complex and dynamic noise environment (not to mention locating and tracking)
Frequency, Hz
300
250
200
150
100
50
0
5
10
15
Time, s
Figure from Urazghildiiev et al., JOE 2009

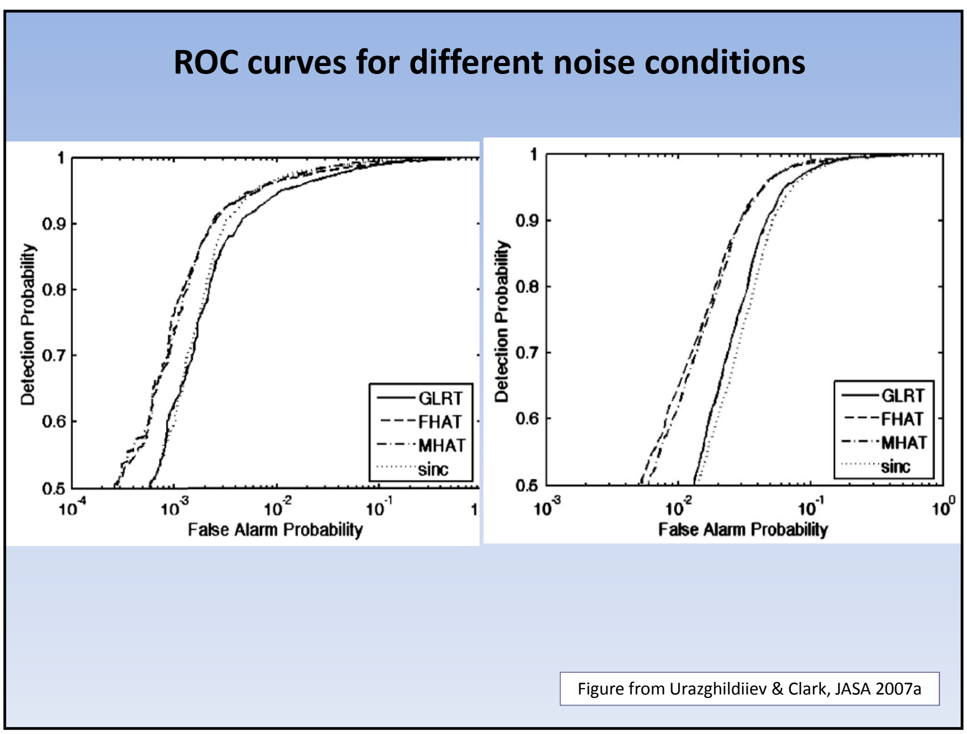

Variability within and between individuals
Whale 1
Whale 2
Whale 3
Frequency (Hz)
Time (s)
C. W. Clark

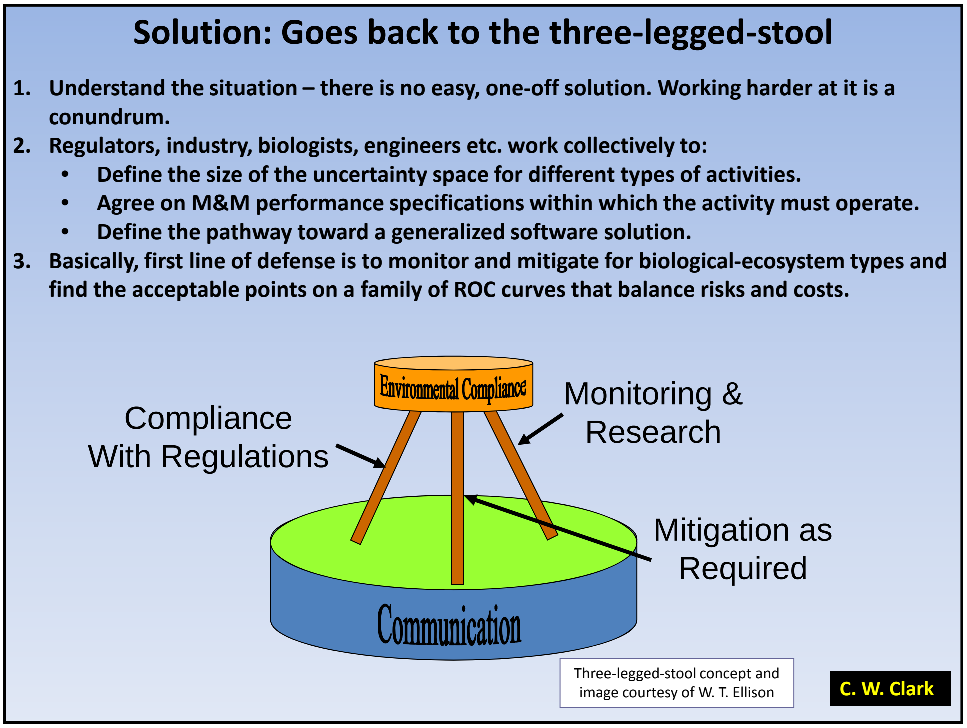

Step 1: Energy detection in a specified frequency band
Energy detection
Feature extraction
Detector output
29-May-2007
Slide courtesy of I. Urazghildiiev


Searching for a specified signal "type" [Waldo]
From the spectrogram filter
Feature vector testing scheme
Decision
Feature extractor
γ1, γ2
Statistic d(γ)
d(γ) < C3
Yes
No
d(γ)
C3
γ1
γ2
1
2
Noise
Signal
From Urazghildiiev et al., JCA 2008


Recognition of a specified signal "type" [Waldo]
Input data
FIR Filter 1
Z1(t)
t
FIR Filter 2
Z2(t)
FIR Filter P
ZP(t)
Multiple-channel detection scheme
maxZp(t)
p
Z(t)
Z(t) > C1
Signal
Yes
To Stage 2
No
Noise
From Urazghildiiev et al., JCA 2008


Impacts of different noise condition
SNR=18 dB
SNR=20 dB
SNR=22 dB
SNR=24 dB
Frequency, Hz
Time, s
Figure from Urazghildiiev & Clark, JASA 2007a


ROC curves for different noise conditions
Detection Probability
False Alarm Probability
GLRT
FHAT
MHAT
sinc
Figure from Urazghildiiev & Clark, JASA 2007a


Solution: Goes back to the three-legged-stool
1. Understand the situation – there is no easy, one-off solution. Working harder at it is a conundrum.
2. Regulators, industry, biologists, engineers etc. work collectively to:
• Define the size of the uncertainty space for different types of activities.
• Agree on M&M performance specifications within which the activity must operate.
• Define the pathway toward a generalized software solution.
3. Basically, first line of defense is to monitor and mitigate for biological-ecosystem types and find the acceptable points on a family of ROC curves that balance risks and costs.
Environmental Compliance
Compliance With Regulations
Monitoring & Research
Mitigation as Required
Communication
Three-legged-stool concept and image courtesy of W. T. Ellison
C. W. Clark


Thank you
The Triangulum emission nebula (NGC604)
http://www.google.com/imgres

Aaron Thode
Scripps Institution of Oceanography
University of California, San Diego
MMS workshop, "Acoustic Monitoring and Mitigation Systems", Nov 17-19, 2009

REPORTING METRICS

Thanks: Greeneridge Sciences, Peter Tyack, Melania Guerra

Metric: "a system or standard of measurement"

"I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind."
Lord Kelvin (William Thomson, 1st Baron) (1824-1907) English physicist and mathematician.

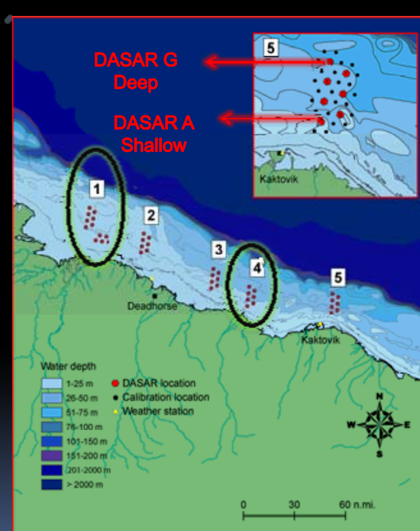
Metrics determine criteria, which determine exclusion zones, which determine PAM configurations.

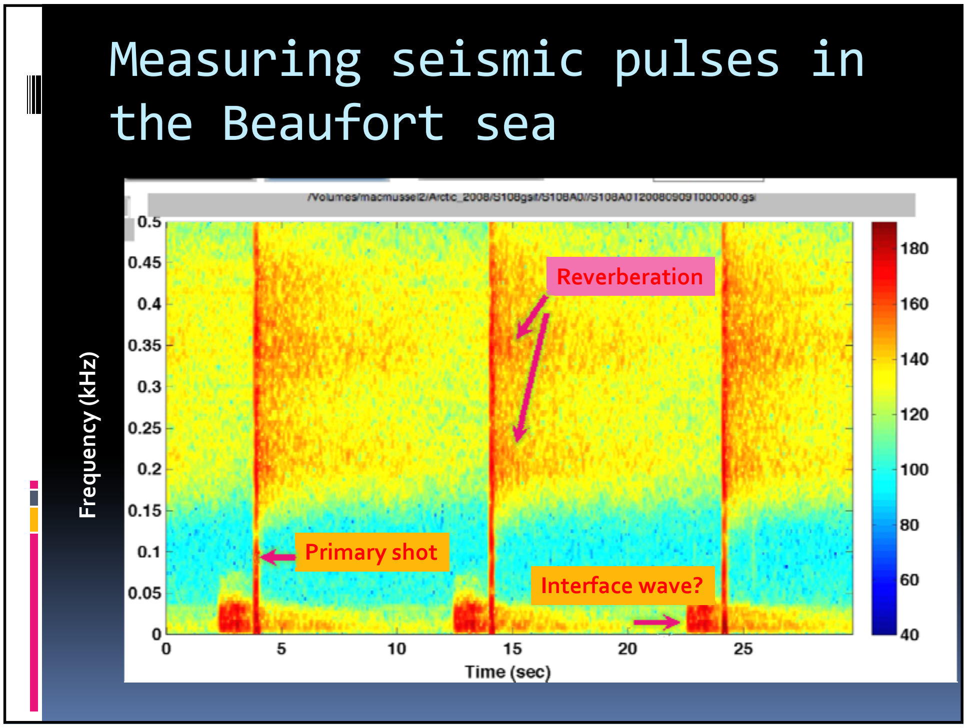
Marine mammals and noise: cliff notes version

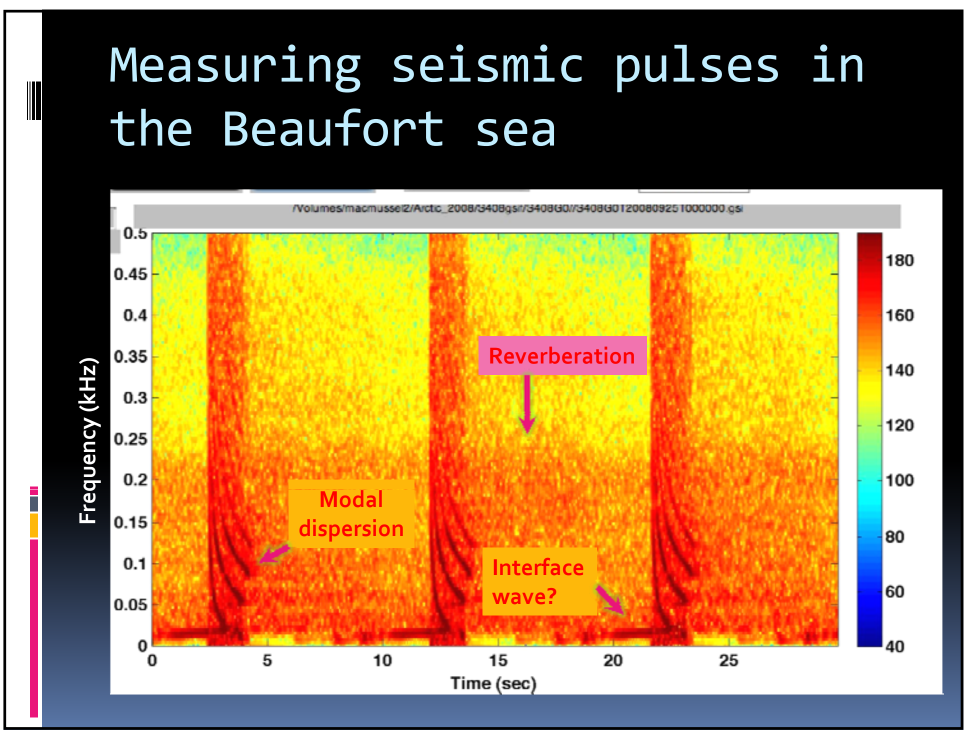
- Are you killing or injuring it?
  - Peak pressure, rms pressure, sound exposure
  - Well developed: focus on short-term ,individuals
  - Example: seismic airgun pulse
- Are you making its life more difficult?
  - "Masking"
  - Diffuse, population scale, long-term "cumulative" effects
  - Key: potential response based only on signal level, energy, or SNR
  - Example: shallow-water seismic reverberation
- Are you freaking it out?
  - Are sounds biologically relevant to animals?
  - Key: potential response based on features besides strict measurements of intensity, "energy", or SNR.
    - Baby crying in a church.
  - The perverse delight biologists have in discussing this.
  - Examples: Naval mid-range sonar, dispersive seismic airgun pulse
- Note this is perception, not response.
- Metrics, not criteria (no thresholds for injury, etc).
- Localization not covered.

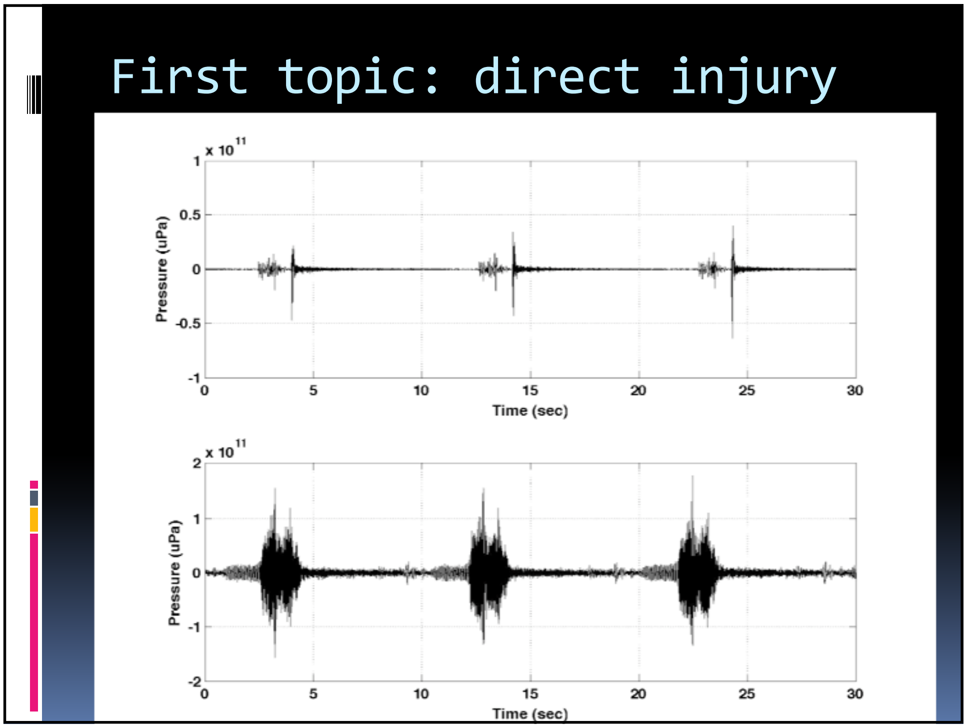
2008 Beaufort Sea Acoustic Project Site

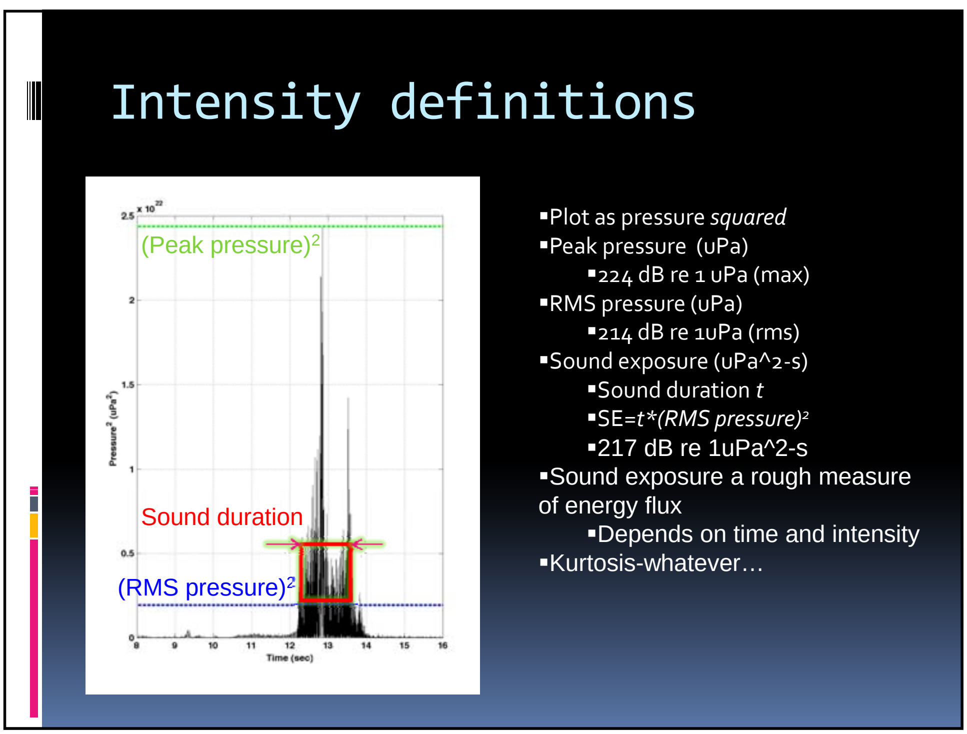
- Narrow continental shelf
  - (30- 60 mi)
- Several marine mammal species are present in the summer months
  - Bowhead whale
- DASAR recording packages @ 1kHz



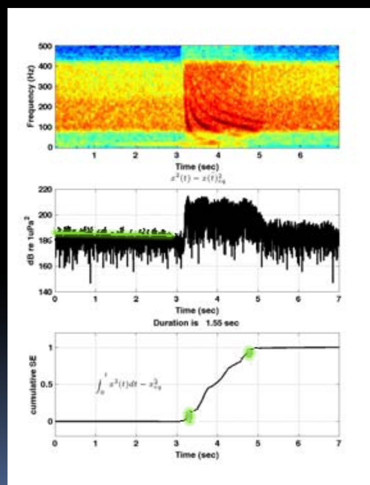

Measuring seismic pulses in the Beaufort sea
Frequency (kHz)
Time (sec)
Reverberation
Primary shot
Interface wave?


Measuring seismic pulses in the Beaufort sea
Frequency (kHz)
Time (sec)
Reverberation
Modal dispersion
Interface wave?


First topic: direct injury
x 10^11
Pressure (uPa)
Time (sec)
x 10^11
Pressure (uPa)
Time (sec)


Intensity definitions
(Peak pressure)²
Sound duration
(RMS pressure)²
Time (sec)
▪Plot as pressure *squared*
▪Peak pressure (uPa)
▪224 dB re 1 uPa (max)
▪RMS pressure (uPa)
▪214 dB re 1uPa (rms)
▪Sound exposure (uPa^2-s)
▪Sound duration *t*
▪SE=*t**(RMS pressure)²
▪217 dB re 1uPa^2-s
▪Sound exposure a rough measure of energy flux
▪Depends on time and intensity
▪Kurtosis-whatever…

How measure transient duration?

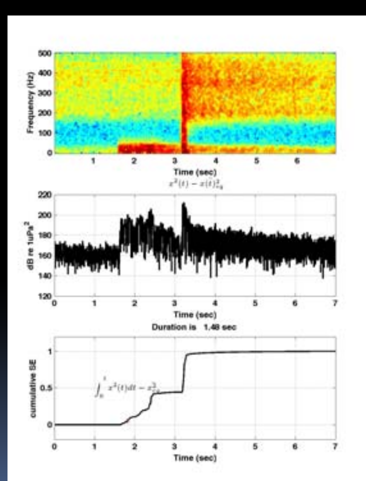


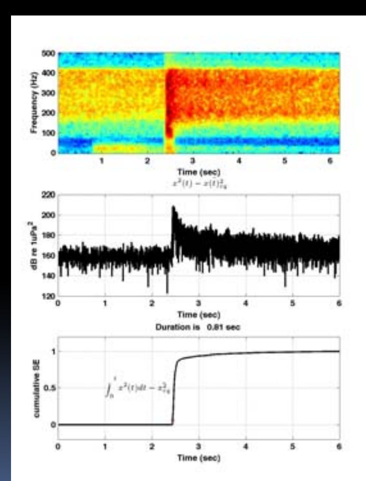
- Measure mean square pressure just before a pulse…
- Subtract this from entire square pressure time series

$$\frac{\int_0^T x^2(t)dt - x_{eq}^2}{\int_0^{T\max} x^2(t)dt - x_{eq}^2}$$

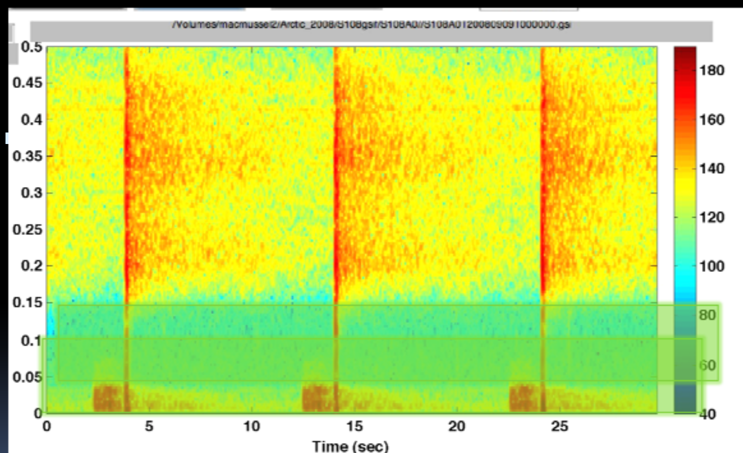
- Pick the 5% and 95% points of cumulative sound exposure..
- Note reverberation less than 2% of total energy.

Metrics depend on frequency band





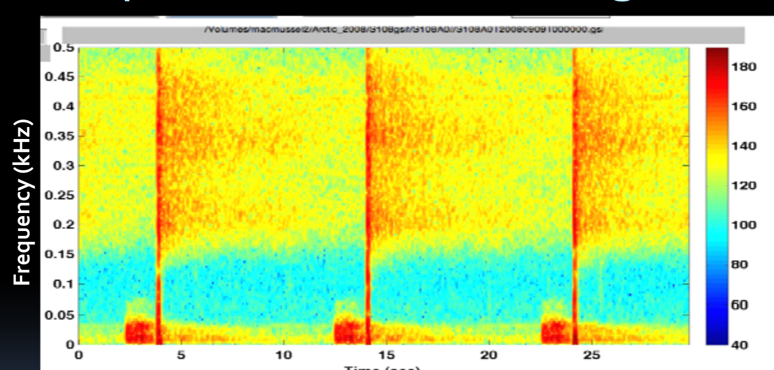
How to minimize biological assumptions in "injury" metric?



-A set of narrowband SEs permit you to incorporate a biological hearing curve for a given species of interest.

-Advantage: as information about hearing sensitivity evolves, can update.

Unresolved issue: should sound exposure measurements from a sequence be added together?



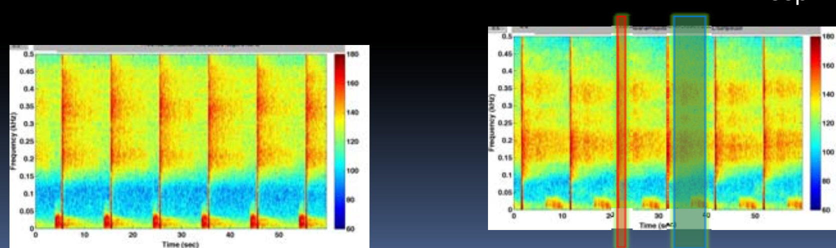
Southall et al (2007)- summation over a 24 hour period

-with10 second interval : 8640 pulses.

- Is that 8640 214 dB re 1uPa^2-sec pulses?
- Or is that a cumulative 214 +10log(8640)=254 dB re 1uPa^2-sec exposure?

Part II: Metrics for long-term, chronic, cumulative effects: masking

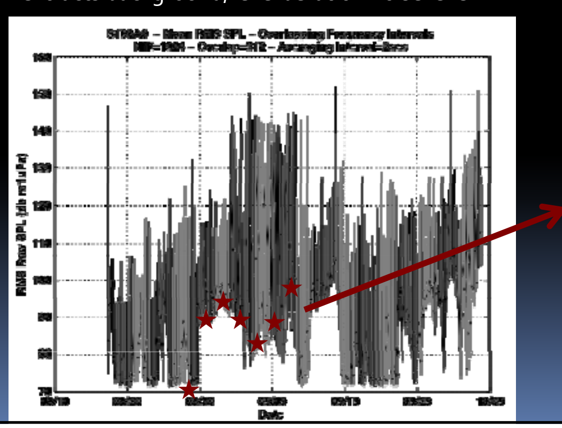
- Signals contribute to increases in background ambient noise
  - Salient characteristics are level and SNR
- Example: reverberation from seismic activity
- How to quantify reverberation levels?
- How to translate into "masking" levels?



Dasars S108A0 & S108G0 – Sept/09/2008 03:31:00
Fs = 1000Hz – NFFT = 256 with 75% overlap

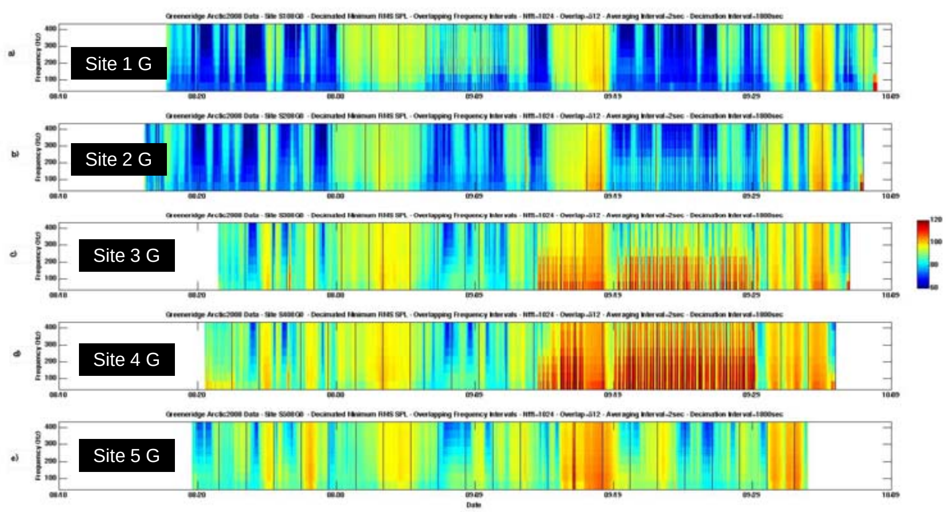
Masking, step 1: report minimum measured levels over 30 minute intervals

- "Secular" = slow varying trend vs short-term oscillatory fluctuations
- Selecting minimum value (or mean, median, etc) over several cycles captures long-term trend of curve
- Selecting minimum value of averaged SEL over a time that spans several airgun pulses extracts background/reverberation noise level

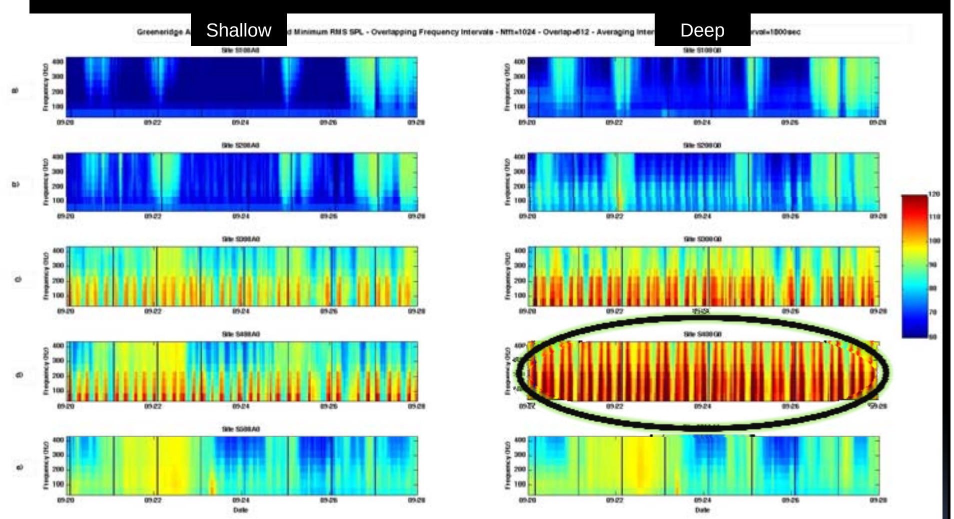


Reverberation Metric

Case study →
Δt_{decim} = 1800sec



- Time/frequency image of minimum background levels over 30 minute blocks – overlapping frequency bands between 10-450Hz

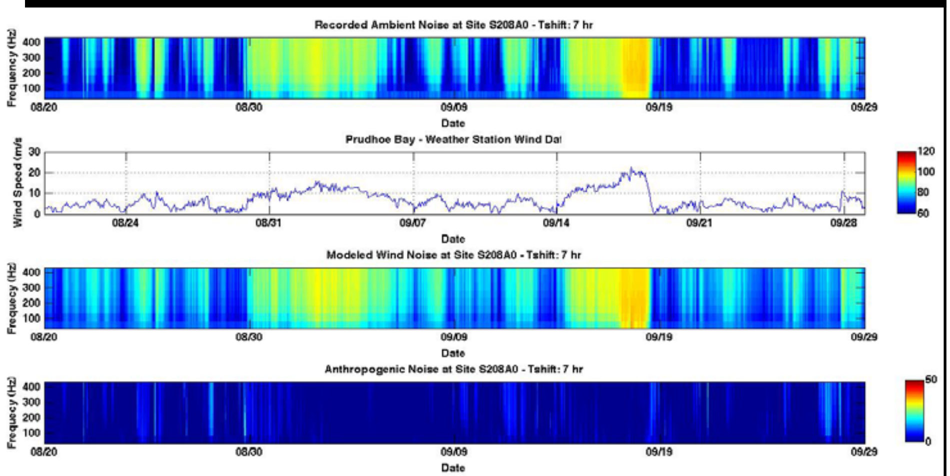


- Deeper locations observe higher reverberation levels
- Reverberation above background at multiple sites, including Site 2
- "Mowing the lawn" effect → range/orientation source dependence

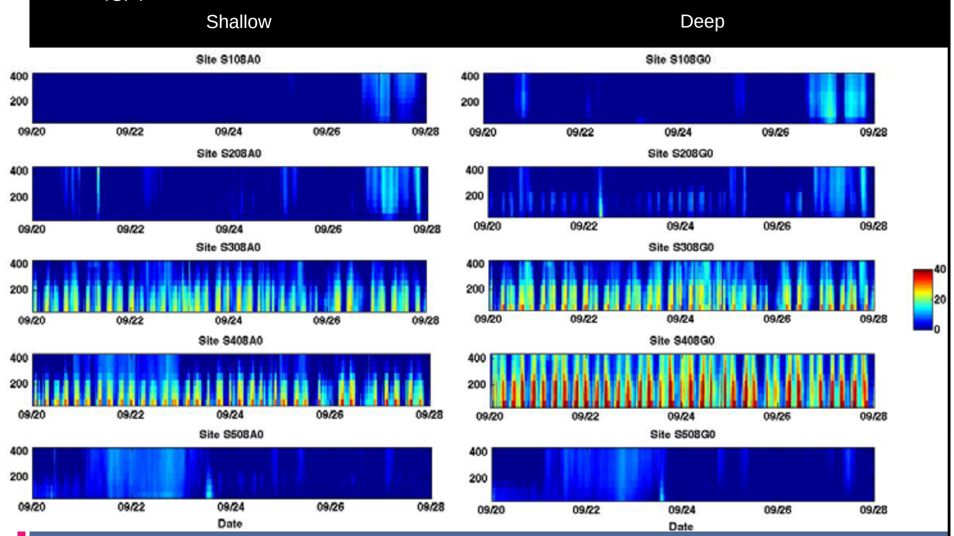
How to convert background noise levels into a masking metric?

- Time invariance: Subtract ambient noise levels from "quiet" day from "active" day
- Space invariance: Subtract ambient noise from "quiet" location from "active" location.
- Environmental modeling: Show that normal ambient levels depend on environmental parameter (sea state, wind). Measure this parameter independently.

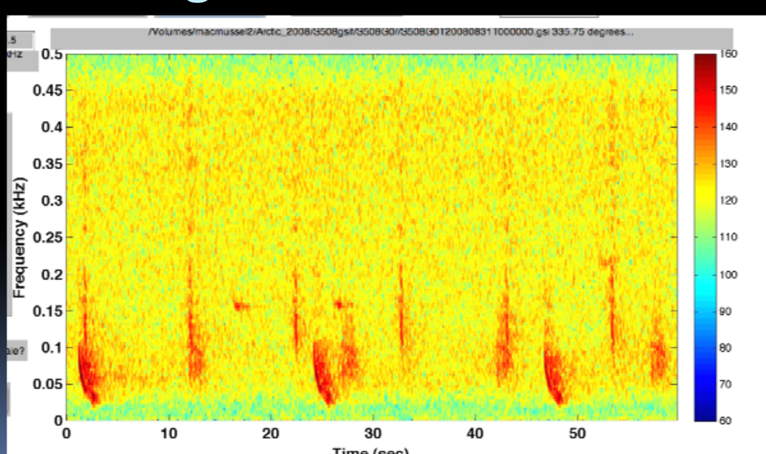
Masking: step 2
– Empirical wind noise model approach -



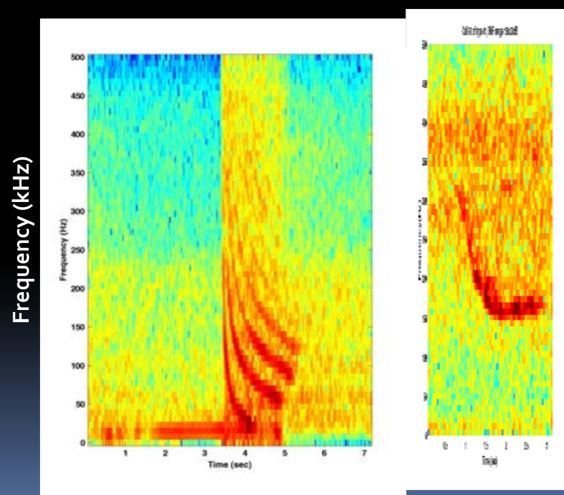
- A conservative estimate of masking subtracts ambient noise fields and quantifies non-wind contributions
- Airgun activity ("Event 2") is evident above background level at Sites 2,3,4



"Cumulative impact" of masking: fraction of time masking metric is nonzero



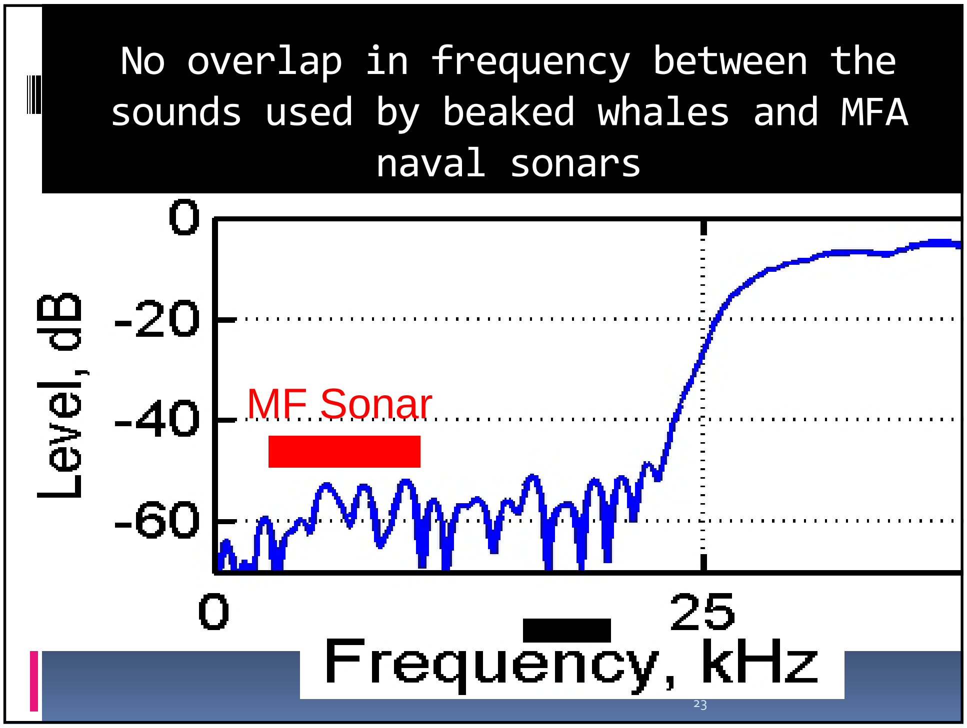
Part 3: Non-masking behavioral impacts

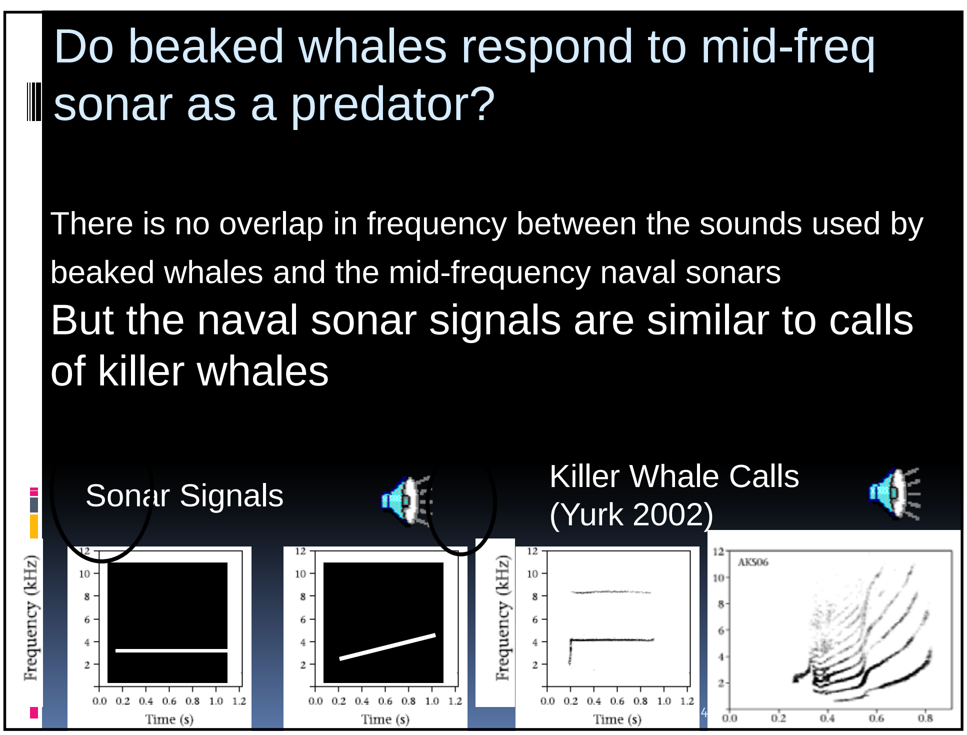


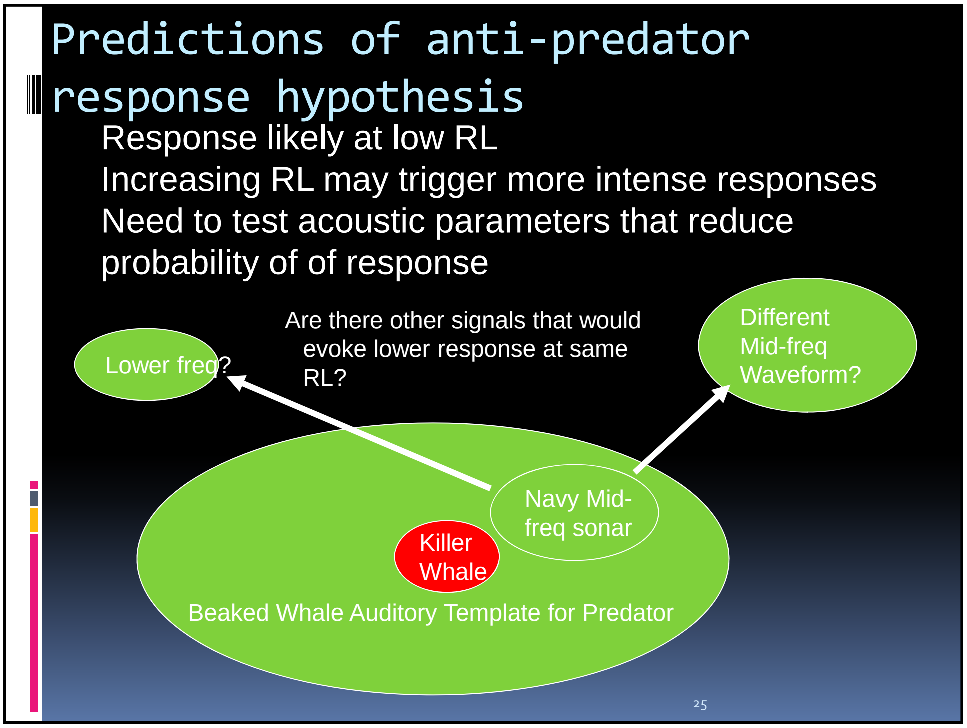
- What if the structure of the call (and not just its level or SNR) is relevent?
- Is the sound similar to other natural sounds of biological relevence?

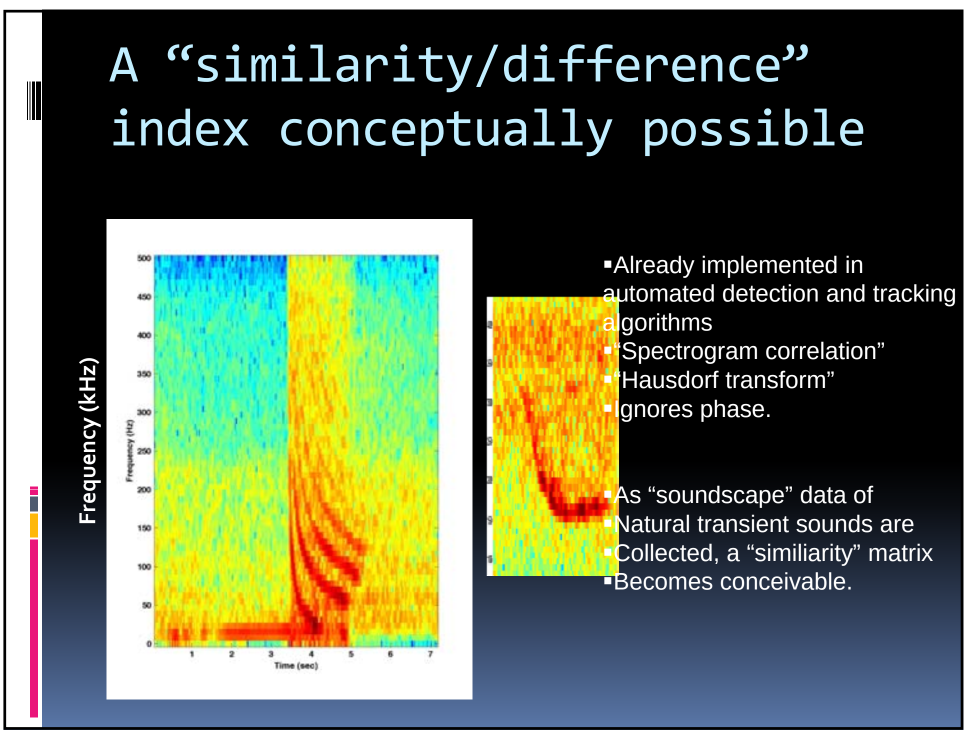
Biologists really enjoy talking about how complicated all this is…

- The biological significance of a sound to an animal depends on its:
  - ___ ___X
  - ___G ___
  - ___H__VOR__AL ___TA___E
  - ___IM__OF___AY


No overlap in frequency between the sounds used by beaked whales and MFA naval sonars
Level, dB
0
-20
-40
-60
MF Sonar
0
25
Frequency, kHz

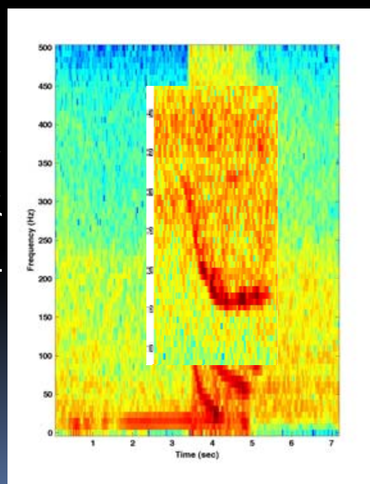

Do beaked whales respond to mid-freq sonar as a predator?
There is no overlap in frequency between the sounds used by beaked whales and the mid-frequency naval sonars
But the naval sonar signals are similar to calls of killer whales
Sonar Signals
Killer Whale Calls (Yurk 2002)
Frequency (kHz)
Time (s)
AKS06


Predictions of anti-predator response hypothesis
Response likely at low RL
Increasing RL may trigger more intense responses
Need to test acoustic parameters that reduce probability of of response
Are there other signals that would evoke lower response at same RL?
Lower freq?
Different Mid-freq Waveform?
Navy Mid-freq sonar
Killer Whale
Beaked Whale Auditory Template for Predator
25


A "similarity/difference" index conceptually possible
Frequency (kHz)
▪Already implemented in automated detection and tracking algorithms
▪"Spectrogram correlation"
▪"Hausdorf transform"
▪Ignores phase.
▪As "soundscape" data of
▪Natural transient sounds are
▪Collected, a "similiarity" matrix
▪Becomes conceivable.

A "similarity/difference" index conceptually possible

Frequency (kHz)

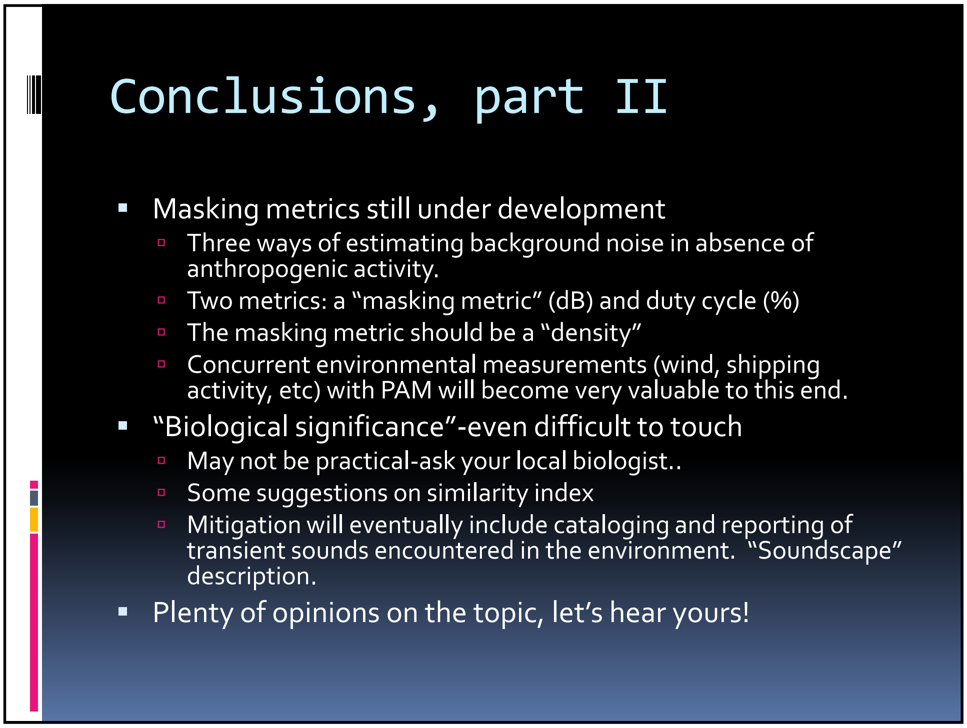


- Already implemented in automated detection and tracking algorithms
- "Spectrogram correlation"
- "Hausdorf transform"
- Ignores phase.

- As "soundscape" data of
- Natural transient sounds are
- Collected, a "similiarity" matrix
- Becomes conceivable.

Conclusions

- Metrics are a fundamental step in PAM
  - Forces clarity in thinking about what and how to collect data.
  - Desire to separate physics from behavior, minimize assumptions about animal hearing capability or behavior: an "intermediate result"
- Metrics for *injury* relatively well developed
  - Opinion: reporting spectral density (or a set of values measured over narrow bandwidths) greater value than a broadband measurement (separates phys/bio)
  - Opinion: for a series of repetitive events, provide metric for a single event, and total number of events (% time present).
  - Highly fluctuating background environment?


Conclusions, part II
Masking metrics still under development
Three ways of estimating background noise in absence of anthropogenic activity.
Two metrics: a "masking metric" (dB) and duty cycle (%)
The masking metric should be a "density"
Concurrent environmental measurements (wind, shipping activity, etc) with PAM will become very valuable to this end.
"Biological significance"-even difficult to touch
May not be practical-ask your local biologist..
Some suggestions on similarity index
Mitigation will eventually include cataloging and reporting of transient sounds encountered in the environment. "Soundscape" description.
Plenty of opinions on the topic, let's hear yours!