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Position Paper 13

The effects of anthropogenic sound on marine mammals

A draft research strategy

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Marine Board – ESF

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- **Strategy:** Identifying and prioritising emergent disciplinary and interdisciplinary marine scientific issues of strategic European importance, initiating analysis and studies (where relevant, in close association with the European Commission) in order to develop a European strategy for marine research;
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The effects of anthropogenic sound on marine mammals
A draft research strategy

This report is based on the activities and proceedings of an Expert Group on anthropogenic sound and marine mammals convened at the joint Marine Board-ESF and National Science Foundation (US) Workshop at Tubney House on October 4-8 2005 in Oxford, with logistical and financial support of the Marine Board-ESF.

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Foreword

The effect of anthropogenic sound on marine mammals has become a serious concern both for marine and maritime research and for economic activities. On one side, marine mammals rely largely on sound for their communication and organisation; on the other side, use of sound is an essential element of remote sensing methods in geophysics, sedimentology, oceanography and ecosystem studies. Furthermore, many human ocean-based activities such as oil exploitation, fisheries or defence activities, rely on emission of sounds of various frequencies and intensity. Marine mammals are a very important trophic and symbolic component of the marine biotope and because they are under threat, their protection has become an ecological issue. This concern has triggered a number of analyses of the issue of anthropogenic sounds and their impacts on marine mammals. Consequently, interaction between anthropogenic sound and marine mammals was identified as a key subject both by the Marine Board-ESF and the US National Science Foundation (NSF), which lead to a joint workshop on this topic. This workshop on "Marine Mammals and Acoustic Geo-Surveying Techniques", hosted by the Marine Board in London on September 27th 2004, gathered 34 international experts, including science managers, engineers, geologists and biologists. Thirteen countries were represented, 11 participants being from North America (10 US and one Canadian) and 23 from Europe (Denmark, Germany, Ireland, Italy, Norway, The Netherlands and UK). A list of participants can be found in Annex II. The joint Marine Board and NSF workshop, co-chaired by Howard Roe (Director, National Oceanography Centre, Southampton, representing the Marine Board-ESF) and Mike Purdy (Director, Lamont Doherty Earth Observatory, Columbia University, representing NSF), addressed the impacts of acoustic geo-surveying techniques on marine mammals, including legal and practical implications for survey work.

The concept for this workshop was first proposed during the October 2003 Marine Board Plenary Meeting, and subsequently developed from discussions between the Marine Board and NSF. The timing was linked to the U.S. Marine Mammal Commission workshop in London 28th-30th September 2004, to facilitate participation at both (see Vos and Reeves [2006] for a full report of the U.S. Marine Mammal Commission workshop). The outcomes of these coupled workshops reach the same consensus: interaction between anthropogenic sound and marine mammals is a complex problem, as the effects of anthropogenic sound on marine mammals depend on many aspects, such as intensity and frequency of sounds, marine mammal species and their age, environmental conditions, etc. In addition, the physiological effects are not clearly understood. Thus, a scientific research strategy was clearly needed.

To follow up on recommendations of these workshops and to build on the momentum generated, it was agreed that a smaller joint Marine Board and NSF Expert Group would be convened to ultimately produce a Position Paper based partly on the workshop proceedings. This international Expert Group, chaired by Ian Boyd from the Sea Mammal Research Unit (SMRU – University of St

Andrews) UK, further worked on establishing the outline of a much needed scientific research strategy. This would also allow the further elaboration of two of the key recommendations made by the 2004 Marine Board and NSF workshop participants, namely (i) establish some mechanism to allow better co-ordination of research between the US and Europe, ultimately leading to jointly funded research programmes between the two; and (ii) establish database(s) to enhance the sharing of data: US and European data must be made compatible.

The resulting Marine Board Expert Group was convened to meet at Tubney House on October 4-8 2005 in Oxford, with financial support of the Marine Board. The participants at the workshop are listed in Annex II. The report presented here describes an outline of a research strategy following the Expert Group's efforts on the subject.

The main recommendation put forward in this report is to use a four-step analytical risk framework process adapted to the issue of marine mammals and anthropogenic sound to assess and identify priority research topics for reducing uncertainty. Such a risk framework includes: (i) hazard identification; (ii) characterizing exposure to the hazard; (iii) characterizing dose-response relationships; and (iv) risk characterization, typically feeding into a risk management step.

The risk assessment framework presented in this report is illustrated by focussing on the breakdown of three of the identified high-level research questions: (i) how can we reduce the risk posed by sonars to beaked whales; (ii) what are the effects of seismics on individual marine mammals and populations; and (iii) what is the interaction between shipping traffic noise and baleen whales? The analysis has only expanded three of the key questions to illustrate the range of possible sub-questions that could form the basis of a research effort to undertake a formal risk assessment. Additional work is required to carry out the same process with the other important questions. To construct a full risk assessment, it is necessary to be able to make all the linkages between issues from *sound production*, through *behaviour change*, *effects on life function*, to *impacts on vital rates* and, by implication, the *effects on populations*. In particular, there is a need to improve knowledge of how *effects on life function* influence *vital rates*.

The Marine Board would like to thank the Expert Group Chair, Dr. Ian Boyd, and its expert participants, whose efforts resulted in this proposal for a research strategy in the field of interactions between anthropogenic sound and marine mammals.

Lars Horn and **Niamh Connolly**
Chairman and Executive Secretary,
Marine Board-ESF

Introduction by Ian Boyd

In some parts of the world the next two decades will probably see increasing levels of offshore industrial development and this will almost certainly lead to increased amounts of noise pollution in the oceans. Added to this, there is a great deal of speculation about whether current or future levels of anthropogenic sound are likely to be harmful to marine life. Some people advocate banning or curtailing some forms of activity and many of these people cite the potential sensitivity of marine mammals to anthropogenic sound as the reason for their concern. A few incidents involving the stranding of cetaceans in proximity to some sources of anthropogenic sound have brought this opinion into sharp relief. This position has been accompanied by some speculation about possible effects of anthropogenic sound on marine mammals that moves well beyond the knowledge available from current data and information.

Marine mammals could be one of the more sensitive groups of marine species because some species have a highly developed auditory system and use sound actively for feeding and for social communication. It is also known that some marine mammal populations are vulnerable to the effects of habitat loss or reduced survival and reproductive rate. Marine mammals have also become totems of environmental awareness and sustainability and this has resulted in a controversial stand-off between environmental groups and those who are responsible for producing sound in the oceans.

The problem faced by society is that many economically important activities are at risk because of a lack of information about the effects of anthropogenic sound on marine mammals. The Precautionary Principle has probably achieved customary status in international maritime legislation where the marine environment is involved, which means that the Precautionary Principle is likely to be applied even if it is not specifically stated. This also probably means that it is no longer satisfactory for users of the oceans to ask for evidence of the effects of some activities before they take action to mitigate these effects. Precautionary regulation is leading to considerable burdens being placed upon future development in some areas, but implementation is patchy. This patchy implementation is evident when one considers the different levels of regulation placed on the oil and gas industry compared with those imposed on the fishing industry. The report presented here brings forward a view from the marine mammal specialists within the scientific community about the research effort that is needed to assess the effects of anthropogenic sound upon marine mammals.

The test of a research strategy is whether funding organisations use it to provide an underpinning rationale for investing in research. Since the workshop that resulted in this report took place, two new research initiatives have been developed. Both initiatives involve multi-stakeholder collaborations because, as recognised in this report, the biological problems associated with investigating the effects of anthropogenic sound on marine life are so large that probably no single organisation is capable of funding the research effort. In one case, a consortium of oil and gas companies has built a fund of more than $25 million to investigate the effects of sound on marine life (see www.soundandmarinelife.org) and in the other case, the US Navy, assisted by other funders that also includes the oil and gas industry Sound and Marine Life Program, have sponsored a sound playback experiment on beaked whales. These initiatives reflect a serious intent on the part of organisations that actively emit sound into the oceans to address current environmental concerns. In both these cases, the research strategy in the report presented here has helped to focus their research effort on the principal research questions and approaches.

The report is a consensus of views from across the community of active researchers in the field of marine mammals. Where there are such controversial issues a consensus is often difficult to achieve. I am grateful to all those involved for entering into this initiative in a spirit of cooperation and for not allowing the debate to become polarised to such an extent that it undermined the outcome. I am also very grateful to the Marine Board of the European Science Foundation for sponsoring the workshop and for endorsing the emerging research strategy. I hope that others will find the research strategy presented here to be a useful reference for a long time into the future.

Ian L. Boyd
Marine Board Workshop Chair

Strategic vision

Marine mammals have always been a flagship group in awareness campaigns to protect the marine environment from the effects of human encroachment. This is because of their status as one of the most visible features of the marine fauna, their high public profile and their likely sensitivity to changes in the ecology of the oceans, including anthropogenic effects. Directed harvesting of marine mammals has declined but pollution and habitat loss are increasingly affecting marine mammals, often in ways that are difficult to observe directly. Marine mammals thus have a symbolic status as a bellwether of the extent to which marine ecosystems are being managed in a sustainable way.

Marine mammals are complex organisms embedded in complex ecosystems and environments. These factors mean that measurement and prediction of marine mammal responses to human presence in the marine environment is not a case of examining simple cause and effect scenarios. Instead, approaches using basic research need to be used to provide sufficient fundamental knowledge about distribution, abundance, behaviour, physiology and population dynamics to recognise the presence of likely anthropogenic impacts on these species. This will enable provision of timely advice about ways in which human impacts on marine mammals can be minimised.

Consequently, there is a need to pursue a vision of future management of marine resources where the expansion of human activities will be accompanied by a sound understanding of the risks and appropriate tools to mitigate those risks. Marine mammals are a particularly important feature of the marine environment to which this vision should be applied.

Figure 1. Harbour seals

Why is sound an issue?

There is a high level of concern about the potential impacts of anthropogenic sound on marine fauna. Awareness of this issue has been heightened by a number of recent cetacean stranding events coincident with exposure to anthropogenic sound. Concern has centred upon marine mammals because they rely on sound as a major source of social communication and environmental information and for that reason have a very developed auditory receptor system. Consequently, anthropogenic sound may affect them in a number of different ways, and these effects may be felt at both the individual and population level.

In response to this, debates on the issues have led to numerous reports on how anthropogenic sound may affect marine mammals (NRC 2003 and 2005; Southall 2005 and see Annex I). Most of these debates and reports have acknowledged that the current level of scientific understanding is insufficient to allow construction of robust advice about the potential impacts of anthropogenic sound. Most reports have also drawn up high-level recommendations for research that is deemed necessary to address the question of where, when and what effects are occurring, and also how to mitigate any resulting impacts. However, most of these recommendations have emerged from discussions concerned principally with describing and managing the effects of anthropogenic sound. To date, there has been no structured analysis of the full research challenge that this presents.

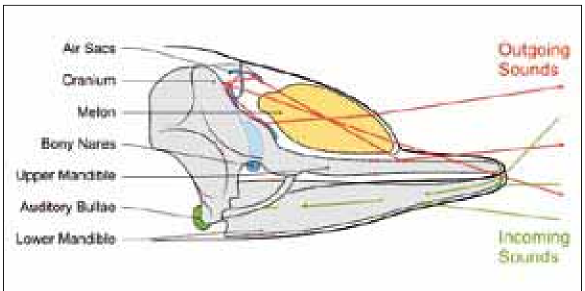


Figure 2. Schematic diagram of sound production and reception in a toothed whale

The arguments about the issue of how and why anthropogenic sounds may affect marine mammals have become highly polarised. This has come about partly because of differing points of view about the level of precaution that needs to be adopted in the face of high scientific uncertainty[1]. Economic and social pressures responsible for the introduction of more anthropogenic sound into the marine environment are important underlying drivers of this process. Reduction in current production of anthropogenic sound could result in financial and opportunity costs to society, and this has created a need for new knowledge about the effects of anthropogenic sound on marine mammals.

1. For a definition of uncertainty in the context of this report see: Harwood, J. and Stokes, T.K. 2003. Coping with uncertainty in ecological advice: lessons from fisheries science. *Trends in Ecology and Evolution* 18(12): 617-622.

Objectives of this report

Our knowledge of the importance of anthropogenic sound to marine mammals has increased rapidly in recent years, mainly as a result of directed research emerging because of current concerns. This report provides a view of research that is most needed in future to address the issues concerning marine mammals and anthropogenic sound. The report starts from the position that there is a need to address all aspects of the importance of sound for marine mammals, and proceeds to develop a protocol for narrowing the focus to address specific issues. The reason for this approach is to ensure that scientific activities that may underlie all, or most, issues concerning the effects of anthropogenic sound on marine mammals, are flagged and prioritised appropriately.

Nevertheless, there is recognition in the structure of the research strategy presented here that investigations of fundamental scientific issues are open-ended in their scope and extent. The report attempts to balance the need to address these issues with the need to produce results that have greatest relevance to current information needs and knowledge gaps.

The report also attempts to reflect the complexity and scale of the scientific challenge. Implicit within the report is a need for a change in the approach taken towards the organisation, management and funding of research. Long-term investment will be needed in research, infrastructure and personnel, together with a focussed approach to creating inter-disciplinary, inter-institutional and international research teams.

The kinds of problems being addressed in the research strategy presented are complex because the observed, or inferred, effects of anthropogenic sound on marine mammals may result from many interacting causes. Therefore, marine mammals are themselves complex transducers of information received from their environment. A key message of this report is that it is unlikely that a small number of focussed experiments will provide the information necessary to solve most of the major concerns. Instead, one must rely upon an accumulation of evidence combined with a process of objective assessment of this evidence through periodic independent review. Recent efforts have focussed upon a review phase in this process (see Cox *et al.* 2006; Southall et al 2007 and other literature cited in Annex I); there is now a need to achieve a rapid improvement in the state of knowledge by undertaking new research that is focussed on specific questions of high priority. This requires concerted, coordinated action across many expert groups within the scientific community.

Some of the stakeholders responsible for introducing sound into the marine environment have shown willingness to engage in addressing the uncertainty that surrounds current scientific understanding. This is particularly evident by their funding of research projects that address their specific needs. The research strategy presented in this report should help to connect the efforts and investments made by different groups working independently in this field.

To date, a major component missing from much of the debate surrounding the effects of anthropogenic sound on marine mammals is coordinated action from the scientific community, independent of the other stakeholders. Consequently, this report sets out to:

(i) Define a strategic framework for future research;
(ii) Provide guidance about prioritisation of research;
(iii) Suggest a process of implementation.

This report is also designed to advise stakeholders about the structure of the research effort that is required to address most of the major issues concerning the effects of anthropogenic sound on marine mammals. It does not specifically recognise the special interests of particular stakeholder groups; rather, it suggests ways that stakeholder groups may wish to contribute to the development of a research effort that could allow a range of stakeholders to benefit from the investments made by others.

Figure 3. Students dissecting a stranded whale

Strategic approach

The authors start from the position that a focussed effort is required to define and reduce the risk presented to marine mammals by anthropogenic sound. In this case, risk can be defined by the probability of disturbance or injury that could affect the viability of individuals or populations.

So that prioritisation can be undertaken based upon a set of objective criteria, the approach adopted in this report has been to assess priorities under a risk assessment framework. This approach has not been adopted in the past by any of the groups considering where research effort should be directed. The risk framework adopted here includes:

(i) Hazard identification
(ii) Characterizing exposure to the hazard
(iii) Characterizing dose-response relationships
(iv) Risk characterization
(v) Risk management

The authors have assumed that some form of quantification is usually required in each of the steps (i) through to (iv) above, in order to establish appropriate measures to manage the risk, while also recognising that the risk assessment framework can be operated using qualitative information.

Research questions that emerged over the past few years have been assessed. A rationale is developed to help prioritise these questions and to develop a set of approaches that could be used to help answer these questions.

Sources of sound and hazards to marine mammals

Most human activities in the marine environment generate sound that has the potential to affect marine mammals. Many features of the marine environment are responsible for producing sound, including many natural factors such as wave action, rainfall and biological sources including fish, crustaceans and marine mammals themselves. Anthropogenic sources of sound include shipping, dredging, pile driving, seismic exploration, and a variety of sonars (both civil and military). The latter include fish-finders and depth profilers that are present in some form on a majority of vessels, as well as more specialized bottom profilers.

The assessment of what constitutes a hazard to marine mammals is to an extent subjective since, in most cases, there is still no direct evidence of an effect, let alone an effect that presents a significant risk to marine mammals. However, the list tabulated in Table 1 represents a set of sound sources that have been recognised as potentially important; all of these could be responsible for creation hazards to marine mammals. The listing is not exhaustive but these sources, which are all types of human activities, are found in most oceans and seas of the world. They are distributed in a very heterogeneous pattern, both in time and space and this alone can lead to a complex anthropogenic sound field.

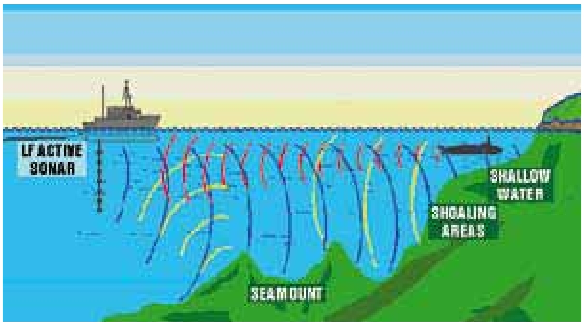


Figure 5. Schematic representation of Low Frequency Active Sonar (LFAS)

Complexity is increased further because different components of anthropogenic sound attenuate at rates that depend upon the frequency involved and environmental conditions. This means that prediction of overall received sound levels, let alone those from a specific source, is surrounded by large uncertainty. This uncertainty has prompted the suggestion that it cannot be assumed that anthropogenic sound is benign, even if experimental evidence fails to show effects, because effects may only occur under special sets of circumstances that are difficult to replicate in experimental conditions. Relative to their frequency of use in the ma-

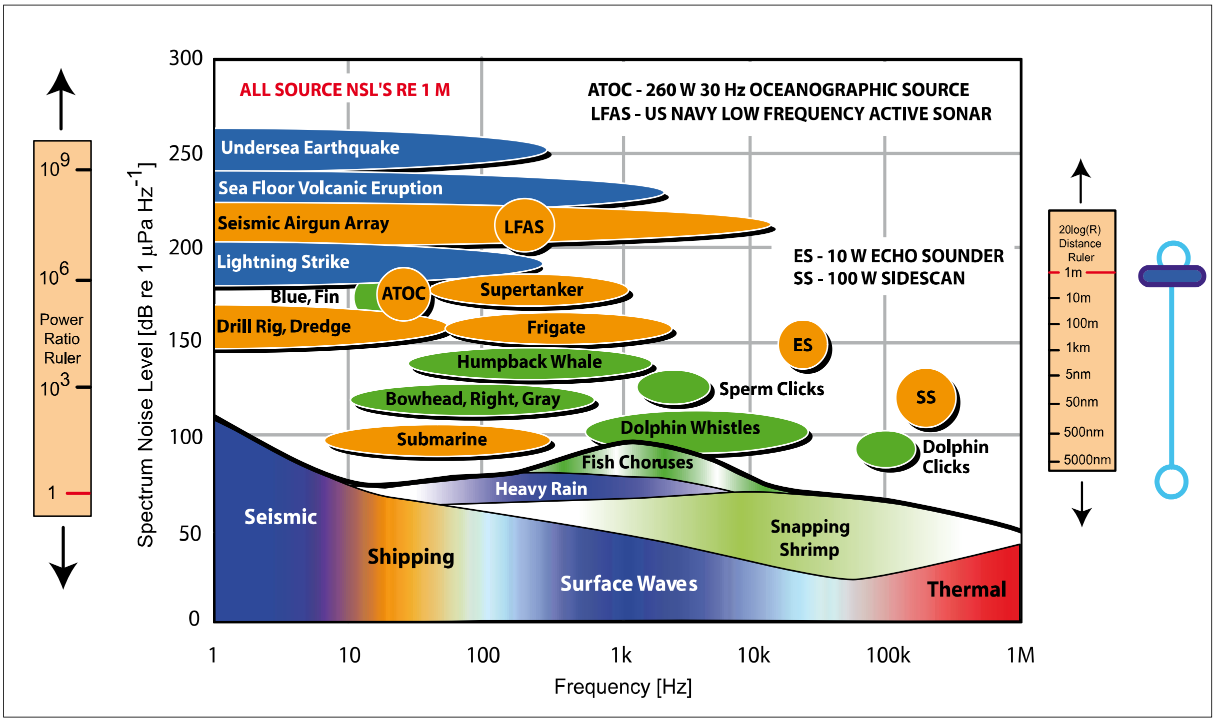


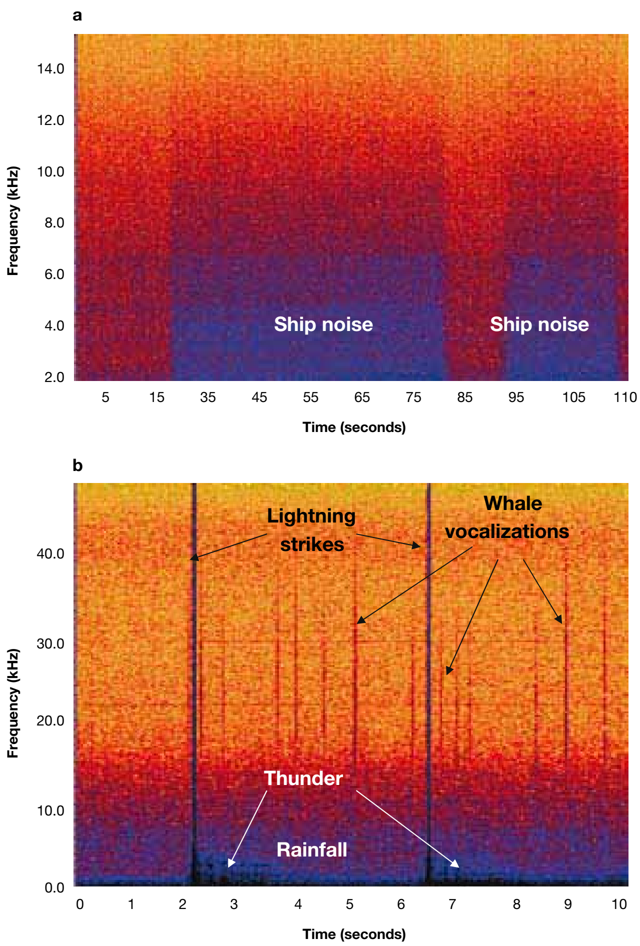
Figure 4. Noise levels and frequencies of anthropogenic and naturally occurring sound sources in the marine environment

rine environment, some sound sources may only have an effect on rare occasions. The important question is whether the magnitude of the effect, even if it only occurs rarely, is sufficient to be of concern.

There is also recognition that the effects of chronic and episodic (or acute) sound may differ. Sound received in short, infrequent pulses may have a different effect to sound at similar power levels received frequently or over long periods of time. However, the effects on marine mammals are generally poorly understood, but it means that a sound source can become a hazard depending upon how it is used, rather than on its operating power levels and signal characteristics.

Table 1. Types of anthropogenic sound sources that could affect marine mammals

Source	Effects of greatest concern
Vessels	Masking Habitat displacement
Air guns	Masking Physical trauma Hearing loss Behavioural change Habitat displacement Behaviourally-mediated effects
Intense low- or mid-frequency sonar	Physical trauma Hearing loss Behavioural change Behaviourally-mediated effects
Pile driving	Physical trauma Hearing loss Behavioural change Behaviourally-mediated effects
Other sonars (depth sounders, fish finders)	Masking Hearing loss Behavioural change Behaviourally-mediated effects
Dredges	Behavioural change Behaviourally-mediated effects Habitat displacement
Drills	Hearing loss Behavioural change Behaviourally-mediated effects
Bottom towed fishing gear	Behavioural change Behaviourally-mediated effects Habitat displacement
Explosions	Physical trauma Hearing loss Behavioural change Behaviourally-mediated effects
Recreational vessels	Masking Behavioural change Behaviourally-mediated effects
Acoustic deterrents	Behaviourally-mediated effects
Over flying aircraft (including sonic booms)	Behaviourally-mediated effects



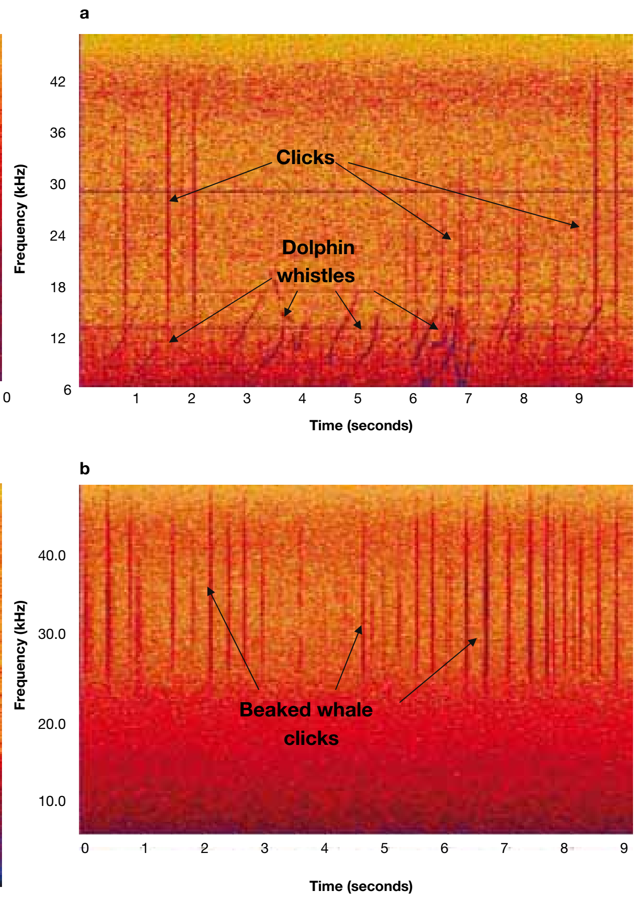


Figure 6. Spectrograms of (a) man-made sound and (b) natural sound. The man-made sound is ship noise where the ship ran its engines intermittently. The natural sounds show two lightning strikes, heavy rainfall, thunder and the sounds of whales vocalizing.

Figure 7. Spectrograms of (a) dolphin vocalizations including whistles that are audible to the human ear and higher frequency clicks and (b) typical clicks from a group of foraging Blainville's beaked whales (*Mesoplodon densirostris*). The frequency of beaked whale clicks is above the threshold of the human ear but beaked whales can hear at frequencies similar to those of the dolphin whistles which are also within the frequency range of many man-made sounds.

Risk framework

The impacts and mitigation of many types of environmental hazards may be considered within a risk framework. This applies to risk to human health as well as to wildlife. Risk frameworks help to rationalise the scientific research effort by focussing it into areas that are most likely to help reduce environmental impacts. The following descriptors for a risk framework applied to the effects of anthropogenic sound on marine mammals are a modification of generic frameworks used for other forms of pollution (NRC 1994b). Further definitions are provided in box 1.

The risk assessment framework as described in Box 1 and shown in Figure 8 is implemented in Table 2 in the context of the problems associated with marine mammals and anthropogenic sound. Not every risk assessment would necessarily encompass all four steps shown above. Risk assessment may sometimes consist only of a hazard assessment designed to evaluate the potential for anthropogenic sound to affect marine mammals. Applying this to the effects of anthropogenic sound on marine mammals will help to define the priority research topics necessary for reducing uncertainty.

The analytical steps described above are typically followed by a fifth step: Risk Management which involves the design and application of mitigation measures to reduce, eliminate, or rectify risks. Aside from identifying priority risks, the scientific community may contribute to risk management primarily by providing information and advice about effective mitigation techniques or strategies, which may be used by stakeholders to reduce these (priority) risks. Such information is also essential for the development of informed knowledge-based policy making.

Box 1. Risk Assessment Framework

A four-step analytic process is applied. A sound leaves a source (e.g., sonar transducer, seismic airgun array), moves through the water, and results in an exposure (marine mammals receiving sound). The exposure creates a dose in the exposed animals (the type and amount of the sound received by the animals, which may be expressed in any of several ways), and the magnitude, duration, timing, and other characteristics of the dose determine the extent to which there is an effect. This model is captured in the following analytic steps:

Step 1:

Hazard Identification: entails identification of the sound sources and the circumstances in which they are used that are suspected to pose hazards, quantification of the concentrations at which they are present in the environment, a description of the specific effects of the sound source, and an evaluation of the conditions under which these effects might be expressed in exposed marine mammals. Information for this step may be derived from environmental monitoring data and the direct correlation of effect with the presence of a hazard as well as other types of experimental work. This step is common to qualitative and quantitative risk assessment.

Step 2:

Dose-Response Assessment: entails a further evaluation of the conditions under which the effects of sound might be manifest in exposed marine mammals, with particular emphasis on the quantitative relation between the dose and the response. This step may include an assessment of variations in response, for example, differences in susceptibility in relation to age, sex, reproductive status and time of year.

Step 3:

Exposure Assessment: involves specifying the population that might be exposed to the hazard, identifying the routes through which exposure can occur, and estimating the characteristics (magnitude, duration, and timing) of the doses that marine mammals might receive as a result of their exposure.

Step 4:

Risk Characterization: involves integration of information from the first three steps to develop a qualitative or quantitative estimate of the likelihood that any of the hazards associated with the sound source will be realized in exposed marine mammals. This is the step in which risk-assessment results are expressed. Risk characterization should also include a full discussion of the uncertainties associated with the estimates of risk.

Box 2. Risk Assessment Definitions

Risk assessment approach:

- **Risk**: "probability that something undesirable will happen" (Harwood 2000); the probability that a given hazard will cause harm (http://www.labour.gov.sk.ca/safety/repguide/basics2.htm)
  – "***something undesirable***": e.g., disturbance or injury of marine mammals (individuals or populations)
  – ***hazard***: any activity, situation or substance (energy) that can cause harm
- **Risk assessment**: methodology for quantifying uncertainties
  – ***Step 1: Hazard Identification***: identification of causal factors/threats
  – ***Step 2: Exposure Assessments and Exposure-Response Assessments*** determination of exposure to hazards and identification of range of possible responses
  – ***Step 3: Risk Characterisation***: determination of the likelihood of undesirable outcomes of sound exposures
- **Risk management:** development and application of means to address risk

Hazard Identification (what are the actual and potential threats?)

– investigation of scenarios where there is suspicion of a relationship between sound and observations of deaths, injuries, and more subtle effects
– determine the causes of harm
– need for greater effort to identify baselines and to develop techniques to identify threats
– need for more detailed efforts to tease out the specific cause(s)

Exposure Assessments (determine exposure to hazards)

– marine mammal numbers and distributions
– sound characteristics and distributions
– overlap between marine mammals and sounds and moderated by species sensitivity

Exposure-Response Assessments (determine range of possible responses)

– marine mammal sensitivities at the species level: auditory effects, non-auditory physiological effects, behavioural effects, trophic and ecosystem effects, population-level effects
– dose-response relationship

Risk Characterization

– determine likelihood of undesirable outcomes of sound exposures

Risk Management

– development of mitigation
– will depend upon whether the risk of harm exceeds trigger levels set by legislation, societal views or because effects are deemed to be biologically significant.

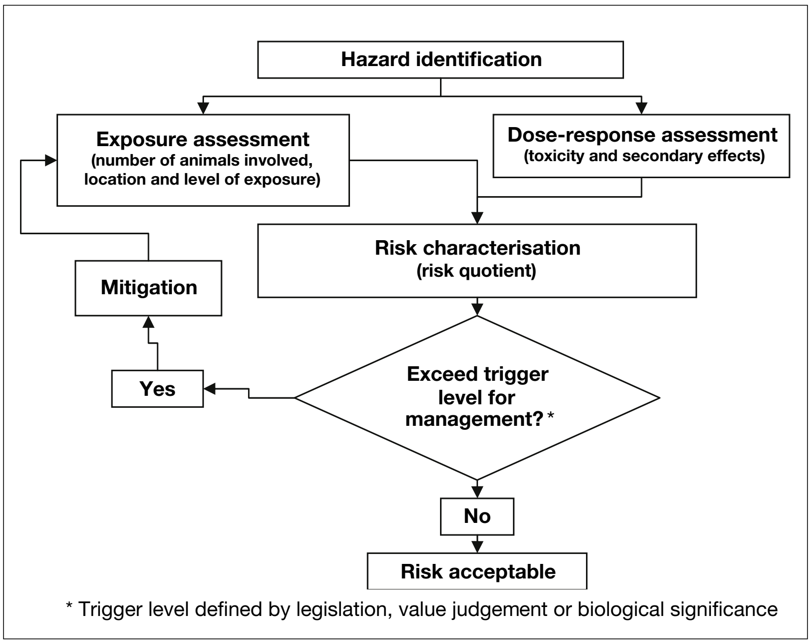


Figure 8. Illustration of the information flow and decision pathway for a risk assessment process. This shows a feedback process involving mitigation when the risk exceeds the trigger level for management action. This is an adaptive approach to managing risk.

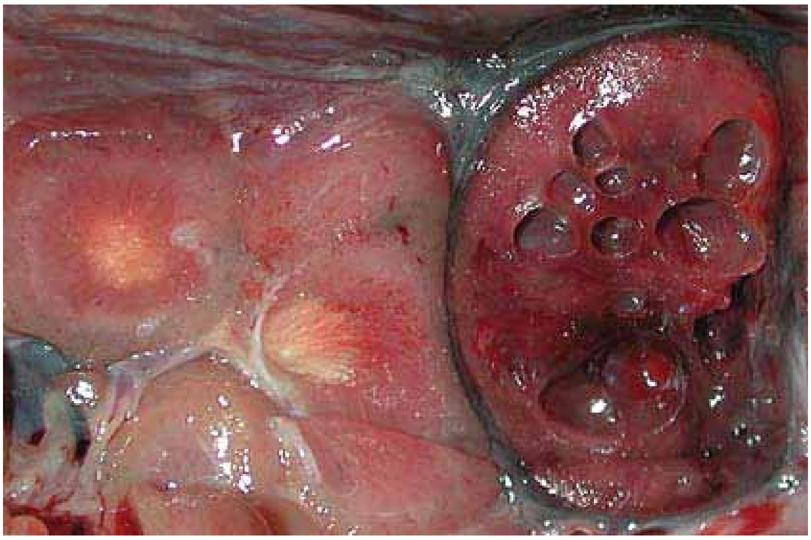


Figure 9. Common dolphin kidney with gas embolism: normal (left) and abnormal (right) kidney lobes. This particular common dolphin stranded singly and it is not known if the dolphin was exposed to sonar (or other high-intensity man-made sound source). There are at least two hypothetical mechanisms for bubble formation in tissues: (i) a behavioural response to sonar exposure (e.g. rapid ascent followed by a series of shallow dives around 25-50m) that drives nitrogen tensions in body tissues to levels that might cause bubbles to form (most supported hypothesis by scientists); and (ii) a direct physical effect of acoustic sound energy on microscopic bubble precursors in tissues leading to instability of the micro-bubbles and a predisposition to grow to a larger size if the surrounding tissues are supersaturated with nitrogen gas (as occurs when a whale surfaces from a series of dives).

Table 2. The risk assessment framework as applied to the issue of marine mammals and anthropogenic sound with an assessment of prioritisation. Note that there is some overlap between the main research issues across the stages of risk assessment. For example, the distribution and abundance of anthropogenic sound sources is relevant to hazard identification, as well as exposure and dose-response assessments.

Stage in risk assessment framework	Main research issues	Sub-issues	Degree of current uncertainty
Step 1: Hazard Identification	Sources of sound in the marine environment	Characteristics of natural and anthropogenic sound sources	Moderate
		Distribution and abundance of sound sources	High
	Sound fields in the marine environment	Ambient noise fields	High
		Sound fields of individual sources	Moderate
		Auditory detection of sound	Moderate
		Non-auditory sensitivity to sound	Moderate
Step 2 & 3: Exposure Assessment and Dose-Response Assessments (both long- and short-term)	Marine mammals as receivers of sound	Distribution and abundance of marine mammals (including vertical)	High
		Auditory detection of sound	Moderate
		Non-auditory sensitivity to sound	Moderate
		Distribution and abundance of sound sources	High
	Effects of sound on individuals	Physiological effects (*e.g.*, TTS, PTS, stress)	Auditory Effects: Moderate Stress Effects: High
		Masking (including potential chronic effects)	High
		Behavioural effects	High
		Life function effects (*e.g.*, body condition, reproductive condition)	High
		Morbidity	High
		Issues related to beaked whale mass strandings (*e.g.*, nitrogen bubble, tissue resonance, and haemorrhagic diathesis hypotheses)	High
		Effects of sound on feeding through prey availability	High
	Effects on populations	Changes in vital rates (*e.g.*, fecundity, survival)	High
	Cumulative and synergistic effects	Effects of multiple exposures to sound	High
		Effects of sound in combination with other stressors	High
Step 4: Risk Characterisation	Risk of impact	Overlap of exposures and effects	High
Step 5: Risk Management	Methods to prevent or reduce risk	Mitigation tools and determining trigger levels for management action	High

Rationale for prioritisation of research and approaches

Individuals or populations?

In order to determine whether the effects of anthropogenic sound on marine mammals result in changes in species viability, we must understand how the responses of individuals to sound change their behaviour and physiology in ways that affect their vital rates[1]. Without such an understanding, linkages between sound exposure and population changes can never be achieved. Although many marine mammal populations have experienced significant declines in the past few decades, the causal factors are difficult to ascertain *post hoc*.

Marine mammals use sound and respond to conspecific, natural, and anthropogenic sound in a variety of ways. Most of the responses are adaptive, which means that behaviour and physiology may change, but they do so in a manner that does not negatively affect the vital rates of the species involved. The question that is difficult to answer is: when do these adaptive responses to an environmental stress, which are within the norms of an animal's capacity to respond, lead to reduced probabilities of surviving or reproducing? In extreme cases this may lead to anthropogenic sound having significant negative consequences for vital rates and populations. This was the subject of a recent US National Research Council report (NRC 1994a, 2000, 2003 and 2005).

The PCAD (Population Consequences of Acoustic Disturbance model, see Figure 11) presented in the US National Research Council report provides a rationale for prioritisation of research. It is represented by a flow diagram showing research topics in areas ranging from *sound production*, through *behaviour change*, *effects on life function*, to *impacts on vital rates* and, by implication, the *effects on populations*. To construct a full risk assessment, it is necessary to be able to make the linkages (labelled as 1-4 in Figure 11) between each subject. Analysis of this structure, in particular reveals the need to improve knowledge of how *effects on life function* influence *vital rates*. This is an area of research that requires a high level of effort, illustrated by the scores given to each transfer in the diagram of Figure 11. Understanding the mechanisms and linkages are fundamental to designing more effective mitigation strategies.

1. "Vital rates" are the factors that determine the rate of growth of a population, such as the reproductive, survival and immigration and emigration rates.

Figure 10. There can be a large overlap between human activities at sea and habitats that are vital for marine mammals

Long-term versus short-term research objectives

The areas most in need of research activities require consolidated long-term effort and funding. Questions focused at the level of populations cannot be easily addressed using conventional competitive funding streams that normally provide funds over comparatively short periods of time (1-4 years). A significant feature of the strategic approach being proposed here is the recognition that many funding agencies/organisations are not currently able to commit to long-term funding. The prioritisation of research therefore should provide a route by which coordination amongst short-term research projects leads to answers that could only be achieved otherwise through long-term strategic research.

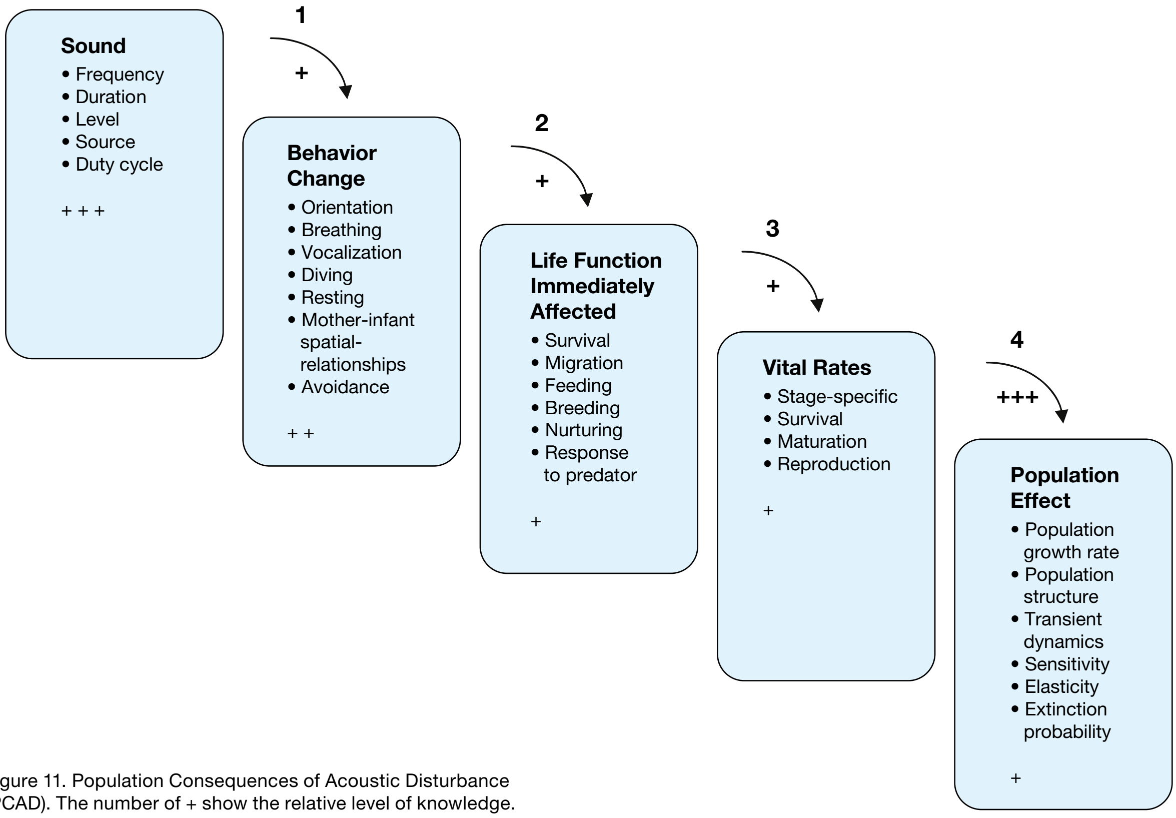


Figure 11. Population Consequences of Acoustic Disturbance (PCAD). The number of + show the relative level of knowledge.

Assessment of approaches

There is usually a limited range of methods that can be used to study marine mammals but, where there is a choice, criteria can be selected and used to focus attention on a narrow range of methods.

Each research approach was assessed with respect to the following evaluation criteria:

(i) Biological significance – an assessment of the contribution made to understanding the biological processes involved in the response to anthropogenic sound;
(ii) Financial cost – an assessment of the absolute financial costs of carrying out a particular approach;
(iii) Cost to animal – an assessment of the impact that a procedure will have on an individual;
(iv) Effectiveness – an assessment of the extent to which the approach will advance knowledge towards the goal of answering the question;
(v) Feasibility – an assessment of the constraints that may reduce the practical implementation of the approach, such as permitting, access to animals and availability of technology.

Costs and benefits of different approaches

This research strategy has not carried out an explicit cost-benefit analysis of different approaches. However, a cost-benefit analysis will be a necessary component of any research activity. The analysis presented in this report provides a structure for the assessment of costs and benefits in the future.

High-level research questions

Since natural sound is an important feature of the marine environment, the central issue concerning the effects of anthropogenic sound on marine mammals involves sources that produce sound above the natural background level, thereby producing localisable effects or adding to ambient noise budgets. The central questions to be answered are:

(i) How do marine mammals respond to sound levels that are above the natural background level?
(ii) What are the consequences of these responses?

These questions can be further expressed as a set of high-level operational research questions in the context of the risk assessment framework:

(i) What are the anthropogenic sound source characteristics and resulting sound fields?
(ii) What level of exposure do marine mammals experience?
(iii) What are the immediate physiological, pathological and behavioural effects of anthropogenic sound exposure?
(iv) What are the long-term effects of anthropogenic sound exposure at the level of both individuals and populations?
(v) How can we mitigate against any effects if they are found to be significant?

Figure 12. Harbor porpoise undergoing scanning

Specific research questions and approaches

Specific thematic questions are given in Table 3. These can be expanded into a set of more detailed questions. Three of these questions (the first three mentioned in Table 3) are considered in more detail to provide examples of this process.

(i) How can we reduce the risk of tactical mid-frequency sonars to beaked whales?
(ii) What are the effects of seismic surveys on individuals and populations of marine mammals?
(iii) What is the effect of shipping noise on marine mammals?

Tables 4, 5 and 6 show a set of sub-questions relating to these questions. The evaluation criteria detailed above were used to assess the general feasibility of each of the approaches that could be taken to investigate each sub-question. These have been arranged in the tables in Annex III to address different parts of the risk assessment process.

The research approaches are not fully exclusive and there is inevitably some overlap and therefore duplication in the assessments (e.g. cost to animal and difficulty in obtaining a permit for the work). Nevertheless, some possible approaches stand out as being better than others at addressing the question being asked. For the purpose of this report, it is better to look at the overall pattern of the assessment, rather than the precise details. The details are available for consultation at http://www.smru.st-and.ac.uk/. The approaches attracting most stars under the titles of biological significance, effectiveness and feasibility, and the fewest stars under financial cost and cost to animal are likely to yield the greatest value as a research investment.

Table 3. High-level research questions that relate to particular hazards

Research Question
• How can we reduce the risk of tactical mid-frequency sonars to beaked whales? (See Table 3)
• What are the individual and population consequences of seismic surveys? (See Table 4)
• What is the effect of shipping noise on marine mammals? (See Table 5)
• What is the effect of commercial sonars such as depth sounders and fish-finders?
• What risks do sonars present to marine mammals other than beaked whales?
• What are the impacts, if any, of new low frequency sonar technologies?
• What is the effect of acoustic oceanography on marine mammals?
• What are the effects of acoustic deterrent devices that target marine mammals?
• How do outboard motors affect marine mammals in the inshore area?
• What are the population consequences of chronic exposure to all sound sources?
• What are the consequences of chronic exposure to continuous low level sound sources?
• How does pile-driving affect marine mammals?
• What are the effects of sounds originating from vessels that follow marine mammals?

Analyses of dependencies and critical paths

Tables 4, 5 and 6 each show an analysis of the dependencies between different sub-questions. This is shown using arrows between sub-questions. The direction of the arrows shows the inter-dependencies of the sub-questions.

As expected, the analyses show a general flow of dependencies from top to bottom of the risk assessment framework. The characterization of the dose-response relationship has a large number of dependencies within the section on exposure characterization. This pattern is similar for the investigation of the effects of sonars on beaked whales (Table 4), the effect of seismics (Table 5) and shipping noise (Table 6) on marine mammals.

Using these tables, it is possible to define critical paths through the research field to help prioritise research. For example, a common concern refers to the probability of an adverse impact of an activity on a marine mammal population. This is expressed as a question under the risk characterization section of Tables 4, 5 and 6. The critical path for research to address this question is defined by dependencies on outputs from a cascade of other questions that leads back to questions about received sound levels and physiological and behavioural responses to these sound levels.

The analyses in Table 4, 5 and 6 suggests that being able to measure the sound received by a cetacean should be a major focus of research, because many other research questions rely upon this capability. This would point to renewed efforts to develop appropriate instrumentation and attachment methods together with efforts to provide fine-scale measurements of the sound field.

Figure 13. Merchant shipping is one of the activities most likely to contribute to increased noise in the marine environment

Analyses of dependencies and critical paths

Table 4. Research sub-questions addressing the higher-level question "how can we reduce the risk of sonars to beaked whales?" Arrows between sub-questions indicate the result of the analysis of the dependencies between the different sub-questions.

Hazard Identification	What is the range of frequencies, intensities and duration of exposure (that causes risk)?
	What is the effect of propagation conditions?
	Are there unique habitat characteristics that create a hazard?
	Have stranding rates changed?
	Where are the sound sources?
Characterising exposure	Where are the beaked whales?
	What is the overlap of beaked whale distribution with sound sources?
	How do behavioural changes modulate exposure?
	What are the received sound characteristics at the whale?
Characterising dose-response relationship	How close are beaked whales to their physiological limits while diving?
	What is the pathological/physiological response?
	Is the response a direct physical effect?
	What is the behavioural response?
	How are behavioural and physiological responses related?
	Is there habitat displacement and over what temporal and spatial scales?
	What proportion of the exposed animals is affected?
	Does sensitivity vary between individuals?
	How are populations and their vital rates affected?
Risk charac-terisation	What is the probability of impacts on individuals?
	What is the probability of adverse population impacts?
Risk Management	What is the effect of changing the acoustic source, operational characteristics and location of the source?
	How can beaked whales be detected within the operational zone in real time?
	How can overlap between beaked whales and sonar be reduced?

Table 5. Research sub-questions addressing the higher-level question "what are the effects of seismics on individuals and populations?" Arrows between sub-questions indicate the result of the analysis of the dependencies between the different sub-questions.

Hazard Identification	What is the range of frequencies, intensities and durations of exposure (that causes risk)?
	What is the effect of propagation conditions?
	Have stranding rates changed?
	Has seismic activity affected the distribution and abundance of any marine mammal?
	Does seismic survey activity affect prey availability for marine mammals?
	Where are the sources?
Characterising exposure	Where are the marine mammals?
	What is the overlap of marine mammal distribution with sound sources?
	How do behavioural changes modulate exposure?
	What are the received sound characteristics?
Characterising dose-response relationship	Are there physiological responses?
	Do airguns have a direct physical effect?
	What is the behavioural response?
	Is there habitat displacement and over what temporal and spatial scales?
	How do we assess the significance of observed habitat shifts?
	Does sensitivity vary between individuals?
	How are populations and their vital rates affected?
Risk charac-terisation	What is the probability of impacts on individuals?
	What is the probability of adverse population impacts?
Risk Management	What is the effect of changing the acoustic source, operational characteristics and location of the source?
	Is ramp-up an effective mitigation measure?
	How can marine mammals be detected within the operational zone in real time?
	How to reduce risk of overlap between marine mammals and seismic surveys?
	How to design Marine Protected Areas to minimize risk to animals in areas where seismic exploration is likely?
	What acoustic buffer zones are required to reduce risk to animals within marine protected areas consistent with goals of the protection?

Table 6. Research sub-questions addressing the higher-level question "what is the interaction of shipping traffic noise with baleen whales?" Arrows between sub-questions indicate the result of the analysis of the dependencies between the different sub-questions.

Hazard Identification	What is the range of frequencies, intensities and duration of exposure (that causes risk)?
	How has vessel noise and traffic noise changed as a component of ambient sound across space and time?
	What is the effect of propagation conditions?
	Are there unique habitat characteristics that create a hazard?
	Does vessel traffic noise affect risk of collision?
Hazard Identification	Where are the sources?
	Where are the baleen whales?
	What is the overlap of marine mammal distribution with sound sources?
	How do behavioural changes modulate exposure?
	What are the received sound characteristics?
Characterising dose-response relationship	Do baleen whales respond to compensate for increased vessel noise?
	What are the functions of sound produced by baleen whales?
	Do whales utilize sounds from other sources (e.g. predator calls, ambient noise) and over what ranges are these effective?
	Do whales use multi-path and echoes of their own calls?
	Is masking occurring from point sources or traffic/ambient noise?
	What is the behavioural response to a communication signal in varying noise?
	Can chronic vessel noise cause threshold shifts?
	Are there indicators of stress related to noise exposure?
	Is there habitat displacement and over what temporal and spatial scales?
	Does sensitivity vary between individuals?
	How are populations and their vital rates affected?
	How is masking related to changes in individual life functions?
Risk charac-terisation	What is the probability of impacts on individuals?
	What is the probability of adverse population impacts?
Risk Management	What is the effect of changing the acoustic source, operational characteristics and location of the source?
	How can baleen whales be detected in real time in order to reduce vessel collisions?
	How can the overlap between baleen whales and vessel noise be reduced?

Setting priorities

The foregoing analysis for the example questions used provides a framework within which research priorities can be established. Additional types of analyses need to be carried out for the remaining research questions but the fundamental messages are likely to differ little from the examples used here. Based upon Tables 4, 5 and 6, questions addressing the characterization of exposure appear to be a high priority. Although these questions depend upon the nature of the hazard, in general, the difficulty associated with researching the hazards is lower than that with characterizing exposure. However, because of the direction of flow in the dependencies in Tables 4, 5 and 6, addressing questions in the later parts of the risk assessment process (towards the lower end of these tables) will be increasingly difficult.

Controlled exposure experiments have been suggested as a high research priority. The analyses suggest that characterising the dose response relationship is an important pre-cursor to assessing the impacts on either individuals or populations. It further shows that opportunistic experiments are unlikely to be valuable unless there is an appropriate measure of the received sound at the level of the individual marine mammal.

It is recommended to develop the research agenda across a broad front and to use the risk framework, and the questions defined in Tables 4, 5 and 6, as ways of assessing where research fits appropriately into the required effort. At some point in the future, it may be appropriate to use this framework to assess progress and to identify critical gaps in knowledge.

Figure 14. Common seal

Methodologies and approaches

Each of the questions defined in Tables 4, 5 and 6 can be addressed using a set of methodologies and approaches. These Tables are expanded further in Annex III to show the methods and approaches that could be used in each case, together with assessments of their biological significance, estimated financial costs, effectiveness and the possible impacts on the animals involved.

Strategic considerations

This analysis has only expanded three of the questions in Table 3 to show the range of possible sub-questions that could form the basis of a research effort to undertake a formal risk assessment. Additional work is required to carry out the same process with the other important questions. Moreover, the present analysis is a first step towards defining a research strategy and will need further review and modification as additional intellectual effort is applied to this field. This research strategy must be subjected to a peer-review process to ensure that it reflects the broad range of experience within the research community and to ensure that it provides coherent strategic guidance.

The process of further development and implementation of this research strategy would be strengthened if the strategy were adopted by organisations with an interest in funding independently peer-reviewed science. There is a strong case for establishing a process of independent peer review of all science proposals and outputs on this topic that are funded by stakeholders.

A key element in this process is that there is some form of oversight of the implementation of this research strategy through regular independent review of ongoing funded research, in terms of how it helps to answer the high-level strategic research questions defined here. This will provide a point of reference for researchers, managers and policy-makers to identify gaps that need additional work.

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Figure 15. Common dolphin

Preferred funding and overview scenario

There has been considerable controversy surrounding some of the research on impacts of anthropogenic sound on marine mammals. For such research to be effective it must not only be based upon robust scientific principles, but it must also be seen as widely credible and unaffected by conflicts of interest. Such impartiality can only be achieved by using a transparent funding structure, independent from both sides of a polarised conservation debate. Therefore, it is critical that as much as possible of this research be funded in a way that insulates the scientists from conflicts of interest, perceived or otherwise.

If possible, an independent body should have responsibility for the apportionment of funds and monitoring and delivery of outputs of research on the effects of anthropogenic sound on marine mammals.

Such an independent body would clearly have to satisfy stakeholders and funding agencies that (i) a transparent process of peer review is used to select the best science performers and approaches; (ii) their funding would be properly audited; (iii) their funding would be distributed to an area of science defined by the interests of the funder; (iv) there would be appropriate overview of project management so that delivery could be guaranteed; and (v) this process would deliver value for money.

Conclusions

There is a high level of concern about the potential impacts of anthropogenic sound on marine fauna in general, and towards marine mammals in particular, since they rely on sound as a major source of social and environmental information. In spite of this concern, the current level of scientific understanding is insufficient to produce robust advice about the potential impacts of anthropogenic sound on marine mammals. To date, there has been no structured analysis of the full research challenge that this presents. In order to do so, there is a need to develop a protocol for narrowing the research focus to address specific issues and to prioritise research activities appropriately.

The ultimate goal of a research strategy should be to define and reduce the risk (probability of disturbance or injury that could affect viability) presented to marine mammals by anthropogenic sound. Therefore, priorities should be assessed under a risk assessment framework.

The main recommendation put forward in this report is to use a four-step analytical risk framework process adapted to the issue of marine mammals and anthropogenic sound to assess and identify priority research topics for reducing uncertainty. Such a risk framework includes: (i) hazard identification; (ii) characterizing exposure to the hazard; (iii) characterizing dose-response relationships; and (iv) risk characterization, typically feeding into a risk management step.

Risk frameworks help to rationalise the research effort by focussing it into areas that are most likely to help reduce environmental impacts. Such frameworks allow for prioritising research questions and identifying appropriate research methods by breaking down high-level research questions into sub-questions with cascades of interdependencies. In addition, as many funding agencies are not currently able to commit to long-term funding, risk frameworks should also provide a route through which coordination amongst short-term research projects leads to answers that could only otherwise be achieved through long-term strategic research.

The risk assessment framework presented in this report is illustrated by focussing on the breakdown of three of the identified high-level research questions: (i) how can we reduce the risk posed by sonars to beaked whales; (ii) what are the effects of seismics on individuals marine mammals and populations; and (iii) what is the interaction of shipping traffic noise with baleen whales? The analysis has only expanded three of the key questions to illustrate the range of possible sub-questions that could form the basis of a research effort to undertake a formal risk assessment. Additional work is required to carry out the same process with the other important questions. To construct a full risk assessment, it is necessary to be able to make all the linkages between issues from *sound production*, through *behaviour change*, *effects on life function*, to *impacts on vital rates* and, by implication, the *effects on populations*. In particular, there is a need to improve knowledge of how *effects on life function* influence *vital rates*.

The present analysis is a first step towards defining a research strategy and will need further review and modification as additional intellectual effort is applied to this field, to ensure that it reflects the broad range of experience within the science community and that it provides coherent strategic guidance. At some point in the future, it would be appropriate to use this framework to assess progress and to identify critical gaps in knowledge.

Another challenge to overcome relates to the polarisation of the debate and arguments about how and why anthropogenic sound may affect marine mammals. The level of polarisation has come about partly because of differing points of view about the level of precaution that needs to be adopted in the face of high scientific uncertainty. As a result of this polarisation, there has been considerable controversy surrounding some of the research. For the research to be effective it must not only be based upon sound scientific principles but it must also be seen as widely credible and unaffected by conflicts of interest. This impartiality can only be achieved using a transparent funding structure, independent from both sides of a polarised conservation debate. Therefore, it is critical that as much as possible of this research be funded in a way that insulates the scientists from conflicts of interest, perceived or otherwise. If possible, an independent body should have responsibility for the dispersal of funds and monitoring and delivery of outputs of research on the effects of anthropogenic sound on marine mammals. Such a body would clearly have to satisfy stakeholders and funders that (i) a transparent process of peer review is used to select the best science performers and approaches; (ii) their funding would be properly audited; (iii) their funding would be distributed to an area of science defined by the interests of the funder; (iv) there would be appropriate oversight of project management and (v) this process would deliver value for money.

Key recommendations

1. Establishing/implementing the proposed scientific research strategy. This would also allow the further elaboration of two of the key recommendations made by the 2004 Marine Board and NSF workshop participants, namely (i) establish some mechanism to allow better co-ordination of research between the US and Europe, ultimately leading to jointly funded research programmes between the two; and (ii) establish database(s) to enhance the sharing of data: US and European data must be made compatible.

2. A key message of this report is that a risk assessment framework needs to be used to define where the research effort can be applied with greatest effect. At some point in the future, it may be appropriate to use this framework to assess progress and to identify continuing critical gaps in knowledge

3. There is a need to achieve a rapid improvement in the state of knowledge by undertaking new research that is focussed on specific questions of high priority. This requires concerted, coordinated action across many expert groups within the scientific community.

4. Focussed experiments should be conducted within a broader strategic framework so that, when combined together, their results are more likely to address larger and more complex questions with particular relevance to policy.

5. Controlled exposure experiments are recommended as a high research priority. The analyses suggest that characterising the dose-response relationship is an important pre-cursor to assessing the impacts on either individuals or populations. It further shows that opportunistic experiments are unlikely to be valuable unless there is an appropriate measure of the received sound at the level of the individual marine mammal.

6. The responsibility for the apportionment of funds and monitoring and delivery of outputs of research on the effects of anthropogenic sound on marine mammals should be within the remit of an independent body (*e.g.* NSF and/or ESF) that would be responsible to stakeholders and funders for (i) a transparent process of peer review to select the best science performers and approaches within the context of this strategy; (ii) auditing the use of funds provided by stakeholders; (iii) distributing funding to an area of science defined by the interests of the funder but within the context of this strategy; (iv) applying appropriate oversight of project management and (v) ensuring this process would deliver value for money.

References

Cox, T.M., Ragen, T.J., Read, A.J., Vos, E., Baird, R.W., Balcomb, K., Barlow, J., Caldwell, J., Cranford, T., Crum, L., D'Amico, A., D'Spain, G., Fernández, A., Finneran, J., Gentry, R., Gerth, W., Gulland, F., Hildebrand, J., Houser, D., Hullar, T., Jepson, P.D., Ketten, D., MacLeod, C.D., Miller, P., Moore, S., Mountain, D., Palka, D., Ponganis, P., Rommel, S., Rowles, T., Taylor, B., Tyack, P., Wartzok, D., Gisiner, R., Mead, J. and Benner, L. 2006. Understanding the Impacts of Anthropogenic Sound on Beaked Whales. *Journal of Cetacean Research and Managemen*, 7(3):177-187.

National Research Council (NRC). 1994a. *Low-Frequency Sound and Marine Mammals*. National Academy Press: Washington, D.C. 75 pp.

National Research Council (NRC). 1994b. *Science and Judgment in Risk Assessment.* Committee on Risk Assessment of Hazardous Air Pollutants. NATIONAL ACADEMY PRESS, Washington, D.C. 652 pp.

National Research Council (NRC). 2000. *Marine Mammals and Low-Frequency Sound*. National Academy Press: Washington, D.C. 146 pp.

National Research Council (NRC). 2003. *Ocean Noise and Marine Mammals*. National Academy Press: Washington, D.C. 192 pp.

National Research Council (NRC). 2005. *Marine Mammal Populations and Ocean Noise: Determining When Noise Causes Biologically Significant Effects*. National Academy Press: Washington, D.C. 96 pp.

Reid, J.B., Evans, P.G.H. and Northridge, S.P. 2003. Atlas of Cetacean distribution in north-west European waters. Joint Nature Conservation Committee, Peterborough.

Southall, B.L. 2005. National Marine Fisheries Service (NMFS). *Report of the "Shipping Noise and Marine Mammals: A Forum for Science, Management, and Technology" Symposium*. 18-19 May 2004, Arlington, VA.

Vos, E., and Reeves, R.R. 2006. *Report of an International Workshop: Policy on Sound and Marine Mammals, 28–30 September 2004, London, England.* Marine Mammal Commission, Bethesda, Maryland. 129 pp.

Annex I

Additional sources of previous research recommendations on sound and marine mammals

Evans, P.G.H. and Miller, L.A. (eds.). 2004. *Proceedings of the Workshop on Active Sonar and Cetaceans*. Las Palmas, Gran Canaria, 8th March 2003, European Cetacean Society Newsletter, No. 42. Special Issue. 79 pp.

International Whaling Commission Scientific Committee (IWC/SC). 2004. *Annex K: Report of the Standing Working Group on Environmental Concerns*. Annual IWC meeting, Sorrento, Italy, 29 June – 10 July 2004. 56 pp.

Jasny, M. and Reynolds, J. 2005. *Sounding the Depths II: The Rise Toll of Sonar, Shipping and Industrial Ocean Noise on Marine Life*. Natural Resources Defense Council: Los Angeles. 76 pp. [Available online at: www.nrdc.org/wildlife/marine/sound/contents.asp.]

Simmonds, M., Dolman, S. and Weilgart, L. (eds.). 2003. *Oceans of Noise: A WDCS Science Report*. Whale and Dolphin Conservation Society: Chippenham, U.K. 165 pp. [Available online at: http://www.wdcs.org/dan/publishing.nsf/allweb/64543E9BBF9860D780256D2D00331176.]

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene, C.R., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J. Thomas, J.A. and Tyack., P.L. 2007. Marine mammal noise exposure criteria: single exposures and single individuals.*Aquatic Mammals*, 33, 411-508.

U.S. Navy Office of Naval Research (U.S. Navy). Website accessed June 2006. Marine Life Sciences: Current Research Topics. http://www.onr.navy.mil/sci%5Ftech/34/341/research%5Ftopics.asp

U.S. Navy Office of Naval Research (U.S. Navy). Website accessed June 2006. Workshop on the Effects of Anthropogenic Noise in the Marine Environment, 10-12 February 1998. http://www.onr.navy.mil/sci%5Ftech/34/341/docs/proceed.pdf

Annex II

A. List of attendees at the Marine Board–ESF and NSF workshop marine mammals and acoustic geo-surveying techniques - September 27th 2004, IEE, London

Arne Bjørge	Institute of Marine Research	Norway
Olaf Boebel	Ifred Wegener Institute for Polar and Marine Research	Germany
Ian Boyd	University of St Andrews - Sea Mammal Research Unit	UK
John Breslin	Marine Institute	Ireland
Elke Burkhardt	Ifred Wegener Institute for Polar and Marine Research	Germany
Claire Burt	Naval Systems	UK
Michael Carron	NATO Undersea Research Center	Italy
Roger Gentry	NOAA	US
Mick Geoghegan	Geological Survey of Ireland	Ireland
Jonathan Gordon	University of St Andrews - Sea Mammal Research Unit	UK
Trevor Guymer	Secretary, IACMST - Southampton Oceanography Centre	UK
Mardi Hastings	ONR	US
John Hildebrand	Scripps Institution of Oceanography	US
Simon Ingram	UCC	Ireland
Paul D. Jepson	Zoological Society of London	UK
Ron Kastelein	SEAMARCO	The Netherlands
Darlene Ketten	WHOI	US
Paul Lepper	Loughborough University	UK
Klaus Lucke	University of Kiel	Germany
Mick Mackey	UCC	Ireland
AgnesMcLaverty	Shell Oil Ireland	Ireland
Lee A. Miller	University of Odense	Denmark
Ole Misund	IMR/EMB	Norway
Paul Nachtigall	Univ. of Hawaii	US
Gianni Pavan	University of Pavia	Italy
Mike Purdy	LDEO/Columbia University	US
Mike Reeve	National Science Foundation	US
Mike Purdy	LDEO/Columbia University	US
W. John Richardson	LGL Ltd	Canada
Howard Roe	Southampton Oceanography Centre/EMB	UK
Roland Rogers	QinetiQ	UK
Maya Tolstoy	Lamont	US
Peter Tyack	Woods Hole Oceanographic	US
Douglas Wartzok	Florida International University	US
Geraint West	Southampton Oceanography Centre	UK
Peter Worcester	Scripps Institution of Oceanography	US

Marine Board Secretariat

Niamh Connolly	ESF Marine Board – Head of Unit	France
Nicolas Walter	ESF Marine Board – Science Officer	France

B. List of Attendees at Expert Group Meeting – Tubney House, Oxford, from 5-9 October 2005

Ian Boyd	Sea Mammal Research Unit, University of St Andrews	UK
Bob Brownell	National Marine Fisheries Service, Pacific Grove	USA
Doug Cato	Defence Science and Technology Organisation	Australia
Chris Clarke	Cornell University, New York	USA
Dan Costa	University of California, Santa Cruz	USA
Peter Evans	Seawatch Foundation, Oxford	UK
Jason Gedanke	Australian Antarctic Division, Hobart	Australia
Roger Gentry	Washington DC	USA
Bob Gisiner	Office of Naval Research, Washington DC	USA
Jonathan Gordon	Sea Mammal Research Unit, University of St Andrews	UK
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Luke Rendell	Sea Mammal Research Unit, University of St Andrews	UK
Mark Tasker	Joint Nature Conservation Committee, Aberdeen	UK
Peter Tyack	Woods Hole Institution of Oceanography, Woods Hole	USA
Erin Vos	Marine Mammal Commission, Washington DC	USA
Hal Whitehead	Dalhousie University, Halifax	Canada
Doug Wartzok	Florida International University	USA
Walter Zimmer	NATO Undersea Research Centre	Italy

Annex III

Research approaches

This annex expands the research questions listed in Tables 4, 5 and 6 of the main document by listing under each question the approaches that can be adopted. In addition, it makes an assessment of the relative utility of each approach using the following criteria:

Financial cost

Total cost of the project, not including aspects such as essential help in kind (e.g. use of naval sonar source)
- Low: < $US 50,000
- Medium: $US 50-500,000
- High: > $US 500000

Note that it is difficult to assess the total cost of research projects that included considerable "in kind" support. For example, since naval sonars are not readily available for hire they are likely to be provided by the navy and not by the researcher. In other cases it will be necessary to include the cost of the source as part of the research program.

Cost to animal

- Low: No impact whatsoever
- Medium: No lethality, behavioural, minor invasive procedures
- High: Potential lethality, major invasive, effects on vital rates, behavioural effects over large area or time scales

Note that the benefit to the population of marine mammals as a whole that would derive from successful completion of the work, followed by action to reduce any overall risk, was not evaluated. The cost to an individual was also not weighed against the benefit to the population. In addition, the cost associated with delaying action because of the time taken to implement and carry out research was included: Low <1 year; High >5 years.

Effectiveness

Assessed based upon:
(i) Likely change in scientific understanding
(ii) Consequences to risk management
(iii) Statistical power
(iv) Significance to other elements of the programme
(v) Enables other elements of the programme

Feasibility

Assessed based upon:
(i) Availability of qualified personnel
(ii) Availability of appropriate research tools
(iii) Dependency on other projects
(iv) Permits and authorisation
(v) Likelihood of success

Table 1. Research questions and approaches addressing the higher-level question “how can we reduce the risk of sonars to beaked whales?” Under each category, an approach has been scored as “high” (three dots), “medium” (two dots) and “low” (one dot). “dep” signifies that the score depends of the species or circumstances.

		Biological significance	Financial cost	Cost to animal	Effectiveness
Hazard identification	**What is the range of frequencies, intensities and duration of exposure (that causes risk)?**				
	i Investigation of naval sonar usage patterns	●	●●●	●●●	●●●
	ii Responses of an instrumented animal in context of sonar and alternate stimuli	●●	●●	●	●
	iii Empirical measurements of sound field and modelling	●	●●	●●●	●●
	What is the effect of propagation conditions?				
	i Survey of historical data sets in presence/absence of naval exercises	●	●●●	●●●	●
	ii Modelling and measurement of sound fields under varying propagation conditions (surface duct, reverberation, other)	●	●●	●●●	●●●
	iii Responses of an instrumented animal in context of sonar in alternate propagation conditions	●●	●	●	●
	Are there unique habitat characteristics that create a hazard?				
	i Survey of historical data sets with varying coastal characteristics and ship tracks	●	●●●	●●●	●
	ii Responses of an instrumented animal to varying coastal characteristics and ship tracks	●	●	●	●
	iii Modelling and measurement of sound fields in varying coastal characteristics and ship tracks	●	●●	●●●	●●●
	Have stranding rates changed?				
	i Epidemiological analysis of historical data on strandings and sonar usage	●●	●●●	●●●	●●●
	Where are the sound sources?				
	i Ask the navies	●	●●●	●●●	●●
	ii Ocean observing systems	●	●	●●●	●
Characterizing exposure	**Where are the beaked whales?**				
	i Surveys (acoustic or visual) throughout year and all oceans	●●●	●	●●●	●●
	ii Recording diving behaviour (instrumented animals, remote observation incl. acoustics)	●●	●●	●●	●●●
	iii Recording movement data (long-term telemetry, photo id, focal follow)	●●	●●	●●	●●
	iv Habitat utilisation models (based on data from surveys; telemetry; past catch data)	●●●	●●●	●●●	●●●
	v Stranding data	●●	●●●	●●●	●●
	What is the overlap of beaked whale distribution with sound sources?				
	i Combine output above two approaches using geospatial and temporal model	●●●	●●●	●●●	●●●
	How do behavioural changes modulate exposure?				
	i Instrumented animals	●●●	●●	●●	●●●
	ii Acoustic tracking in three dimensions	●●	●●	●●	●●●
	iii Behavioural models	●	●●●	●●●	●
	iv Measure behavioural states and relate to observed response to exposure	●●	●●	●●	●●
	v Visual behavioural observation	●	●●	●●	●●
	What are the received sound characteristics at the whale?				
	i Instrumented animal	●●●	●●	●●	●●
	ii Hydrophone(s)	●	●●●	●●●	●●●
	iii Model	●	●●●	●●●	●●●
Characterizing dose-response relationship	**How close are beaked whales to their physiological limits while diving?**				
	i Dive behaviour in detail using instrumented animals	●●	●●	●●	●●●
	ii Baseline physiological measurements coupled with physiological models	●●●	●●	●●	●●
	iii Experiments with captive and surrogate animals	●●●	●●	●●	●
	iv Necropsy/Pathology of stranded animals	dep	●●	●●	●
	What is the pathological/physiological response?				
	i Necropsy/Pathology/Biopsy of stranded/newly dead/injured/live animals (compare presence/absence of sonar)	dep	●●	●●●	●●
	ii In vitro tissue experiments (e.g. nitrogen saturation)	●●	●●	●●●	●●●
	iii Physiological tags (e.g. samples at short intervals)	●●●	●	●●	●●●
	iv Measure nitrogen saturation	●●●	●●	●●	●●●
	Is the response a direct physical effect?				
	i Determine mechanisms of micro-bubble formation and stabilisation	●●	●●	●●●	●●
	ii Determine threshold of direct acoustic trauma	●	●●	●●●	●●●
	iii Model threshold of direct acoustic trauma	●	●●	●●●	●
	iv Measure and model tissue and airspace resonance	●	●●	●●●	●●
	v Experiments and modelling with surrogate species	●●	●●	●	●
	What is the behavioural response?				
	i Measure changes in behaviour in presence/absence of sonar with tags, visual observation acoustic means	●●●	●●	●●	●●●
	ii AUVs	●	●	●●	●
	iii Experiments and modelling with surrogate species	●	●	●	dep
	How are behavioural and physiological responses related?				
	i Combine/integrate above approaches	●●●	●●	●●●	●●●
	ii Modelling	●	●●●	●●●	●●●
	Is there habitat displacement and over what temporal and spatial scales?				
	i Photo ID	●●	●●	●●	●●
	ii Satellite tags	●●	●	●	●●
	iii Survey and monitoring (visual and acoustic)	●●	●●	●●●	●●●
	iv Genetics	●	●●	●●	●
	v Voices of animals (dialects)	●	●●	●●●	●
	vi Dietary assessment/ parasite fauna	●	●●	●●	●
	What proportion of the exposed animals is affected?				
	i Abundance surveys and monitoring	●	●●	●●●	●
	ii Modelling	●	●●●	●●●	●
	iii Long-term photo-id and/or genetics across study period	●●	●●	●●	●●
	Does sensitivity vary between individuals?				
	i Measure responses of known individuals	●●	●●	●●	●●●
	ii Compare stranded “population structure” with at sea “population structure” including mass versus single strandings	●●	●●●	●●●	●●
	How are populations and their vital rates affected?				
	i Long-term studies of identified individuals (multiple techniques)	●●●	●●	●●	●●●
	ii Studies of population and social structure with and without/before and after exposure	●●	●●	●●	●●●
Risk character-ization	**What is the probability of impacts on individuals**				
	i Models that integrate exposure and response of individuals	●●●	●●●	●●●	●●●
	What is the probability of adverse population impacts?				
	i Define extent of population	●●●	●●	●●	●●●
	ii Extrapolate individual models to populations	●	●●●	●●●	●●
	iii Models that integrate exposure and changes of population parameters	●●●	●●●	●●●	●●●
Risk management	**What is the effect of changing the acoustic source, operational characteristics and location of the source?**				
	i Re-engineer sound source based on understanding of causes (physical and biological) of adverse effect and whale biology and test results of these changes	●●	●	●	●●●
	ii Modelling informed by the above	●	●●●	●●●	●●
	iii Experimental variation in source acoustics/operation/location, monitor response	●●	●●	●	●●●
	iv Monitoring effects of (non-experimental) variation in sources/operation/location	●	●	●●	●●●
	How can beaked whales be detected within the operational zone in real time?				
	i AUVs	●	●●●	●●	●
	ii Test effectiveness of active acoustic	●	●	●●	●
	iii Test effectiveness of passive acoustic	●●	●●	●●●	●●●
	iv Test effectiveness of visual observations	●	●●●	●●●	●●
	v Test effectiveness of radar	●	●●	●●●	●
	vi Test effectiveness of lidar	●	●	●●	●
	vii Test effectiveness of infra-red	●	●	●●●	●
	viii Test effectiveness of aerial / satellite imagery	●	●	●●●	●
	How can overlap between beaked whales and sonar be reduced				
	i Develop methods to find cold and hot spots (time and space)	●●●	●●	●●●	●●●
	ii Develop simulators and modify live training in order to improve effectiveness of sonar operators (in order to reduce live use of sonar)	●●	●●	●●●	●●

Table 2. Research questions and approaches addressing the higher-level question "what are the effects of seismics on individuals and populations?" Under each category, an approach has been scored as "high" (three dots), "medium" (two dots) and "low" (one dot). "dep" signifies that the score depends of the species or circumstances.

		Biological significance	Financial cost	Cost to animal	Effectiveness
Hazard identification	**What is the range of frequencies, intensities and duration of exposure (that causes risk)?**				
	i Responses of an instrumented animal in the context of seismic airguns	●●	●●	●●●	●●
	ii Observational (visual and acoustic) studies of animals exposed to seismic airguns and under control conditions	●●	●●	●	●
	iii Empirical measurements of sound field and modelling		●●	●	●●
	What is the effect of propagation conditions?				
	i Modelling and measurement of sound fields under varying propagation conditions (surface duct, reverberation, other)		●●	●	●●
	ii Responses of an instrumented animal in context of air guns in alternate propagation conditions	●●	●	●●	●●●
	iii Observational (visual and acoustic) studies of animals exposed to seismic airguns in varying propagation conditions	●●	●●	●	●
	Have stranding rates changed?				
	i Epidemiological analysis of historical data on seismic survey activity	●●	●●	●	●●
	Has seismic activity affected the distribution and abundance of any marine mammal?				
	i Analysis of historical distribution data and seismic activity	●	●●	●	●
	Does seismic survey activity affect prey availability for marine mammals?				
	i Analysis of fishery survey and catch rates with respect to seismic activity	●	●●	●	●●
	ii Direct experimental studies of the effects of seismic airguns on prey	●●	●●	●	●●
	iii Dietary assessments of marine mammals pre- and post-exposure	●●	●●	●●	●●
	iv Foraging assessments (e.g. feeding rates) of marine mammals pre- and post-exposure				●●
	Where are the sources?				
	i Query existing databases and solicit data from companies and regulators		●	●	●●●
	ii Ocean observing systems		●●●	●	●●
Characterizing exposure	**Where are the marine mammals?**				
	i Surveys (acoustic or visual) throughout year and all oceans including pinniped haulouts	●●	●●●	●	●●●
	ii Target effort at existing and prospective seismic survey sites	●●●	●●●	●	●●●
	iii Recording diving behaviour (instrumented animals, remote observation incl. acoustics)	●●●	●●	●●	●●●
	iv Recording movement data (long-term telemetry, photo id, focal follow)	●●●	●●	●●●	●●
	v Habitat utilisation models (based on data from surveys; telemetry; past catch data)	●●	●●	●	●●
	vi Stranding and haulout data	●	●	●	●●
	What is the overlap of marine mammal distribution with sound sources?				
	i Combine output above two approaches using geospatial and temporal model	●●●	●	●	●●●
	How do behavioural changes modulate exposure?				
	i Instrumented animals	●●	●●	●●	●●
	ii Acoustic tracking in three dimensions	●●	●●	●	●●
	iii Visual behavioural observation	●●	●	●	●●
	What are the received sound characteristics?				
	i Instrumented animal	●●●	●●	●●	●●
	ii Hydrophone(s)		●●	●	●●●
	iii Modelling received sound characteristics		●	●	●●●
Characterizing dose-response relationship	**Are there physiological responses?**				
	i Molecular and physiological indices of stress in exposed and unexposed animals	●●●	●●	●●	●●●
	ii Physiological tags (e.g. samples at short intervals)	●●●	●●	●●●	●●
	iii Sampling stranded or by-caught animals for evidence of chronic stress in areas of seismic activity and non-activity	●	●●	●	●●
	Do airguns have a direct physical effect?				
	i Determine threshold of direct acoustic trauma	●●	●●	●	●●●
	ii Model threshold of direct acoustic trauma	●	●	●	●●
	iii Experiments and modelling with surrogate species	●	●●	●	●●
	iv Experiments to determine onset of TTS (and PTS?) from varying number of airgun pulses at varying levels	●●●	●●●	●●	●●●
	v Compare hearing function (using ABR) in individuals that have probably had a high vs lo exposure to seismic	●	●●	●●	●●●
	What is the behavioural response?				
	i Measure changes in behaviour in presence/absence of seismics with tags, visual observation acoustic means	●●●	●●●	●●	●●●
	ii Experiments and observations with model species selected as vulnerable and use of surrogate species where endangered species are concerned	●	●●●	●●	●●●
	Is there habitat displacement and over what temporal and spatial scales?				
	i Photo ID	●●	●●	●●	dep
	ii Satellite tags	●●	●●	●●●	●●●
	iii Survey and monitoring (visual and acoustic)	●●	●●	●	●●
	iv Genetics	●	●	●●	dep
	v Voices of animals (dialects)	●	dep	●	●
	vi Dietary assessment/ parasite fauna	●	●●	dep	●
	How do we assess the significance of observed habitat shifts?				
	i Compare reproductive behaviour in both habitats (those animals remaining and those shifting and /or pre- and post-shift)	●●	●●●	dep	●●●
	ii Compare foraging rates in both habitats (those animals remaining and those shifting and/or pre- and post-shift)	●	●●●	●	●●●
	iii Compare survival and reproductive rates in both habitats (those animals remaining and those shifting and/or pre- and post-shift)	●●	●●	●●	●●●
	Does sensitivity vary between individuals?				
	i Measure responses of known individuals	●●●	●●	●●	●●●
	ii Compare pre- and post-exposure age/sex distributions	●●	●●●	●●●	●●
	How are populations and their vital rates affected?				
	i Long-term studies of identified individuals (multiple techniques)	●●●	●●	●●	●●●
	ii Studies of population and social structure with and without/before and after exposure	●●●	●●	●●	●●
Risk character-ization	**What is the probability of impacts on individuals**				
	i Models that integrate exposure and response of individuals	●●●	●	●	●●
	ii Models that integrate exposure and response of prey species	●●	●	●	●●
	What is the probability of adverse population impacts?				
	i Define extent of population	●●●	●●	●●	●●●
	ii Extrapolate individual models to populations	●●	●	●	●●
	iii Models that integrate exposure and changes of population parameters	●●	●	●	●●
Risk management	**What is the effect of changing the acoustic source, operational characteristics and location of the source?**				
	i Re-engineer sound source based on understanding of causes (physical and biological) of adverse effect and whale biology and test results of these changes	●●●	●●●	●●	●
	ii Modelling informed by the above	●●	●	●	●●●
	iii Experimental variation in source acoustics/operation/location, monitor response	●●●	●●●	●●●	●●●
	iv Monitoring effects of (non-experimental) variation in sources/operation/location	●	●●	●●	●●
	Is ramp-up an effective mitigation measure?				
	i Monitoring (viaual or acoustic) of ranges of marine mammals with varing number of guns operating	●	●●	●●	●
	ii Experimental or observational acoustic studies of instrumented animals during ramp-up period	●●	●●	●●	●●●
	iii Monitoring behaviour of animals (viaual and acoustic) tracked during ramp-up	●●	●●	●●	●●
	How can marine mammals be detected within the operational zone in real time?				
	i Test effectiveness of active acoustic	dep	●●●	●●	●●●
	ii Test effectiveness of passive acoustic	dep	●●	●	●●
	iii Test effectiveness of visual detection	●●	●●	●	●●
	iv Test effectiveness of Radar	●	●●	●	●●
	v Test effectiveness of lidar	●	●●●	●●	●
	vi Test effectiveness of infra-red	●	●●●	●	●●
	vii Test effectiveness of aerial / satellite imagery	●	●●	●	●
	How to reduce risk of overlap between marine mammals and seismic surveys				
	i Within current prospective survey area, find season with lowest abundance and/or vulnerability	●●●	●●	●	●●●
	ii To avoid unnecessary exposure, encourage/legislate sharing of seismic data		●	●	●●●
	How to design MPAs to minimize risk to animals in areas where seismic exploration is likely?				
	i Survey	●	●●	●	●●●
	ii Movement patterns	●●	●●	●●	●●
	iii Studies of response/vulnerability as listed above		●	●	●●●
	iv Habitat characterization modelling	●●	●●	●	●●●
	What acoustic buffer zones are required to reduce risk to animals within marine protected areas consistent with goals of the protection?				
	i Measure and model propagation from MPS boundary		●●	●	●●●
	ii Monitor sound field within and along boundary of MPA during seismic activity		●●	●	●●●

Table 3. Research questions and approaches addressing the higher-level question "what is the interaction of shipping traffic noise with baleen whales?" Under each category, an approach has been scored as "high" (three dots), "medium" (two dots) and "low" (one dot). "dep" signifies that the score depends of the species or circumstances.

		Biological significance	Financial cost	Cost to animal	Effectiveness	Feasibility
Hazard identification	**What is the range of frequencies, intensities and duration of exposure (that causes risk)?**					
	i Compare spectral overlap of baleen whale calls with distribution of third octave levels (TOLs) of shipping noise	●●	●	●	●●●	●●●
	ii Compare spectral overlap of other ecologically important sounds with distribution of third octave levels (TOLs) of shipping noise	●●	●	●	●●●	●●●
	iii Measure TOLs of ambient and identified noise in important habitats near shipping channels, etc.	●	●	●	●●●	●●●
	iv Empirical measurements of sound filed and modelling	●	●	●	●●●	●●●
	How has vessel noise and traffic noise changed as a component of ambient sound across space and time?					
	i Long-term monitoring (e.g. ocean observing systems)	●	●	●	●●●	●●●
	ii Analysis of historical data on source characteristics, shipping trends and ambient noise levels	●	●	●	●●	●●
	What is the effect of propagation conditions?					
	i Map distribution of animals as a function of noise to test whether noise field affects distribution	●●●	●	●	●●	●
	ii Modelling and measurement of sound fields under varying propagation conditions					
	Are there unique habitat characteristics that create a hazard?					
	i Survey of historical data sets with varying coastal characteristics and ship tracks and marine mammal distributions (e.g. migration choke points that are also critical for shipping)	●●	●	●	●●●	●
	ii Modelling and measurement of sound fields in varying coastal characteristics, ship tracks and marine mammal distributions	N/A	●●	●	●●●	●●●
	Does vessel traffic noise affect risk of collision?					
	i Epidemiological analysis of historical data on collision/other threats and vessel/traffic noise	●	●	●	●	●
	ii Experimental studies by changing vessel noise and monitoring reactions	●●	●●	●●	●●●	●●●
	iii Modelling sound fields	●	●	●	●●	●
Characterizing exposure	**Where are the sources?**					
	i Shipping company databases, vessel monitoring systems and logs	●	●	●	●●●	●●●
	ii Ocean observing systems	N/A	●●●	●	●●●	●●●
	Where are the baleen whales?					
	i Surveys (acoustic or visual) throughout year and all oceans	●●●	●●●	●	●●●	●●●
	ii Recording diving behaviour (instrumented animals, remote observation incl. Acoustics)	●●●	●●	●●	●●●	●●●
	iii Recording movement data (long-term telemetry, photo id, focal follow)	●●●	●●	●●●	●●●	●●●
	iv Habitat utilisation models (based on data from surveys; telemetry; catch data)	●●	●	●	●●●	●●●
	v Stranding data	●	●	●	●	●●●
	What is the overlap of marine mammal distribution with sound sources?					
	i Combine output above two approaches using geospatial and temporal model	●●	●●	●	●●●	●●●
	How do behavioural changes modulate exposure?					
	i Instrumented animals	●●●	●●	●●	●●●	●●●
	ii Acoustic tracking in three dimensions	●●	●●	●	●●●	●●●
	iii Behavioural models	●	●	●	●	●●●
	iv Typify behavioural states and relate to exposure	●	●●	●●	●●	●●
	v Visualt behavioural observation	●●	●●	●●	●●	●
	What are the received sound characteristics?					
	i Instrumented animal	●●●	●●	●●	●●●	●●●
	ii Long- and short-term acoustic monitoring	●●	●●	●	●●●	●●●
	iii Model received sound characteristics	●●	●	●	●●●	●●
Characterizing dose-response relationship	**Do baleen whales respond to compensate for increased vessel noise?**					
	i Acoustic behaviour in detail with measurements of noise level at animal and source level of calls (instrumented animals)	●●●	●●	●●	●●●	●●●
	ii Baseline observations of calling behaviour from hydrophones	●●	●●	●	●●●	●●●
	iii Measure behaviour (e.g. spacing) of animals in high and low noise environments	●●	●●	●	●●	●●●
	What are the functions of sound produced by baleen whales?					
	i Passive acoustic measurement of calling behaviour in signaller and responder	●●●	●●	●	●●●	●●
	ii Acoustic measurement of caller, measure responses on instrumented animal	●●●	●●	●●	●●	●●
	iii Experimental playbacks of baleen whale calls, measure response	●●●	●●	●●	●●●	●●●
	Do whales utilize sounds from other sources (e.g. predator calls, ambient noise) and over what ranges are these effective?					
	i Playback of sounds of predators and prey, monitor response	●●●	●●	●●	●●●	●●
	Do whales use multi-path and echoes of their own calls?					
	i Statistical analysis of tracks relative to bathymetry	●●	●●	●	●●	●●●
	ii Modelling reverberation and multi-path	●	●	●	●●	●●
	iii Animals instrumented to detect echoes and possible responses	●●●	●●●	●●	●●	●
	iv Use of echo repeaters					
	Is masking occurring from point sources or traffic/ambient noise?					
	i Measure audiogram of baleen whales	●●	●●	●●	●●●	●
	ii Measure responses of whales to calibrated playbacks that usually stimulate a response in varying noise backgrounds	●●	●●	●●	●●●	●●
	iii Modelling masking in baleen whales	●	●	●	●●	●●●
	iv Experiments and modelling with surrogate species	●	●●	●●	●●	●●
	v Compare behaviours in noisy versus quieter environments	●	●●	●	●●	●●●
	vi Model difference in masking in areas with different levels of "natural" ambient and traffic noise	●	●	●	●●	●●●
	What is the behavioural response to a communication signal in varying noise?					
	i Measure changes in behaviour to playback in presence/absence of vessel, using tags, acoustic and visual observation	●●	●●●	●●	●●●	●●
	Can chronic vessel noise cause threshold shifts?					
	i Compare the auditory brain stem response (ABR) of whales from noisy and quiet environments	●	●●●	●●●	●	●
	ii Experiments and modelling with surrogate species	●	●●	●●	●●	●●●
	iii Modelling exposure in baleen whales over time	●	●	●	●●	●●
	iv Develop threshold shift.ABR tags	●●	●●	●●	●●	●
	v Anatomical studies from noisy and quiet environments	●●	●●	●	●	●●●
	Are there indicators of stress related to noise exposure?					
	i Measure molecular and physiological indices of stress in noisy and quieter environments	●●●	●●	●●	●●●	●
	ii Measure hormone levels concurrent with behavioural observations	●●●	●●	●●	●●●	●
	iii Use anatomical indices of stress in noisy and quieter environments	●●●	●	●	●●●	●●
	Is there habitat displacement and over what temporal and spatial scales?					
	i Measure movements using photo ID coupled with sound field measurements	●●	●●	●●	●●	●●●
	ii Measure movement using satellite tags coupled with sound field measurements	●●	●●	●●●	●●●	●●●
	iii Survey and monitoring (visual and acoustic) coupled with sound field measurements	●●●	●●	●	●●	●●●
	iv Measure the voices of animals (dialects) coupled with sound field measurements	●	●●	●	●●	●
	Does sensitivity vary between individuals?					
	i Measure vocalization behaviour and measure masking of communication signals in known individuals	●	●●	●●	●●●	●
	ii Measure masking of other ecologically-important signals in known individuals	●	●●	●●	●●	●
	iii Compare population distributions of hearing sensitivity and critical ratios to predict probability of masking across populations	●●	●●●	●●	●	●●
	How are populations and their vital rates affected?					
	i Long-term studies of identified individuals (multiple techniques) in different noise conditions	●●●	●●●	●●	●●	●
	ii Studies of population and social structures	●●●	●●	●●	●●	●●●
	iii Compare populations in quiet and noisy areas	●	●●●	●●	●●	●
	How is masking related to changes in individual life functions?					
	i Studies of energetics in quiet and noisy areas	●	●●	●●	●●	●
	ii Compare changes/variation in survival (predation)	●	●●	●●	●●	●
	iii Compare changes/variation in reproduction	●	●●	●●	●●	●
Risk character-ization	**What is the probability of impacts on individuals?**					
	i Models that integrate the exposure and response of individuals	●●●	●	●	●●●	●●●
	What is the probability of adverse population impacts?					
	i Models that integrate exposure and response of individuals	●●●	●●	●●	●●●	●●
	ii Extrapolate individual models to populations	●●	●	●	●●	●
	iii Models that integrate exposure and changes of population parameters	●●	●	●	●●	●
Risk management	**What is the effect of changing the acoustic source, operational characteristics and location of the source?**					
	i Re-engineer vessel propulsion to reduce sound levels in frequency range of whale calls	●●	●●●	●	●●●	●●●
	ii Modelling informed by the above	●	●	●	●●	●●●
	iii Experimental variation in source acoustics/operation/location and monitor response	●	●●	●●	●●	●
	iv Monitoring effects of uncontrolled variation in sources/operation/location	●	●●	●	●●●	●●
	How can baleen whales be detected in real time in order to reduce vessel collisions?					
	i Active acoustic detection	●●●	●●●	●●	●●	●
	ii Passive acoustic	●●●	●●	●	●●	dep
	iii Visual	●●	●●	●	●	●●
	iii Radar	●●	●●	●	●	●●
	iv Infra-red	●	●●	●	●●	●●
	How can the overlap between baleen whales and vessel noise be reduced?					
	i Develop new routing methods informed by the geospatial temporal models	●●●	●●	●	●●●	●●●

Annex IV

Workshop (2004) Presentations

Expert Group Workshop held by the Marine Board–ESF and NSF on marine mammals and acoustic geo-surveying techniques – September 27th 2004, IEE, London

EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

MARINE BOARD

NSF

Marine Board-ESF and NSF Workshop
Marine Mammals and Acoustic Geo-Surveying Techniques

Sept 27th 2004, IEE, London

This Annex gathers abstracts and presentations given during a joint Marine Board-ESF/NSF workshop held in London on September 27, 2004. This event gathered 34 international experts, of which 10 came from the United States.

The workshop was jointly chaired by Howard Roe (Director, Southampton Oceanographic Centre, representing the Marine Board - ESF) and Mike Purdy (Director, Lamont Doherty Earth Observatory, Columbia University, representing NSF); it was co-ordinated by the Marine Board-ESF secretariat.

Objectives and Outcome

The workshop addressed the impacts of acoustic surveying techniques on marine mammals, including legal and practical implications for survey work. It was agreed that a smaller joint Marine Board- NSF working group would be convened, to ultimately produce this position paper, based in part on the workshop proceedings.

The group agreed on the following recommendations:

1. establish some mechanism to allow better co-ordination of research between the US and Europe, ultimately leading to jointly funded research programmes between the two;

2. establish database to enhance the sharing of data; US and European data must be made compatible;

Agenda

09:00 Coffee

09:15 Welcome by Marine Board (N. Connolly)
Introduction to workshop's Co-Chairs - M. Purdy (LDEO/Columbia University) - H. Roe (Southampton Oceanography Centre)

09:30 <u>Topic 1</u> : Marine geo-surveying techniques

Presentation *(M. Geoghegan, Geological Survey of Ireland – J. Breslin, Marine Institute)* – 20 min.
An overview of the surveying techniques employed during the Irish National Seabed Survey & mitigation measures adopted during recent Irish Surveys onboard the RV Celtic Explorer to avoid disturbance to cetaceans
Discussion - 30 min.

10:15 <u>Topic 2:</u> Recent results relating acoustics to marine mammal strandings and how these are being interpreted by government and other officials in respective countries

Presentation: *(P. Tyack)* – 20 min
Facts related to acoustics and strandings.
Discussion - *lead: Richardson*

11:00 Coffee Break

11:20 <u>Topic 3:</u> What is known about beaked whales and "the bends"? Is there a scientifically viable "bends" scenario that could explain some stranding events?

Presentation *(P. Jepson, Zoological Society of London)* – 20 min.
Bubble lesions
Discussion - *lead: Natchigall plus P. Jepson*.

12:05 <u>Topic 4:</u> What is the impact of regulations on the use of active acoustics for ocean research? What is the impact on research on marine mammals?

Presentation *(C. Burt, Naval Systems UK; R.Rogers QinetiQ)* – 20 min.
The Royal Navy Environmental Research Programme
Discussion - *lead: Hastings plus C. Burt*.

<u>12:50 Lunch Break</u>

13:50 Topic 5: Mitigation strategies - best practices. From a scientific perspective, what works and what doesn't. Status of new technologies such as passive/active detection

Presentation *(G. West, Southampton Oceanography Centre)* – 20 min.
Can we adopt coherent/uniform mitigation strategies across NSF/ESF
Discussion - *lead: Gentry plus G. West*

14:35 Topic 6: Scientific techniques and results for assessing acoustical Impacts on marine mammals. How does the science community rate the impact of acoustics on marine mammals in comparison to other potential threats to marine mammal populations?

Presentation *(J. Gordon, University of St Andrews)* – 20 min.
Scientific techniques and results for assessing acoustical mpacts on marine mammals; marine mammal acoustic research and expertise at SMRU
Discussion - *lead: Tolstoy plus J. Gordon*.

15:20 Coffee Break

15:40 General discussion - What can we do together? (lead: M. Purdy and H. Roe)

Topics to include: Possibilities for joint research projects, sharing of new and existing marine mammal data bases; new technologies, cooperation on response to strandings including measurement protocols.

17:30 End of the Workshop

Topic 1 : Marine geo-surveying techniques

Mitigation measures adopted during Celtic Explorer geophysical surveys to minimise disturbance to Cetaceans

John Breslin (Marine Institute, Ireland) and Mick Geoghegan (Geological Survey of Ireland)

The Marine Institute and GSI observe the Joint Nature Conservation Committee (JNCC) regulations as a precautionary measure to avoid disturbance to marine mammals.

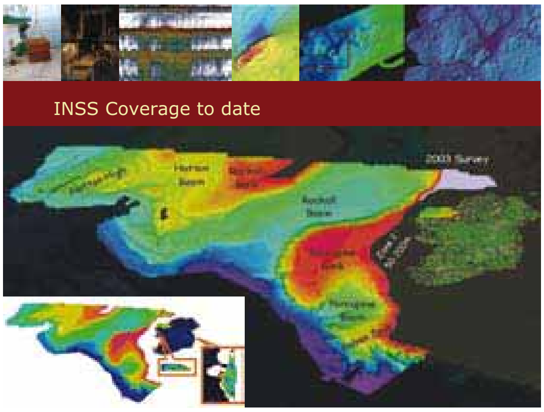
All cetacean species in Irish waters are protected by the 1976 Wildlife Act (and Wildlife Amendment Act 2000). Irish waters, including the EEZ were declared a whale and dolphin sanctuary in 1991. All cetacean species are also protected under the EU Habitats Directive 92/43/EEC Article 12 and the harbour porpoise and bottlenose dolphin are listed under Annexe II of the Habitats Directive, requiring the designation of special areas of conservation (SACs) for their protection.

Currently the waters covered by the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) do not extend to Irish waters and Ireland is not a signatory. However it is expected that offshore operators carrying out seismic surveys have due regard for the aforementioned guidelines.

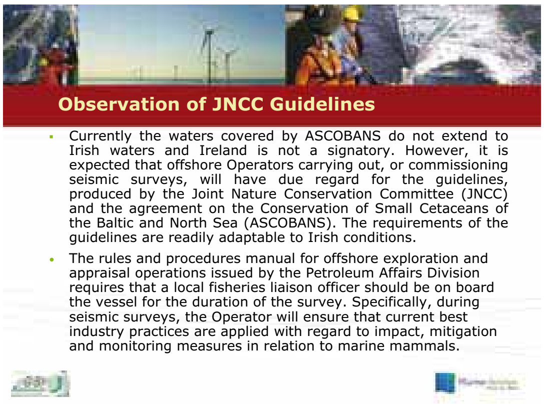
During the Irish National Seabed Survey (INSS) and seismic surveys the Irish Whale and Dolphin Group are invited by the Marine Institute to place an observer on board the Celtic Explorer. Observers are required to oversee the implementation of JNCC guidelines along with providing a report detailing sightings, methods of detection, problems encountered, and recommendations for improving future mitigation strategies. At the survey planning stage, consultation with mammal experts is undertaken and literature searches are carried out to determine the likelihood that mammals will be encountered.

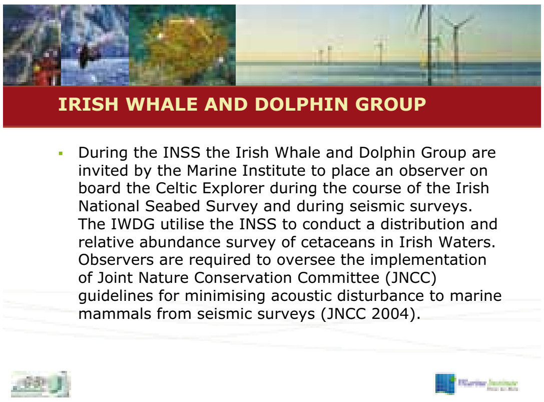
During the INSS surveys a 'soft start' procedure has been established to allow mammals to move away from the area. Prior to beginning operations within an SAC the Marine Institute were notified that it would be prudent to avoid surveying within the area due to presence of calving dolphins within the SAC at the time of the survey. The survey vessel maintained an exclusion zone of 1km from the Western boundary of the SAC throughout the survey. If a pod of cetaceans came within 500m of the vessel, all systems were switched off until they departed. The utilisation of PAM devices for the 2005 survey may be investigated.


Marine Board & NSF Workshop
September 27th, 2004. IEE London
Mitigation measures adopted during Celtic Explorer geophysical surveys to minimise disturbance Cetaceans
John Breslin
Manager Research Vessel Operations
Marine Institute, Ireland
www.marine.ie

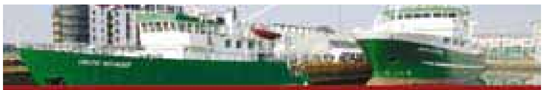

INSS Coverage to date
2003 Survey


Observation of JNCC Guidelines
The Marine Insitute and GSI observe the the JNCC regulations as a precautionary measure to avoid disturbance to marine mammals.
All cetacean species in Irish waters are protected by the 1976 Wildlife Act (and Wildlife Amendment Act 2000) and Irish waters, including the EEZ were declared a whale and dolphin sanctuary in 1991.
All cetacean species are protected under the EU Habitats Directive 92/43/EEC Article 12 and the harbour porpoise and bottlenose dolphin are listed under Annexe II of the Habitats Directive, requiring the designation of special areas of conservation (SACs) for their protection.


Observation of JNCC Guidelines
Currently the waters covered by ASCOBANS do not extend to Irish waters and Ireland is not a signatory. However, it is expected that offshore Operators carrying out, or commissioning seismic surveys, will have due regard for the guidelines, produced by the Joint Nature Conservation Committee (JNCC) and the agreement on the Conservation of Small Cetaceans of the Baltic and North Sea (ASCOBANS). The requirements of the guidelines are readily adaptable to Irish conditions.
The rules and procedures manual for offshore exploration and appraisal operations issued by the Petroleum Affairs Division requires that a local fisheries liaison officer should be on board the vessel for the duration of the survey. Specifically, during seismic surveys, the Operator will ensure that current best industry practices are applied with regard to impact, mitigation and monitoring measures in relation to marine mammals.


IRISH WHALE AND DOLPHIN GROUP
During the INSS the Irish Whale and Dolphin Group are invited by the Marine Institute to place an observer on board the Celtic Explorer during the course of the Irish National Seabed Survey and during seismic surveys. The IWDG utilise the INSS to conduct a distribution and relative abundance survey of cetaceans in Irish Waters. Observers are required to oversee the implementation of Joint Nature Conservation Committee (JNCC) guidelines for minimising acoustic disturbance to marine mammals from seismic surveys (JNCC 2004).


Mitigation Measures to avoid disturbance
Planning Stage
Consultation with mammal experts and literature searches to determine the likelihood that mammals will be encountered
Planning – Ensure work carried out outside calfing and breeding seasons when animals are likely to concentrate in discrete locations
Ensure that appropriately qualified personnel are available to act as mammal observers onboard the vessel.
Use the lowest practicable power levels throughout the surveys
Marine Institute



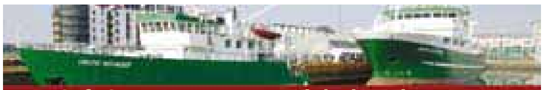
Mitigation Measures Cont.

During Surveys

- Follow the correct 'soft start' procedure to allow mammals to move away from the area should they wish to.
- No unnecessary shooting of guns and no protracted shooting of guns which is not part of a survey line.

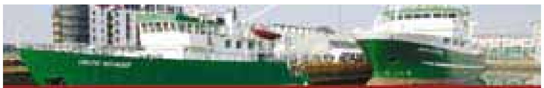
Reporting

- Marine mammal observers to provide a detailed report to the Marine Institute and GSI detailing sightings, methods of detection, problems encountered, and recommendations for improving future mitigation strategies



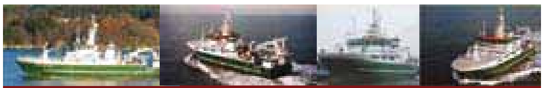
Soft Start Measures used during air gun (60cu inch) work for Site Survey

- 50min before commencement of the survey line and 20min before starting the air guns a 30min survey for mammals was conducted from the observation platform.
- Provided no mammals were present within 500m of the vessel in those 30min, the soft start process was initiated 20minutes prior to commencement of the survey line.
- Once all clear given. Pop gun at 1000psi at 1min intervals for 10min.



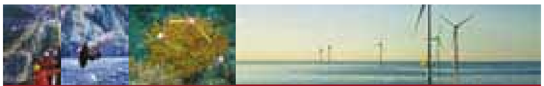
Soft Start Measures - air gun (60cu inch) work Cont.

- Increase pressure to full (2000psi) and pop at 1min interval for 5min.
- Keep pressure on full and pop at 30sec intervals for 5min.
- If no mammals observed – commence survey.
- Transects were only 100m apart so gun firing was maintained at full pressure during turns.



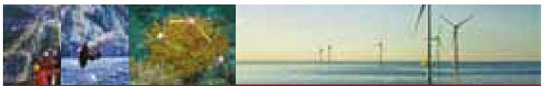
RV *Celtic Explorer* – Summary of acoustic systems

- Multibeam echo sounder Kongsberg Simrad EM1002 (95kHz)
- Kongsberg Simrad EA600 Hydrographic Echosounder capable of operating in passive or active mode (12kHz, 18kHz, 38kHz, 120kHz, 200kHz)
- SES Sub-bottom profiler (4kHz)



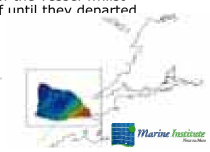
Soft Start Mitigation Strategy used during INSS

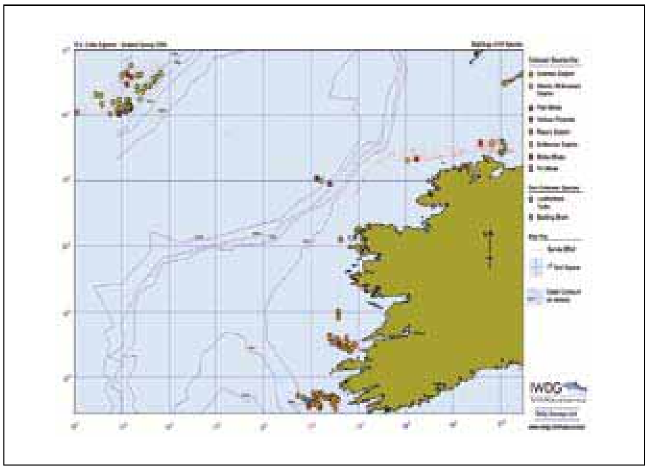
- 20min before soft start begins. Mammal Observer must scan to give all clear.
- Once all clear given. All acoustic systems are started at low power at 1min intervals for 10min.
- If no mammals are observed the power on all systems is set to full power at 1 minute intervals for 10 min.
- If no mammals observed – commence survey.
- During turns the survey operations continued with all systems operational and on full power

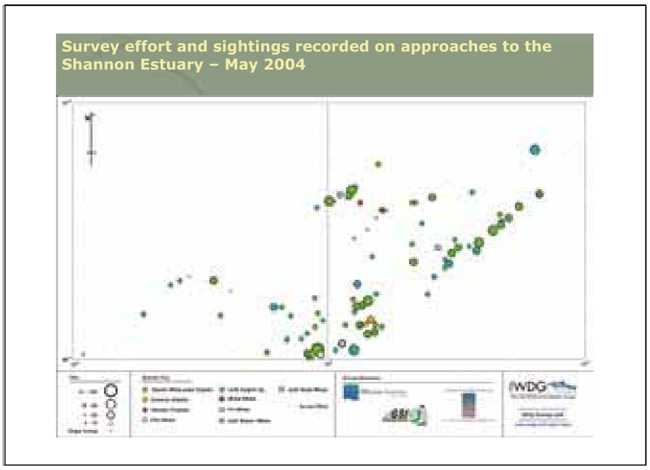


SAC –Mitigation Strategy

- Prior to beginning operations within an SAC the Marine Institute were notified that it would be prudent to avoid surveying within the area due to presence of calving dolphins within the SAC at the time of the survey.
- The survey vessel maintained an exclusion zone of 1km from the Western boundary of the SAC through the survey.
- If a pod of cetaceans came within 500m of the vessel whilst operational, all systems were switched off until they departed
- Soft start guidelines were adhered to on start up.
- The utilisation of PAM devices For the 2005 survey may be investigated

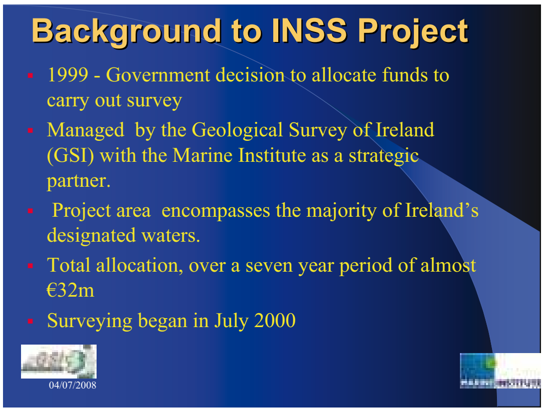


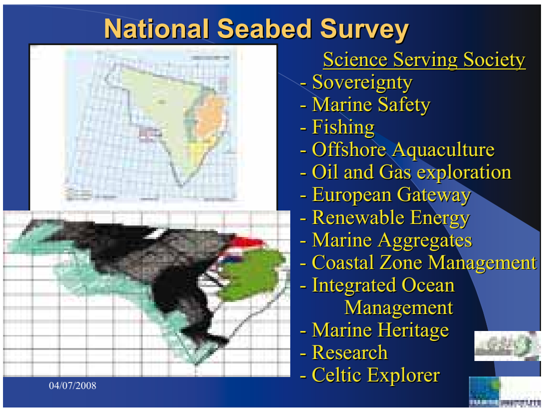


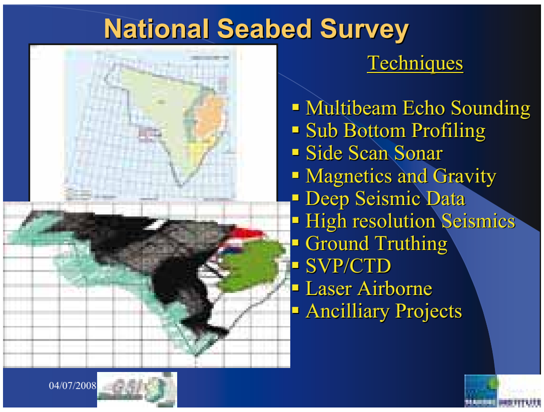

Survey effort and sightings recorded on approaches to the Shannon Estuary – May 2004


Thank You & Questions


Irish National Seabed Survey
Marine Board ESF and NSF
Marine Mammals & Acoustic
Surveying Workshop
London September 27th
Michael Geoghegan, GSI & John
Breslin, MI
04/07/2008

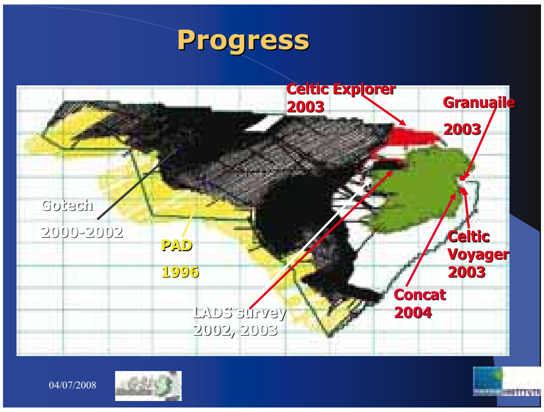

Background to INSS Project
1999 - Government decision to allocate funds to carry out survey
Managed by the Geological Survey of Ireland (GSI) with the Marine Institute as a strategic partner.
Project area encompasses the majority of Ireland's designated waters.
Total allocation, over a seven year period of almost €32m
Surveying began in July 2000
04/07/2008

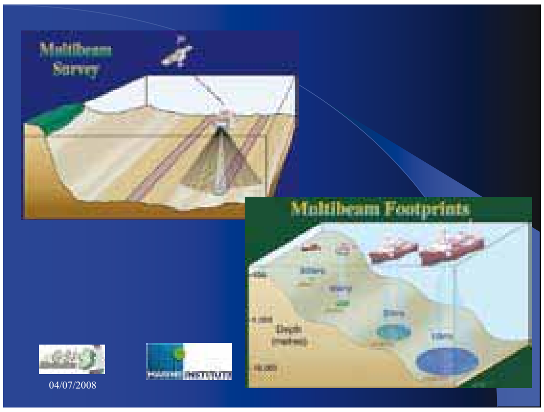

National Seabed Survey
Science Serving Society
- Sovereignty
- Marine Safety
- Fishing
- Offshore Aquaculture
- Oil and Gas exploration
- European Gateway
- Renewable Energy
- Marine Aggregates
- Coastal Zone Management
- Integrated Ocean Management
- Marine Heritage
- Research
- Celtic Explorer
04/07/2008


National Seabed Survey
Techniques
Multibeam Echo Sounding
Sub Bottom Profiling
Side Scan Sonar
Magnetics and Gravity
Deep Seismic Data
High resolution Seismics
Ground Truthing
SVP/CTD
Laser Airborne
Ancilliary Projects
04/07/2008

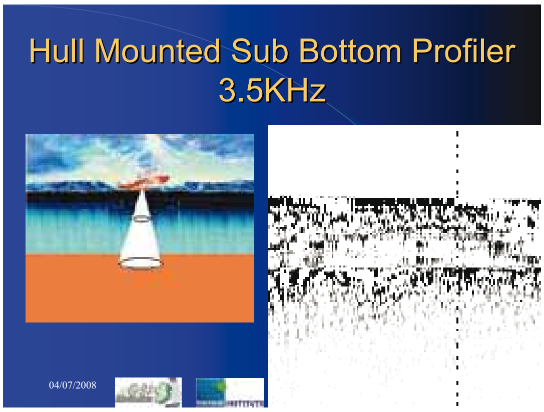

Vessels
RV Celtic Voyager
SV BLIGH
SV Siren
Professor Logachev
Ocean Seeker
Akademic Boris Petrov
Granuaile
04/07/2008

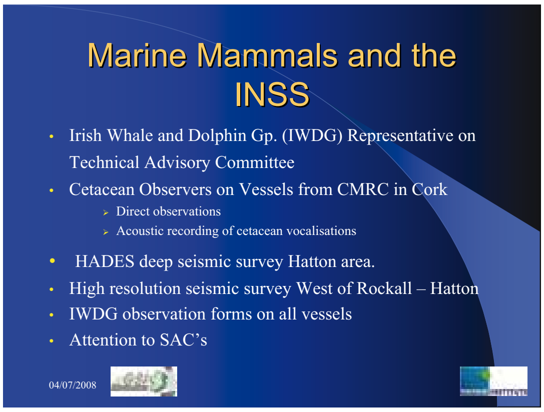

Celtic Explorer
04/07/2008

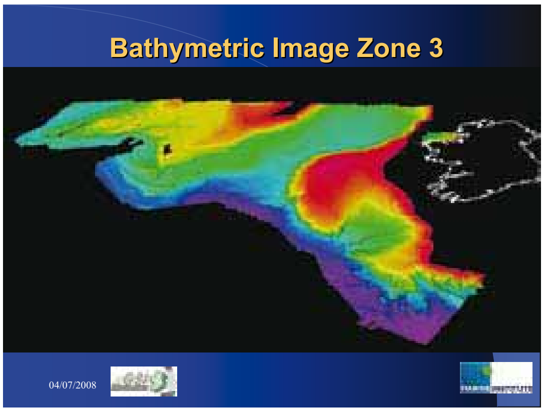

Progress
Celtic Explorer
2003
Granuaile
2003
Gotech
2000-2002
PAD
1996
Celtic
Voyager
2003
Concat
2004
LADS survey
2002, 2003
04/07/2008

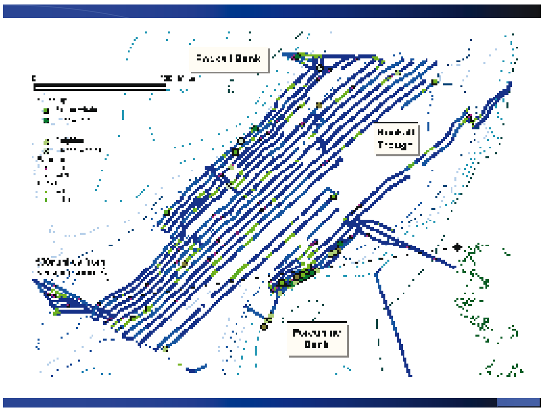

Multibeam
Survey
Multibeam Footprints
04/07/2008

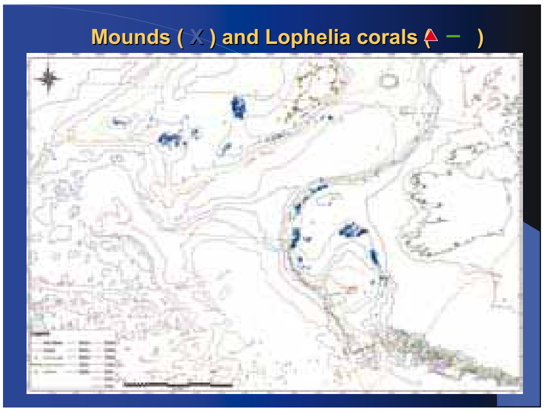

GOTECH
EM 120 SV Bligh
04/07/2008

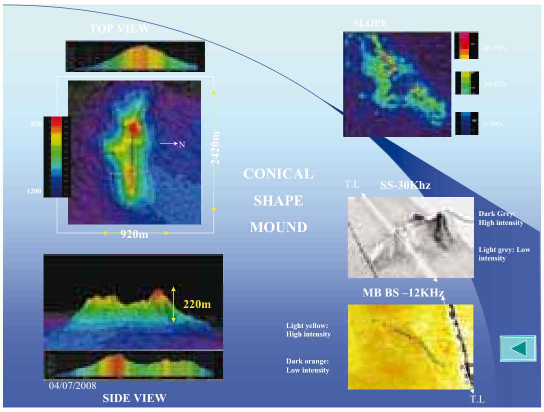

Hull Mounted Sub Bottom Profiler
3.5KHz
04/07/2008


Marine Mammals and the
INSS
Irish Whale and Dolphin Gp. (IWDG) Representative on
Technical Advisory Committee
Cetacean Observers on Vessels from CMRC in Cork
Direct observations
Acoustic recording of cetacean vocalisations
HADES deep seismic survey Hatton area.
High resolution seismic survey West of Rockall – Hatton
IWDG observation forms on all vessels
Attention to SAC's
04/07/2008


Bathymetric Image Zone 3
04/07/2008




Mounds (X) and Lophelia corals (—)


TOP VIEW
SLOPE
2420m
920m
CONICAL
SHAPE
MOUND
T.L
SS-30Khz
Dark Grey: High intensity
Light grey: Low intensity
MB BS –12KHz
Light yellow: High intensity
Dark orange: Low intensity
220m
04/07/2008
SIDE VIEW
T.L


Ground Truthing Logachev 2003

Seismic work – Observers Role

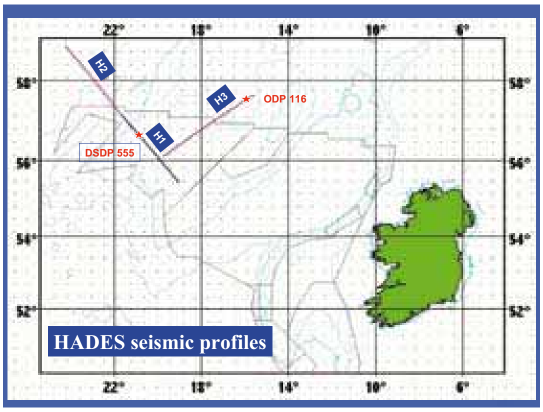
- " To carry out duties of marine mammal observers as outlined in JNCC guidelines on minimising acoustic disturbance to marine mammals during periods of active seismic survey"
- To observe Cetacean and bird activity in areas surveyed

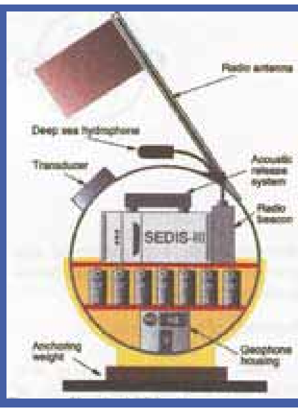
04/07/2008

Actions taken to minimise disturbance

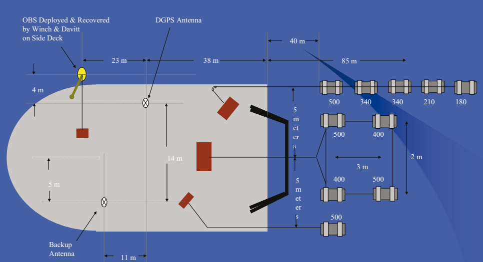
- Tech Advisory Comm laid down broad guidelines
- 1995 UK DoE and JNCC guidelines implemented e.g. 500m range visual obs taken for 30 mins before seismic activity
- Two observers present
- Hydrophone array

04/07/2008





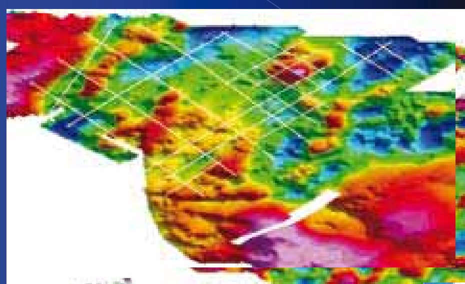
04/07/2008



Source array on RV Akademik Boris Petrov

04/07/2008

High Resolution Seismics 2004



04/07/2008

High resolution seismics parameters

Source	:	Single Sodera 210 cubic inch GI
Source Parameters	:	Fired @ 25m. 5.0m tow depth,
pressured to 2000 psi		
Streamer	:	Teledyne 1200m Active, 96
channels, 12.5m groups		
Recording	:	TAP TL3, 96 channels plus 5 aux.
Record to 4 secs.		
Acquisition format	:	25m CMP interval, quarter fold
data set		

04/07/2008

Operations on the Granuaile

04/07/2008

Pre-soft Start Observations.

The guidelines for minimising acoustic disturbance to marine mammals during seismic surveys, devised by the JNCC, have been adhered to throughout the survey. Specific 360° scans for cetaceans were conducted around the vessel for 30 minutes before all soft-start seismic activities. The only cetaceans recorded during this pre-soft start period involved a group of unidentified dolphins actively swimming 1000m from the ship, which is twice the recommended distance listed in the JNCC guidelines. As such, no downtime due to the presence of whales and dolphins has been incurred during the current survey.

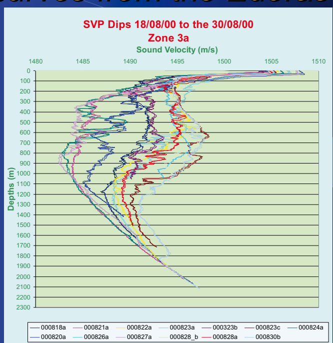
04/07/2008

Cetacean Observation example

Nine cetacean species have been recorded during the first two weeks of the survey. As has been during previous seismic surveys in the Hatton-Rockall region, the Long-finned Pilot Whale is the most numerous and frequently encountered cetacean species. Of the 34 cetacean encounters (n=277 animals) recorded thus far, approximately 40% involved Long-finned Pilot Whales (n=178 animals). The most interesting observations have been recorded southwest of the Hatton Bank and along the eastern slope of the Iceland Basin. Eight of the nine species recorded, were observed in this region in a two-day period. These included rarely encountered species such as Northern Bottlenose Whales, False Killer Whales, Sowerby's Beaked Whales and Killer Whales. The only baleen whale species recorded to date involved the sighting of a single Humpback Whale breaching 3-4km ahead of the ship southwest of the Hatton Bank. Approximately 75% of all sightings were recorded during seismic operations.

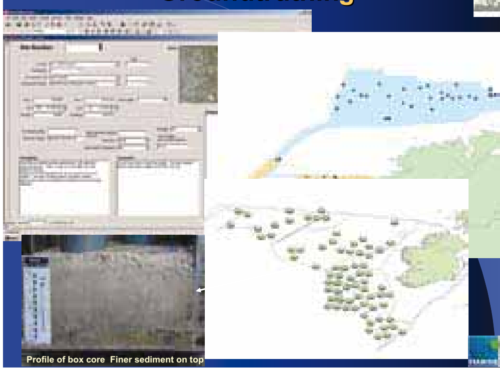
04/07/2008

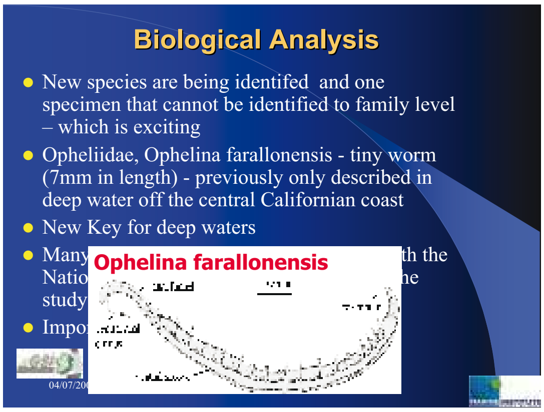
SVP curves from the Edoras Bank

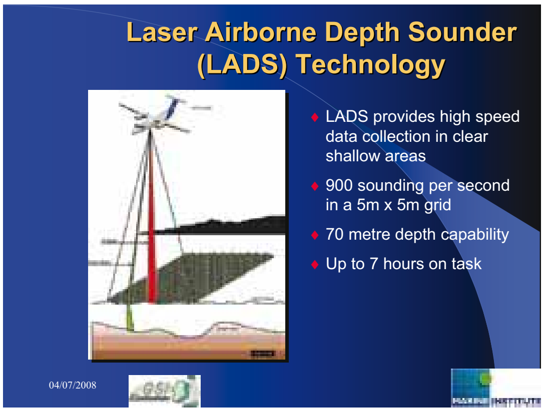


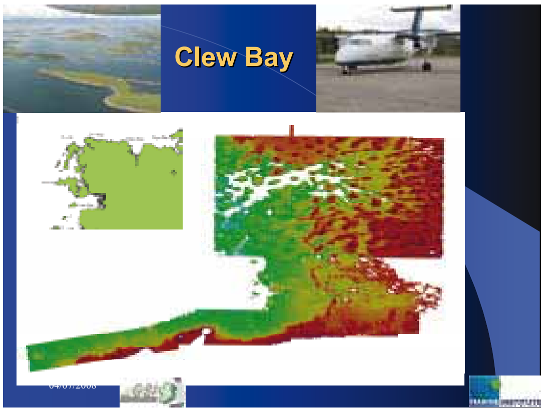
04/07/2008

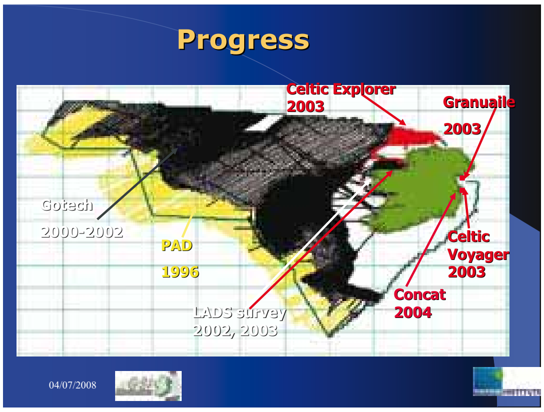
Groundtruthing




Biological Analysis
New species are being identifed and one specimen that cannot be identified to family level – which is exciting
Opheliidae, Ophelina farallonensis - tiny worm (7mm in length) - previously only described in deep water off the central Californian coast
New Key for deep waters
Many
Natio
study
Impo
th the
he
Ophelina farallonensis
04/07/20


Laser Airborne Depth Sounder (LADS) Technology
LADS provides high speed data collection in clear shallow areas
900 sounding per second in a 5m x 5m grid
70 metre depth capability
Up to 7 hours on task
04/07/2008


Clew Bay


Progress
Celtic Explorer 2003
Granuaile 2003
Gotech 2000-2002
PAD 1996
Celtic Voyager 2003
Concat 2004
LADS survey 2002, 2003
04/07/2008

Topic 2: Recent results relating acoustics to marine mammal strandings and how these are being interpreted by government and other officials in respective countries

Recent results relating atypical marine mammal strandings to anthropogenic sound.

Peter L. Tyack (Biology Department, Woods Hole Oceanographic Institution)

Records of strandings of marine mammals go back two millennia, and most strandings are thought to be caused by natural factors such as storms and disease. Mass strandings are usually defined as involving >2 or 3 animals, usually stranding in same place and time. Since 1963 there have been atypical mass strandings of beaked whales, often species not sighted in same group, within a few hours but over tens of km of coast. Atypical mass strandings have been defined by Frantzis (1996) as involving many beaked whales, especially Ziphius cavirostris and Mesoplodon sp. stranding within a few hours in dispersed groupings over tens of km of shore. They have been reported to coincide with naval maneuvers off Greece (1), Canary Islands (7), Italy (2), Bahamas (1), Madeira (1) [List from US Marine Mammal Commission Beaked Whale Workshop Report submitted to Journal of Cetacean Research and Management]. All cases in which the ships are known involve ships with mid-frequency sonars

The actual acoustic fields have only been estimated for two cases: Greece 1996 and Bahamas 2000. The Greek case involved a NATO sonar research exercise. 16 Ziphius strand alive along 30-35 km of coast within hours of sonar transmissions (D'Amico 1998). The Bahamas case involved a multinational anti-submarine training exercise with several ships operating in New Providence channel (US NMFS and Navy 2001). 17 cetaceans stranded within 36 hr over 240 km. 7 died (5 *Ziphius*, 1 *Mesoplodon densirostris*, 1 *Stenella frontalis*). Necropsies have been conducted of stranded whales in 3 cases. Ketten (in Evans & Miller 2004) detailed necropsy results from examination of heads of beaked whales from strandings in Madeira and the Bahamas. She reported hemorrhage in the space between brain and outer membrane, inner ear, and small hemorrhage in acoustic fats. Fernández (in Evans & Miller 2004) necropsied whole bodies of beaked whales stranded in the Canaries and reported severe, diffuse congestion and hemorrhage especially within the ears, brain, lungs, kidneys and the acoustic fat of the jaws. Jepson et al. (2004) report from the same necropsies, vascular and tissue changes consistent with gas bubble lesions and fat emboli in vital organs.

While there is a correlation between these atypical mass strandings of beaked whales and naval exercises, the cause is unknown. The US NMFS and Navy (2001) Interim report on Bahamas strandings states "acoustic or impulse trauma [that] led to their stranding and subsequent death." One hypothesis suggested for injury at relatively low levels concerns the idea that resonant structures in beaked whales might be particularly sensitive to sound at the resonant frequency. A US NMFS (2002) workshop concluded resonance unlikely cause of injury or strandings. Jepson et al. (2004) reported evidence for gas emboli in stranded cetaceans, and they suggest that emboli may be caused by a direct acoustic effect on supersaturated tissue or an abnormal behavioral reaction to sound.

Experimental results from other species suggest different ranges of exposures may relate to each of these hypotheses. For lung resonance, 184 dB re 1 µPa marks the onset of tissue damage in mouse for 5 min at the resonant freq (US NMFS 2002). Larger animals require higher exposures, and the resonant frequency estimated for beaked whales is <30 Hz. Acoustically enhanced bubble growth is a function of supersaturation, duration, and intensity. Crum and Mao expect little risk for exposures <190-200 dB re 1 µPa. By contrast a behavioral reaction could occur at any level that is detectable to the animal. For an example from a different species, right whales rapidly ascend to surface on exposure to similar sounds at RL in the 130-150 dB re 1 µPa (Nowacek et al. 2004)

References

- CRUM, L. A. & MAO, Y. (1996). Acoustically enhanced bubble growth at low frequencies and its implications for human diver and marine mammal safety. *J. Acoust. Soc. Amer.* 99, 2898}2907.
- D'AMICO A (1998) Summary Record, SACLANTCEN Bioacoustics Panel, La Spezia, Italy, 15-17 June 1998 (available at http://www.saclantc.nato.int/whales/ or at http://enterprise.spawar.navy.mil/spawarpublicsite/)
- EVANS P. G. H. & L. A. MILLER (2004) Proceedings Of The Workshop On Active Sonar And Cetaceans. European Cetacean Society Newsletter No. 42 – Special Issue (Feb 2004)
- FRANTZIS, A. (1998). Does acoustic testing strand whales? *Nature* 392, 29.
- NOWACEK, D., JOHNSON, M., AND P. TYACK. (2004) 'North Atlantic right whales (*Eubalaena glacialis*) ignore ships but respond to alarm stimuli', Proc. R. Soc. B., 271:227-231.
- US NMFS (2002) Report of the Workshop on Acoustic Resonance as a Source of Tissue Trauma in Cetaceans. www.nmfs.noaa.gov/pr/readingrm/MMSURTASS/Res_Wkshp_Rpt_Fin.PDF
- US NMFS and Navy (2001) Joint Interim Report Bahamas Marine Mammal Stranding Event of 15-16 March 2000. www.nmfs.noaa.gov/prot_res/overview/Interim_Bahamas_Report.pdf

Recent results relating acoustics to marine mammal strandings and how these are being interpreted by government and other officials in respective countries

Peter L. Tyack
Biology Department
Woods Hole Oceanographic Inst

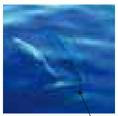
Marine Board

Marine Board-ESF and NSF Workshop
Marine Mammals and Acoustic Geo-Surveying Techniques
Sept 27th 2004, IEE, London

Strandings

- Strandings of marine mammals are normal events. Records of strandings go back two millenia
- Mass strandings involve >2or3 animals, usually stranding in same place and time
- Since 1963 there have been atypical mass strandings of beaked whales, often species not sighted in same group, within a few hours but over tens of km of coast

Atypical mass stranding events



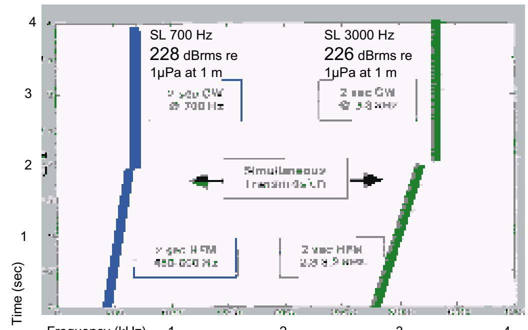
- >10 Beaked whales, especially *Ziphius cavirostris* and *Mesoplodon* sp. strand within a few hours in dispersed groupings over tens of km of shore.
- Reported to coincide with naval maneuvers off Greece (1), Canary Islands (7), Italy (2), Bahamas (1), Madeira (1) [List from MMC Beaked Whale Workshop Report]
- All known cases involve ships with mid-frequency sonars

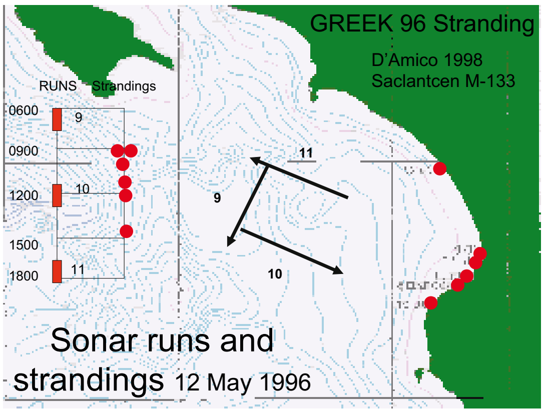
Actual acoustic fields only known for two cases: Greece 1996 and Bahamas 2000

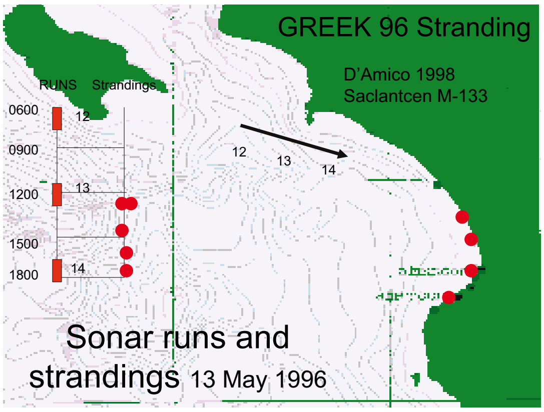
- Greece: NATO sonar exercise. 16 *Ziphius* strand alive along 30-35 km of coast within hours of sonar transmissions
- Bahamas: multinational ASW exercise with several ships operating in New Providence channel. 17 cetaceans stranded within 36 hr over 240 km. 7 died (5 *Ziphius*, 1 *Mesoplodon densirostris*, 1 *Stenella frontalis*).

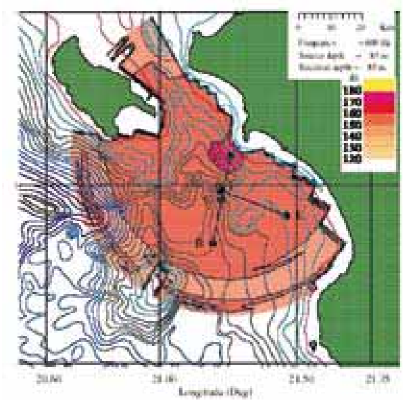
Sonar Signals used in Greece

D'Amico 1998 Saclantcen M-133









Received Levels during 12 May 96 Greek Sonar Test

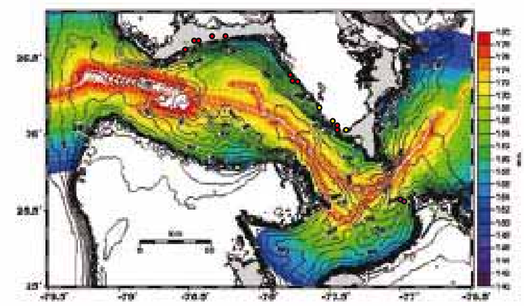
85 m receiver depth

D'Amico 1998
Saclantcen M-133

Bahamas 15 March 2000

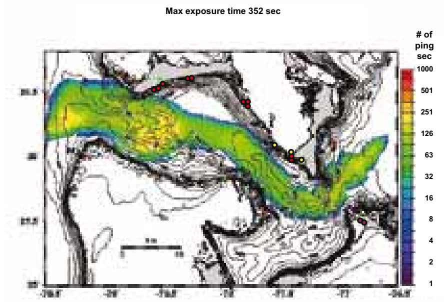
- Naval sonar exercise as ships passed through New Providence Channel near Abaco
- 4 of 5 ships used mid freq sonars
  - AN/SQS-53C 2.6-3.3 kHz ~235 dB re 1 μPa
  - AN/SQS-56 6.8-8.2 kHz ~223 dB re 1 μPa
- 17 cetaceans stranded within 36 hr over 240 km. 7 died (5 *Ziphius*, 1 *Mesoplodon densirostris*, 1 *Stenella frontalis*).

BAHAMAS Peak Sound Pressure Level for all Ships over 21 hr period



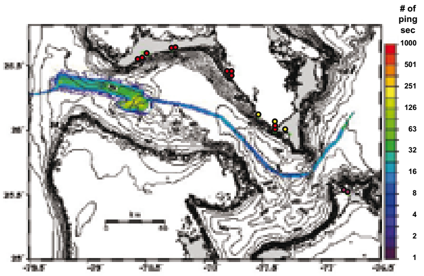
Hildebrand presentation to July MMC

Duration of exposure to received levels from 165-170 dBrms re 1μPa at 15 m depth



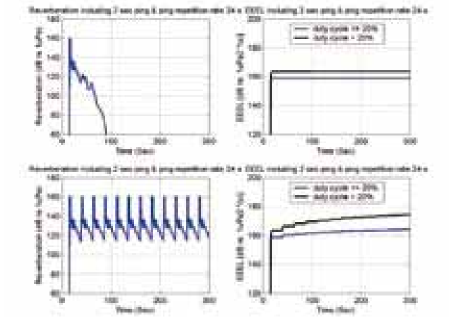
Hildebrand presentation to July MMC

Duration of exposure to received levels from 175-180 dBrms re 1μPa at 15 m depth

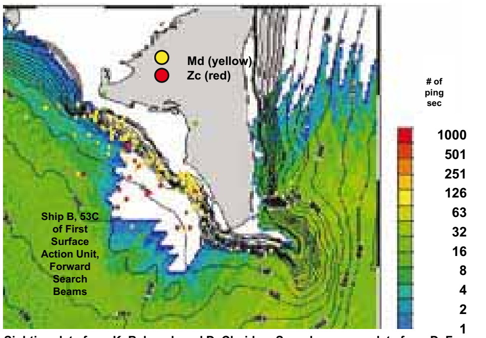


Hildebrand presentation to July MMC

Reverberation with ping, Rep Rate 24 s, Total time 5 min

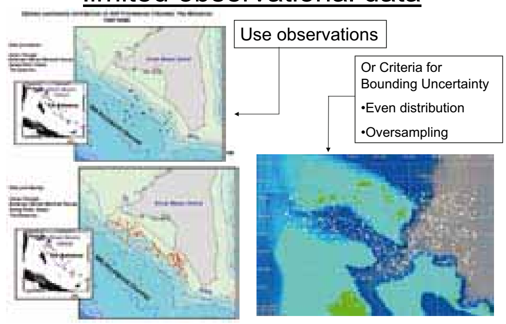


Sighting Data with Exposure to Sound Pressure Levels between 160-163 dB using SPL at 15 m depth



Sighting data from K. Balcomb and D. Claridge. Sound exposure data from D. Fromm

Simulations can compensate for limited observational data



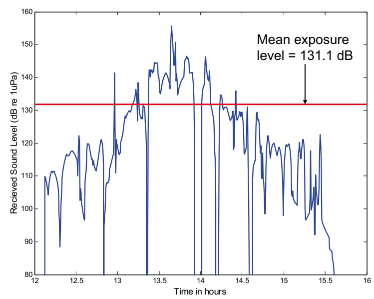
Gisiner presentation to July MMC

Parameters for Simulations

- **Acoustic propagation: *e.g. In situ* surface duct v. downward refracting**
- **Distribution – Uniform v. Field Data**
- **Dive behavior: Normal Diver v. Duct-only diver**
- **Horizontal swim behavior: No aversion to sound level v. Graded aversion to sound level**

Adapted from Gisiner presentation to July MMC

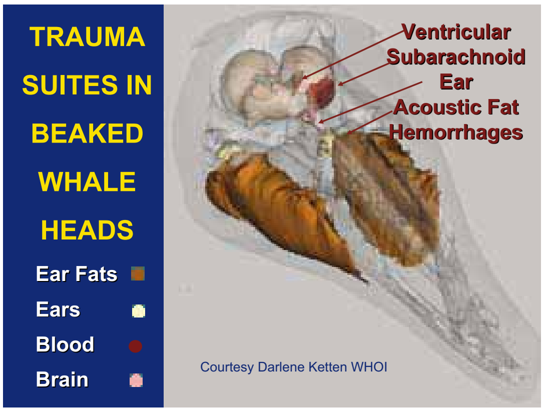
Example Exposure History



Gisiner presentation to July MMC

Necropsies of stranded whales in 3 case

- Bahamas (Ketten: detailed necropsy limited to heads) : hemorrhage in space between brain and outer membrane, inner ear, and small hemorrhage in acoustic fats
- Madeira (Ketten: detailed necropsy limited to heads) : similar to Bahamas
- Canaries (Fernández: whole body): severe, diffuse congestion and hemorrhage especially within the ears, brain, lungs, kidneys and the acoustic fat of the jaws. Vascular and tissue changes consistent with gas bubble lesions and fat emboli in vital organs.



Hypotheses re cause of strandings

- While there is a correlation between strandings and naval exercises, the cause is unknown.
- US NMFS and Navy (2000) Interim report on Bahamas strandings: "acoustic or impulse trauma that led to their stranding and subsequent death"
- Resonance: US NMFS (2002) workshop concluded resonance unlikely cause of injury or strandings
- Jepson et al. (2004) covered in next talk. Gas emboli caused by
  - Acoustic effect on supersaturated tissue
  - Abnormal behavioral reaction to sound

Exposures related to hypotheses

- Lung resonance: 184 dB re 1 μPa onset of tissue damage in mouse for 5 min @ resonant freq (<30 Hz for beaked whale)
- Acoustically enhanced bubble growth: function of supersaturation, duration, and intensity. Little risk <190-200 dB re 1 μPa
- Behavioral reaction could occur at any level that is detectable to the animal (right whales rapidly ascend to surface on exposure to similar sounds at RL in the 130-150 dB re 1 μPa)

NMFS 2002 Acoustic Resonance Rept; Crum&Mao 1996 JASA; Nowacek et al. 2003 Proc Roy Soc B

Other cases of **typical** strandings where association with manmade sound is controversial

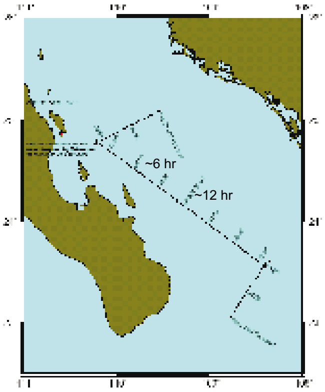
- Beaked whale stranding and seismic signals
  - Gulf of California
  - Galapagos
- Mid-frequency sonar and
  - Harbor porpoise strandings (Pac NW US)
  - Melon-headed whales (swam into bay, Hawaii)

Gulf of California

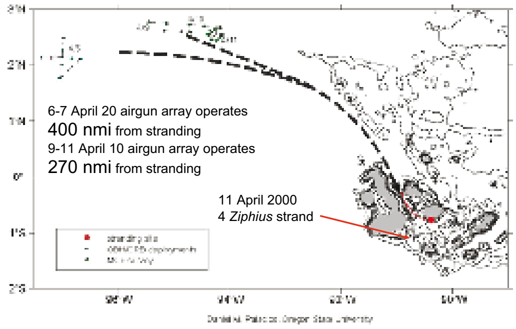
- 2 *Ziphius* found stranded together freshly dead
- RV surveying within tens of km on same day with following sources:
  - Airgun array broadband impulse directed downwards SL 236-262 dBp re 1μPa at 1 m
  - Multi-beam sonar 15.5 kHz omnidirectional SL 237 dBrms re 1μPa at 1 m
  - Sub-bottom profiler 3.5 kHz directed downwards SL 204 dBrms re 1μPa at 1 m

Track of Seismic RV wrt Stranding of 2 *Ziphius*

Range ~75nmi @ stranding and approaching for 1st time



Galapagos stranding during seismic survey



www.nmfs.noaa.gov/prot_res/PR2/Health_and_Stranding_Response_Program/Mass_Galapagos_Islands.htm

Official government interpretations

- US on beaked whales and mid-freq tactical sonar
- NATO (Italian Navy similar)
- US, UK guidelines for seismic
- Technical reports for Royal Dutch Navy

US NMFS and Navy

- Bahamas: "tactical mid-range frequency sonars aboard US Navy ships that were in use during the sonar exercise in question were the most plausible source of this acoustic or impulse trauma." [definition of trauma may be more generalized in final report]

NMFS-Navy Joint Interim Report Dec 2001
http://www.nmfs.noaa.gov/prot_res/overview/Interim_Bahamas_Report.pdf

NATO Research Rules

(Italian Navy working on similar draft rules)

- Select area away from breeding grounds, sanctuary. Advance public comment
- Minimum SL to meet science objectives
- Trained visual observers, passive acoustic monitoring 30 min before to 30 min after ops
- Max RL at animal <160 dB re 1 μPa
- Only start if no animals near exclusion zone
- Ramp up from SL = 150 dB re 1 μPa
- Stop if animals detected that might enter exclusion zone

D'Amico 1998 Saclantcen M-133

US, UK guidelines for commercial seismic operations

- Visually monitor 500m exclusion zone for 30 min
- If no whales, begin rampup for 20-40 min
- Shutdown if whale detected <500m
- As long as transmissions maintain SL >=160 dB can continue operations when monitoring is ineffective (night, fog, high seas)
- UK encourages passive acoustic monitoring and requires in some settings. US allows ramp up during reduced visibility only if passive monitoring is used.

US MMS Notice to Lessees Gulf of Mexico 2004-G01
UK DTI Pos'n paper Sept 2003 (www.og.dti.gov.uk)

Technical Reports to Royal Netherlands Navy

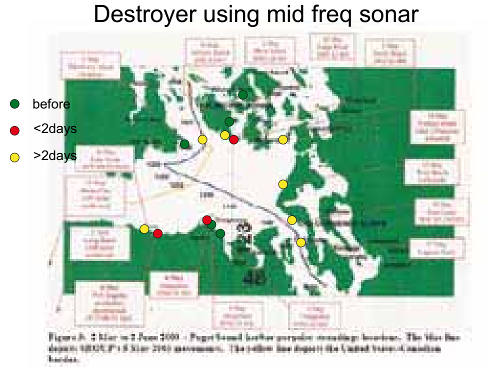
- Based upon hearing sensitivity groups
- Max Exposure Levels TTS-15or20dB
  - Baleen whales and dolphins 160-185 dB
  - Sperm and killer whales 140-160dB
  - Porpoise 135-155 dB
- Monitoring and Mitigation
  - Visual and Passive Acoustic Monitoring (0Hz-200kHz)
  - Active whale detection not advised because of additional potential for impact
  - Exclusion zones (hearing group specific)
  - Ramp up (but notes unproven; may attract odontocetes)

Verboom 2000 TNO-HAG-RPT-000037; Verboom 2001 TNO-HAG-RPT-010058

Melon-headed whales swim into Hawaii Bay during sonar exercise

- \- Sonar exercise 60-80 nm away from Hanalei Bay the afternoon before the event, ending shortly after midnight. 1-2 ships transmitting at a time.
- \- Sonar exercise 26 nm away from the bay on the day animals sighted in bay at 0730. A ship tested sonar at 0645, and the exercise involved intermittent sonar use until 1624. Noise level from sonar would have been below ambient at Hanalei Bay.
- \- At 1624, Navy officials were notified of the whales in the bay and ceased all sonar transmissions. They didn't resume sonar until 6 July. - A single juvenile stranded and died of starvation.

Strandings of Porpoise and Track of USN Destroyer using mid freq sonar



Topic 3: What is known about beaked whales and "the bends"? Is there a scientifically viable "bends" scenario that could explain some stranding events?

Beaked whales and "the bends"

Paul D. Jepson (Zoological Society of London) & Antonio Fernández (Institute of Animal Health, Veterinary School, University of Las Palmas de Gran Canaria)

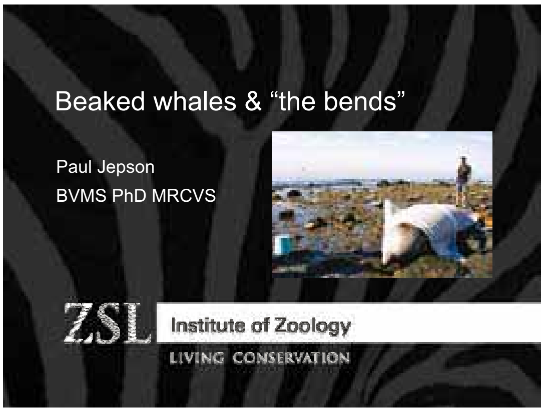
The demonstration of spatio-temporal links between some deployments of active mid-frequency naval sonar and mass cetacean strandings (predominantly involving beaked whales) is now widely accepted to be indicative of cause (sonar) and effect (stranding), although the underlying mechanism(s) have remained a topic of intense scientific debate.

Among potential mechanisms proposed for these stranding events, theoretical mechanisms for *in vivo* bubble formation in marine mammals mediated by exposure to loud anthropogenic sound sources (e.g. naval sonar) have been proposed. More recently, pathological findings consistent with *in vivo* bubble formation and decompression sickness (DCS) has been reported in three beaked whale species (involving 10 necropsied individuals) that mass stranded in the Canary Islands in 2002 contemporaneously with naval sonar use.

Bubble formation associated with acute and chronic tissue injury has been conclusively demonstrated in some individually-stranded cetaceans in the UK, although the definitive cause of these bubbles has not been established. These pathological findings demonstrate that cetaceans can suffer tissue injury associated with gas bubble development, most probably through a mechanism similar to DCS.

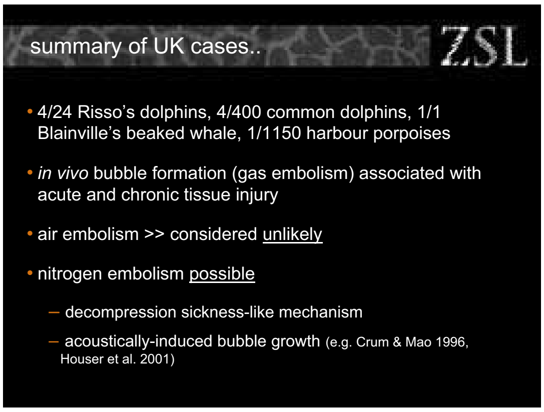
Emerging data from beaked whale dive profiles suggest that these species may be adapted to deep-diving through a combination of slow ascent rates and short surface intervals. There is now a growing scientific consensus that an initial behavioural disruption to normal beaked whale dive profiles (e.g. accelerated ascent combined with extended surface interval) induced by loud acoustic exposure such as naval sonar may precipitate a potentially fatal physiological response resulting in bubble formation in tissues and leading to mass stranding events.

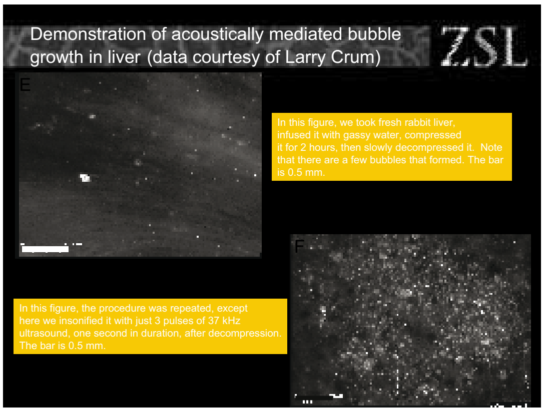
The confirmation of *in vivo* bubble formation in cetaceans as a mechanism in sonar-induced beaked whale mass strandings, including the quantification of received levels of acoustic sonar activity necessary to trigger a specific and adverse behavioural response, undoubtedly necessitates the adoption of an experimental approach.

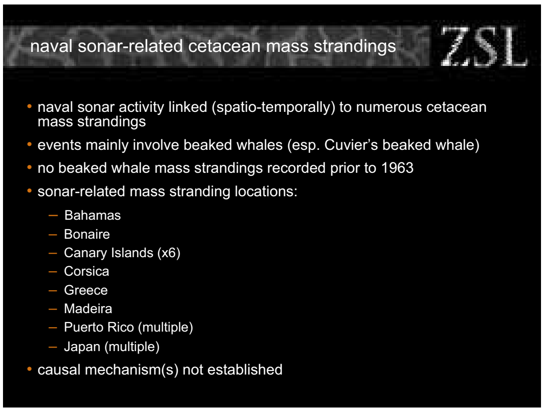

Beaked whales & "the bends"
Paul Jepson
BVMS PhD MRCVS
ZSL
Institute of Zoology
LIVING CONSERVATION

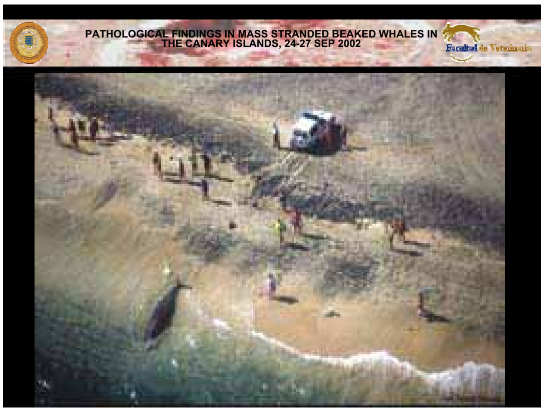

UK-stranded cetaceans:
new disease - unusual hepatic/renal pathology
ZSL


HISTOPATHOLOGY
ZSL
Jepson, P.D. et al. Acute and chronic gas bubble lesions in cetaceans stranded in the United Kingdom. *Veterinary Pathology* (in press)

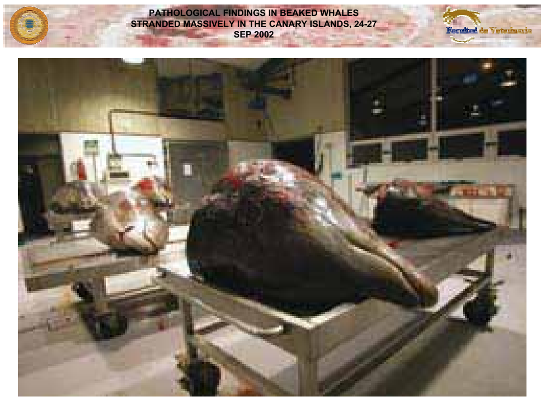

summary of UK cases..
ZSL
• 4/24 Risso's dolphins, 4/400 common dolphins, 1/1 Blainville's beaked whale, 1/1150 harbour porpoises
• *in vivo* bubble formation (gas embolism) associated with acute and chronic tissue injury
• air embolism >> considered unlikely
• nitrogen embolism possible
– decompression sickness-like mechanism
– acoustically-induced bubble growth (e.g. Crum & Mao 1996, Houser et al. 2001)

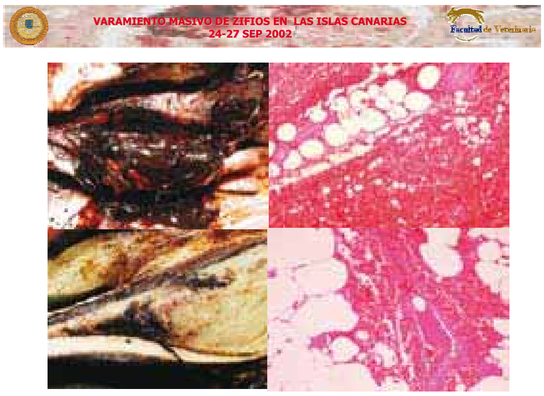

Demonstration of acoustically mediated bubble growth in liver (data courtesy of Larry Crum)
ZSL
E
In this figure, we took fresh rabbit liver, infused it with gassy water, compressed it for 2 hours, then slowly decompressed it. Note that there are a few bubbles that formed. The bar is 0.5 mm.
F
In this figure, the procedure was repeated, except here we insonified it with just 3 pulses of 37 kHz ultrasound, one second in duration, after decompression. The bar is 0.5 mm.

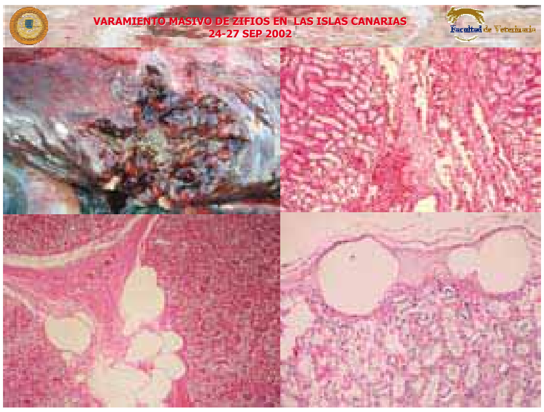

naval sonar-related cetacean mass strandings
ZSL
• naval sonar activity linked (spatio-temporally) to numerous cetacean mass strandings
• events mainly involve beaked whales (esp. Cuvier's beaked whale)
• no beaked whale mass strandings recorded prior to 1963
• sonar-related mass stranding locations:
– Bahamas
– Bonaire
– Canary Islands (x6)
– Corsica
– Greece
– Madeira
– Puerto Rico (multiple)
– Japan (multiple)
• causal mechanism(s) not established

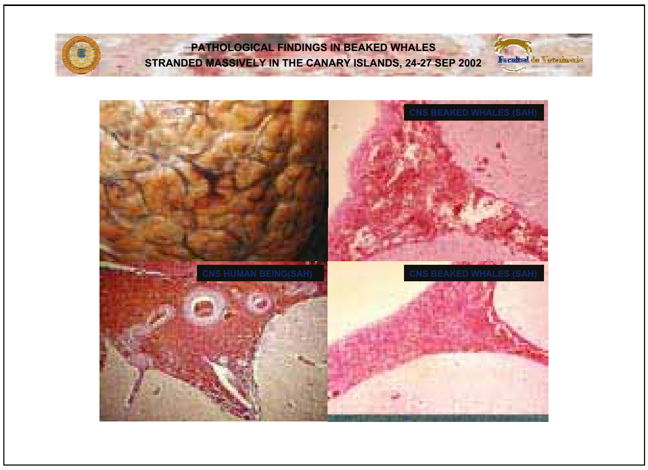


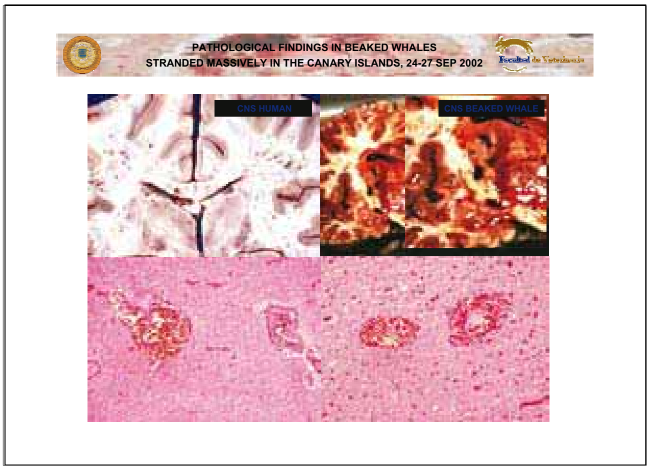
Ref	Species	Sex	Strand. date	Island	Preser. status	Necropsy
CET 180	*Mesoplodon densirostris*	female	24-9-02	Fuerteventura	fresh	36 h.p.m. (4ºC. 24h.)
CET 181	*Ziphius cavirostris*	male	24-9-02	Fuerteventura	fresh	36 h.p.m. (4ºC. 24h.)
CET 182	*Ziphius cavirostris*	male	24-9-02	Fuerteventura	fresh	36 h.p.m. (4ºC. 24h.)
CET 183	*Ziphius cavirostris*	male	24-9-02	Fuerteventura	fresh	36 h.p.m. (4ºC. 24h.)
CET 184	*Ziphius cavirostris*	male	24-9-02	Fuerteventura	fresh	36 h.p.m. (4ºC. 24h.)
CET 185	*Mesoplodon europaeus*	female	24-9-02	Fuerteventura	fresh	36 h.p.m. (4ºC. 24h.)
CET 186	*Ziphius cavirostris*	male	25-9-02	Fuerteventura	autolitic	30 h.p.m. (Env. T)
CET 187	*Ziphius cavirostris*	male	25-9-02	Lanzarote	very autolitic	54 h.p.m. (Env. T)
CET 188	*Ziphius cavirostris*	male	24-9-02	Lanzarote	very autolitic	54 h.p.m. (Env. T)
CET 189	*Ziphius cavirostris*	female	27-9-02	Fuerteventura	very autolitic	72 h.p.m. (Env. T)



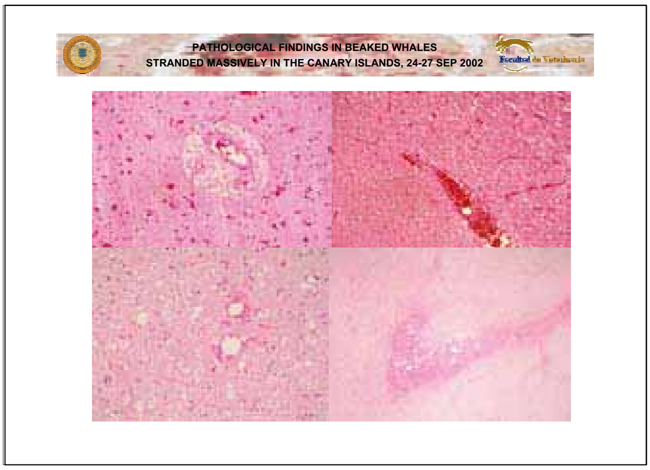


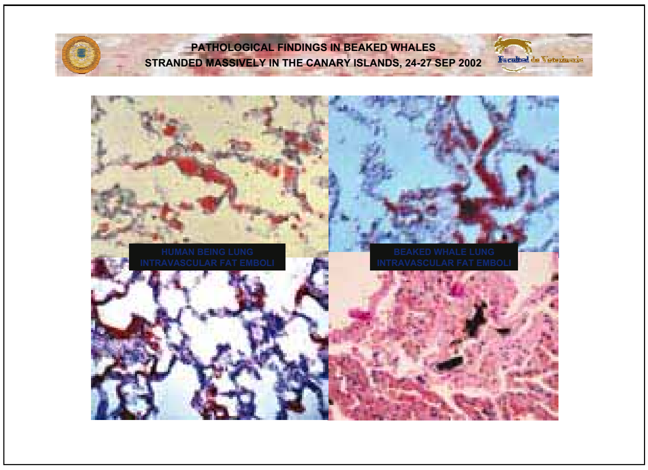


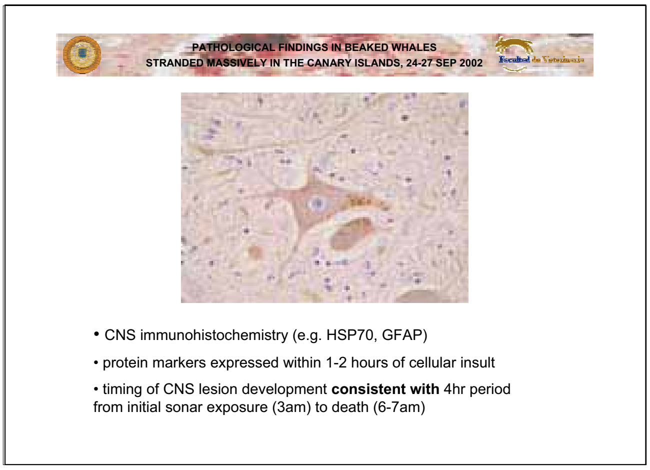

PATHOLOGICAL FINDINGS IN BEAKED WHALES
STRANDED MASSIVELY IN THE CANARY ISLANDS, 24-27 SEP 2002
CNS BEAKED WHALES (SAH)
CNS HUMAN BEING(SAH)
CNS BEAKED WHALES (SAH)


PATHOLOGICAL FINDINGS IN BEAKED WHALES
STRANDED MASSIVELY IN THE CANARY ISLANDS, 24-27 SEP 2002
CNS HUMAN
CNS BEAKED WHALE


PATHOLOGICAL FINDINGS IN BEAKED WHALES
STRANDED MASSIVELY IN THE CANARY ISLANDS, 24-27 SEP 2002


PATHOLOGICAL FINDINGS IN BEAKED WHALES
STRANDED MASSIVELY IN THE CANARY ISLANDS, 24-27 SEP 2002


PATHOLOGICAL FINDINGS IN BEAKED WHALES
STRANDED MASSIVELY IN THE CANARY ISLANDS, 24-27 SEP 2002
HUMAN BEING LUNG
INTRAVASCULAR FAT EMBOLI
BEAKED WHALE LUNG
INTRAVASCULAR FAT EMBOLI


PATHOLOGICAL FINDINGS IN BEAKED WHALES
STRANDED MASSIVELY IN THE CANARY ISLANDS, 24-27 SEP 2002
• CNS immunohistochemistry (e.g. HSP70, GFAP)
• protein markers expressed within 1-2 hours of cellular insult
• timing of CNS lesion development **consistent with** 4hr period from initial sonar exposure (3am) to death (6-7am)

Team at Las Palmas, Gran Canaria

ZSL

Joint publication of UK/Canaries pathology

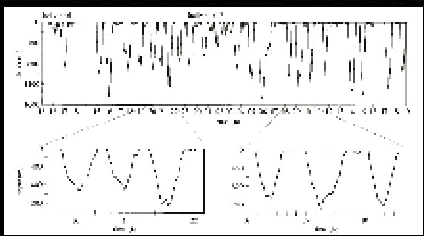
ZSL

- Gas bubble lesions exist in cetacea
- UK cases: acute and chronic (predominantly hepatic) lesions
- Canaries cases: acute and widely disseminated lesions (similar to DCS)
- Suggest decompression sickness-like mechanism for bubble genesis
- Propose hypothetical mechanism for sonar-related beaked whale mass stranding(s) via sonar-induced behavioural response (+/- acoustically mediated bubble growth) >> fatal gas bubbles/emboli

Jepson, P.D. et al. (2003) Gas-bubble lesions in stranded cetaceans. *Nature*, **425,** 575-576

Northern bottlenose whale dive profiles

ZSL

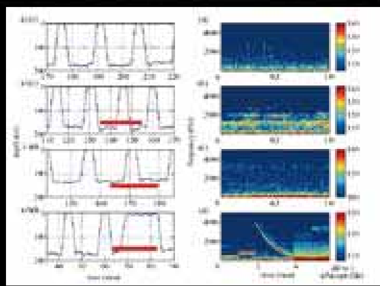


- slow ascent rates (for a cetacean!)
- absence of extended surface intervals

Hooker, S.K. & Baird, R.W. (1999) *Proceedings of the Royal Society* **266**, 671-676.

Evidence for altered dive profiles in northern right whales

ZSL



Nowacek, D.P., Johnson, M.P. & Tyack, P.L. (2004) *Proc. Roy. Soc. B*, **271**, 227-231

Hypothetical mechanism

ZSL

- Environmental conditions (e.g. surface ducts) can enhance acoustic propagation
- Initial behavioural response to mid-freq. sonar exposure, e.g.
  - **accelerated surface ascent**
  - **extended surface interval**
- >> induce high/excessive levels of nitrogen **supersaturation >>** predispose/induce **bubble generation**
- +/- physical effect (nuclei destabilisation) of sonar ping >> may enhance bubble growth in supersaturated tissues
- Continued sonar exposure/shelf edge topography prevents whales from diving (& recompressing bubbles)
- Patho-physiological consequences >> massive bubble formation/gas embolism >> death

MMC BW Workshop (Baltimore, April 2004): **testing the "bubble hypothesis"**

ZSL

- **Behavioural**
  - normal dive profiles
  - controlled acoustic exposure experiments (bottom-up)
- **Physiological**
  - confirm bubble formation in cetacea (e.g. Tursiops)
  - quantify critical level of nitrogen supersaturation
- **Physical**
  - acoustically-mediated bubble growth (in vitro)
- **Pathological**
  - revise necropsy protocols (detect emboli)
  - retrospective/prospective investigation of cetacean gas-bubble lesions


Acknowledgements
ZSL
• Canary Islands research funded by the Ministry of Science and Research (Ren-2002-04162-C02-01/MAR), GD Fisheries (EU), Ministry of Defence and Canary Islands Regional Government
• UK research funded by UK Department for Environment, Food, and Rural Affairs (defra)

Topic 4: What is the impact of regulations on the use of active acoustics for ocean research? What is the impact on research on marine mammals?

The Royal Navy Environmental Protection Research Programme

Claire Burt (Naval Systems Department, Defense Science and Technology Laboratories, UK)

This presentation describes the current UK policy and research on the Impact of Sound on marine mammals.

It stated the Secretary of States policy that all practicable and reasonable steps, consistent with maintaining operational effectiveness, are to be taken within the RN with due regard for environmental legislation by taking any necessary measures to protect the environment.

The mitigation measures currently undertaken at sea including current command guidance are explained.

The shortfalls and capability gaps identified from above has resulted in a comprehensive research programme to close those gaps. All aspects of the research programme are discussed and presented including future aspirations. The realisation into an Environmental Risk Management capability for the Fleet was shown.

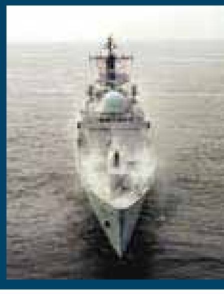
The Royal Navy Environmental Protection Research Programme

Claire Burt
Dstl Naval Systems

Tel: +44 (0) 1305 256025
Email: cmburt@dstl.gov.uk

Contents

- Background Requirements
- Current Research Projects
- Future Projects
- Summary



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Background Requirements

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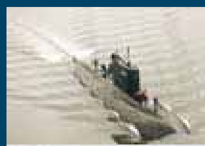
Background

- Quieter submarine threats
- New challenges for their detection
- Detection by passive sonar is difficult, especially in littoral regions
- Active sonar systems needed to maintain an effective defensive capability



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MoD Environmental Protection Requirements are Policy Driven

" …carry out environmental policy appraisals of all new or revised policies and equipment acquisition programmes and environmental impact assessments of all new projects and training activities".

- ***"Where the Ministry has been granted specific exemptions, disapplications or derogations from legislation, international treaties or protocols, Departmental standards and arrangements are to be introduced which will be, so far as is reasonably practicable, at least as good as those required by the legislation. I will only invoke any powers given to me to disapply legislation on the grounds of national security when such action is absolutely essential for the maintenance of operational capability."***

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ENVIRONMENTAL IMPACT

- **CINCFLEET RN Safety Management System dated 21 Mar 02:**
  - ***" All practicable and reasonable steps, consistent with maintaining operational effectiveness, are to be taken within the RN in accordance with this RNSMS."***
  - ***"Protect and enhance the natural environment in line with HM Government's Environmental Strategy and the principles of stewardship and sustainability, within overriding operational constraints."***
- **In summary, the aim is to achieve/maintain operational effectiveness with due regard for environmental legislation by taking any necessary measures to protect the environment.**

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ENVIRONMENTAL IMPACT

'...it is now timely and appropriate to issue guidance on the use of in-service active sonars. The guidance is designed to be straightforward, to bring clarity to this requirement and will provide an initial mitigating measure against marine mammal disturbance ahead of the longer term measures….' 28 Nov 03.

Vice Admiral Mark Stanhope OBE

Deputy Commander in Chief Fleet

Command Guidance
Mitigation Against Marine Mammal Disturbance

Guidance is mandatory

Guidance to be applied when operationally safe to do so.

The priority remains the safety of own ship and units in company

The final decision on applying guidance is vested in the CO

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Top-Level Requirement

- The MoD requirement is to apply the Policy of the Secretary of State for Defence on protection of the natural environment
- This Policy **requires that legislation is applied** except where the MoD has been granted specific exemption
- For active sonar the primary goal is to minimise the risk to marine environment from acoustic transmissions whilst maintaining operational capability
- To **rapidly transition** the technical capabilities **to the Fleet**

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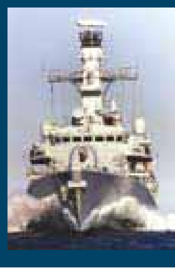
Environmental Protection Requirements for Active Sonar Operations

- MoD must undertake an **Environmental Impact Assessment** for:
  - New equipment
  - New training activities
  - Trials
  - Exercises



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Route Map

Global EIA

Impact on Receptors (Humans/Mammals/Fish)

• Likely Areas of Operation

• Legal & Policy

Trial Specific EIA

Migration into Operational use

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Mitigation Procedures

Before each Trial:

• Assess Area. Avoidance areas to be implemented with respect to sensitive areas and habitats for marine mammals (Based on PTS/TTS)

•Establish Mitigation Action (Zones etc.)

Monitoring Before, During & After Trial

.

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Mitigation Measures (2)

- Visual and passive acoustic monitoring for marine mammals to be undertaken from the source ship and during trials from an independent environmental monitoring platform
- Avoidance of areas where fish spawning is likely to occur and monitoring for potentially visible fish species (eg Basking Shark)
- Modification of the sonar trials programme in response to environmental monitoring (eg: cessation, temporary reduction or relocation of sonar transmissions, use of "soft start"

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Example of MoD Environmental Assessment Capability

- Environmental Strategy
- Screening/Scoping Study
- Global & Trials EIA
- Support to Business Case
- PR Strategy - Web Page, Conference Papers, Mitigation Migration Strategy
- Organic monitoring
- EP Support for Trials

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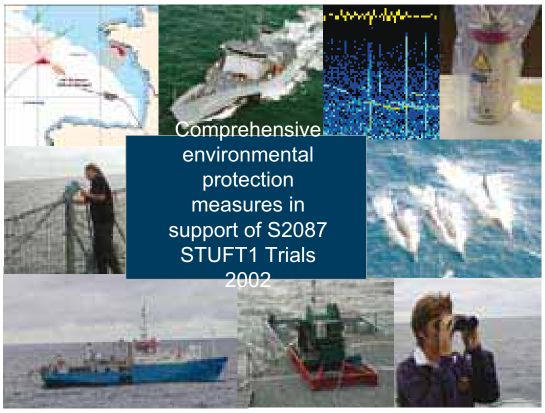

Current Research Projects

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Current Capability Gaps defined by Royal Navy

Critical shortfalls associated with defining marine biology

- Capability of 24-hour all-weather **marine mammal detection**
- UK **databases** of marine mammal distribution and abundance
- Understanding of natural **marine mammal behaviour** and that in response to acoustic transmissions
  - e.g. exposure to prolonged low level transmissions or multiple frequencies, pulse types etc

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Marine Mammal DCL

- MoD’s aim is to have an **integrated** 24-hour all-weather marine mammal **Detection, Classification** and **Localisation** capability
- Envisaged **primary methodology** is via **passive acoustics**
- Passive acoustics will be **supported by other detection technologies**

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Marine Mammal DCL

- Research ongoing into detecting, classifying and localising marine mammals by:
  - Passive Acoustics
  - Visual Monitoring
  - Radar
  - Electro-optical sensors

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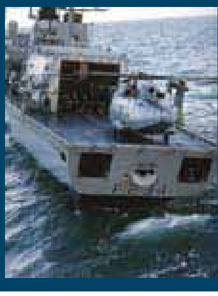
Passive Acoustics

- Development of a passive acoustic marine mammal DCL capability **integrated with in service sonar**
- QinetiQ undertaken research and are producing MMADS software
- Current version has excellent detection capability and can classify down to class level
- Tested at sea including during recent S2087 trials in the NW Approaches



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Visual Monitoring

- All RN vessels maintain a watch
- RN watch keepers now undergo basic training
- MoD currently involved with “Ocean Eye” project to quantify observer performance and identify where improvements to MMO training can be made.
- Results will lead to further developments in RN watch training programme

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Ocean Eye Full Bridge Simulator

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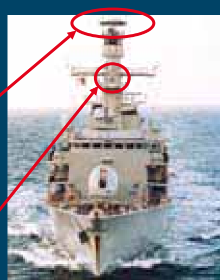
Radar and Electro-Optical Sensors

- A US/UK funded study has recently completed looking at utilising shipborne radar to detect and localise marine mammals
- MoD funded follow on work looking at using the Type 23 frigate radar to detect/ localise marine mammals
- Electro-Optical Sensors fitted to the Type 23 Frigate have been assessed to examine their suitability for marine mammal DCL
- Sensors assessed include T23 IR pod and Night Vision Goggles



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Marine Mammal Behaviour

- Various projects being conducted by QinetiQ and Sea Mammal Research Unit
- Assessment of the reliability of determining the temporal & spatial probabilities of encountering marine mammals in military training and exercise areas
- Acquire & assess current information on marine mammal behaviour
- Assess current MoD biological databases
- Will improve knowledge of risks to marine mammals

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SMRU - JGS Funded Work

- Two Joint Grants Scheme projects, started Dec 02 (50% MOD, 50% UK research councils)
- 3 Year research projects on mitigating the effects of high power sonar systems on marine mammals:
  - Distribution of small cetaceans in shallow shelf sea water and their response on exposure to acoustic energy
  - Correlation of cetacean distribution with oceanographic features in the deep/shallow waters of the NW Approaches
- The outcomes will feed into the Fleet

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Future Research Projects

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Platform Based DCL

- Dstl studying RAF Nimrod and RN Merlin contribution to support MoD Environmental Protection requirements
- Study concentrates on Searchwater and Blue Kestrel radars, but EO sensors also to be considered
- Also study looking into potential to use submarine passive acoustic sonar arrays to achieve marine mammal DCL

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How is this transitioned to the Fleet?

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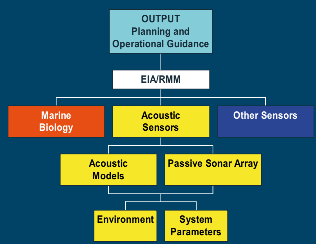
Environmental Risk Management Capability (ERMC)

- **AIM** - To develop and procure an EIA “toolkit”
- **Commences** late **2004**
- **Initial capability** provided mid-**2006**



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ERMC

- Two applications of the ERMC:
  – **Planning aid component** to replace the existing EIA process
  – **Real-time at sea guidance** to command about the current levels of risk to the environment
- The ERMC will draw on research undertaken across MoD, and other National/ International Programmes
  – Dstl takes the MoD lead on knowledge integration process
- Initial 2006 in-service date will support S2087 equipped platforms, with other active sonar equipped platforms to follow

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Topic 5: Mitigation strategies - best practices. From a scientific perspective, what works and what doesn't. Status of new technologies such as passive/active detection

Acoustics & Marine Mammals - Mitigation Strategies

Geraint West (UK Ocean Research Services, Southampton Oceanography Centre)

This presentation is an examination of general mitigation methodology in the context of practical experience on a UK Natural Environmental Research Council (NERC) seismic cruise in the Indian Ocean as well as a number of guidelines issued by the following:

- UK Joint Nature conservancy Council (JNCC) – adopted by NERC in the practical example.
- NATO SACLANTCEN
- Environment Australia
- US Minerals Management Service (MMS)

Although these guidelines all adopt a common approach to mitigation strategy comparison of them highlights quite extreme divergence in detail, especially as far as applicability is concerned. In general though, mitigation measures can be examined under a simple set of headings (as adopted by the UK Royal Navy):

Plan
- Use of marine mammal distribution/habitat information sources;
- Identification of populations at risk (particularly protected species);
- Evaluation of impact of acoustic source;
- Adoption of appropriate protocols.

Look
- Visual methods
    - Requirement for and training of Marine Mammal Observers (MMO)
    - Recording of observations;
- Other aids including
    - Radar;
    - IR,
    - Electro-optical;

Listen
- Passive acoustics;
- Active

Act
- Pre-start observation
- Soft start protocols
- Turn/interruption protocol
- (; feasibility of meeting guidelines, e.g. how measure every 2km?. Procedure adopted for Sonar 2087 trial - don't want to be doing this for scientific surveys. Aim should be to reduce risk.

These areas all have significant outstanding issues which need further work or clarification:

Planning

- Marine mammal distribution/habitats is sparse or non-existent for some species and/or some geographical areas.
- Modelling of acoustic source can be extremely difficult in some areas, especially shallow waters.
- There is little scienti9fic knowledge of how marine mammals actually react to sources and therefore how effective protocols such as 'soft start' really are.

Look

- There is no international standard for MMO training and considerable variability in the standards published by different guidelines.
- Reduced visibility at night, in fog or high sea-states significantly degrades the effectiveness of visual observational methods; in some cases cessation of acoustic transmission may therefore be necessarys

Listen

- Deployment of passive acoustic devices is costly both interms of the capital costs of the equipment and the deployment scenarios which may be appropriate especially if this requires use of a separate platform from the source ship.
- Even with advances in software, interpretation of information from passive sources can be extremely difficult.
- Acoustic sources may offer an alternative, but their use is likely to be highly controversial.

Act

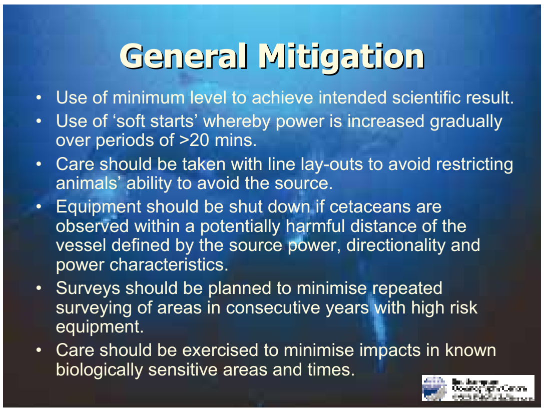
- Given that we have little information on how marine mammals react to acoustic sources; it can be difficult to assess how information from monitoring techniques should be used to modify operational protocols.

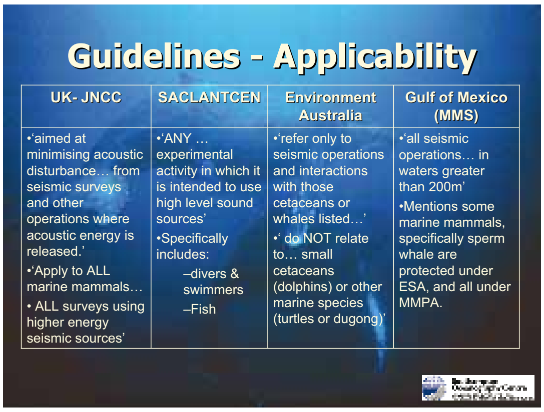
At the most basic level it would clearly be highly desirable to harmonise guidelines, however the variety of these suggest that there is little international agreement on how high the bar should be set and how operational protocols might be rationalised: Unfortunately this is a particularly difficult issue when set in the context of national regulatory regimes which also vary quite widely.

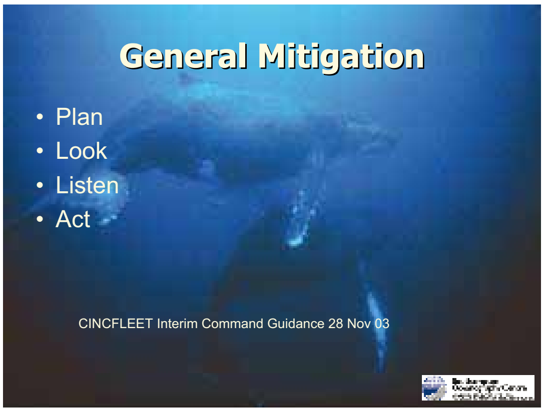

Acoustics & Marine Mammals
Mitigation Strategies
Geraint West
UK Ocean Research Services


Acoustics & Marine Mammals
Mitigation Strategies

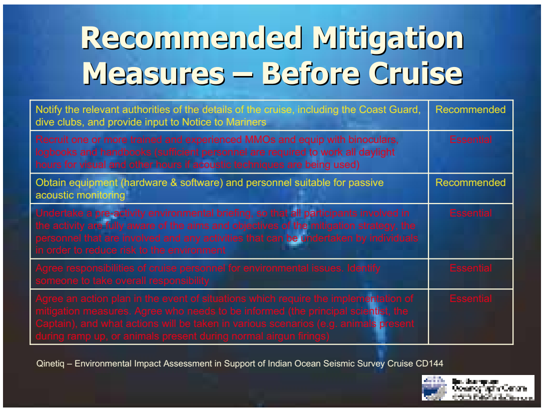

Marine Mammals Mitigation Strategies
• General Mitigation Methodology
– Charles Darwin Cruise 144
– Comparison of Guidelines
• Joint Nature Conservancy Council (JNCC) Guidelines JNCC
• SACLANTCEN
• Environment Australia
• USA Minerals Management Service (MMS)


General Mitigation
• Use of minimum level to achieve intended scientific result.
• Use of 'soft starts' whereby power is increased gradually over periods of >20 mins.
• Care should be taken with line lay-outs to avoid restricting animals' ability to avoid the source.
• Equipment should be shut down if cetaceans are observed within a potentially harmful distance of the vessel defined by the source power, directionality and power characteristics.
• Surveys should be planned to minimise repeated surveying of areas in consecutive years with high risk equipment.
• Care should be exercised to minimise impacts in known biologically sensitive areas and times.

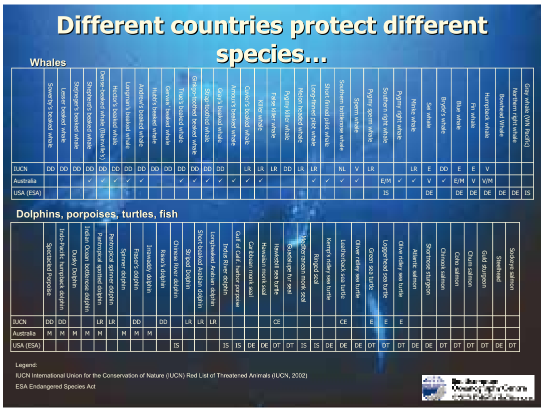

Guidelines - Applicability
UK- JNCC
•'aimed at minimising acoustic disturbance… from seismic surveys and other operations where acoustic energy is released.'
•'Apply to ALL marine mammals…
• ALL surveys using higher energy seismic sources'
SACLANTCEN
•'ANY … experimental activity in which it is intended to use high level sound sources'
•Specifically includes:
–divers & swimmers
–Fish
Environment Australia
•'refer only to seismic operations and interactions with those cetaceans or whales listed…'
•' do NOT relate to… small cetaceans (dolphins) or other marine species (turtles or dugong)'
Gulf of Mexico (MMS)
•'all seismic operations… in waters greater than 200m'
•Mentions some marine mammals, specifically sperm whale are protected under ESA, and all under MMPA.


General Mitigation
• Plan
• Look
• Listen
• Act
CINCFLEET Interim Command Guidance 28 Nov 03

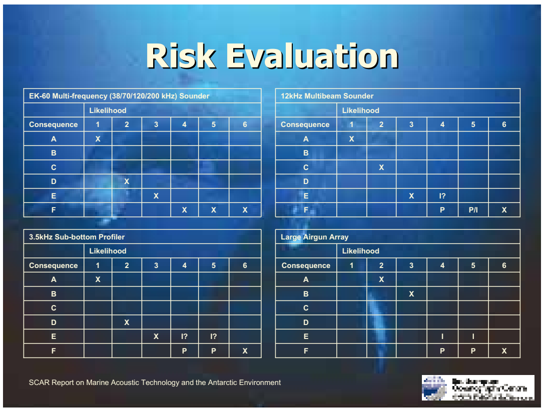
Plan
Data Sources
Source Assessment
Operational Protocol



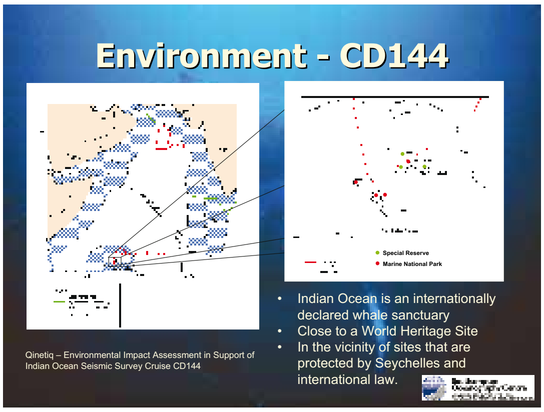
Recommended Mitigation Measures – Before Cruise
Notify the relevant authorities of the details of the cruise, including the Coast Guard, dive clubs, and provide input to Notice to Mariners
Recommended
Recruit one or more trained and experienced MMOs and equip with binoculars, logbooks and handbooks (sufficient personnel are required to work all daylight hours for visual and other hours if acoustic techniques are being used)
Essential
Obtain equipment (hardware & software) and personnel suitable for passive acoustic monitoring
Recommended
Undertake a pre-activity environmental briefing, so that all participants involved in the activity are fully aware of the aims and objectives of the mitigation strategy, the personnel that are involved and any activities that can be undertaken by individuals in order to reduce risk to the environment
Essential
Agree responsibilities of cruise personnel for environmental issues. Identify someone to take overall responsibility
Essential
Agree an action plan in the event of situations which require the implementation of mitigation measures. Agree who needs to be informed (the principal scientist, the Captain), and what actions will be taken in various scenarios (e.g. animals present during ramp up, or animals present during normal airgun firings)
Essential
Qinetiq – Environmental Impact Assessment in Support of Indian Ocean Seismic Survey Cruise CD144



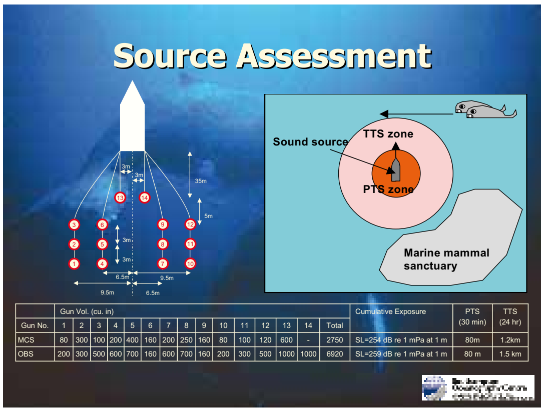
Different countries protect different species…
Whales
IUCN
Australia
USA (ESA)
Dolphins, porpoises, turtles, fish
IUCN
Australia
USA (ESA)
Legend:
IUCN International Union for the Conservation of Nature (IUCN) Red List of Threatened Animals (IUCN, 2002)
ESA Endangered Species Act



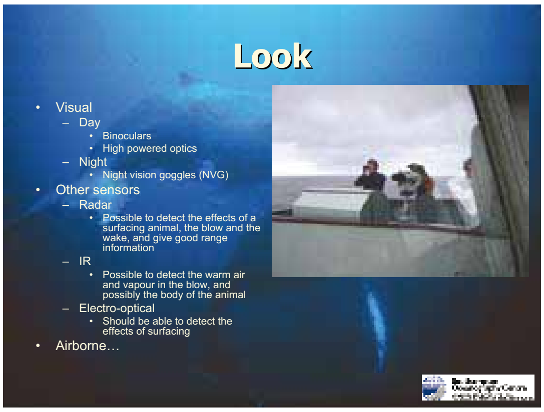
Risk Evaluation
EK-60 Multi-frequency (38/70/120/200 kHz) Sounder
12kHz Multibeam Sounder
3.5kHz Sub-bottom Profiler
Large Airgun Array
Likelihood
Consequence
SCAR Report on Marine Acoustic Technology and the Antarctic Environment

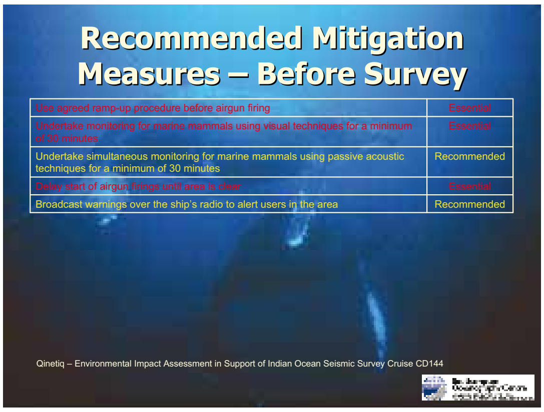


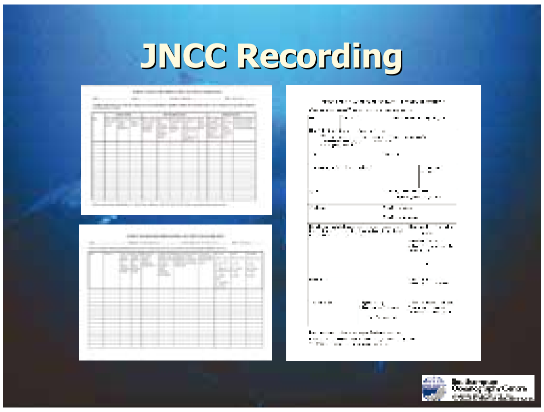
Environment - CD144
Special Reserve
Marine National Park
Indian Ocean is an internationally declared whale sanctuary
Close to a World Heritage Site
In the vicinity of sites that are protected by Seychelles and international law.
Qinetiq – Environmental Impact Assessment in Support of Indian Ocean Seismic Survey Cruise CD144

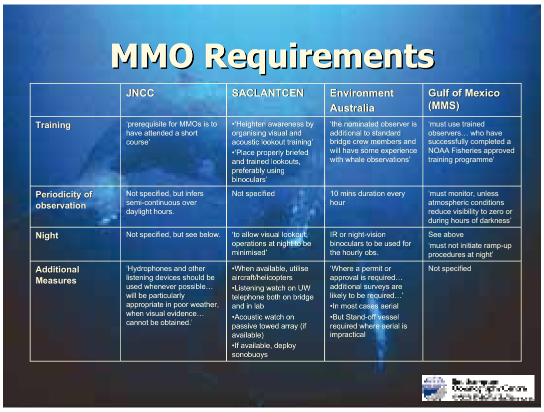


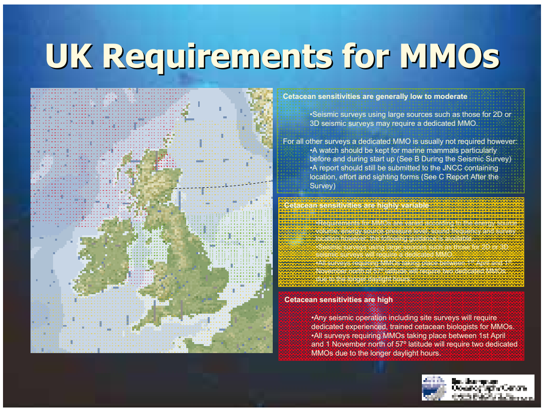
Source Assessment
Sound source
TTS zone
PTS zone
Marine mammal sanctuary
9.5m
6.5m
3m
5m
Gun Vol. (cu. in)
Gun No.
Total
Cumulative Exposure
PTS (30 min)
TTS (24 hr)
MCS
80 300 100 200 400 160 200 250 160 80 100 120 600 - 2750
SL=254 dB re 1 mPa at 1 m
80m
1.2km
OBS
200 300 500 600 700 160 600 700 160 200 300 500 1000 1000 6920
SL=259 dB re 1 mPa at 1 m
80 m
1.5 km

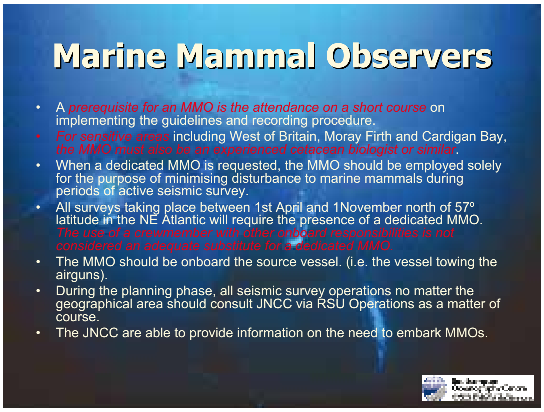

Look
Visual
Day
Binoculars
High powered optics
Night
Night vision goggles (NVG)
Other sensors
Radar
Possible to detect the effects of a surfacing animal, the blow and the wake, and give good range information
IR
Possible to detect the warm air and vapour in the blow, and possibly the body of the animal
Electro-optical
Should be able to detect the effects of surfacing
Airborne…


Recommended Mitigation Measures – Before Survey
Use agreed ramp-up procedure before airgun firing
Essential
Undertake monitoring for marine mammals using visual techniques for a minimum of 30 minutes
Essential
Undertake simultaneous monitoring for marine mammals using passive acoustic techniques for a minimum of 30 minutes
Recommended
Delay start of airgun firings until area is clear
Essential
Broadcast warnings over the ship's radio to alert users in the area
Recommended
Qinetiq – Environmental Impact Assessment in Support of Indian Ocean Seismic Survey Cruise CD144


JNCC Recording

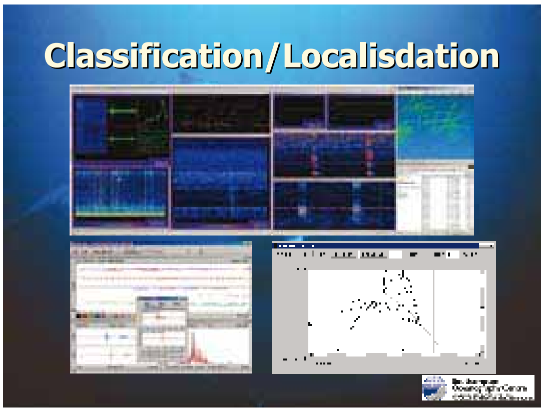

MMO Requirements
JNCC
SACLANTCEN
Environment Australia
Gulf of Mexico (MMS)
Training
'prerequisite for MMOs is to have attended a short course'
•'Heighten awareness by organising visual and acoustic lookout training'
•'Place properly briefed and trained lookouts, preferably using binoculars'
'the nominated observer is additional to standard bridge crew members and will have some experience with whale observations'
'must use trained observers… who have successfully completed a NOAA Fisheries approved training programme'
Periodicity of observation
Not specified, but infers semi-continuous over daylight hours.
Not specified
10 mins duration every hour
'must monitor, unless atmospheric conditions reduce visibility to zero or during hours of darkness'
Night
Not specified, but see below.
'to allow visual lookout, operations at night to be minimised'
IR or night-vision binoculars to be used for the hourly obs.
See above
'must not initiate ramp-up procedures at night'
Additional Measures
'Hydrophones and other listening devices should be used whenever possible… will be particularly appropriate in poor weather, when visual evidence… cannot be obtained.'
•When available, utilise aircraft/helicopters
•Listening watch on UW telephone both on bridge and in lab
•Acoustic watch on passive towed array (if available)
•If available, deploy sonobuoys
'Where a permit or approval is required… additional surveys are likely to be required…'
•In most cases aerial
•But Stand-off vessel required where aerial is impractical
Not specified

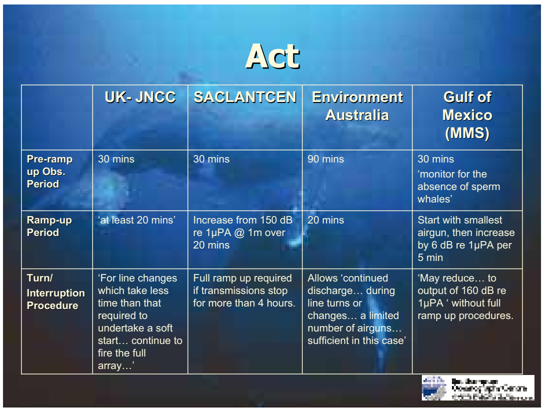

UK Requirements for MMOs
Cetacean sensitivities are generally low to moderate
•Seismic surveys using large sources such as those for 2D or 3D seismic surveys may require a dedicated MMO.
For all other surveys a dedicated MMO is usually not required however:
•A watch should be kept for marine mammals particularly before and during start up (See B During the Seismic Survey)
•A report should still be submitted to the JNCC containing location, effort and sighting forms (See C Report After the Survey)
Cetacean sensitivities are highly variable
•Requirements for MMOs are varied according to the energy source volume, energy source pressure level, sound frequency and survey location however, the following guidance is available
•Seismic surveys using large sources such as those for 2D or 3D seismic surveys will require a dedicated MMO
Cetacean sensitivities are high
•Any seismic operation including site surveys will require dedicated experienced, trained cetacean biologists for MMOs.
•All surveys requiring MMOs taking place between 1st April and 1 November north of 57º latitude will require two dedicated MMOs due to the longer daylight hours.


Marine Mammal Observers
A prerequisite for an MMO is the attendance on a short course on implementing the guidelines and recording procedure.
For sensitive areas including West of Britain, Moray Firth and Cardigan Bay, the MMO must also be an experienced cetacean biologist or similar.
When a dedicated MMO is requested, the MMO should be employed solely for the purpose of minimising disturbance to marine mammals during periods of active seismic survey.
All surveys taking place between 1st April and 1November north of 57º latitude in the NE Atlantic will require the presence of a dedicated MMO. The use of a crewmember with other onboard responsibilities is not considered an adequate substitute for a dedicated MMO.
The MMO should be onboard the source vessel. (i.e. the vessel towing the airguns).
During the planning phase, all seismic survey operations no matter the geographical area should consult JNCC via RSU Operations as a matter of course.
The JNCC are able to provide information on the need to embark MMOs.

Listen

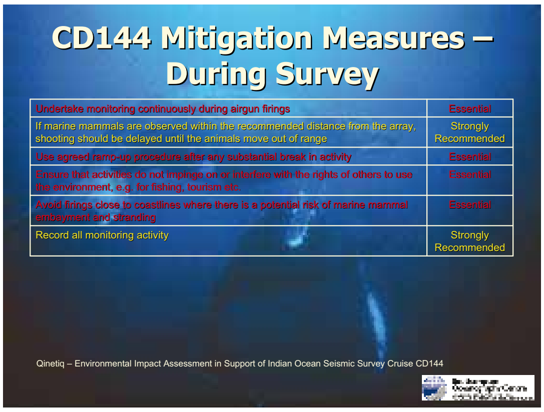
- Passive acoustic monitoring (PAM)
  - Wide variety of hardware systems:
    - Towed arrays
    - Sonobuoys
    - Ball hydrophones
  - Software
    - Ishmael (total bandwidth)
    - Whistle (for dolphins),
    - Rainbow Click (for sperm whale clicks)
    - Logger (logs location, observations and acoustic detections)
  - Operation
    - Detect
    - Classify
    - Localise
  - Ideally fully automated to eliminate the need for additional manpower
  - Ideally high probability of detection and a low false alarm rate
  - Particularly important during activities after dark
  - Does not detect silent animals transiting the area.
  - Poor for range estimation
- Active acoustic monitoring
  - Fish finding sonars are widely used by the fishing industry to detect shoals
  - US Navy are developing a sonar system designed to detect, locate and track marine mammals (SURTASS, 2001).
  - Enable silent animals to be detected
  - Introduces more sound into the marine environment - potential to pose additional risk
  - Therefore somewhat controversial.





Act

	UK- JNCC	SACLANTCEN	Environment Australia	Gulf of Mexico (MMS)
Pre-ramp up Obs. Period	30 mins	30 mins	90 mins	30 mins 'monitor for the absence of sperm whales'
Ramp-up Period	'at least 20 mins'	Increase from 150 dB re 1μPA @ 1m over 20 mins	20 mins	Start with smallest airgun, then increase by 6 dB re 1μPA per 5 min
Turn/ Interruption Procedure	'For line changes which take less time than that required to undertake a soft start… continue to fire the full array…'	Full ramp up required if transmissions stop for more than 4 hours.	Allows 'continued discharge… during line turns or changes… a limited number of airguns… sufficient in this case'	'May reduce… to output of 160 dB re 1μPA ' without full ramp up procedures.



CD144 Mitigation Measures – During Survey

Undertake monitoring continuously during airgun firings	Essential
If marine mammals are observed within the recommended distance from the array, shooting should be delayed until the animals move out of range	Strongly Recommended
Use agreed ramp-up procedure after any substantial break in activity	Essential
Ensure that activities do not impinge on or interfere with the rights of others to use the environment, e.g. for fishing, tourism etc.	Essential
Avoid firings close to coastlines where there is a potential risk of marine mammal embayment and stranding	Essential
Record all monitoring activity	Strongly Recommended

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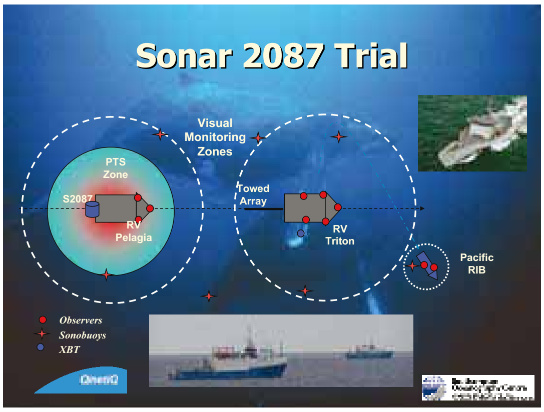
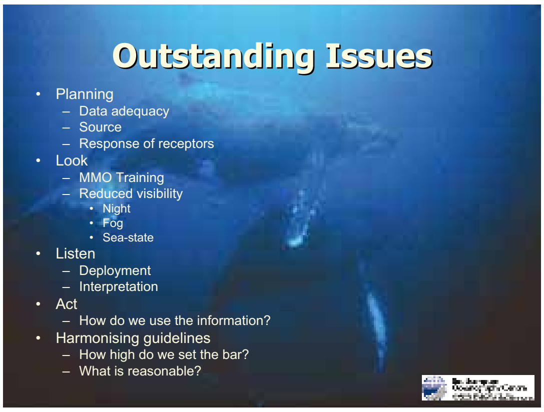
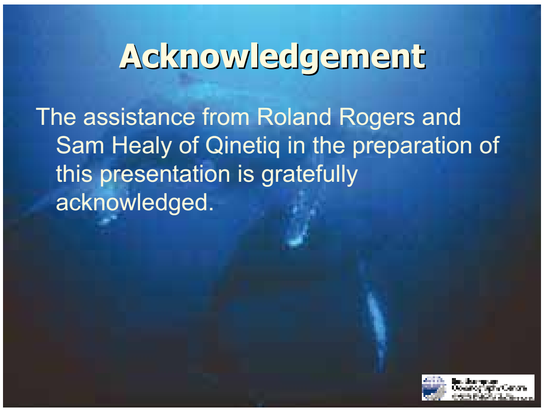




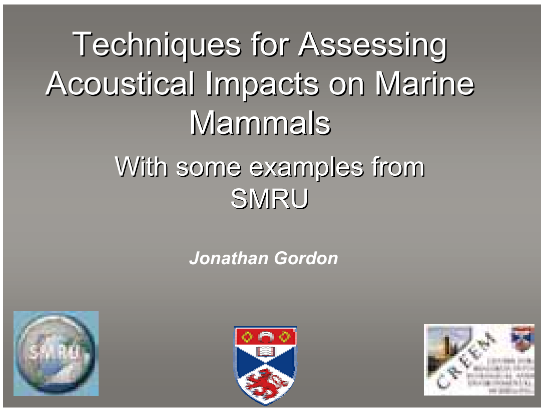
Outstanding Issues

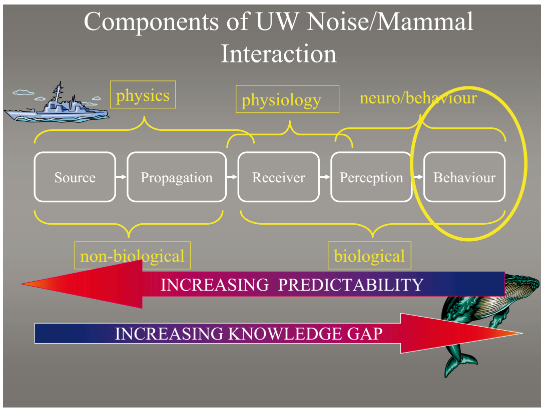
- Planning
  - Data adequacy
  - Source
  - Response of receptors
- Look
  - MMO Training
  - Reduced visibility
    - Night
    - Fog
    - Sea-state
- Listen
  - Deployment
  - Interpretation
- Act
  - How do we use the information?
- Harmonising guidelines
  - How high do we set the bar?
  - What is reasonable?

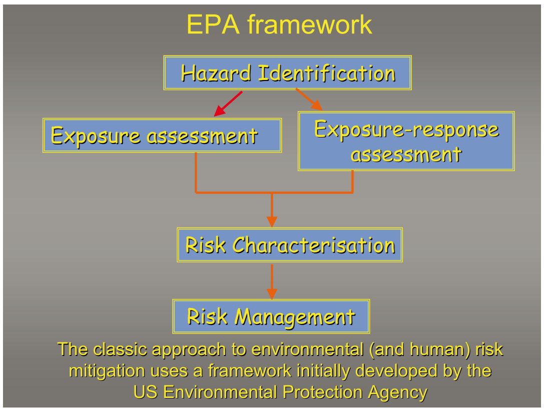

Acknowledgement
The assistance from Roland Rogers and Sam Healy of Qinetiq in the preparation of this presentation is gratefully acknowledged.

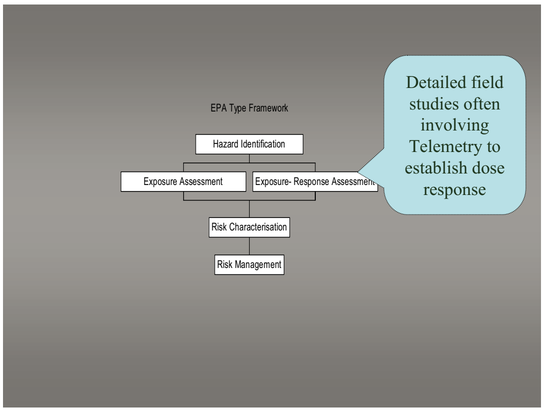
<u>Topic 6:</u> Scientific techniques and results for assessing acoustical Impacts on marine mammals. How does the science community rate the impact of acoustics on marine mammals in comparison to other potential threats to marine mammal populations?

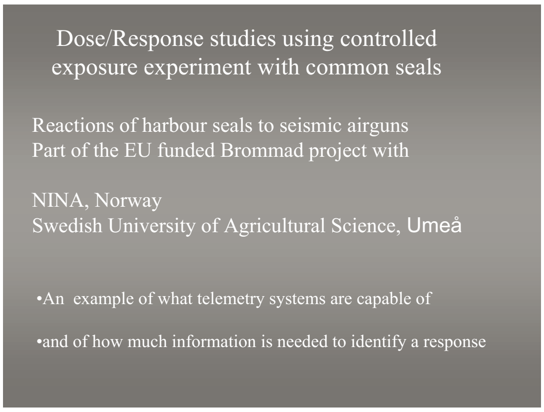
Scientific techniques and results for assessing acoustical impacts on marine mammals; marine mammal acoustic research and expertise at SMRU

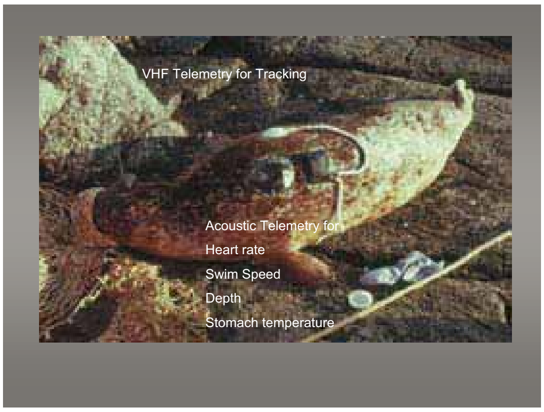

Techniques for Assessing Acoustical Impacts on Marine Mammals
With some examples from SMRU
Jonathan Gordon
SMRU
CREEM

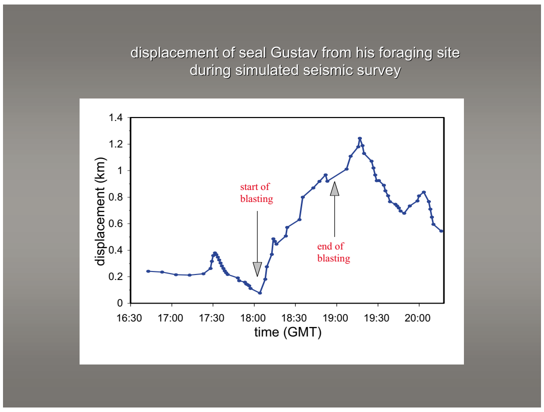

Components of UW Noise/Mammal Interaction
physics
physiology
neuro/behaviour
Source
Propagation
Receiver
Perception
Behaviour
non-biological
biological
INCREASING PREDICTABILITY
INCREASING KNOWLEDGE GAP

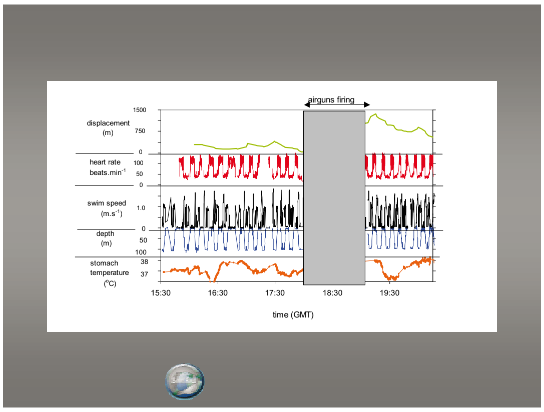

EPA framework
Hazard Identification
Exposure assessment
Exposure-response assessment
Risk Characterisation
Risk Management
The classic approach to environmental (and human) risk mitigation uses a framework initially developed by the US Environmental Protection Agency


EPA Type Framework
Hazard Identification
Exposure Assessment
Exposure- Response Assessmen
Risk Characterisation
Risk Management
Detailed field studies often involving Telemetry to establish dose response


Dose/Response studies using controlled exposure experiment with common seals
Reactions of harbour seals to seismic airguns
Part of the EU funded Brommad project with
NINA, Norway
Swedish University of Agricultural Science, Umeå
•An example of what telemetry systems are capable of
•and of how much information is needed to identify a response


VHF Telemetry for Tracking
Acoustic Telemetry for
Heart rate
Swim Speed
Depth
Stomach temperature





Monitored heart rate, movements, dive behaviour, feeding events in 14 controlled exposure experiment.
7 met criteria for successful experiment

In all but one case

- Intense initial reaction,
- Usually moved rapidly away from source of noise.
- Complete disruption of foraging behaviour
- quickly reverted to 'normal' behaviour
- no apparent avoidance of disturbed areas

Preliminary Conclusions

•Seals seem to show adaptive responses, which given appropriate soft start should minimise risk of hearing damage

•Potential for long term habitat exclusion by full scale survey a matter for concern

•A preliminary study that should be followed up with a more extensive program of research

Generic Points

- Capacity founded on long experience of telemetry and field studies knowledge of typical/natural behaviour and biology which provided
  - Understanding of behaviour and heart rate response to a range of variables/conditions
  - Development of appropriate equipment and techniques and study sites
  - Appreciation of when and where components of the population most vulnerable to disturbance
- Low cost approach appropriate for an initial feasibility study
  - Replicates
  - Heart rate?
  - Longer term exposures and observations around full scale surveys

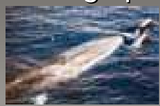
Cetaceans

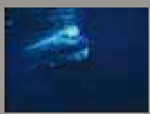
- For some species passive acoustic monitoring and tracking can provide useful information on underwater behaviour
- Telemetry has always been more difficult because of attachment difficulties but..

Cetacean Telemetry - Catching up

- Simone Panigada

Telemetry of fin whales





- Patrick Miller

WHOI d-Tagging detailed telemetry including onboard recording of sperm whales

- Sasha Hooker

Telemetry and acoustic recordings of bottlenose whales

Behavioural responses are inherently variable. Must expect variation with:

- Species
- Sex
- Age
- Motivation
- Experience (habituation, sensitisation)
- Location

Therefore studies must include sufficient replicates to capture variability

- This should be budgeted and planned for from the start
- May require development of low cost methods – cost as important as sophistication
- When there is a trade off between fewer detailed precise measurements and simpler (cheaper) ones favour the latter

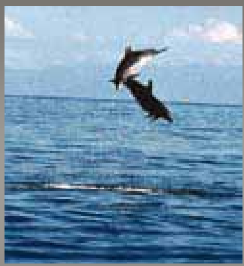
Controlled Exposure Experiments Workshop

- Preliminary workshop on techniques at St Andrews
- Broader workshop at European Cetacean Society
- ECS Report and Marine Technology Journal paper

- Lessons to be learnt from Ethologists' playback experiments
  - e.g. Peter Slater's bird communication group

Vincent Janik and co-workers
at SMRU

Playbacks of signature whistles and feeding brays to wild bottlenose dolphins to understand their role in communication



Controlled Exposure Experiments Workshop: CEE vs Opportunistic

- NOT ALTERNATIVES!
- CEEs only useful for studying short term responses
- Only approach available for new sound sources, e.g. new sonar
- Particularly useful for demonstrating cause and effect
- More likely to get a truly representative sample including more sensitive individuals

Controlled Exposure Experiments Workshop: CEE vs Opportunistic

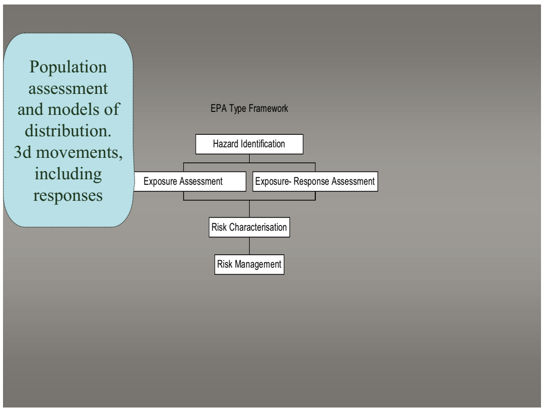
- Usually CEE will result in more observations per unit time
  – Can work in the best areas at the best times
  – Can apply stimulus when the necc. control data has been collected
  – Can focus on the animals of most interest

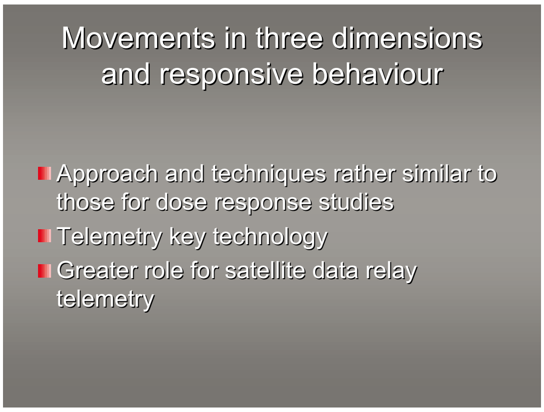
Controlled Exposure Experiments Workshop: CEE vs Opportunistic

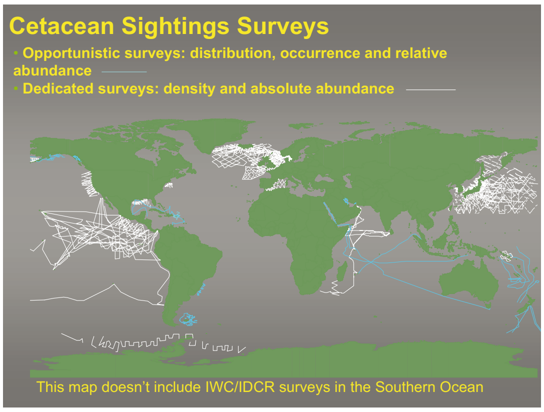
- Opportunistic observations, no concerns about the realism of the "experimental" situation
- Only option for research into long term exposures
- Some full scale noise sources can be prohibitively expensive for a series of experiments involving many replicates

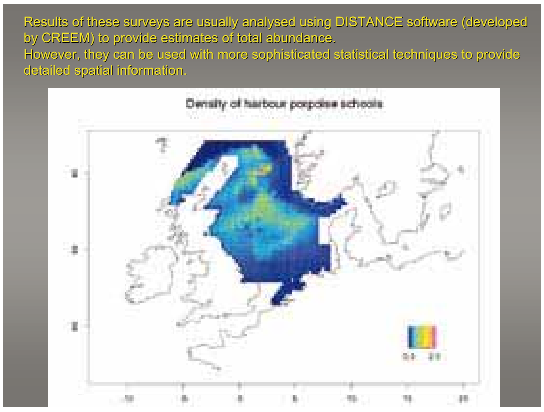
Exposure Experiments: Final Points

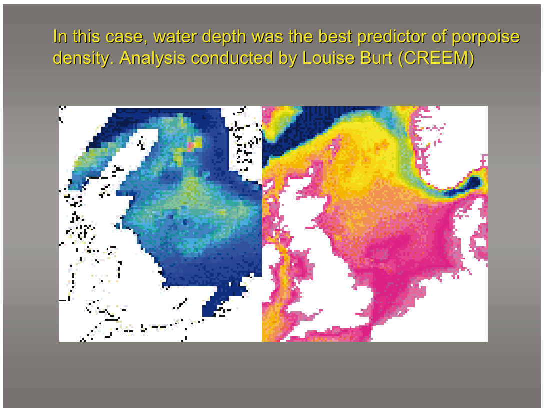
- Protocols to minimise the risk of harm to experimental animals
- Choosing focal animals
  – Precautionary approach would be to choose the most sensitive – Mothers and calves?
- Need for clarity in defining research questions
  – Address key knowledge gaps,
  – Measure biologically significant behaviour
  – Must be achievable
- Importance of collaboration

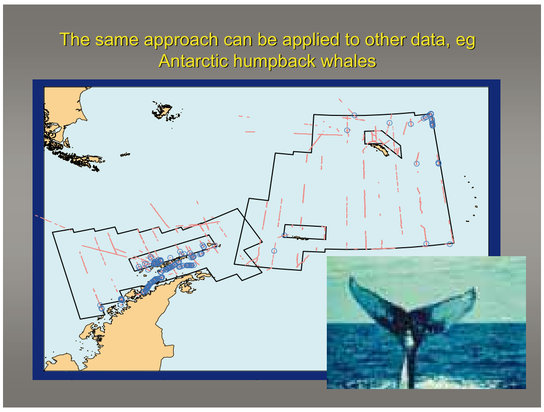

Population assessment and models of distribution. 3d movements, including responses
EPA Type Framework
Hazard Identification
Exposure Assessment
Exposure- Response Assessment
Risk Characterisation
Risk Management

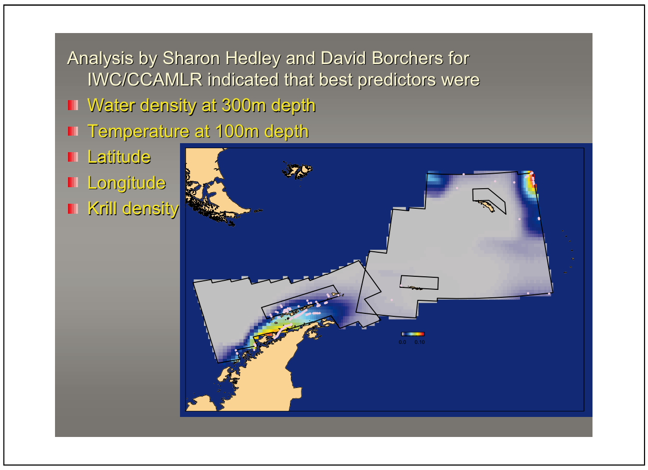

Movements in three dimensions and responsive behaviour
Approach and techniques rather similar to those for dose response studies
Telemetry key technology
Greater role for satellite data relay telemetry

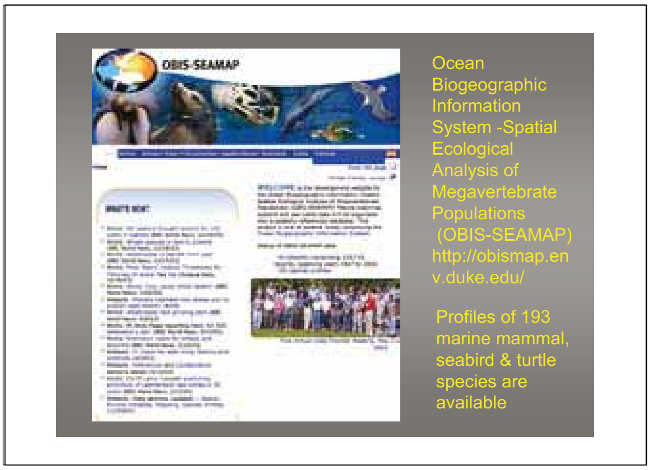

Cetacean Sightings Surveys
Opportunistic surveys: distribution, occurrence and relative abundance
Dedicated surveys: density and absolute abundance
This map doesn't include IWC/IDCR surveys in the Southern Ocean

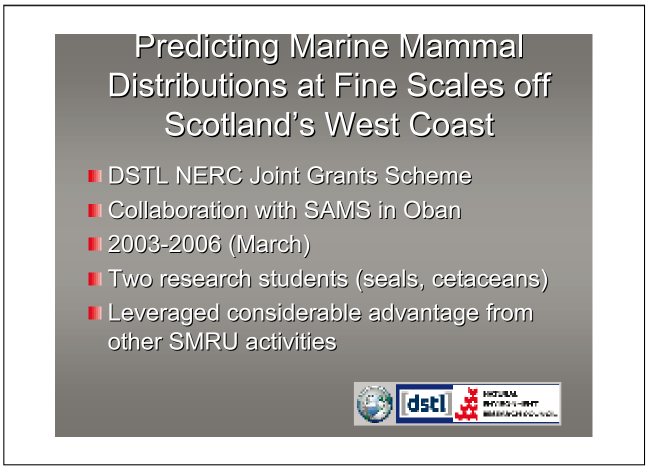

Results of these surveys are usually analysed using DISTANCE software (developed by CREEM) to provide estimates of total abundance.
However, they can be used with more sophisticated statistical techniques to provide detailed spatial information.
Density of harbour porpoise schools


In this case, water depth was the best predictor of porpoise density. Analysis conducted by Louise Burt (CREEM)

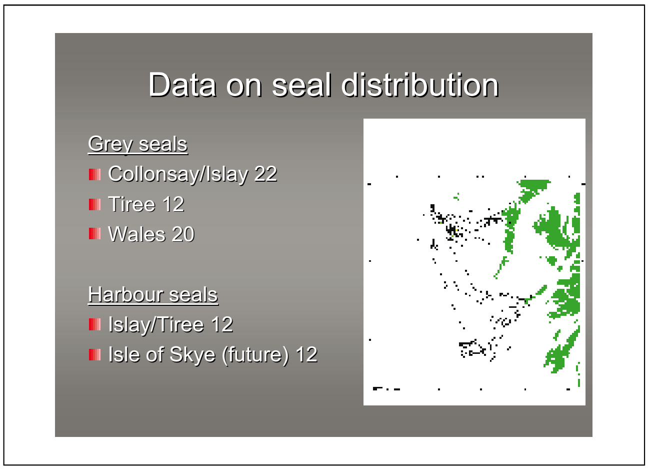

The same approach can be applied to other data, eg Antarctic humpback whales

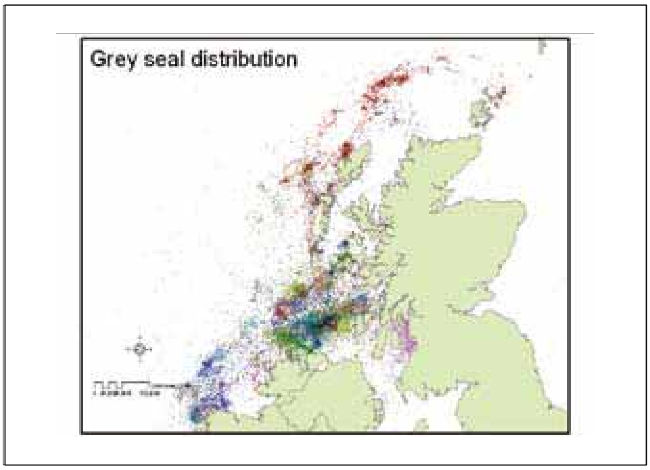

Analysis by Sharon Hedley and David Borchers for
IWC/CCAMLR indicated that best predictors were
Water density at 300m depth
Temperature at 100m depth
Latitude
Longitude
Krill density

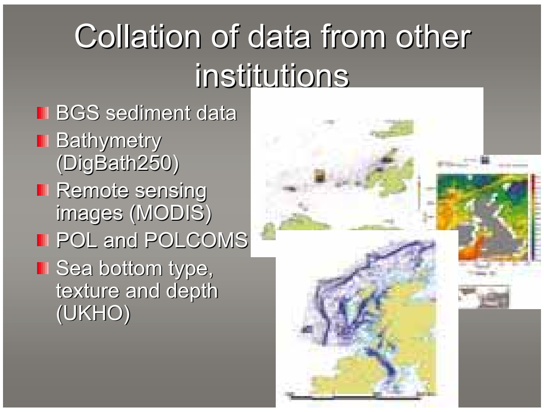

OBIS-SEAMAP
Ocean
Biogeographic
Information
System -Spatial
Ecological
Analysis of
Megavertebrate
Populations
(OBIS-SEAMAP)
http://obismap.en
v.duke.edu/
Profiles of 193
marine mammal,
seabird & turtle
species are
available

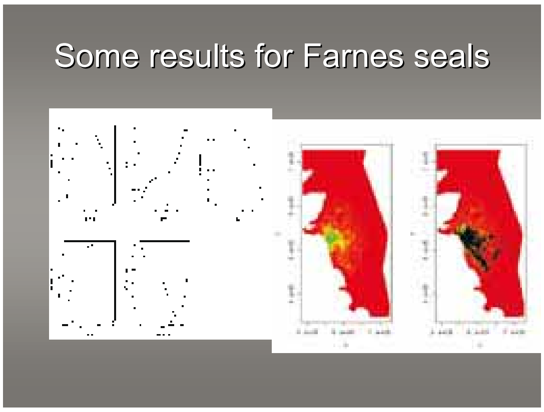

Predicting Marine Mammal
Distributions at Fine Scales off
Scotland's West Coast
DSTL NERC Joint Grants Scheme
Collaboration with SAMS in Oban
2003-2006 (March)
Two research students (seals, cetaceans)
Leveraged considerable advantage from
other SMRU activities
dstl

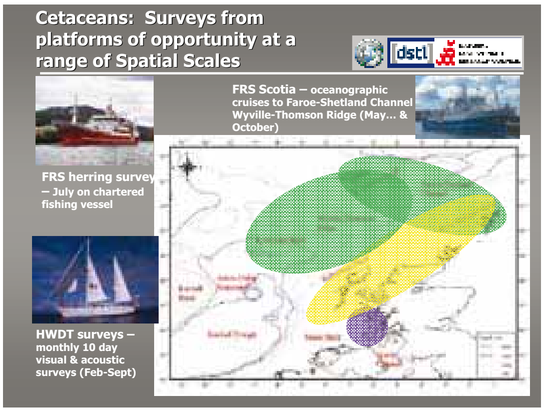

Grey seal with Argos Satellite Relay DataLogger (SRDL)


Data on seal distribution
Grey seals
Collonsay/Islay 22
Tiree 12
Wales 20
Harbour seals
Islay/Tiree 12
Isle of Skye (future) 12

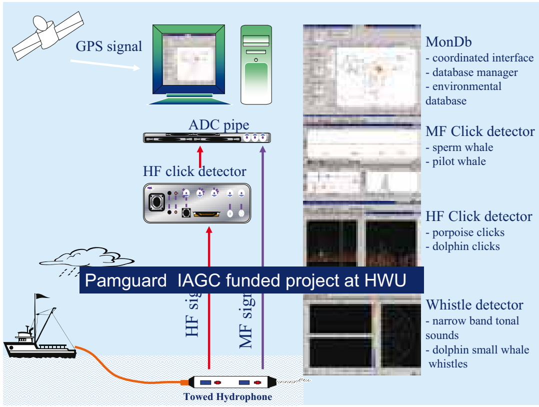

Grey seal distribution

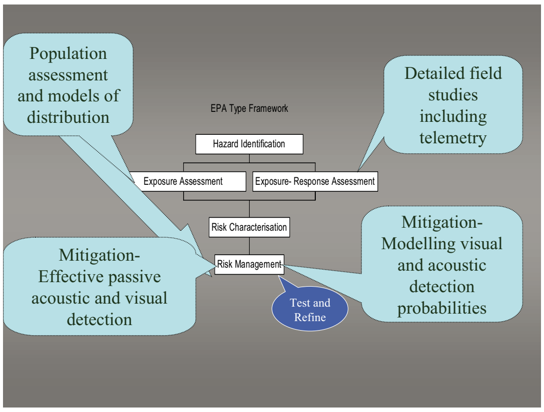

Collation of data from other institutions
BGS sediment data
Bathymetry (DigBath250)
Remote sensing images (MODIS)
POL and POLCOMS
Sea bottom type, texture and depth (UKHO)


Some results for Farnes seals


Cetaceans: Surveys from platforms of opportunity at a range of Spatial Scales
dstl
FRS Scotia – oceanographic cruises to Faroe-Shetland Channel Wyville-Thomson Ridge (May... & October)
FRS herring survey – July on chartered fishing vessel
HWDT surveys – monthly 10 day visual & acoustic surveys (Feb-Sept)

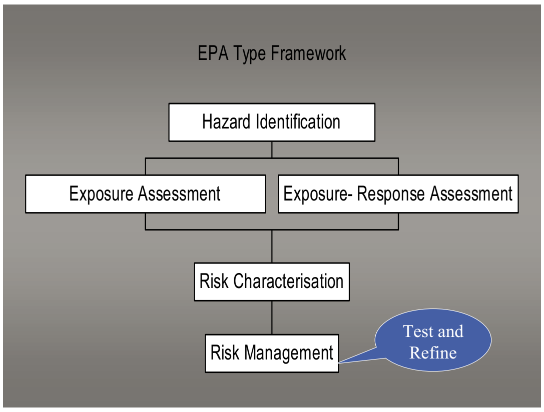

Scotia oceanographic cruise – Passive Acoustic Monitoring
dstl
USB-serial connection to GPS
Quattro sound card
Depth panel
VHF receiver for sonobuoys
Audio amplifier
Porpoise detector boxes

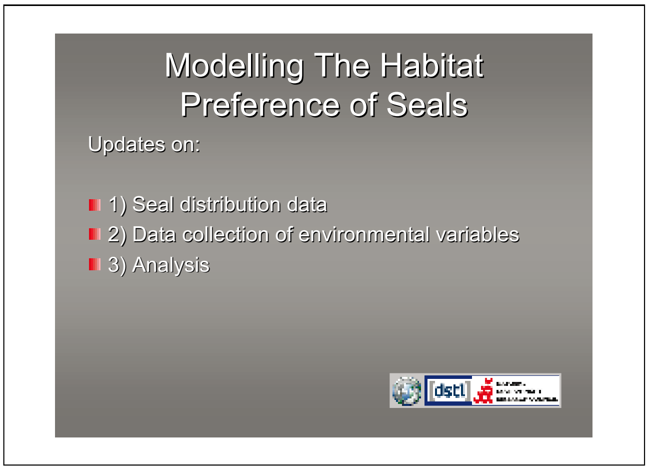

GPS signal
ADC pipe
HF click detector
Pamguard IAGC funded project at HWU
Towed Hydrophone
MonDb
- coordinated interface
- database manager
- environmental database
MF Click detector
- sperm whale
- pilot whale
HF Click detector
- porpoise clicks
- dolphin clicks
Whistle detector
- narrow band tonal sounds
- dolphin small whale whistles

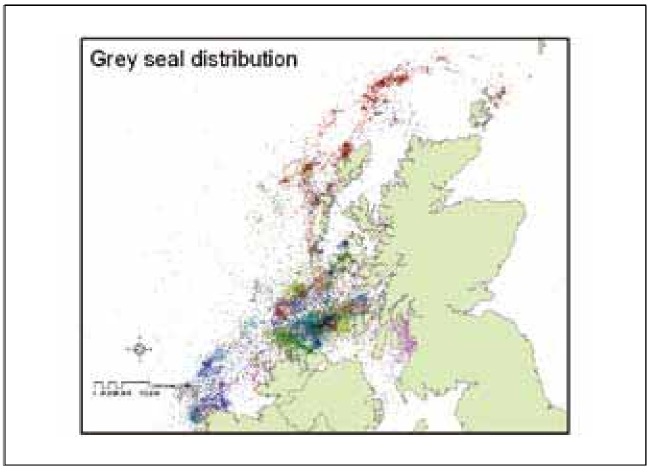

Population assessment and models of distribution
Detailed field studies including telemetry
EPA Type Framework
Hazard Identification
Exposure Assessment
Exposure- Response Assessment
Risk Characterisation
Risk Management
Test and Refine
Mitigation- Effective passive acoustic and visual detection
Mitigation- Modelling visual and acoustic detection probabilities

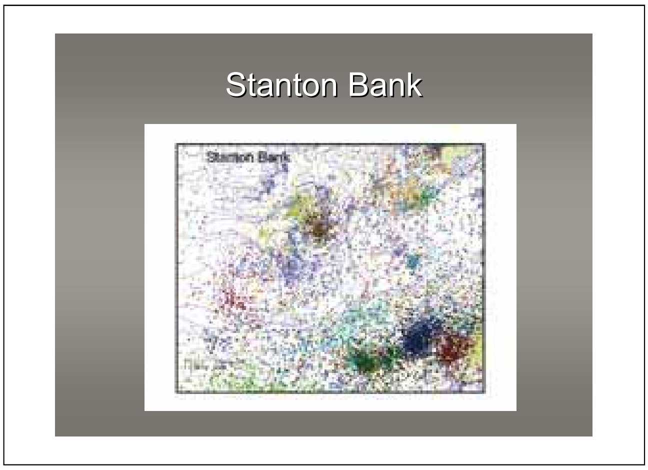
What about distribution in the water column?

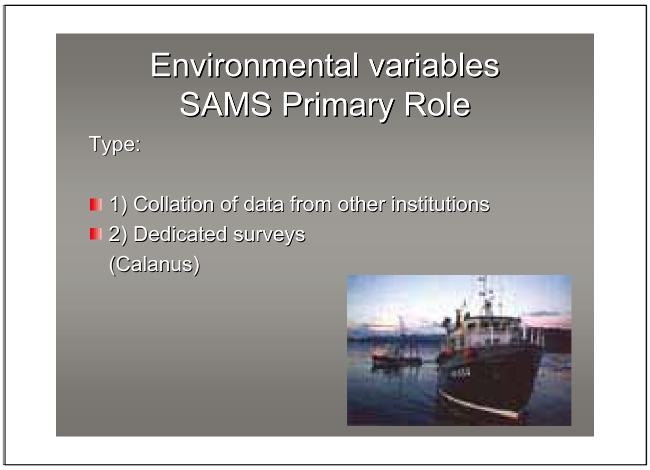
- Telemetric studies of individual animals
- VHF and archival tags provide large amounts of detailed information over short time periods
- Satellite-linked data loggers provide limited amounts of data (including location) over longer time periods

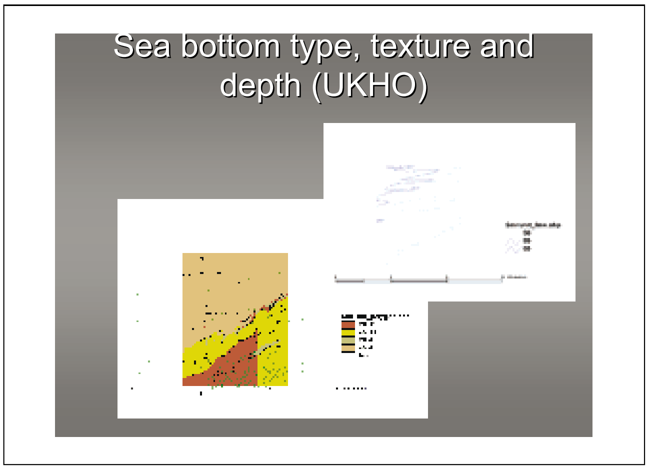


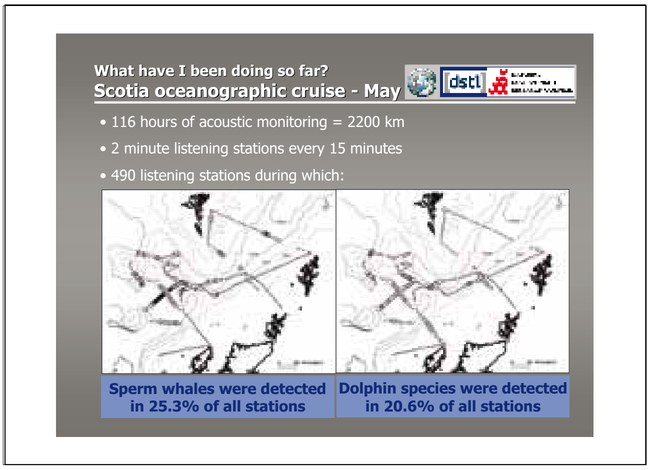

Modelling The Habitat Preference of Seals
Updates on:
1) Seal distribution data
2) Data collection of environmental variables
3) Analysis
dstl

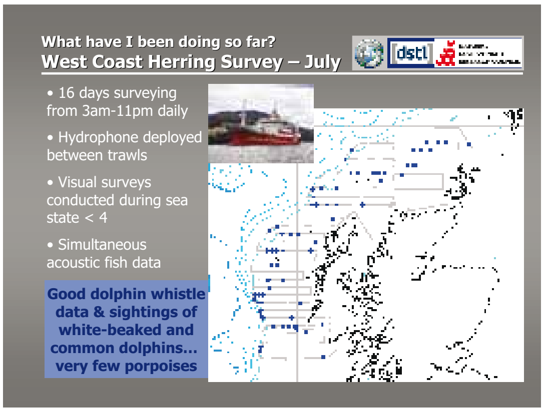

Grey seal distribution

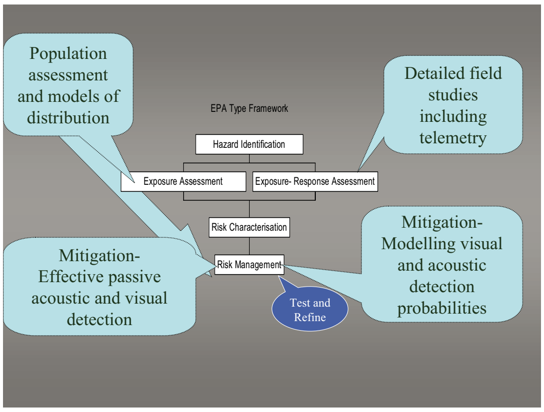

Stanton Bank
Stanton Bank


Environmental variables SAMS Primary Role
Type:
1) Collation of data from other institutions
2) Dedicated surveys
(Calanus)


Sea bottom type, texture and depth (UKHO)


What have I been doing so far?
Scotia oceanographic cruise - May
dstl
• 116 hours of acoustic monitoring = 2200 km
• 2 minute listening stations every 15 minutes
• 490 listening stations during which:
Sperm whales were detected in 25.3% of all stations
Dolphin species were detected in 20.6% of all stations


What have I been doing so far?
West Coast Herring Survey – July
• 16 days surveying from 3am-11pm daily
• Hydrophone deployed between trawls
• Visual surveys conducted during sea state < 4
• Simultaneous acoustic fish data
Good dolphin whistle data & sightings of white-beaked and common dolphins… very few porpoises


Population assessment and models of distribution
Detailed field studies including telemetry
EPA Type Framework
Hazard Identification
Exposure Assessment
Exposure- Response Assessment
Risk Characterisation
Risk Management
Mitigation- Effective passive acoustic and visual detection
Mitigation- Modelling visual and acoustic detection probabilities
Test and Refine

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DFG

FCT
Fundação para a Ciência e a Tecnologia

FNRS

FWO

H.C.M.R

Helmholtz Gemeinschaft

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Ifremer

Institute of Marine Research
Havforskningsinstituttet

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