



**Position Paper 13** 

# The effects of anthropogenic sound on marine mammals

A draft research strategy

June 2008





# Marine Board-ESF

The increasing interdependence of marine research policies and programmes at national and at European levels, as well as the rapidly changing environment of European marine sciences, call for a new approach to the development of European research strategies. To this end, the Marine Board, established in 1995 by its Member Organisations, to facilitates enhanced coordination between the directors of European marine science organisations (research institutes, funding agencies and research councils) and the development of strategies for marine science in Europe. The Marine Board operates within the European Science Foundation.

As an independent non-governmental advisory body, the Marine Board is motivated by, and dedicated to the unique opportunity of building collaboration in marine research. The Marine Board develops insight, recognising opportunities and trends, presenting compelling and persuasive arguments that shape the future of marine research in Europe.

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- Provides insights necessary to transfer research to knowledge for leadership and decision making;
- Develops foresight initiatives to secure future research capability and to support informed policy making;
- Places marine research within the European sociopolitical and economic issues that profoundly affect Europe.

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- Forum: Bringing together 27 marine research organisations (four of which are new associated members) from 19 European countries to share information, to identify common problems and, as appropriate, find solutions, to develop common positions, and to cooperate;
- **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:
- Synergy: Fostering European added value to component national programmes, facilitating access and shared use of national marine research facilities, and promoting synergy with international programmes and organisations.

# 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 subquestions 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 re-

sulted 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.

lan 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.

thropogenic 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 uncertainty¹. 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.

The arguments about the issue of how and why an-

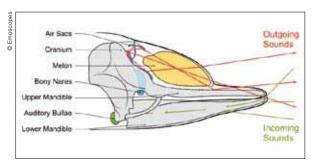


Figure 2. Schematic diagram of sound production and reception in a toothed whale

<sup>1.</sup> 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, interinstitutional 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

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Figure 3. Students dissecting a stranded whale

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.

# 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.

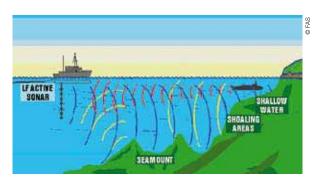


Figure 5. Schematic representation of Low Frequency Active Sonar (LFAS)

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-

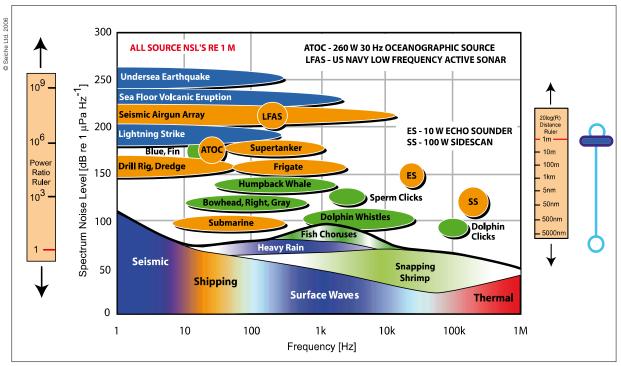


Figure 4. Noise levels and frequencies of anthropogenic and naturally occurring sound sources in the marine environment

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

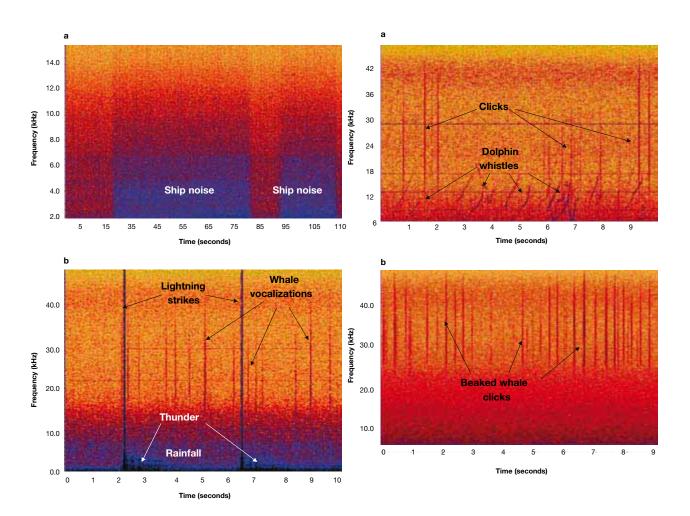


Figure 6. Spectrograms of (a) man-made sound and (b) natural sound. The man-made sound is ship noise where the ship ran its engines intermittently. The natural sounds show two lightning strikes, heavy rainfall, thunder and the sounds of whales vocalizing.

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 knowledgebased 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/repquide/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
- 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.

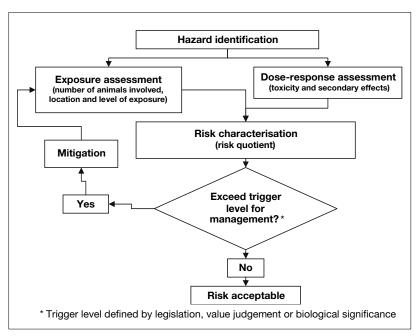


Figure 8. Illustration of the information flow and decision pathway for a risk assessment process. This shows a feedback process involving mitigation when the risk exceeds the trigger level for management action. This is an adaptive approach to managing risk.

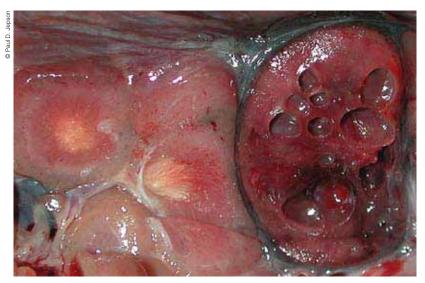


Figure 9. Common dolphin kidney with gas embolism: normal (left) and abnormal (right) kidney lobes. This particular common dolphin stranded singly and it is not known if the dolphin was exposed to sonar (or other high-intensity man-made sound source). There are at least two hypothetical mechanisms for 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	Marine mammals as receivers of	Distribution and abundance of marine mammals (including vertical)	High
(both long- and short-term)	sound	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 rates1. 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.

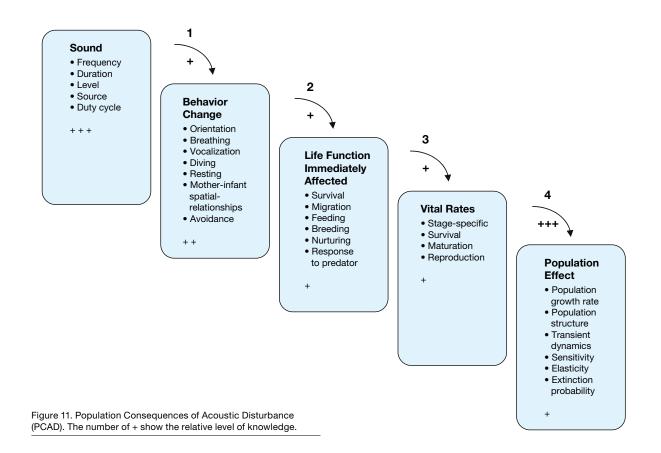


Figure 10. There can be a large overlap between human activities at sea and habitats that are vital for marine mammals

### 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.

<sup>1. &</sup>quot;Vital rates" are the factors that determine the rate of growth of a population, such as the reproductive, survival and immigration and emigration rates



#### 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:

- 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 midfrequency sonars to beaked whales? (See Table
- 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 subquestions.

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

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.

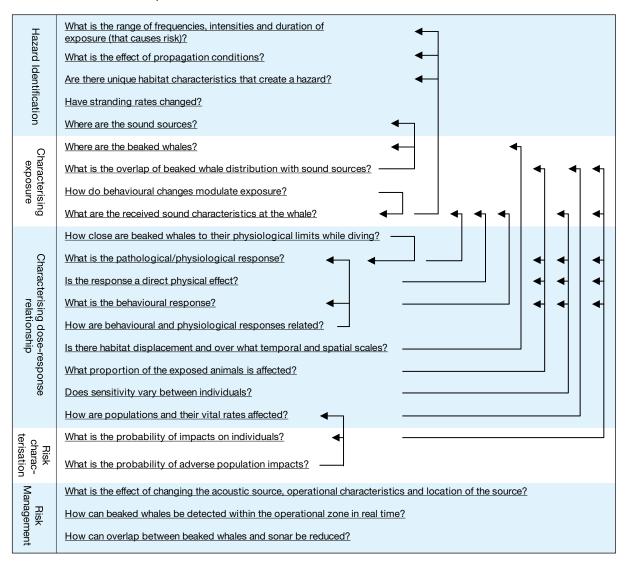


Table 5. Research sub-questions addressing the higher-level question "what are the effects of seismics on individuals and populations?" Arrows between sub-questions indicate the result of the analysis of the dependencies between the different sub-questions.

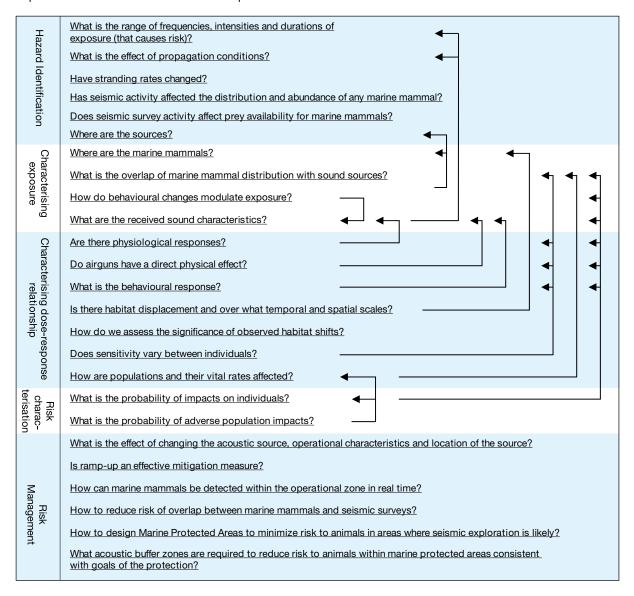
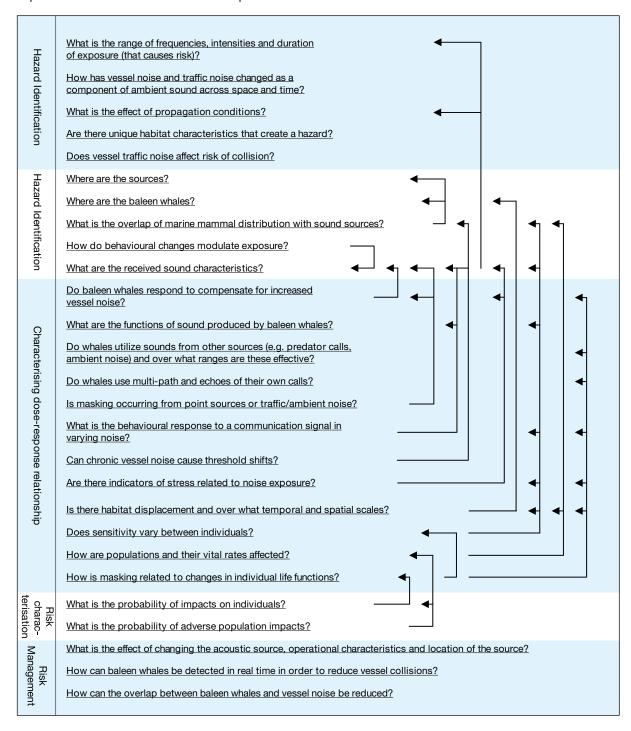


Table 6. Research sub-questions addressing the higher-level question "what is the interaction of shipping traffic noise with baleen whales?" Arrows between sub-questions indicate the result of the analysis of the dependencies between the different sub-questions.



# 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

# **Implementation**

#### 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.



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 frame-

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 shortterm research projects leads to answers that could only otherwise be achieved through long-term strategic re-

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 subquestions 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
- 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.
- 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.

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# 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, 8<sup>th</sup> March 2003, European Cetacean Society Newsletter, No. 42. Special Issue. 79 pp.

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

Arne Bjørge	Institute of Marine Research	Norway
Olaf Boebel	Ifred Wegener Institute for Polar and Marine Research	Germany
lan 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

lan 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
Paul Jepson	Institute of Zoology, London	UK
Patrick Miller	Sea Mammal Research Unit, University of St Andrews	UK
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

#### 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</li>Medium: \$US 50-500,000High: > \$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
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?	•	•••	•••	•••
III Empirical measurements of sound field and modelling     What is the effect of propagation conditions?     Survey of historical data sets in presence/absence of naval exercises     Survey of historical data sets in presence/absence of naval exercises     Modelling and measurement of sound fields under varying propagation conditions (surface duct, reverberation, other)     Responses of an instrumented animal in context of sonar in alternate propagation conditions     Are there unique habitat characteristics that create a hazard?     Survey of historical data sets with varying coastal characteristics and ship tracks     Responses of an instrumented animal to varying coastal characteristics and ship tracks     Responses of an instrument of sound fields in varying coastal characteristics and ship tracks     Responses of an instrument of sound fields in varying coastal characteristics and ship tracks     Responses of an instrument of sound fields in varying coastal characteristics and ship tracks	•	•••	••••	•
ii Responses of an instrumented animal to varying coastal characteristics and ship tracks iii 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 iii Modelling and measurement of sound fields in varying coastal characteristics and ship tracks		•••	••••	•••
i Epidemiological analysis of historical data on strandings and sonar usage  Where are the sound sources?  i Ask the navies  ii Ocean observing systems	••	•••	•••	•••
Where are the beaked whales?  i Surveys (acoustic or visual) throughout year and all oceans  ii Peneralise divide behavior of the property of the peneralise includes the pene	•••	•	•••	•••
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	•••	•••	•••	•••
in Recording driving behaviour (instantiance) entire Uses value (in Secondary Control	•••	•••	•••	•••
What are the received sound characteristics at the whale?  i Instrumented animal  ii Hydrophone(s)	•••	•••	::	•••
iii Model  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  What is the pathological/physiological response?	●●● dep	•••	::	•
i Necropsy/Pathology/Biopsy of stranded/newly dead/injured/live animals (compare presence/absence of sonar) ii In vitro tissue experiments (e.g. nitrogen saturation) iii Physiological tags (e.g. samples at short intervals) iv Measure nitrogen saturation	dep	•••	•••	•••
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  Experiments and modelling with surrogate species  What is the behavioural response?  What is the behavioural response?  ii Measure changes in behaviour in presence/absence of sonar with tags, visual observation acoustic means  ii AUVs  ii Experiments and modelling with surrogate species  How are behavioural and physiological responses related?  i Combine/integrate above approaches  ii Modelling  ii Sthere 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	••	•••	•••	•
U 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	•••	••	•	•
The properties of the proper	•••	•	•	dep
Is there habitat displacement and over what temporal and spatial scales?   Photo ID	••	••	••	••
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  What is the probability of impacts on individuals	•••	••	••	•••
what is the probability of impacts of 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	•••	•••	•••	•••
i' iii Models that integrate exposure and changes of population parameters  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 cha 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.	nges	••••	:	•••
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  ii Test effectiveness of visual observations  v Test effectiveness of ridar  v Test effectiveness of ridar  vi Test effectiveness of infra-red  vi Test effectiveness of infra-red	•	•••	•••	•
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

	cored as "high" (three dots), "medium" (two dots) and "low" (one dot). "dep" signifies that ore depends of the species or circumstances.	Biologica significar	Financial	Cost to a	Effectiver
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	••	••	•	••
ntif	Has seismic activity affected the distribution and abundance of any marine mammal?  i Analysis of historical distribution data and seismic activity	•	••	•	•
cati	Does seismic survey activity affect prey availability for marine mammals?  i Analysis of fishery survey and catch rates with respect to seismic activity	•	••	•	••
ion	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  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	••	•••	:	•••
င္က	iii Recording diving behaviour (instrumented animals, remote observation incl. acoustics)	•••	••	••	•••
Characterizing exposure	iv Recording movement data (long-term telemetry, photo id, focal follow) v Habitat utilisation models (based on data from surveys; telemetry; past catch data)	•••	••	•••	••
teriz	vi Stranding and haulout data  What is the overlap of marine mammal distribution with sound sources?	•	•	•	••
zing	i Combine output above two approaches using geospatial and temporal model  How do behavioural changes modulate exposure?	•••	•	•	•••
ex	i Instrumented animals ii Acoustic tracking in three dimensions	••	••	••	••
soq	iii Visual behavioural observation	••	•	•	••
ure	What are the received sound characteristics?  i Instrumented animal  ii Hydrophone(s)  iii Modelling received sound characteristics	•••	•••	••	•••
	Are there physiological responses?				
	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	•	••	•••	::
င္က	Do airguns have a direct physical effect?  i Determine threshold of direct acoustic trauma	••	••	•	•••
arac	ii Model threshold of direct acoustic trauma iii Experiments and modelling with surrogate species	•	•	•	••
teri	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	•••	•••	••	•••
Characterizing dose-response relationship	What is the behavioural response?  i Measure changes in behaviour in presence/absence of seismics with tags, visual observation acoustic means  if Experiments and observations with model species selected as vulnerable and use of surrogate species where endangered species are concerned	•••	•••	••	•••
ose	Is there habitat displacement and over what temporal and spatial scales?	••	••	••	dep
<u>-</u>	i Photo ID ii Satellite tags	••	••	•••	•••
spo	iii Survey and monitoring (visual and acoustic) iv Genetics	••	••	••	●● dep
nse	v Voices of animals (dialects) vi Dietary assessment/ parasite fauna	•	dep	● dep	•
<u>6</u>	How do we assess the significance of observed habitat shifts?	••	•••	dep	•••
atio	i Compare reproductive behaviour in both habitats (those animals remaining and those shifting and /or pre- and post-shift) ii Compare foraging rates in both habitats (those animals remaining and those shifting and/or pre- and post-shift)	•	•••	•	•••
nsh	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?	••	••	••	•••
ਰੋਂ:	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	•••	••	••	•••
_: 앜	What is the probability of impacts on individuals  i Models that integrate exposure and response of individuals	•••	•	•	••
Ris nara izati	ii Models that integrate exposure and response of prey species  What is the probability of adverse population impacts?	••	•	•	••
Risk haracter- ization	i Define extent of population     ii Extrapolate individual models to populations     iii Models that integrate exposure and changes of population parameters	•••	••	••	•••
	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?	-			-
	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	•	•••	••	•••
끖	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 iii Test effectiveness of visual detection	dep ●●	••	•	••
nan	v Test effectiveness of Radar	•	••	•	••
age	vi Test effectiveness of infra-red	•	•••	•	••
Risk management	wil Test effectiveness of aerial / satellite imagery  How to reduce risk of overlap between marine mammals and seismic surveys  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	•	••	•	•••
	iii Studies of response/vulnerability as listed above iv Habitat characterization modelling		•	•	•••
	IN 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				

able 3. Research questions and approaches addressing the higher-level question "what the interaction of shipping traffic noise with baleen whales?" Under each category, an opproach 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	Financial cost	Cost to animal	Effectiveness	Feasibility
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	••	•	•	•••	•••
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	•	•	•	•••	•••
<ul> <li>ii Analysis of historical data on source characteristics, shipping trends and ambient noise levels</li> <li>What is the effect of propagation conditions?</li> </ul>	•	•	•	••	••
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?  ii Nurvey 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 Medelling and measurement of count fields in varying negetal pharacteristics, whip tracks and marine mammal distributions	•••	•	•	••	•
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	••	•	•	•••	•
- If wodeling and measurement of sound fields in varying coastal characteristics, ship tracks and marine marinial 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	••	••	•••	•••	•••
Where are the sources? i Shipping company databases, vessel monitoring systems and logs	•	•	•	•••	•••
ii Ocean observing systems Where are the baleen whales?	N/A	•••	•	•••	•••
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 Surveys (acoustic or visual) throughout year and all oceans in 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 v Typify behavioural states and relate to exposure v Visualt behavioural observation	••	••	•	•••	•••
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  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	•	•	•	••	••
Sulfan of only accounts					
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?	_		••	1	
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				•••	
i 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?				•	
Long-term studies of identified individuals (multiple techniques) in different noise conditions     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  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?	•••	•	•	•••	•••
what is the probability of impacts on individuals    Models that integrate the exposure and response of individuals   What is the probability of adverse population impacts?   Models that integrate exposure and response of individuals   Extrapolate individual models to populations   Models that integrate exposure and changes of population parameters	•••	••	••	•••	••
iii Models that integrate exposure and changes of population parameters  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	••	•••	•	•••	•••
iii Experimental variation in source acoustics/operation/location and monitor response	•	••	••	••	•
ii Modelling informed by the above ii 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 iii Visual iii Radar iv Infra-red		••		•••	••
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







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

#### Sept 27<sup>th</sup>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 Topic 1: 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 Topic 2: 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 Topic 3: 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 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?

Presentation (C. Burt, Naval Systems UK; R.Rogers QinetiQ) - 20

The Royal Navy Environmental Research Programme Discussion - lead: Hastings plus C. Burt.

#### 12:50 Lunch Break

13:50 <u>Topic 5</u>: 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 <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?

**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.

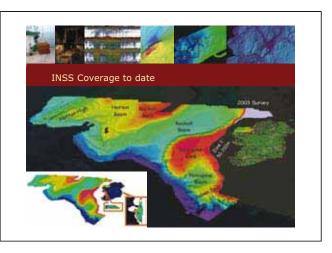
All cetacean species in Irish waters are protected by the 1976 Wildlife Act (and Wildlife Amendment Act 2000). Irish waters, including the EEZ were declared a whale and dolphin sanctuary in 1991. All cetacean species are also protected under the EU Habitats Directive 92/43/EEC Article 12 and the harbour 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.

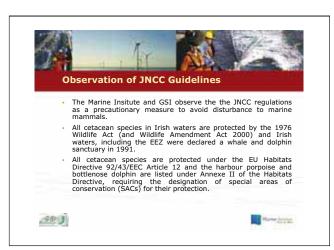
Currently the waters covered by the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) do not extend to Irish waters and Ireland is not a signatory. However it is expected that offshore operators carrying out seismic surveys have due regard for the aforementioned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

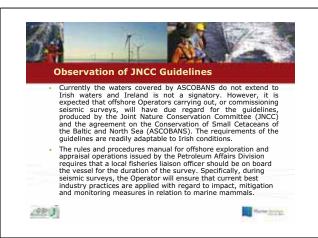
During the Irish National Seabed Survey (INSS) and seismic surveys the Irish Whale and Dolphin Group are invited by the Marine Institute to place an observer on board the Celtic Explorer. Observers are required to oversee the implementation of JNCC guidelines along with providing a report detailing sightings, 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.

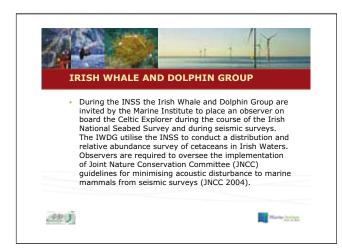
During the INSS surveys a 'soft start' procedure has been established to allow mammals to move away from the area. Prior to beginning operations within an SAC the Marine Institute were notified that it would be prudent to avoid surveying within the area due to presence of calving dolphins within the 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.















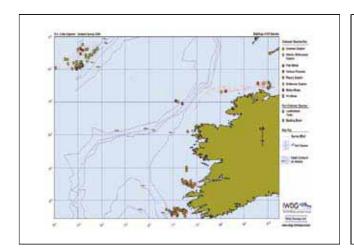


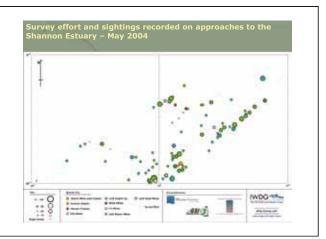








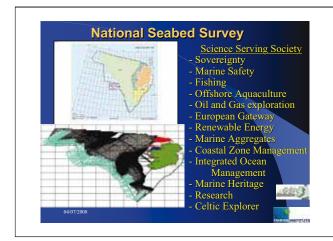


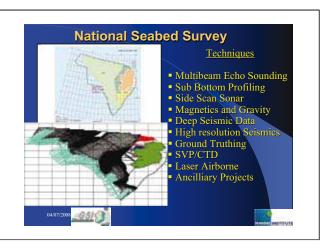






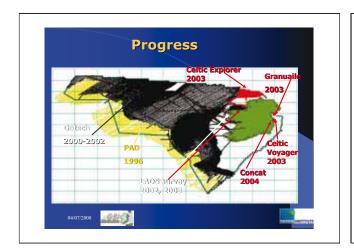


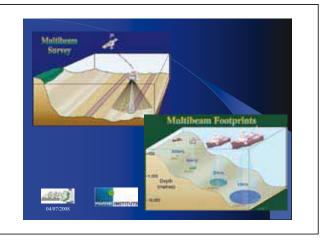


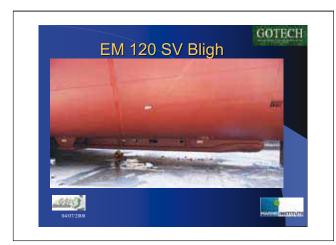


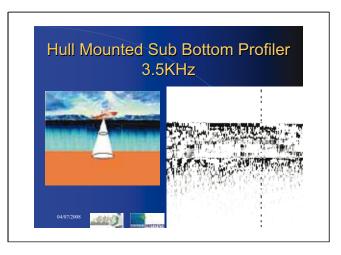


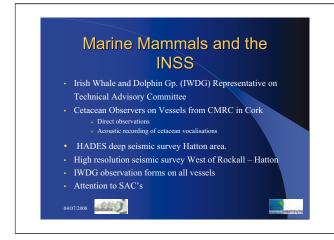


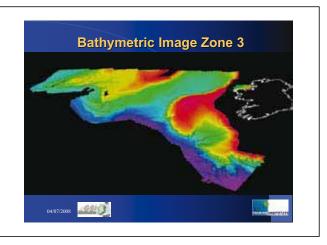


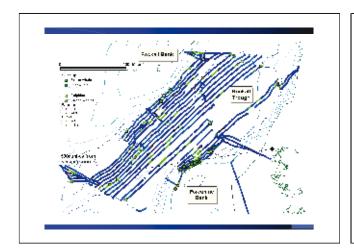


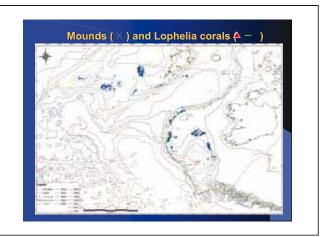


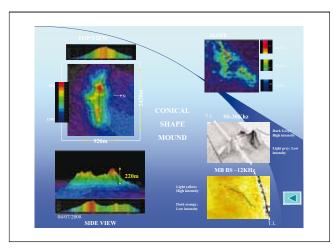




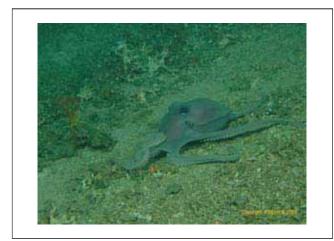




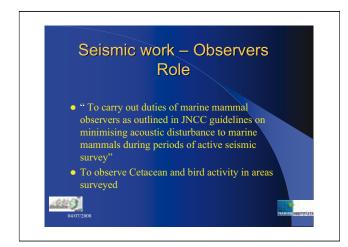




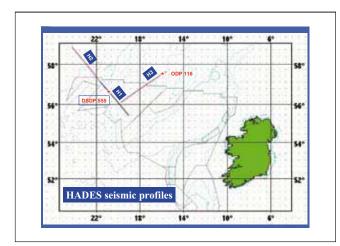


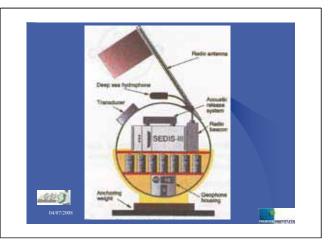


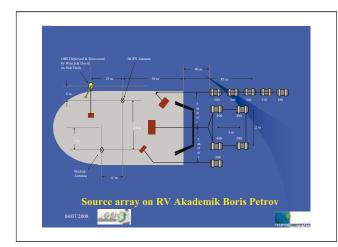


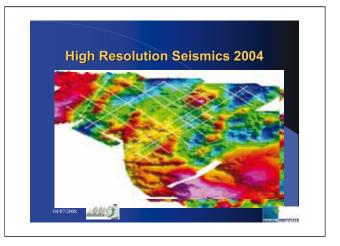


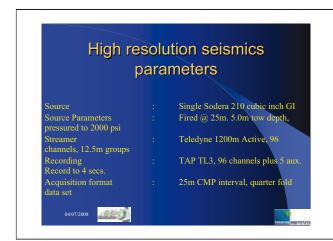






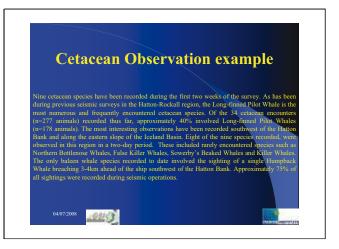


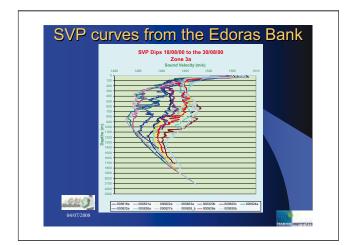




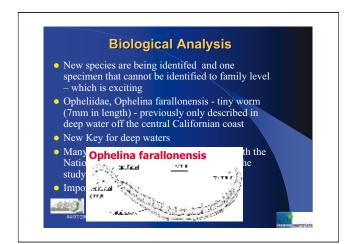


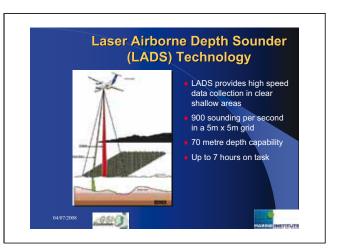
## Pre-soft Start Observations. The guidelines for minimising acoustic disturbance to marine mammals during seismic surveys, devised by the JNCC, have been adhered to throughout the survey. Specific 360° scans for cetaceans were conducted around the vessel for 30 minutes before all soft-start seismic 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 been incurred during the current survey. 04/07/2008

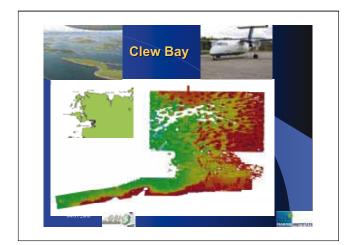


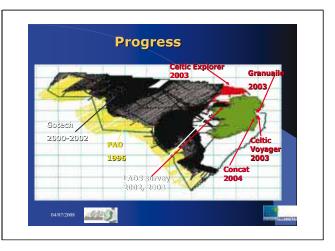












#### Topic 2: Recent results relating acoustics to marine mammal strandings and how these are being interpreted by government and other officials in respective countries

#### 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 midfrequency 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  $\mu$ Pa 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  $\mu$ Pa. 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  $\mu$ Pa (Nowacek et al. 2004)

#### References

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- D'AMICO A (1998) Summary Record, SACLANTCEN Bioacoustics Panel, La Spezia, Italy, 15-17 June 1998 (available at <a href="http://www.saclantc.nato.int/whales/">http://www.saclantc.nato.int/whales/</a> or at <a href="http://enterprise.spawar.navy.mil/spawarpublicsite/">http://enterprise.spawar.navy.mil/spawarpublicsite/</a>)
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   Special Issue (Feb 2004)
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- 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





Marine Board-ESF and NSF Workshop

Marine Mammals and Acoustic Geo-Surveying Techniques
Sept 27th2004, 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



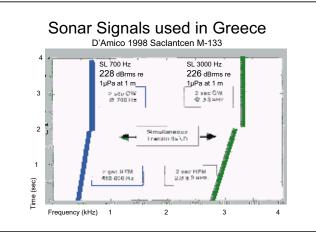
#### Atypical mass stranding events

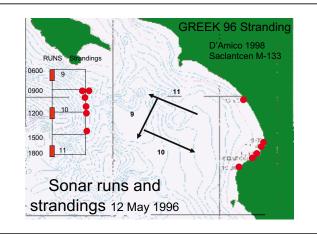


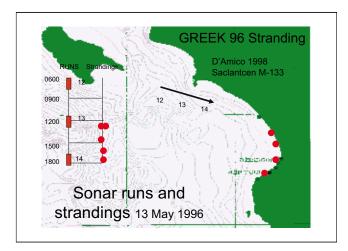
- >10 Beaked whales, especially Ziphius cavirostris and Mesoplodon sp. strand within a few hours in dispersed groupings over tens of km of shore.
- · Reported to coincide with naval maneuvers off Greece (1), Canary Islands (7), Italy (2), Bahamas (1), Madeira (1) [List from MMC Beaked Whale Workshop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

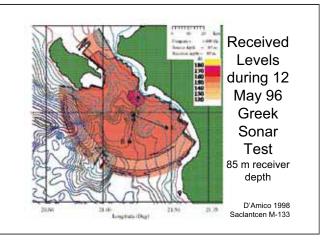
#### Actual acoustic fields only known for two cases: Greece 1996 and Bahamas 2000

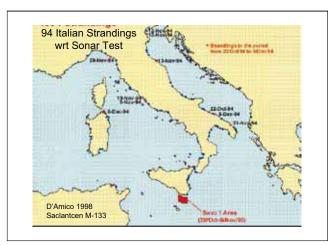
- Greece: NATO sonar exercise. 16 Ziphius strand alive along 30-35 km of coast within hours of sonar transmissions
- · Bahamas: multinational ASW exercise with several ships operating in New Providence channel. 17 cetaceans stranded within 36 hr over 240 km. 7 died (5 Ziphius, 1 Mesoplodon densirostris,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







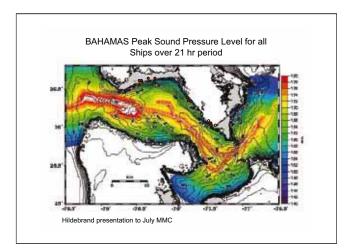


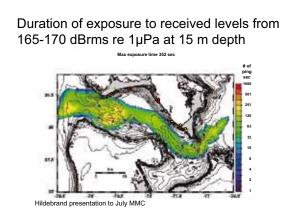


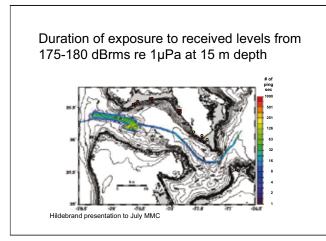


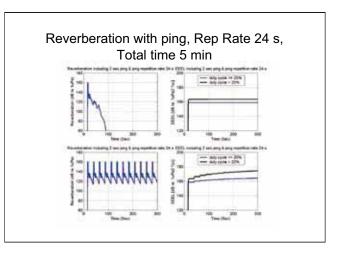
#### Bahamas 15 March 2000

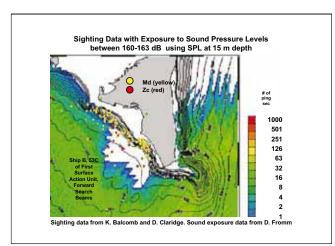
- Naval sonar exercise as ships passed through New Providence Channel near Abaco
- 4 of 5 ships used mid freq sonars - AN/SQS-53C 2.6-3.3 kHz ~235 dB re 1 μPa - AN/SQS-56 6.8-8.2 kHz ~223 dB re 1 μPa
- 17 cetaceans stranded within 36 hr over 240 km. 7 died (5 Ziphius, 1 Mesoplodon densirostris, 1 Stenella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

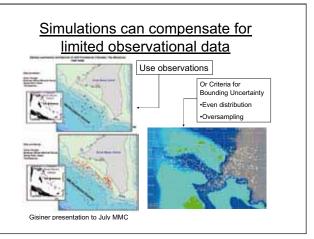








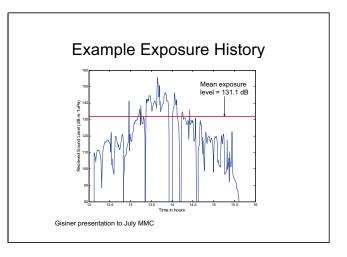




#### **Parameters for Simulations**

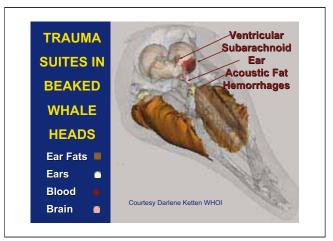
- · Acoustic propagation: e.g. In situ surface duct v. downward refracting
- Distribution Uniform v. Field Data
- · Dive behavior: Normal Diver v. Duct-only
- · Horizontal swim behavior: No aversion to sound level v. Graded aversion to sound level

Adapted from 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)</li>
- Acoustically enhanced bubble growth: function of supersaturation, duration, and intensity. Little risk <190-200 dB re 1 µPa</li>
- 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)

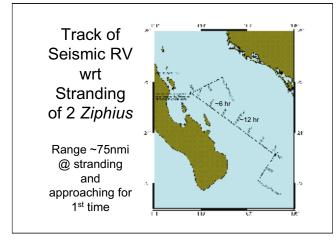
NMFS 2002 Acoustic Resonance Rept; Crum&Mao 1996 JASA; Nowacek et al. 2003 Proc Roy Soc B

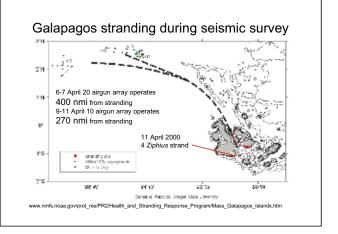
## Other cases of **typical** strandings where association with manmade sound is controversial

- · 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





## Official government interpretations

- US on beaked whales and midfreq 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</li>
- 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 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)

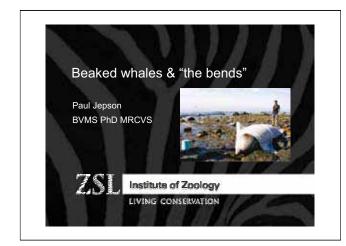
The demonstration of spatio-temporal links between some deployments of active mid-frequency naval sonar and mass cetacean strandings (predominantly involving beaked whales) is now widely accepted to be indicative of cause (sonar) and effect (stranding), although the underlying mechanism(s) have remained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

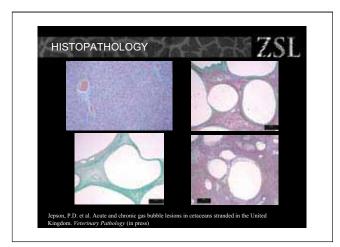
Bubble formation associated with acute and chronic tissue injury has been conclusively demonstrated in some individually-stranded cetaceans in the UK, although the definitive cause of these bubbles has not been established. These pathological findings demonstrate that cetaceans can suffer tissue injury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

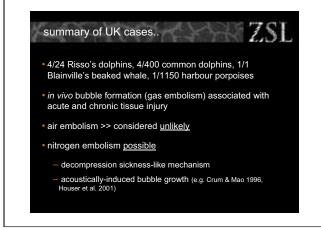
Emerging data from beaked whale dive profiles suggest that these species may be adapted to deep-diving through a combination of slow ascent rates and short surface intervals. There is now a growing scientific consensus that an initial behavioural disruption to normal beaked whale dive profiles (e.g. 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.

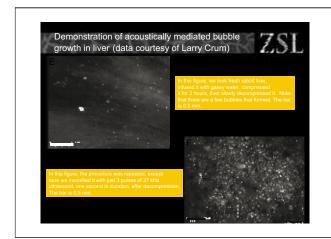
The confirmation of in vivo bubble formation in cetaceans as a mechanism in sonarinduced beaked whale mass strandings, including the quantification of received levels of acoustic sonar activity necessary to trigger a specific and adverse behavioural response, undoubtedly necessitates the adoption of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





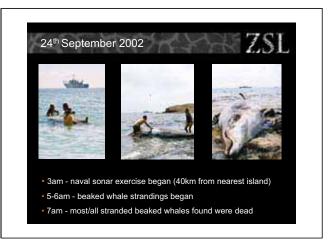






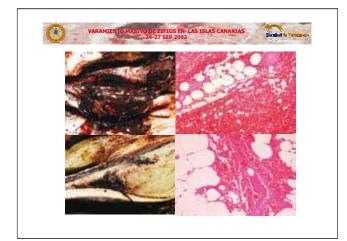
naval sonar-related cetacean mass strandings naval sonar activity linked (spatio-temporally) to numerous cetacean mass strandings events mainly involve beaked whales (esp. Cuvier's beaked whale) • no beaked whale mass strandings recorded prior to 1963 sonar-related mass stranding locations: Bonaire Canary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

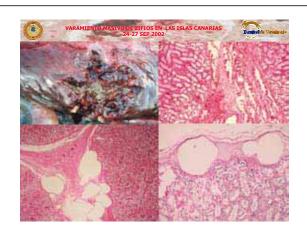


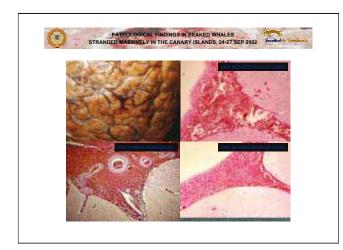


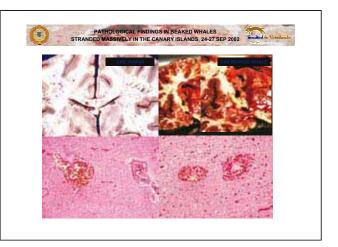


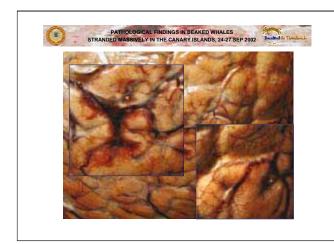


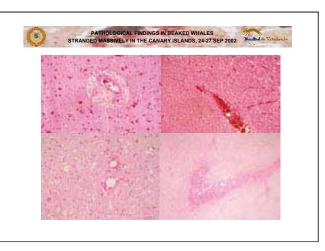


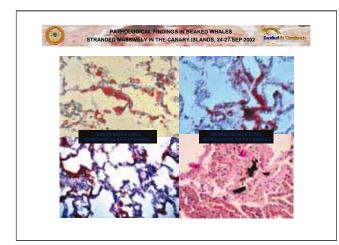


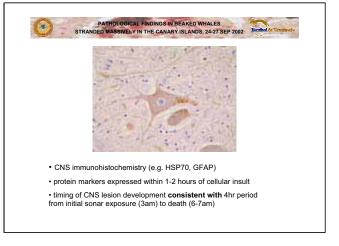




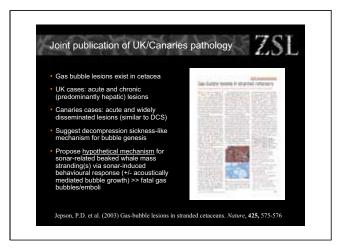


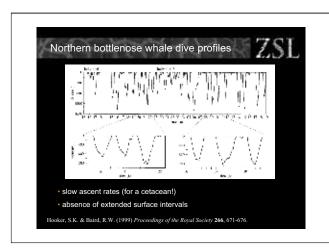


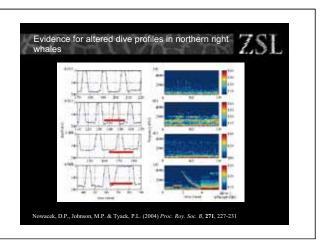












#### Hypothetical mechanism Environmental conditions (e.g. surface ducts) can enhance acoustic • Initial behavioural response to mid-freq. sonar exposure, e.g. accelerated surface ascent extended surface interval >> induce high/excessive levels of nitrogen supersaturation >> predispose/induce bubble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

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

## 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)

# <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?

## 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.











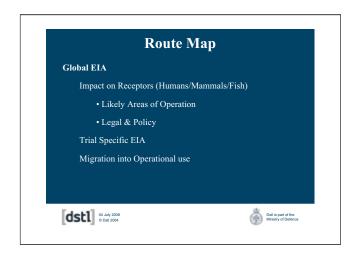




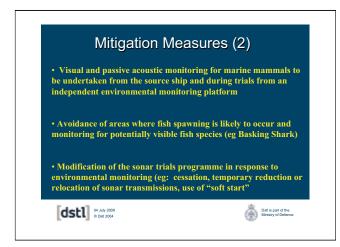


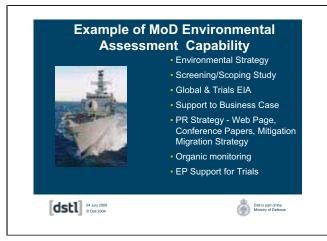






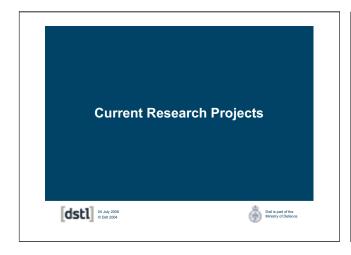


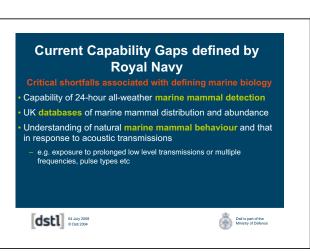














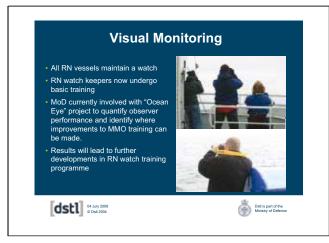


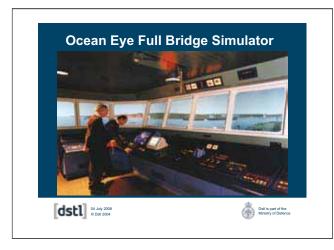
capability

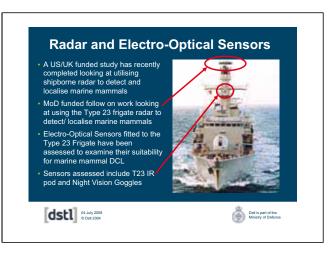




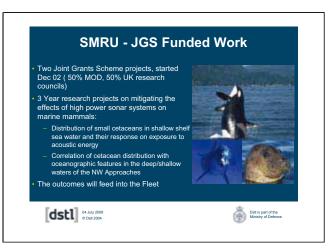








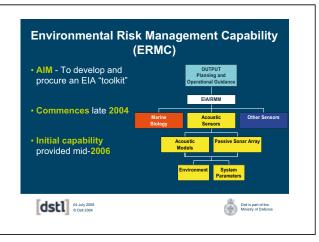












## **ERMC**

- 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







### 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

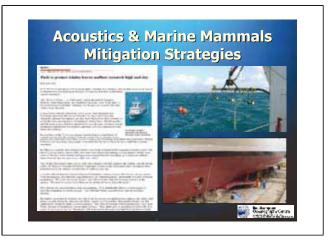
- Deployment of passive acoustic devices is costly both interms of the capital costs of the equipment and the deployment scenarios which may be appropriate especially if this requires use of a separate platform from the source ship.
- Even with advances in software, interpretation of information from 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.

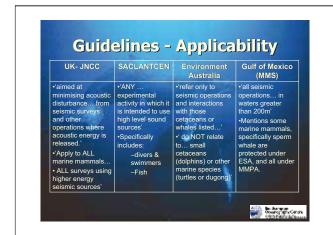
At the most basic level it would clearly be highly desirable to harmonise guidelines, however the variety of these suggest that there is little international agreement on how high the bar should be set and how operational protocols might be rationalised: Unfortunately this is a particularly difficult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

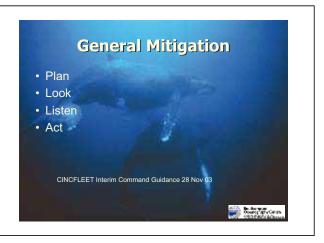






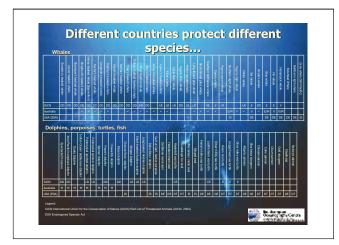


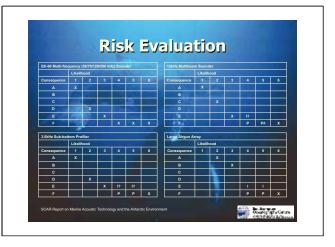


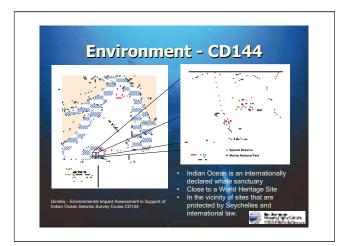


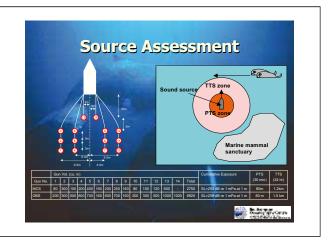


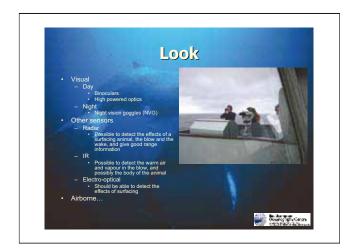




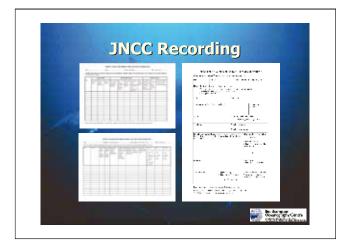


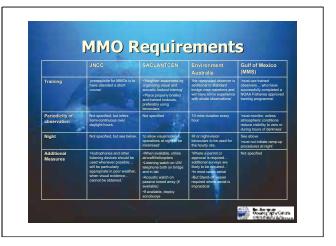


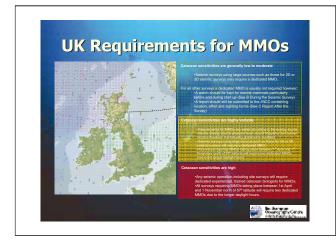


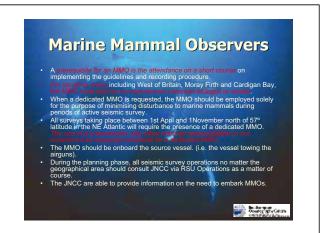




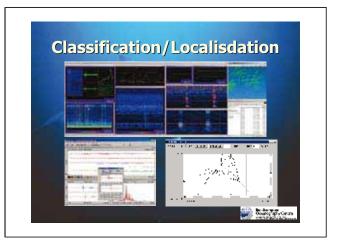


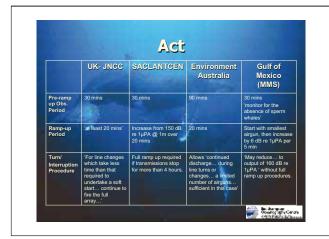


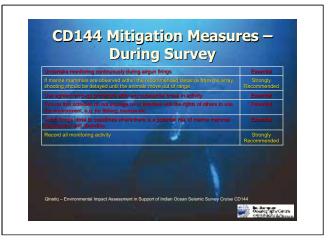




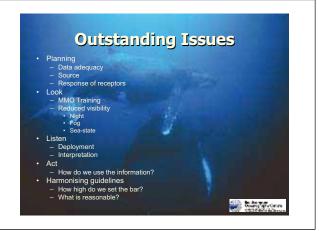


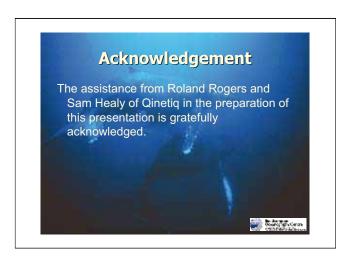






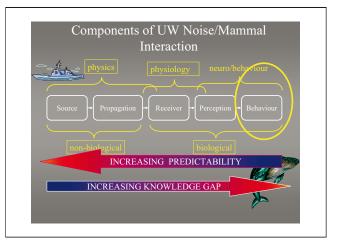


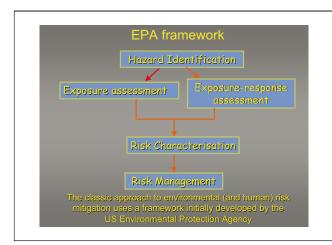


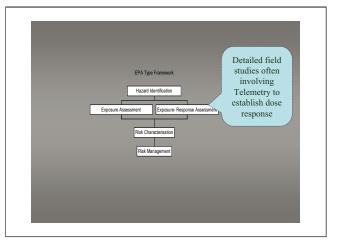


Topic 6: Scientific techniques and results for assessing acoustical
Impacts on marine mammals. How does the science community rate
the impact of acoustics on marine mammals in comparison to other
potential threats to marine mammal populations?
Scientific techniques and results for assessing acoustical
imports on marine memmels marine memmel acquetie
impacts on marine mammals; marine mammal acoustic
research and expertise at SMRU

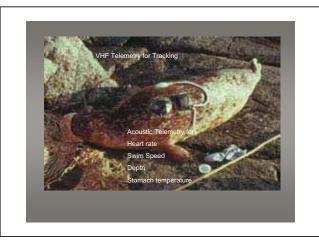


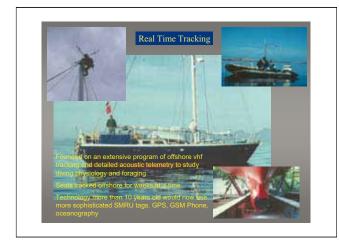




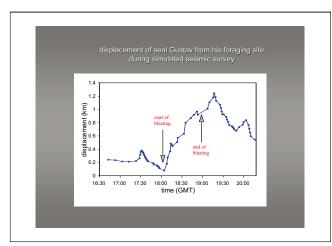


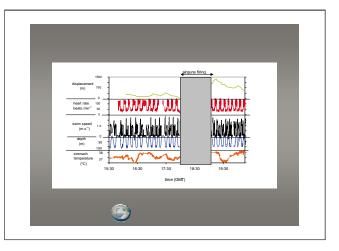
Dose/Response studies using controlled Reactions of harbour seals to seismic airguns Part of the EU funded Brommad project with



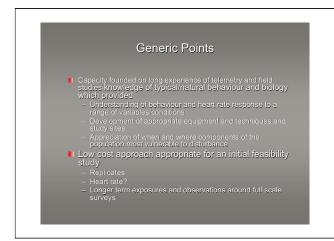




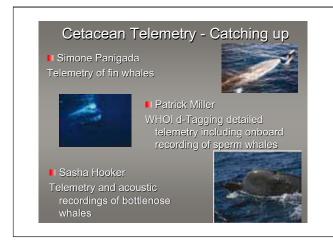


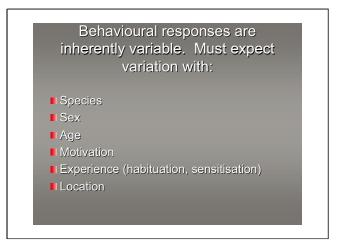


■Intense initial reaction, ■Usually moved rapidly away from source of Complete disruption of foraging behaviour quickly reverted to 'normal' behaviour no apparent avoidance of disturbed areas



# Cetaceans ■ For some species passive acoustic monitoring and tracking can provide useful information on underwater behaviour ■ Telemetry has always been more difficult





# Therefore studies must include sufficient ■ This should be budgeted and planned for ■ May require development of low cost ■ When there is a trade off between fewer simpler (cheaper) ones favour the latter

# Controlled Exposure Experiments Workshop ■ Lessons to be learnt from Ethologists' playback experiments - e.g. Peter Slater's bird communication group

Vincent Janik and coworkers 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

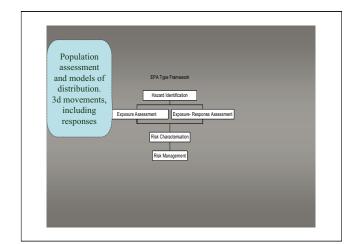
# Controlled Exposure Experiments Workshop: CEE vs Opportunistic

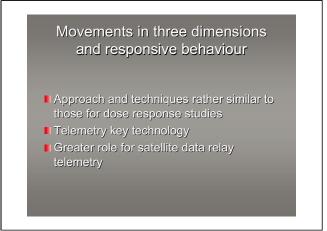
- Opportunistic observations, no concerns about the realism of the "experimental" situation
- Only option for research into long term exposures
- Some full scale noise sources can be prohibitively expensive for a series of experiments involving many replicates

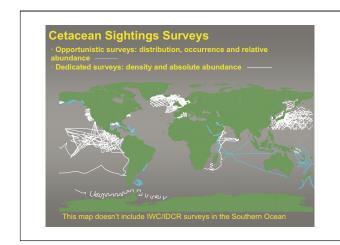


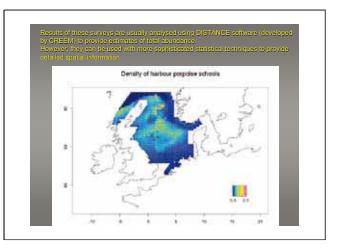
## Exposure Experiments: Final Points

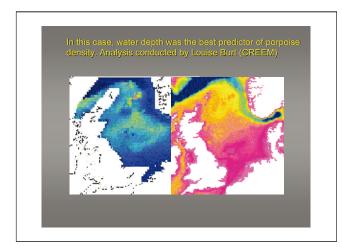
- Protocols to minimise the risk of harm to experimental animals
- Choosing focal animals
  - Precautionary approach would be to choose the mos sensitive – Mothers and calves?
- Need for clarity in defining research questions
  - Address key knowledge gaps
  - Measure biologically significant behaviour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

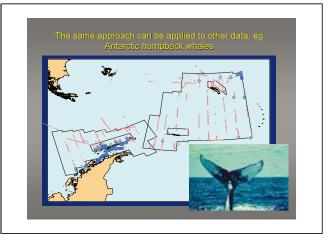


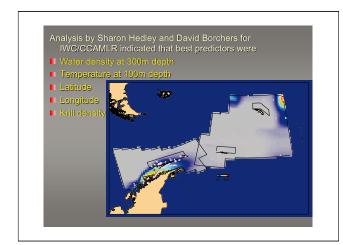












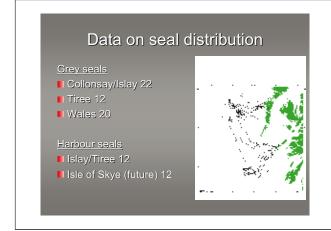


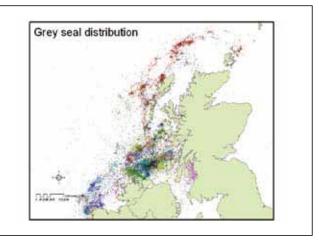
### Predicting Marine Mammal Distributions at Fine Scales off Scotland's West Coast ■ DSTL NERC Joint Grants Scheme ■ Collaboration with SAMS in Oban ■ 2003-2006 (March) ■ Two research students (seals, cetaceans)

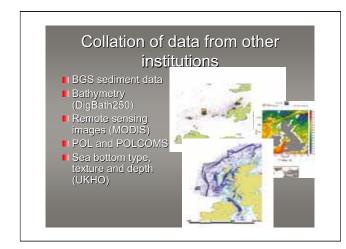
■ Leveraged considerable advantage from other SMRU activities

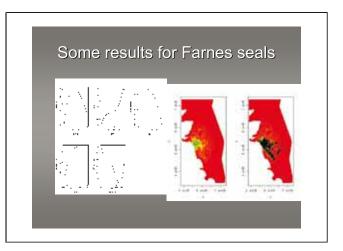


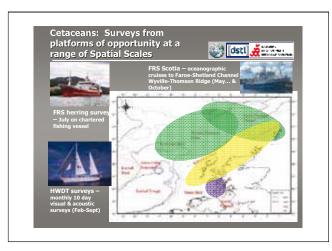


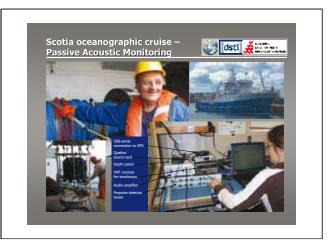


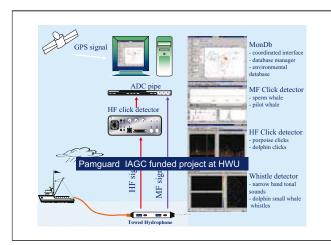


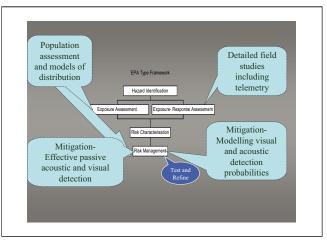








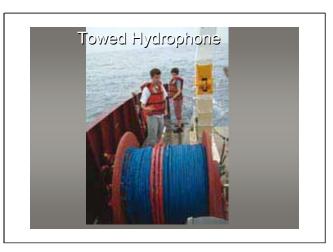




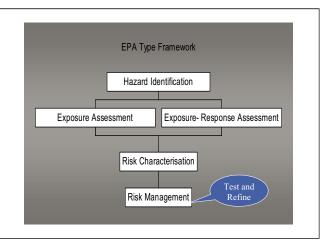


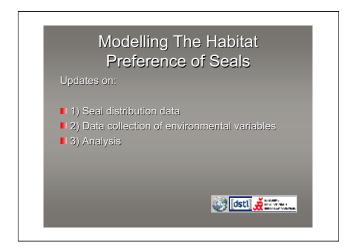


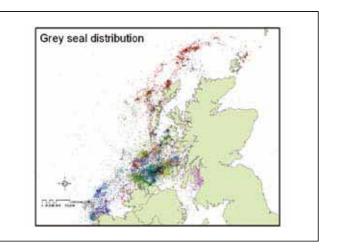


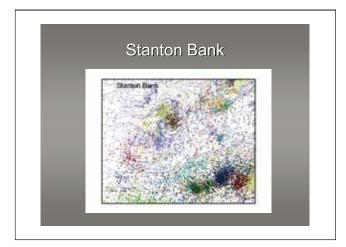


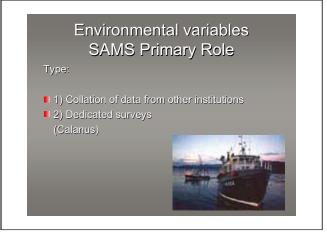
■ Telemetric studies of individual animals ■ VHF and archival tags provide large amounts of detailed information over short time periods Satellite-linked data loggers provide limited amounts of data (including location) over longer time periods

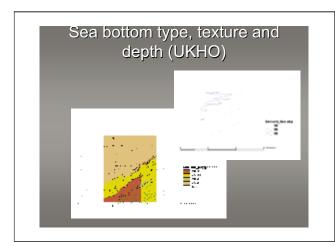


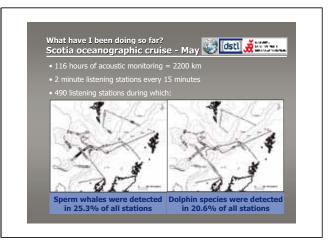


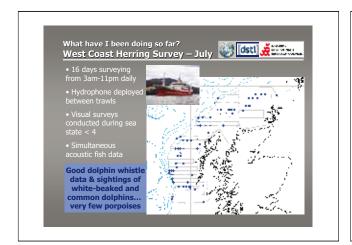


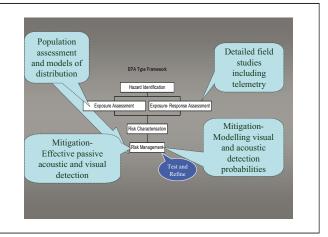












## **European Science Foundation**

European Science Foundation (ESF) was established in 1974 to create a common European platform for cross-border cooperation in all aspects of scientific research.

With its emphasis on a multidisciplinary and pan-European approach, the Foundation provides the leadership necessary to open new frontiers in European science.

Its activities include providing science policy advice (Science Strategy); stimulating co-operation between researchers and organisations to explore new directions (Science Synergy); and the administration of externally funded programmes (Science Management). These take place in the following areas: Physical and engineering sciences; Medical sciences; Life, earth and environmental sciences; Humanities; Social sciences; Polar; Marine; Space; Radio astronomy frequencies; Nuclear physics.

Headquartered in Strasbourg with offices in Brussels and Ostend, the ESF's membership comprises 75 national funding agencies, research performing agencies and academies from 30 European nations.

The Foundation's independence allows the ESF to objectively represent the priorities of all these members.

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## Marine Board-ESF Associated Member Organisations













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### Marine Board-ESF Associated Members











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