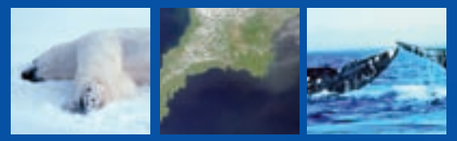
Report of the IACMST Working Group on

Underwater Sound and Marine Life

Inter-Agency Committee on
Marine Science and Technology

National Oceanography Centre
Empress Dock
Southampton SO14 3ZH
www.marine.gov.uk

IACMST Working Group Report No. 6
January 2006



Report of the IACMST Working Group on

Underwater Sound and Marine Life

Recommendation 1: A more detailed study should be made to produce a research strategy for the effects of underwater sound on marine life, from a UK perspective. This should include consideration of both inputs and impacts.

Recommendation 2: To authorise through the appropriate authorities the careful and well planned use of Controlled Exposure Experiments, which have the potential to yield much needed quantifiable information on the effects of different sound sources on marine animals.

Recommendation 3: To better inform the framing of future regulation, systematic and comprehensive mapping of noise in the ocean at appropriate space/time resolution needs to be undertaken.

Recommendation 4: In consultation with stakeholders, Government needs to establish standardised protocols for testing the extent to which sources radiate sound in the marine environment. This needs to include a system for depositing data in appropriate formats so that they can be used in future models predicting ambient noise in the oceans.

Recommendation 5: That relevant tools, technology and databases be shared via appropriate Government incentives.

Recommendation 6: The applicability of existing regulations and treaties for protection of the environment in general and the marine environment specifically to cover underwater sound should be investigated. Where necessary, amendments should be proposed.

Recommendation 7: The UK, with EU and international partners where appropriate, should build a modern, regulatory, risk-based framework relating to noise in the marine environment, based on existing legislation and the application of the precautionary principle. Its purpose should be to provide agreed impact/harm criteria, eliminate confusions over terminology, and enable more consistent mitigation measures.

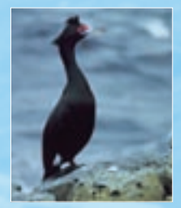
Recommendation 8: A Marine Environmental Noise Assessment for UK waters should be undertaken and permits for activities that generate noise should be issued within it.

Recommendation 9: That a UK forum be created at which a coordinated approach to underwater sound and its effects can be discussed across all sectors of industry, military, scientists, other sound producers, environmental NGOs, regulators and ocean resource users. (As an interim measure, until such a forum is set up by the appropriate authorities, IACMST could provide such a role but would need additional resources.)

Preface

The effect of sound in the sea on whales, dolphins, porpoises and other marine creatures is a topic of growing interest scientifically and more generally to the public, news media and decision makers. There are many interests involved and the implications for how the use of sound in the marine environment should be regulated are the subject of considerable discussion at both national and international levels.

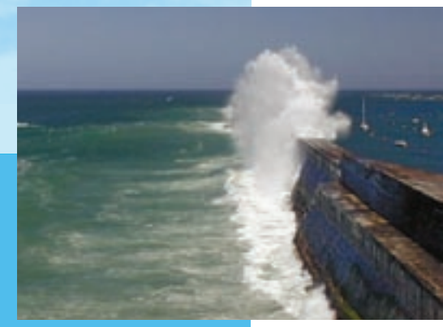
The sources of sound in the sea are many and various and include seismic surveys for hydrocarbon prospecting, shipping, offshore wind farms, military sonars and scientific research, inter alia. With so many different interests, any study of the topic needs to be carried out on a cross-sectoral basis. In the U.K. the Inter-Agency Committee on Marine Science and Technology (IACMST) is well placed to conduct such investigations, since it is a cross-departmental body whose remit is to enhance coordination across all relevant departments and agencies. IACMST seeks to identify and address issues that are of interest to many departments etc. and to commission studies and publish reports on them.



Sound in the sea is such an issue and clearly an important and timely one. With this in mind the IACMST set up a short-life Working Group to address the topic in September 2004. Membership of the Group included individuals from government departments, conservation bodies, the research community and industry, and evidence was also provided by a number of people expert in particular aspects of the topic. The report of the Group was presented to IACMST in September 2005 and approved for publication. The recommendations made in the report are primarily for government. However, it should be noted that publication as an IACMST report does not necessarily imply endorsement by that body or its member departments of each and every recommendation in the report.

I would like to thank members of the Group and all others who have contributed to the Report, as well as particularly the IACMST Secretariat. We trust that the Report proves stimulating and of interest to the many people and organisations concerned with the proper use of sound in the marine environment.

Peter Liss
Chair, IACMST Working Group
on Underwater Sound and Marine Life



Report of the IACMST Working Group on Underwater Sound and Marine Life

Members of the Working Group

Peter Liss (Chairman)	UEA
Richard Briggs	DARDNI
Claire Burt	MoD
Theresa Crossley	DfT
Paul Fernandes	FRS
Jonathan Gordon	SMRU
Carolyn Heeps	Crown Estate
Paul Leonard	Defra
Ron Mitson	Private
Kevin O'Carroll	DTI
David Palmer	Environment Agency
Roland Rogers	QinetiQ
Liz Sandeman	The Marine Connection
Geraint West	NERC
Trevor Guymer (Secretary)	IACMST

Secretariat assistance was also provided by Steve Hall of the National Oceanography Centre, Southampton

Purpose of the report

This report was commissioned by IACMST at its meeting in September 2004. It does not attempt a synthesis of available knowledge on underwater sound and its effects of marine life; the interested reader is referred elsewhere for such information[1,2]. The distinctive contribution of this study is to examine the issue from a cross-sectoral perspective and to make recommendations on what steps are needed, in the light of present knowledge, to achieve a well-justified, regulatory framework for controlling the generation of sound in the marine environment. IACMST will need to identify the most appropriate bodies (national, European or international) to take forward these recommendations.

NOAA/National Undersea Research Programme

Introduction

1.1 Nature of the Problem

Sound in the sea and its potential to affect marine life is a topic that is receiving increasing amounts of attention from scientists, policy makers and the public. Why is this so? The fundamental reason is because, unlike light and other forms of electro-magnetic radiation, sound (especially at low frequency) is poorly attenuated in seawater and can travel great distances. This coupled with the fact that sound is the most important sense for cetaceans (whales, dolphins and porpoises) and pinnipeds (seals, sealions, walrus, etc.) who use it for navigation, communication and to search for food, means that significant disruption of the marine sound field can have adverse effects on such creatures, Fish also have a highly developed auditory capacity and use sound extensively for communication, particularly during spawning. Other marine creatures such as crustaceans, and possibly turtles and cephalopods (squids and octopi), might also be affected by anthropogenic sound. Humans are increasingly introducing sound into the marine environment from a multitude of activities including seismic surveys for oil and gas prospecting and scientific research, shipping, wind farms, pile driving and military sonars, amongst many others. Thus, such activities have the potential to adversely affect marine mammals and other marine organisms that are sensitive to sound (see Fig. 1).

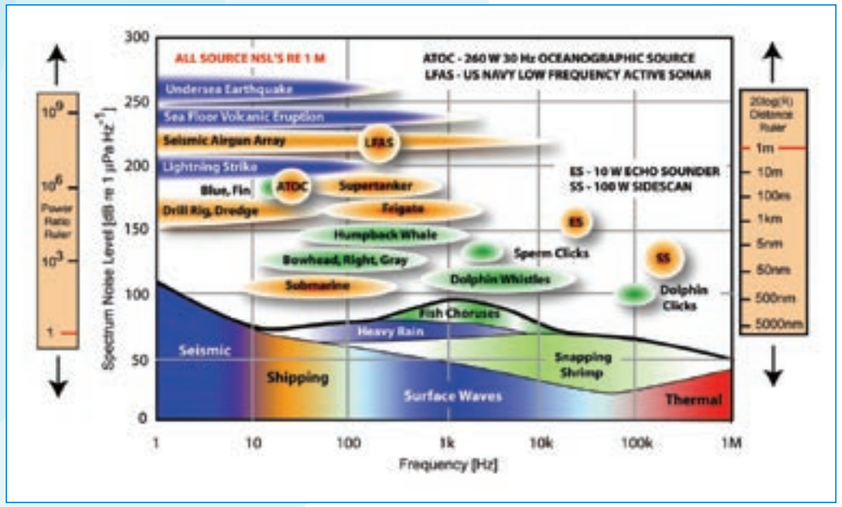


Fig. 1 The relationship of man made noise sources and naturally occurring sources of sound in the marine environment in terms of noise levels (dB re 1 μPaHz^{-1}) and frequency (Hertz). © Seiche. Source[3]

However, as we shall see, much of the evidence for deleterious effects of sound on marine creatures is essentially circumstantial; since it has proved very difficult to observe effects which can be directly attributed to human-introduced sound in the sea and to a large extent the research that would be required to do this has not been carried out. It is very difficult to make the relevant observations at sea without directed research of which

NOAA/National Undersea Research Programme

there has been very little. In these circumstances much of the argument for action must rely on probabilities and statistical analysis, rather than direct cause and effect. This has led some to be sceptical of the proposed association between sound and harmful biological effects; a viewpoint which is possibly reinforced by the fact that sound in the oceans and particularly its effects on marine life are poorly understood and appreciated by humans who, as land creatures, are poorly aware of underwater sound.

1.2 How the idea of the Working Group arose

The Working Group has its origins in discussions that took place between MoD and NERC at a Co-operative Arrangement for Research on Ocean Science (CAROS) meeting in April 2004. They reached the conclusion that, while impacts of underwater sound were an important issue for them, it was also one that needed to be addressed across other UK marine sectors. Rather than inventing a new structure, they suggested it was a suitable topic for consideration by IACMST. Accordingly, Claire Burt (MoD) was invited to make a presentation on the subject and this was given in September 2004. As a result of the discussion, it was decided to set up a short-life working group under the chairmanship of Prof P. Liss, an independent member of IACMST, Terms of Reference were set (see 1.3) and the Group was asked to present its final report at the IACMST Plenary meeting in September 2005.

1.3 Terms of Reference

(i) To summarise the recommendations from recent documents on of the impact of underwater noise on marine life, especially mammals (but also including fish and turtles).

(ii) In the light of (i) to consider the adequacy of existing UK procedures governing the use of underwater sound sources in a way which minimises the risk to the above organisms.

(iii) To recommend what further work is needed to improve our knowledge (including estimated costs and how they might be met).

(iv) To produce a report on i - iii above for consideration by IACMST at its September 2005 meeting.

Those aspects of the ToRs that could not be addressed owing to lack of time/resources are indicated by brackets above.

NOAA/National Undersea Research Programme

1.4 An overview of the significance of the problem of the impact of underwater sound on marine life[4]

The following lists some of the possible observed effects of underwater sound on marine life and in particular marine mammals, highlighting their broad range. By its nature, the surety of the evidence is stronger for some of the listed impacts than for others.

Physical

Non Auditory

- Damage to body tissue
- Induction of the "bends"

Auditory

- Gross damage to ears
- Permanent hearing threshold shift
- Temporary hearing threshold shift

NOAA/National Undersea Research Programme

Perceptual

- Masking of communication with co-specifics
- Masking of other biologically important noises
- Interference with ability to acoustically interpret environment
- Adaptive shifting of vocalisations (with efficiency and energetic consequences)

Behavioural

- Gross interruption of normal behaviour (i.e. behaviour acutely changed for a period of time)
- Behaviour modified (i.e. behaviour continues but is less effective/efficient)
- Displacement from area (short or long term)
- Disruption of social bonds, including mother-calf associations.

Chronic/Stress

- Decreased viability of individual
- Increased vulnerability to disease
- Increased potential for impacts from negative cumulative effects (e.g. chemical pollution combined with noise-induced stress)
- Sensitisation to noise (or other stresses) – exacerbating other effects
- Habituation to noise – causing animals to remain close to damaging noise sources

Indirect Effects

- Reduced availability of prey.
- Increased vulnerability to predation or other hazards, such as collisions with fishing gear, strandings, etc.
- Behavioural changes leading indirectly to physical damage, e.g. animals may be embayed and strand, may be made more vulnerable to predation.
- Behavioural change may possibly trigger damaging physiological changes, such as decompression sickness.

*Table 1 is from a paper submitted to the IWC and provides an historical listing of stranding events involving primarily beaked whales and the possible association of the stranding events with man made noise such as naval sonar and seismic airguns.

The more recent stranding events; 1996 onwards, are reasonably well documented with the Bahamas stranding in 2000 and the Canary Islands stranding 2002 being the subject of significant investigation by the international community. These key events show how important and significant both an understanding and the possible regulation of anthropogenic sound in the marine environment are becoming at State and international community levels.

To underpin how serious the members of the community that use sound as a 'tool' to undertake their business in the oceans view this problem the following cost of compliance example is provided.

The Defence Procurement Agency (DPA) Integrated Project Team (IPT) for Sonar 2087, which at the time of writing the report was being fitted to the RN's Type 23 Frigates, has voluntarily spent 4 million pounds on minimising the risk to the marine environment from the deployment of this active sonar system. The total value of the project is 340 million pounds. The approach adopted by the S2087 IPT in relation to the money spent achieving the desired level of environmental risk reduction has been policy driven rather than being led by any environmental legislation.

*Table 1 on following page

Year	Location	Species (numbers)	Correlated Activity
1914	United States (NY)	Zc (2)	
1963	Italy	Zc (15+)	
1965	Puerto Rico	Zc (5)	
1968	Bahamas	Zc (4)	
1974	Corsica	Zc (3). Stenella coeruleoalba (1)	Naval patrol
1974	Lesser Antilles	Zc (4)	Naval explosion
1975	Lesser Antilles	Zc (3)	
1980	Bahamas	Zc (3)	
1981	Bermuda	Zc (4)	
1981	United States (AK)	Zc (2)	
1983	Galapagos	Zc (6)	
1985	Canary Islands	Zc (12+), Me (1)	Naval manoeuvres
1986	Canary Islands	Zc (5), Me (1)	
1987	Canary Islands	Zc (group), Me (2)	
1987	Italy	Zc (2)	
1988	Canary Islands	Zc (3), Me (1), Hyperoodon ampullatus (1), Kogia breviceps (2)	Naval manoeuvres
1989	Canary Islands	Zc (19+), Me (2), Md (3)	Naval manoeuvres
1991	Canary Islands	Zc (2)	Naval manoeuvres
1991	Lesser Antilles	Zc (4)	
1993	Taiwan	Zc (2)	
1994	Taiwan	Zc (2)	
1996	Greece	Zc (12)	Navy LFAS trails
1997	Greece	Zc (3)	
1997	Greece	Zc (8)	
1998	Puerto Rico	Zc (5)	
2000	Bahamas	Zc (9), Md (3), ziphiid sp. (2), Balaenoptera acutorostrata (2), Stenella frontalis (1)	Naval manoeuvres
2000	Galapagos	Zc (3)	Seismic airgun
2000	Madeira	Zc (3)	Naval manoeuvres
2001	Solomon Islands	Zc (2)	
2002	Canary Islands	Zc (7), Me (2), Md (1), ziphiid sp, (9)	Naval manoeuvres
2002	Baja California	Zc (2)	Seismic airgun
2003	Australia	Zc (2+)	Naval manoeuvres

Table 1. The association between stranding events and two of the types of man made sources of sound in the marine environment that are giving cause for concern. Strandings involving at least two Ziphius cavirostris(Zc) from Smithsonian records (James Mead, pers. comm., with author updates) These represent the only known multiple stranding events for Mesoplodon europaeus (Me) and Mesoplodon denisirostris (Md.) The correlation between the stranding events and the activities attributed as being the causal agent prior to 1996 is difficult to prove. Some of these events were challenged and refuted at IWC. Source[5]

1.5 Outline of research being undertaken by the UK in the area of the impact of underwater sound on marine life.

The key funding agencies for this work in the UK are:

- The Ministry of Defence (DSTL, RN, DPA)
- UKHO
- Defra
- DTI
- NERC (NOCS, BAS)
- Oil Industry (e.g. Shell, Chevron, TotalFinaElf, Texaco)
- Crown Estates
- Non Governmental Organisations (e.g. WDCS, IFAW, Greenpeace)
- Sonar Industry

Some of the key research organisations in the UK which receive this funding are:

- Herriot Watt University
- Aberdeen University
- Southampton Institute
- Bangor University
- Imperial College
- Institute of Zoology
- Sea Mammal Research Unit – University of St Andrews
- Subacoustech
- Ecologic
- Fawley Aquatic Research Laboratories Ltd
- QinetiQ
- Biscay Dolphin Research Programme
- Loughborough University
- Insyte
- CEFAS

Some of the key areas of research funded in the UK are:

- Marine mammal distribution studies
- Marine mammal behaviour studies
- Regulation of noise in the marine environment
- Training of marine mammal observers
- The impact of underwater noise on fish
- The impact of underwater noise on divers
- Monitoring and modelling of noise in the marine environment
- Marine mammal monitoring technology
- Development and population of marine receptor databases
- Development of underwater sound impact criteria
- Modelling of the impact of underwater sound on the marine environment
- Representation of marine mammal observations in operational systems
- Cetacean stranding studies
- Modelling marine mammal distribution
- Mitigation Studies

There are a limited number of external organisations that have funded studies in this area with UK organisations such as the US Office of Naval Research. A small number of the UK research funding agencies have placed funding outside of the UK or have participated in collaborative funding of science along with other States that have an interest in this subject.

NOAA/National Undersea Research Programme

1.6 Scope of report

The main driver for this report is concern over the effects of underwater sound on marine mammals. Although priority has been given to this it is nevertheless recognised that the other forms of marine life are sensitive to sound, as reflected in the Terms of Reference. Given the time and resources available, the effort has been concentrated on sound and marine mammals but reference has also been made to other marine receptors such as fish.



Rationale leading to conclusions and associated recommendations

The following recommendations address issues of both research and regulation, the former being required to underpin the latter. This progression from research to regulation is reflected in the order in which the recommendations are given.

2.1 Understanding the Effects of Sound on Marine Mammals

There is a need to continue and expand research into potential noise pollution on cetaceans. Stranding investigations are very important at present in furthering our understanding of noise pollution and its potential impacts on a variety of species in a number of habitats and scenarios. Much of the knowledge of the causes of these events has come from information collected in recent years from strandings and floating carcasses and it is likely that analyses of these statistics will continue to provide an important source of knowledge for many years to come. Acquiring and improving the quality of such data should therefore form a component of a future research strategy.

NOAA/National Undersea Research Programme

A more fundamental issue is the need to look at both the input and the impact of sound distinguishing between actual levels, as a function of location with respect to the source, and the effect on organisms. Both are important and further research is needed to map the distribution of sound as well as increasing understanding of the way that different species respond to sound intensity, duration, frequency, etc. Incidental monitoring and ongoing long-term monitoring of populations are also basic research priorities. Whilst considerable work has been conducted already, as listed in 1.5, there is a need to produce a more strategic approach, an activity which is beyond the scope of this Working Group.

Recommendation 1: A more detailed study should be made to produce a research strategy for the effects of underwater sound on marine life, from a UK perspective. This should include consideration of both inputs and impacts.

2.2 Controlled Exposure and Similar Experiments[6]

As pointed out earlier, some evidence for harm/damage to marine mammals from man-made sound sources is circumstantial, being largely based on correlations between strandings of cetaceans and the major concurrent deployment of underwater sound in the adjacent marine area. Supporting evidence comes from the observation of physiological damage to beached animals which is compatible with damage from exposure to intense sound or, more probably, behavioural response to it. While it is now accepted that in these instances mid-frequency sonar has caused mortality and stranding the underlying mechanism remains unknown, and this hampers attempts to find a solution.

One obvious way forward in trying to understand the process that causes mortality and stranding in these circumstances is to observe the behaviour of animals when they are exposed to the signals of interest in realistic circumstances. There are basically two approaches that can be used here and each has its strengths and shortcomings. Controlled exposure experiments involve exposing an animal with a sound source that is under the control of the experimenter and measuring its response. This approach can provide results that are easier to interpret, animals can be exposed once adequate control data has been collected and the exposure can be terminated if any worrying responses are observed. However, it can be difficult and expensive to realistically replicate powerful sound sources such as sonar. Observations can also be made of animals exposed in a non-controlled manner during existing activities (such as a naval exercise). Such observations can be more difficult to collect and interpret, but at least the sound source and its operation is realistic. These approaches are complementary and most studies will seek to use a combination of both. What is common to both approaches is a requirement to carefully measure and record the behaviour of wild, unrestrained marine mammals in the field. Approaches to this may vary from species to species but usually a combination of visual observation and passive acoustic monitoring and telemetry will be required. UK research groups have experience and expertise in working in this way with many marine mammals, though some work will certainly be required to develop an appropriate methodology for beaked whales, which are particularly difficult species.

NOAA/National Undersea Research Programme

Experimental and observational work of this type would be very valuable and would help to establish a modern regulatory framework. There are sound scientific objectives for such research and UK research groups have the necessary expertise, at least for some species; although there is a need for several groups to be brought together in carrying them out (e.g. SMRU, MOD, Oil and Gas Producers, DTI, as well as NGOs). However, the current state of legislation for conducting this type of research in the UK is unclear and there is little to go on by way of precedent. We realise there are ethical and political, as well as practical, difficulties with this sort of work, but we consider that the potential gains outweigh the disadvantages, providing appropriate regulatory safeguards are put in place to protect the organisms. It has been suggested that it may be helpful for an internationally agreed protocol for Controlled Exposure Experiments be developed in order to minimise legal and political difficulties.

Recommendation 2: To authorise through the appropriate authorities the careful and well planned use of Controlled Exposure Experiments, which have the potential to yield much needed quantifiable information on the effects of different sound sources on marine animals.

2.3 Mapping of ambient noise[7]

As scientists and legislators have only recently begun to investigate the effects of anthropogenic noise on marine life and how it might be best regulated, it is not known yet exactly which noise characteristics are of most importance and how these vary with each environmental situation. It is argued that a systematic and comprehensive approach for establishing an ocean sound energy budget* needs to be put in place as an effective regulatory and marine environmental management tool. This proposed ocean sound energy budget approach should take account of the different types of sound sources and their relative magnitudes and, where possible, temporal trends. It is also important to ascertain the level of background or ambient noise in the ocean and how the individual sources of man-made sound may be contributing to it. Although there appears on initial investigation a relatively large amount of measured data for this, much of it is thought to be classified either for military or commercial reasons and therefore not readily accessible to the marine community as a whole. Greater access to this information would raise awareness of the complex scientific and technical issues involved in trying to understand the potential impact of noise on marine mammals. It is therefore, vital that such information be made public wherever possible and in a form that is comprehensible to the wider community.

The anthropogenic sources most likely to contribute to increased noise in the marine environment over the past few decades and in the future are:

- commercial shipping
- oil/ gas exploration
- military exercises

*The term 'ocean sound energy budget' is mentioned in key documents in this area
(e.g. see : http://www.nap.edu/books/0309094496/html/13.html)
The term is used in this document in the context of the management of sound/noise in the marine environment to reduce adversely affecting the environment. The sound energy budget for a discreet managed maritime area for a given period of time would be defined on the assessed levels of sound which the marine receptors found in that area would be capable of tolerating without being adversely impacted. That amount of sound energy, which would be represented in terms of frequency, source level, duration and modus operandi, would then set the levels against which stakeholder anthropogenic activity would be permitted/allocated in that area by the appropriate authorities. In the case of UK waters this type of approach could be used in Marine Spatial Planning where in practice there could be a number of legitimate activities that generate sound/noise in the marine environment wishing to operate at the same time in the same area of water where sensitive marine receptors were present.

- fishing
- dredging
- pile driving
- marine wind farms
- leisure craft

A reasonable amount of research and development work has been undertaken in the area of modelling or forecasting ambient noise in the oceans. The military community lead in this field with a number of operational ambient models in use in military forecast centres. However, this capability has not been properly investigated for its utility in managing noise in the marine environment as part of a noise budget methodology.

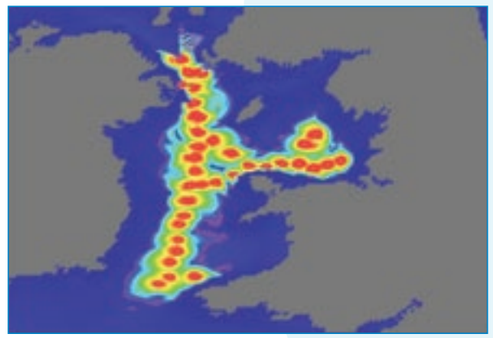


Figure 2a Output from an ambient noise model, DTI SEA Area 6, July, with receiver at 10 m for a frequency of 1kHz. Source[8]

In order to demonstrate what could be achieved, the QinetiQ QUEST ambient model has been used to predict ambient noise maps for the SEA Area 6 including shipping lanes represented as point sources through to Liverpool from the north and south of Ireland, gas rigs in Morecambe Bay and the Holyhead to Dublin Ferry route. The results are shown in Figs 2a and 2b for July and October respectively. The red area is the highest ambient noise, while the blue area is the lowest level. It should be emphasised that these figures are to demonstrate what could be done with a noise model and not to provide accurate data. The sound field shapes at the extreme north and south are distorted by modelling artefacts.

An extension of this exercise is to calculate some cumulative exposure of marine mammals (and other marine life) from these sound fields. A major knowledge gap in such a study is the distribution of marine mammals in 3D space, i.e. a combination of their geographical distribution and diving behaviour.

Recommendation 3: To better inform the framing of future regulation, systematic and comprehensive mapping of noise in the ocean at appropriate space/time resolution needs to be undertaken.

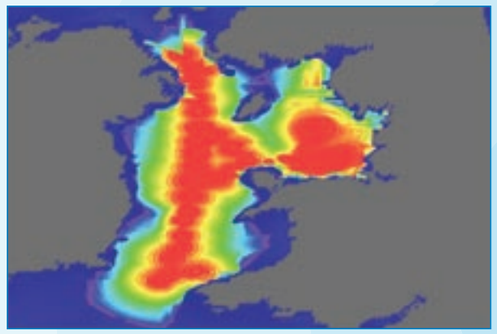


Figure 2b Output from an ambient noise model DTI SEA Area 6, October, with receiver at 10 m for a frequency of 1kHz. Source[8]

2.4 Availability of sound source information

Currently it is not known which noise characteristics are of most importance and how they vary with the environmental conditions. Therefore, it will be necessary to establish a comprehensive database of sound source information, as indicated in Table 2. At this time some of this information is not accessible on certain types of sources of sound for military or commercial reasons and some system information is simply not available in a useable format. It is suggested that such information should be made public in an agreed format and wherever possible in a form that is also comprehensible to the wider community.

Sound Source	SPL dB re 1μPa @1m	Ping Energy (dB re 1μPa^2*s)	Ping Duration	Duty Cycle (%)	Peak Frequency (Hz)	Band Width (Hz)	Directionality
Underwater Nuclear Device (30 kilo-ton)	328	?	1000 s	Intermittent	Low	Broad	Omni
Ship Shock Trial (10,000 lb TNT)	299	?	100 s	Intermittent	Low	Broad	Omni
Military Sonar (SURTASS/LFA)	235	243	6-100 s	10	250	30	Horizontal
Airgun Array 2000 psi and 8000 in^3	256	241	30 ms	0.3	50	150	Vertical
Military Sonar (53C)	235	232	0.5 – 2 s	6	2,600 – 3,300	Narrow	Horizontal
Super Tanker 270 m long	198		CW	100	23	5-100	Omni
Research Sonar (ATOC Source)	195		20 minutes	8	75	37.5	Omni
Acoustic Harrassment Device	185	185	0.5 – 2 s	50	10,000	600	Omni
Multibeam (Echosounder Hull-mounted)	235	218	20 ms	0.4	12,000	Narrow	Vertical
Research Sonar (RAFOS float)	195		120 s	small	250	100	Omni
Fishing Vessel 12 m long (7 knots)	150		CW	100	300	250 - 1000	Omni
Acoustic Deterrent Device (AquaMark300)	132	127	300 ms	8	10,000	2000	Omni

Table 2 Sound source information that should be collected for use in the management of the impact of sound on the marine environment as part of any sound budgeting regulatory process. Source[5].

Recommendation 4: In consultation with stakeholders, Government needs to establish standardised protocols for testing the extent to which sources radiate sound in the marine environment. This needs to include a system for depositing data in appropriate formats so that they can be used in future models predicting ambient noise in the oceans.

2.5 Sharing of tools, technology and databases

A monitoring programme is essential to track future changes in ocean noise and the best way of mitigating in the longer term is to share tools, technology and databases. Scientific information about ocean noise is growing but there is no central network that has all of it. Sharing an agreed set of tools would allow progress to be made towards developing common standards and metadata. As an example, some government and commercial organisations may have software for modelling aspects of the problem which is too expensive for use by non-governmental organisations. There may be certain constraints on sharing tools and databases arising from Intellectual Property Rights issues.

An example of good practice is PAMGUARD (www.pamguard.org) which is funded by the Industry Research Funders Coalition (IRFC)* and hosted by Heriot-Watt University. The project is intended to supply open-source, industry-standard software for seismic operators to perform basic bearing location. This will evolve in line with changing user and legislative requirements and expectations. PAMGUARD is also anticipated to become a not-for-profit, self-sustaining venture. In the initial phases of the PAMGUARD project:

(i) A PAM software guardianship centre is being established, which will facilitate the on going development of open source PAM software.
(ii) Existing software systems will be functionally replicated, which will allow existing users to integrate the PAMGUARD software at no cost.
(iii) The functions of the existing systems will be extended in line with new regulations and identified user requirements.

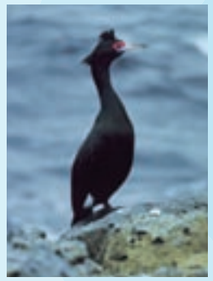
Recommendation 5: That relevant tools, technology and databases be shared via appropriate Government incentives.

2.6 Use of existing regulations as a basis for the regulation of sound in the marine environment[9,10]

There are several international and regional regulations, treaties and conventions that could be applied to the regulation of underwater sound, though they may require amendment.

NOAA/National Undersea Research Programme

A pertinent example is the United Nations Convention on the Law of the Sea (UNCLOS) where any energy source (e.g.noise) that is introduced into the marine environment is recognised as a form of pollution. The UNCLOS definition of pollution of the marine environment includes the following "the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results in or is likely to result in such deleterious effects as harm to living resources and marine life...". Further, Articles 204-206 of the Convention require States to assess the potential impact of their activities on the marine environment and communicate the results of such assessments.



Other examples where existing legislation may provide a suitable framework by amendment are: The International Whaling Convention, OSPAR, EU Habitats Directive, ASCOBANS, and the UK's Wildlife and Countryside Act. However, some amendment may be necessary.

The WG concluded that it was necessary and inevitable that the same philosophy and methodology used for other pollutants and material should be applied to underwater sound.

Recommendation 6: The applicability of existing regulations and treaties for protection of the environment in general and the marine environment specifically to cover underwater sound should be investigated. Where necessary, amendments should be proposed.

*IRFC - Industry Research Funders Coalition: current membership includes BHP Billiton Petroleum (Americas), Inc., BP Exploration and Production, Inc., ChevronTexaco Exploration and Production Company, ConocoPhillips Company, ExxonMobil Exploration Company, Shell Exploration and Production Company, and the members of the International Association of Geophysical Contractors (IAGC). IRFC is funding the initial phases of PAMGUARD.

2.7 Guidelines for establishing agreed procedures and criteria[11,12]

There are many ways of defining the 'Precautionary Principle' although here it will probably suffice to state it as 'when the environmental consequences of human action are in doubt, we should err on the side of caution and try to avoid those with the potential to cause significant damage'. In practice, in applying the principle a balance has generally to be struck between the seriousness of the threat to the environment and the social and economic consequences of its application. However, given the high level of uncertainty surrounding the topic of sound in the sea it is a natural consequence that a strong version of the principle be adopted for restrictions and mitigation measures. The motivation for research to reduce these levels of uncertainty and allow a less burdensome operation is clear.

Although there is some legislation addressing disturbance which could be applied to certain noise producers there is a need for guidelines to be expressed in quantifiable terms. The Working Group considers there is an excellent opportunity for the UK to take the lead on this matter. It was also suggested that such guidelines would need to take account of other countries using the same waters, otherwise over-regulation could lead to competitive disadvantage. Any regulatory regime would need to embrace the philosophy expressed in the Hampton Review* and fit in with the Government's ideology for modern regulation. Such a regulatory framework would need to be vested in an appropriate competent authority, which might be a Marine Agency should this be proposed in the forthcoming Marine Bill. A regulatory framework would need to embody an understanding of the effects of sound pollution at differing sound levels and length of exposure to differing species. More research is needed in this area to enable any permits that might be granted to be robust. Noise mapping techniques to provide background noise levels and a knowledge of important conservation areas would allow permits to be granted according to environmental need. These permits, in line with the Hampton Review, would be self-regulated, with the competent authority having an audit role. Environmental Impact Assessments, prepared by the applicant for a permit, and modelling techniques to look at the impact of the activity would also be taken into account when setting the conditions of the permit.

There is confusion over terminology. Much of this stems from a fundamental lack of knowledge of the effects of sound on marine life and it is this that should determine how the sound properties are expressed. Because of the way different groups use different units and terminology it is difficult to compare like with like. For example, the

Image supplied courtesy of NASA

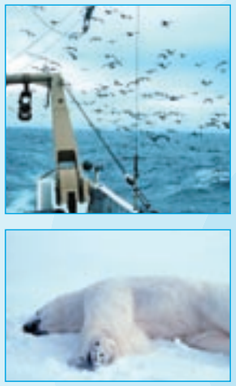
Image supplied courtesy of NASA

*http://www.hm-treasury.gov.uk/budget/budget_05/other_documents/bud_bud05_hampton.cfm

Image supplied courtesy of NASA

US and British navies use the same nomenclature but seismic experts in the oil and gas sector employ different terms. In some cultures there is also a difference between 'noise' and 'sound'. All of this is particularly confusing when disseminating information to the general public. When it comes to regulation common metadata will be needed. Standardisation should be international, wherever appropriate.

There are also differences in mitigation procedures. The JNCC for example have guidelines that are aimed at minimising acoustic disturbance from seismic surveys and other operations where acoustic energy is released. These guidelines apply to all marine mammals and to all surveys using higher energy seismic sources. The DTI regulates the use of sound in relation to the offshore oil and gas industry via the PON 14 process. The JNCC and FRS are statutory advisers to this process. The current advice with regard to seismic operations and fish is already established and can be examined at http://www.ukooa.org/issues/fisheries/v000051 2.htm. Fisheries sensitivity maps are provided via the following page at http://www.ukooa.org/issues/fisheries/v0000513.htm.NATO also has guidelines which specifically include protection for swimmers, divers and fish. However, it is entirely appropriate for there to be a variety of approaches given that different species, noise sources and situations require a different mix of mitigation measures. Procedures in use are largely based on common sense and intuition. Moreover, the way these procedures relate to particular objectives is rarely made explicit and their effectiveness in terms of reducing risk has not been measured. There is a need to put mitigation measures in a risk reduction framework. They need to be applied to a wide range of species, including humans and fish. Environmental Impact Assessments may provide a context for the regulatory risk framework (see 2.8).



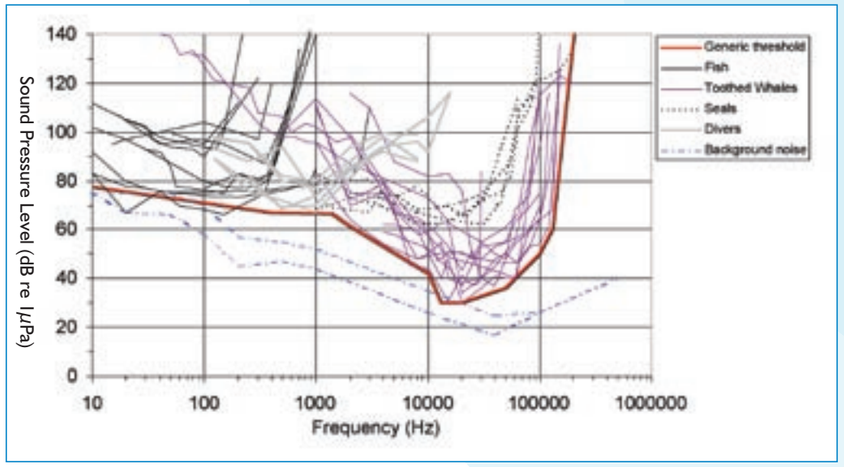


Figure 3 In-water threshold of hearing for fish, humans and marine mammals. Also shown are typical ambient noise levels and the generic threshold curve.

Figure 3 shows a threshold curve currently used by the Royal Navy to calculate Stand Off Ranges (SOR) for its active sonars, which form the basis for the application of mitigation measures to reduce the likelihood of adversely impacting the identified marine receptors. The approach adopted is a self-regulatory one and with the bringing into service of the Environmental Risk Management Capability will be superseded by a more risk-based approach currently being developed by the SMRU. Source[13]

Recommendation 7: The UK, with EU and international partners where appropriate, should build a modern, regulatory, risk-based framework relating to noise in the marine environment, based on existing legislation and the application of the precautionary principle. Its purpose should be to provide agreed impact/harm criteria, eliminate confusions over terminology, and enable more consistent mitigation measures.

2.8 Marine Environmental Noise Assessment

It was agreed that a Marine Environmental Noise Assessment for UK waters would need to be carried out. This would be the base on which regulatory activities should be set (discussed under 2.7). It would consist of an understanding of ambient historical, forecast and monitored noise data (discussed in 2.3) in order to establish a background assessment. Against this background assessment, proposed activities resulting in sound generation would be regulated. Individual EIAs would form additional information supplementing the background noise assessment (described above), and these can also be used for the granting of a permit to make noise.

Recommendation 8: A Marine Environmental Noise Assessment for UK waters should be undertaken and permits for activities that generate noise should be issued within it.

2.9 Need for better coordination

The presentation by C Burt to IACMST which triggered the formation of the Working Group concluded with the statement that there is a need for a more coordinated approach across all the marine science and technology sectors. Although the topic had been considered by CAROS this represented only MoD and NERC. Discussion takes place in other small groups, usually on a sectoral basis, but there is no overall coordination; indeed, there is no general forum where all the sectors come together. Working groups with wider representation do exist but are mainly international. It was therefore agreed that setting up a national forum is an important step. The

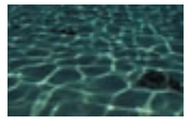
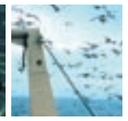
NOAA/National Undersea Research Programme

draft Marine Bill, due to be introduced in the present session of Parliament, is relevant because it will hopefully identify a competent authority to tackle such issues. However, it is likely that an interim solution will be needed.

A number of international bodies are considering the effects of underwater sound on marine life, particularly mammals. These include ESF, NATO WGs, IAGC, International Research Ship Operators, ASCOBANS, OSPAR, IWC, IMO, GESAMP, NOAA (Protected Resources Division), ICES (Advisory Committee on Ecosystems and the Fisheries Acoustic Science and Technology Working Group), and the EU Environment Directorate.

Much relevant research is conducted by the US where it is better funded than in the UK. However, this should not be seen as a substitute for a dedicated UK research activity; US regulations and marine environmental context differ from the UK's, therefore different research is required to underpin and implement our regulations. Nevertheless, because some of the approaches are common, useful exchange of data/information does take place and should be further developed.

Recommendation 9: That a UK forum be created at which a coordinated approach to underwater sound and its effects can be discussed across all sectors of industry, military, scientists, other sound producers, environmental NGOs, regulators and ocean resource users. (As an interim measure, until such a forum is set up by the appropriate authorities, IACMST could provide such a role but would need additional resources.)

Key papers referenced in this report

1. Richardson WJ, Greene Jr. CR, Malme CI, and Thomson DH 1995 Marine Mammals and Noise, Academic Press, San Diego.
2. ICES 2005 Report of the Ad-hoc Group on the Impact of Sonar on Cetaceans and Fish" (AGISC) ICES CM2005/ACE:01.
3. SCAR Report on Marine Acoustic Technology and the Arctic Environment. Information Paper. ATCM. XXVII Meeting. IPO78
4. Simmonds M, Dolman S, Wellgart L (eds) 2003. Oceans of Noise, WDCS Science Report May 2003
5. Hildeband J. Impacts of Anthropogenic Sound on Cetaceans. 56th Meeting of the IWC Scientific Committee. IWC/SC/56/E13
6. Nowacek D P, Johnson M P, and Tyack P L, 2004 North Atlantic right whales (Eubalaena glacialis) ignore ships but respond to alerting stimuli Proc. Roy. Soc. Lond. B, 271, 227-231
7. Andrew R K, Howe B M, and Mercer J A 2002 Ocean ambient sound: Comparing the 1960s with the 1990s for a receiver off the California coast, Acoustics Research Letters Online, 3, 65-70.
8. Harland E, Jones S A S, Clarke T, [2005]. SEA 6 – Technical Report – Underwater Ambient Noise. QinetiQ/S&E/MAC/CR050575. March 2005
9. McCarthy E International Regulation of Underwater Sound – Establishing Rules and Standards to Address Ocean Noise Pollution. Kluwer Academic Publishers
10. Hoyt E. Marine protected Areas for Whales, Dolphins and Porpoises. – A World handbook for Cetacean habitat Conservation. Earthscan
11. Heathershaw A D, Ward P D, David A M. [2001]. The Environmental Impact of Underwater Sound. Proceedings Institute of Acoustics Volume 23, Part 4, 1-12 2001.
12. Nedwell J R, Edwards B, Turnpenny A W H, Gordon J. [2004]. Fish and Marine Mammal Audiograms – A summary of available information. Subacoustech Report No. 534R0214. 3rd September 2004 (available from www.subacoustech.com)
13. MoD/DPA. S2087 IPT. Sonar 2087 and the Environment. November 2003 (2ndEdition)


4. List of papers compiled during the preparation of this report

(Note: The list is included here as it may be of interest to the reader. Inclusion does not imply endorsement of conclusions by the Working Group. Entries followed by a * indicate that the documents are available at http://www.oceannet.org/medag/reports/underwater_noise/index.html)

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

Crum, L.A., Bailey, M.R., Guan, J., Hilmo, P.R., Kargl, S.G., Matula, TJ. and Sapozhnikov, O.A. (2005) Monitoring bubble growth in supersaturated blood and tissue ex vivo and the relevance to marine mammal bioeffects. Acoustics Research Letters Online [DOI: 10.1121/1.1930987]

Fernandez, A., Edwards, J.F., Rodriguez, F., Espinosa de los Monteros, A., Herráez, P., Castro, P., Jaber, J.R., Martin, V., Arbelo, M. (2005) "Gas and fat embolic syndrome" involving a mass stranding of beaked whales (family Ziphiidae) exposed to anthropogenic sonar signals. Veterinary Pathology 42: 446-457.

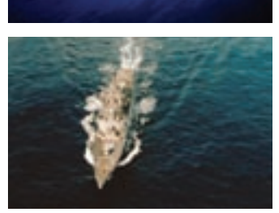
Jepson, P.D., Deaville, R., Patterson, I.A.R., Pocknell, Ross, H.M., Baker, J.R., Howie, F.E., Reid, R.J., Colloff, A. and Cunningham, A.A. (2005) Acute and chronic gas bubble lesions in cetaceans stranded in the United Kingdom. Veterinary Pathology 42: 291-305

ICES 2005 The answer from ICES to a request from the Director General (Environment) of the European Commission for scientific information concerning the impact of sonar activities on cetacean populations*

SCAR 2002 Impacts Of Marine Acoustic Technology On The Antarctic Environment, Ad Hoc Group on marine acoustic technology and the environment. Unpublished, 62pp*


List of acronyms

ASCOBANS	Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas
BAS	British Antarctic Survey
CAROS	Co-operative Arrangement for Research on Ocean Science
CEFAS	Centre for Environment, Fisheries and Aquaculture Science
DPA	Defence Procurement Agency
DSTL	Defence Science and Technology Laboratory
DTI	Department for Trade and Industry
EIA	Environmental Impact Assessment
ESF	European Science Foundation
EU	European Union
GESAMP	Group of Experts for the Scientific Assessment of Marine Pollution
IAGC	International Association of Geophysical Contractors
ICES	International Council for the Exploration of the Sea
IFAW	International Fund for Animal Welfare
IPT	Integrated Project Team of the DPA
IRFC	Industry Research Funders Coalition
IMO	International Maritime Organisation
IWC	International Whaling Commission
JNCC	Joint Nature Conservation Committee
MoD	Ministry of Defence
NATO	North Atlantic Treaty Organisation
NERC	Natural Environment Research Council
NGO	Non-Governmental Organisation
NOAA	National Oceanic and Atmospheric Administration
NOCS	National Oceanography Centre, Southampton
OSPAR	Oslo Paris Commission
SEA	Strategic Environmental Assessment
SMRU	Sea Mammal Research Unit
UKHO	UK Hydrographic Office
UNCLOS	United Nations Convention on the Law of the Sea
WDCS	Whale and Dolphin Conservation Society

List of experts contributing to the study

Ian Boyd	SMRU
Sarah Dolman	Whale & Dolphin Conservation Society
Tim Francis	Geotek
Quentin Huggett	Geotek (representing DTI Environmental Assessment)
Paul Jepson	Zoological Society of London
Don Smith	International Association of Oil and Gas Producers