PROCEEDINGS OF THE WORKSHOP ON

ACTIVE SONAR AND CETACEANS

Held at the
European Cetacean Society's 17th Annual Conference,
Auditorio Alfredo Kraus, Las Palmas, Gran Canaria, 8th March 2003

Editors:

Peter G. H. Evans[1, 2] and Lee A. Miller[3]

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INTRODUCTION

Peter G. H. Evans[1, 2] and Lee A. Miller[3]

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Active sonar, operating with sound source levels of up to 245 dB re 1µPa @ 1 m at frequencies mainly between 1 and 150 kHz, is frequently used for fish-finding, oceanography, charting and in military activities (for example locating submarines). Since the mid-1990s, concern has been expressed over the potential impact these sounds may have upon cetaceans (particularly deep diving toothed whales of the Sub Order Odontoceti such as the beaked whales, family Ziphiidae), and post mortem studies of mass stranded animals in the Bahamas, Madeira and, most recently, in the Canaries have revealed multifocal haemorrhaging and ear damage.

The purpose of this workshop was to bring together whale biologists, pathologists, acousticians, and representatives of governments, oceanographic institutes and national navies with interests in this topic, to objectively review the existing evidence and, where detrimental effects are implicated, to identify possible mitigation measures. Attention focused upon the species involved and any characteristics that may make them especially vulnerable, as well as on the nature of the sound source (sound levels, peak frequencies, usage, and sound transmission in relation to oceanographic conditions).

Following an introduction to different types of active sonar, their characteristics and physical attributes of transmission through the water, a review was made of previous mass stranding incidents that had been linked with the use of active sonar. The major ones were in Greece (May 1996), the Bahamas (March 2000), Madeira (May 2000), and the Canaries (September 2002).

Pathological and physiological aspects of the potential impacts of active sonar were then considered with reference to the last three mass strandings, where opportunities existed for detailed post-mortem examination. This was followed by a session addressing research needs with consideration of controlled exposure experiments, measurements of hearing using acoustic brainstem responses, and the use of passive acoustic tools. Finally, mitigation measures currently adopted were considered both in the context of US legislation and of those used by NATO. Proposals for future measures that could be potentially effective were also made, including a range of precautionary measures that could be adopted.

The workshop took place on Saturday, 8 March 2003 at the Convention Centre in Las Palmas, Gran Canaria, immediately before the start of the 17th Annual Conference of the European Cetacean Society. It was attended by around 110 persons from 21 countries (see list of participants at the end of this volume), representing a wide variety of disciplines and interests. We specially welcomed representatives of NATO and several navies at the meeting.

For the Proceedings of the Workshop, we invited two extra contributions to those presented at the meeting – one from Joseph Johnson, Chief of Naval Operations for the Undersea Surveillance Branch in Washington, USA (who at the last minute had to cancel attending the meeting), and the other from Walter Zimmer of the NATO SACLANT Undersea Research Centre in La Spezia, Italy. We are very grateful to all contributors for their efforts, and to the University of Las Palmas and the government of the Canary Islands for kindly hosting the meeting.

INTRODUCTION TO ACTIVE SONAR

E. J. Harland

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INTRODUCTION This contribution aims to provide a basic introduction to active sonar. There is increasing interest in the potential impact of active sonar on marine mammals, and this presentation was put together to provide a grounding in the principles of active sonar for those not directly involved in the subject. Urick (1983) and Waite (1998) give more details of active sonar systems.

Active sonar (SOund Navigation And Ranging) is defined as the use of a source of sound in conjunction with an acoustic receiver to ensonify and thereby detect, classify and localise a target. The key elements are a sound source, a target, a receiver and an acoustic path between all elements (Fig 1). This paper will deal with each of the elements in turn.

The first active sonars appeared around 1900 and used an underwater bell as the sound source and a tube submerged in the water as a receiver. The first true active sonar as we know it today was proposed immediately after the loss of the RMS TITANIC, and the first workable systems appeared in 1914, working in the range 500-1000 Hz. These could detect icebergs out to two miles. Development through WW1 continued apace and the first submarine was detected in 1918 at a range of 1.5 km. Echo sounders came into use in 1925. Slow progress was made in the period between the wars, but this accelerated as WWII approached. The standard attack sonar during WWII used a searchlight beam hand-trained by the operator, and the echo was detected by the operator listening to the signal on headphones.

Following WWII, the size and capability of active sonars steadily increased until, by the early 1970s, the military active sonar as we know it today had appeared. At this point, the military concentrated on passive sonars that listen for the sounds made by underwater targets, and active sonar development stagnated for around twenty years. Then, as targets got quieter and quieter and passive sonars became less effective, the research work started again on active sonars, and this has led to the current LFA research systems and the next generation of hull-mounted sonars.

Today, active sonars cover a large variety of systems ranging from echo-sounders through sidescan systems, bottom profilers, and fish-finders to the large military systems and the seismic systems used by the oil industry.

SOURCES The source is required to generate sufficient sound level to ensonify the target and produce an echo at the receiver that is strong enough to be detected against ambient noise. The frequency is determined by the application. Low frequencies are used for long-range systems, and high frequencies for short range, high-resolution systems. The output of the source is termed the Source Level (SL), and this is defined as the ratio of intensity at a reference range compared with a reference level. In underwater acoustics, the reference range is 1 metre and the reference level is 1 micro Pascal (µPa). Some older textbooks and the seismic industry use the Bar as the pressure unit rather than the Pascal. A useful number to remember is that one Watt radiated omni-directionally has a Source Level of 170.8 dB re 1 µPa@1m. Note that it is normal to use RMS values for the Source Level, but for very short pulses such as echo-sounders and seismic sources, peak to peak values are routinely used:

$$SL = 10Log_{10}\left(I_{range} / I_{ref}\right)$$

PROPAGATION PATH As the signal propagates from the source, the level falls. This is caused by spreading loss, absorption, and scattering. Spreading loss is proportional to distance squared in free space, corresponding to spherical spreading. In shallow water, where the sound interacts with the surface and the seabed, the loss can be proportional to distance, corresponding to cylindrical spreading, but more normally lies somewhere between cylindrical and spherical spreading. Absorption is caused by the sound interacting with the molecular structure of the water and the dissolved salts. It generally increases with frequency and is typically around 20 dB/km at echolocation frequencies. Scattering loss occurs when the sound is scattered from the seabed or the sea surface, but can also be caused by suspended solids, plankton, fish or cetaceans. The Propagation Loss (PL) is the sum of all the path losses:

$$PL = 20Log_{10}(R) + \alpha R + scl$$

THE TARGET If the propagating sound encounters an object which has a different acoustic impedance to the water, then some of the sound is reflected. The level of the reflected signal is given by the Target Strength (TS). This is defined as the ratio of returned energy to the incident energy, both referred to a distance of 1 metre. Note that because the reference distance is 1 metre, it is possible for large targets to have a positive target strength, implying more energy is returned than is incident. This is not possible and is merely an artefact of the definition. Typical values for target strength are 0 db for a 2 m diameter sphere at high frequencies, 5-40 dB for a submarine, and –30 dB for a squid. The equation is:

$$TS = 10Log_{10}\left(I_{refl} / I_{inc}\right)$$

REVERBERATION Apart from the wanted target, be it submarine or fish, there are many other unwanted targets in the sea. These include surface waves, seabed roughness, suspended solids, fish, and marine mammals. The multiple echoes from these unwanted targets merge together to give a background level against which the active sonar has to detect the wanted target. The three types of reverberation are referred to as bottom reverberation, surface reverberation and volume reverberation. Note that in a highly reverberant environment, as the Source Level is increased, a point is reached where the received noise is entirely composed of reverberation, and increasing the Source Level makes no difference to the received signal/noise ratio. The sonar is then said to be reverberation limited.

AMBIENT NOISE The world's oceans are a very noisy environment. Active sonars have to detect the wanted echo against this background noise. Depending on the location and weather, the ambient noise will be dominated by either shipping noise or natural noise sources. Natural noise sources include wind, precipitation, seismic, sediment transport, and biological noise. Anthropogenic noise sources include shipping, construction, industrial and military activities. The Ambient Noise level (N) is defined as the sum of all these sources.

RECEIVERS The simplest receiver is a single omni-directional hydrophone. A hydrophone is a transducer that converts pressure variations to electrical signals. These are then amplified and processed to extract the required echo. In practice, most active sonars use directional hydrophones with gain to improve the signal/noise ratio. The increased performance can be obtained by increasing the size of the single hydrophone so that it becomes directional, a technique used by simple echo-sounders, or by using arrays of simple hydrophones. The performance is characterised by two factors, Array Gain (AG) and Directivity Index (DI). Array gain is defined as the ratio of the signal/noise ratio from the array compared to the signal/noise ratio from a single hydrophone. Directivity Index is defined as the ratio of peak intensity to the average intensity of the radiation pattern. AG is easier to calculate, but DI is the parameter normally used.

The output of the receiver is normally compared to a fixed reference called the Detection Threshold (DT). Signals that exceed the Detection Threshold are detected; those that do not are not detected. DI is expressed by the following equation:

$$DI = 10Log_{10}\left(I_{pk} / I_{av}\right)$$

BRINGING IT ALL TOGETHER All the factors described above are brought together in the Sonar Equation:

$$SE = SL - PL + TS - PL + DI - N - DT$$

where SE is the signal excess and all factors are expressed in dB re 1 µPa. In words, the sonar equation tells us that starting with the sound generated by the source (SL), this is diminished by the propagation path to the target (PL). The sound is then reflected by the target (TS) and then diminished further by a second path loss (PL). On arrival at the receiver, the signal/noise ratio is enhanced by the Directivity Index (DI) and the signal /noise determined by the ambient noise level (N). The resultant receiver output is then compared with the Detection Threshold (DT) to give the Signal Excess (SE).

ACTIVE SONAR SYSTEMS Active sonars today perform a variety of tasks. Most ships, yachts and boats that go to sea today have an echo-sounder fitted which will work in the range 25 kHz for the long-range sounders up to 300 kHz for short-range units. They generate a simple short pulse with source levels up to 225 dB re 1 µPa@1m. Vessels may also carry fish-finding sonars and forward-looking scanning sonars working in a similar frequency range. Survey vessels may carry side-scan sonars, bottom profilers, and Doppler profilers. Again, these mostly work in the tens of kHz region and with source levels up to 230 dB.

Military ships will carry far more sophisticated systems capable of transmitting complex signals optimised for particular tasks. They cover the frequency range 200 Hz to 15 kHz and with source levels up to, and in excess of, 230 dB re 1 µPa@1m.

Seismic survey boats use low-frequency air gun arrays that generate a single half-cycle using a complex firing sequence for the guns. Source levels up to 250 dB re 1 µPa@1m with peak energy below 100 Hz are achieved, but the pulse is directed downwards into the seabed.

Bioacoustic systems include the short pulse systems used by the odontocetes and some birds, and the long sophisticated pulses used by bats. It is believed that bottlenose dolphins can achieve source levels around 227 dB re 1 µPa@1m.

REFERENCES

Urick, R.J. 1983. *Principles of underwater sound.* McGraw-Hill Book Co. ISBN 0-07-066087-5. Third edition.

Waite,A.D. 1998. *Sonar for practising engineers*. Thomson-Marconi Sonar Ltd. ISBN 0-9528033-1-3. Second edition.

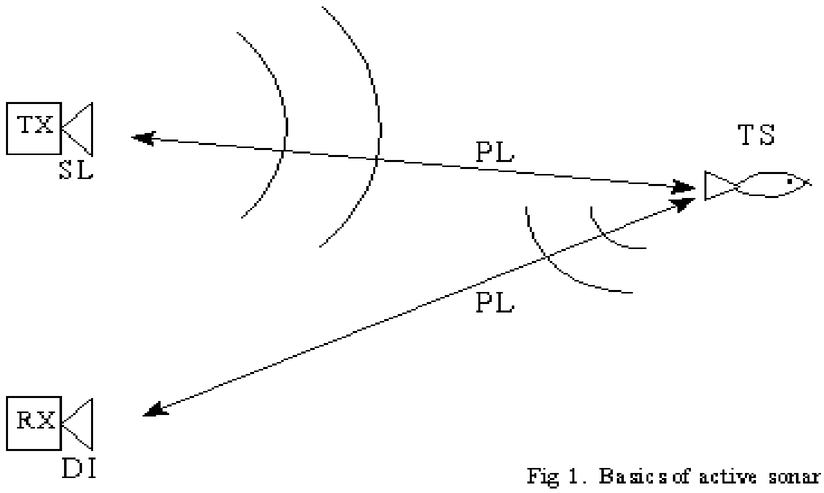

Fig 1. Basics of active sonar

SONAR SYSTEMS AND STRANDING OF BEAKED WHALES

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There is increasing evidence that some military sonar operations coincide with mass stranding of beaked whales. Two of these stranding events were analysed extensively and relevant sonar parameters disclosed.

Although the controversy around the National Marine Fishery Service permit for the SURTASS-LFA (US) continues to fuel public and legal interest, the focus on SURTASS-LFA is misleading in understanding the cause and effect between sonar systems and beaked whale mass stranding events. This presentation summarises information on the recent stranding events and the sonar systems involved, and addresses the need of appropriate acoustic risk assessment and mitigation.

STRANDING EVENTS

The following stranding events related to military sonar activities aroused considerable public interest:

Greece 1996

On 12 and 13 May, 12-13 Cuvier's beaked whales *Ziphius cavirostris* stranded along 35 km of the coast in Kyparissiakos Gulf. During this period, NATO Undersea Research Centre (SACTCEN, formerly SACLANTCEN) carried out low and mid-frequency active sonar trials (D'Amico, 1998).

Findings: No investigations of the whales' inner ear were carried out. (D'Amico, 1998).

Bahamas 2000

"On 15 and 16 March, … a multi species stranding of seventeen marine mammals was discovered in the Northeast and Northwest Providence Channels on Bahamas Islands. The stranding took place within 24 hours of U.S. Navy ships using mid-range sonar as they passed through the Northeast and Northwest Providence Channels" (Evans and England, 2001).

Findings: "All [specimens examined] showed cerebral ventricular and subarachnoid haemorrhages, small (petechial) haemorrhages in the acoustic fats of the jaw and melon, and blood in the inner ear without round window damage (that is, the blood may have either originated in the inner ear or diffused to it from haemorrhages sites in the subarachnoid space). No conclusion has yet been reached on whether these hemorrhages occurred before or after stranding." (Evans, 2002).

Madeira 2000

Three Cuvier's beaked whales stranded in the Madeira archipelago coinciding with NATO Naval Exercises in the area surrounding Porto Santo Island, including the channel between Madeira and Porto Santo (Freitas, this volume).

Findings: The results showed haemorrhages at the inner ear and sub-rachnoidal spaces, consistent with a temporary acoustic induced trauma (Ketten, 2003).

Canary Islands 2002

"In September 2002, a mass stranding of 14 animals belonging to three different species of the family Ziphiidae took place in the Canary Islands" (Degollada *et al.*, 2003; Fernández, this volume). This event coincided with a Spanish-led Navy manoeuvre.

Findings: "The most remarkable feature were inner ear haemorrhages and edema starting in the VIIIth cranial nerve and extending into the spriral ganglion and the cochlear channels" ((Degollada *et al*., 2003; Fernández, this volume).

SONAR TYPES

Active sonar emits pulses ("pings") and times the arrival of returning echoes. The distance of the target from the sonar is then given by one-half the round-trip travel time multiplied by the speed of sound. Most sonar systems are designed to fulfil a specific task with minimum amount of sound energy.

Based on the purpose, active sonar systems may be described as:

- *Long-range detection sonar*
  LFAS
  Tactical sonar

- *Short-range imaging sonar*
  Side-scan sonar
  Multi beam sonar

- *Environmental sonar*
  Depth sounder
  Acoustic Doppler Current Profilers (ADCP)
  Acoustic tomography (e.g. ATOC)

Table 1. Sonar systems related or possibly relevant to beaked whale stranding events

Sonar Model	SURTASS LFA	SLC TVDS LF	SLC TVDS MF	AN/SQS-53C	AN/SQS-56
Reference	4	1	1	2	2
Stranding Event	nil	Greece 96	Greece 96	Bahamas 00	Bahamas 00
Frequency (kHz)	0.1-0.5	0.45-0.65, 0.7	2.8-3.2, 3.3	2.6, 3.3	6.8, 7.5, 8.2
Level (dB//uPa@1m)	240 (18*215)	214-228	223-226	235+	223
Pulse duration (s)	6-100	2+2	2+2	0.5-2	
max Bandwidth (Hz)	30	200	400	100	100
Repetition interval (s)	360-900	60	60	26	26
vert Beam width (deg)	5.5?	23	24	40	30
hor Beam width (deg)	360	360	360	360/120	360
Depth (m)	122	60-90	60-90	7.9	6.1
duty cycle (%)	10-20	7	7	8	8

Table 1 summarises the publicly available information on sonar system parameters. These systems are typical long-range detection sonar, and are characterised by :

- The (long) pulse repetition rate
- Small vertical beam width
- Large horizontal aperture (mostly omni-directional in azimuth).

The vertical beam width of the SURTASS LFA is shown with a question mark as this value is estimated assuming 18 projectors spaced vertically to generate a far field gain of 25 dB.

The AN/SQS systems are operational sonar systems used mainly by the US Navy. The SLC TVDS system was an experimental system operated by SACLANTCEN in the middle of the 1990s. It is out of use now. The SURTASS LFA has been developed by the US Navy and is the system subject to the legal dispute in the USA. However, it was never related to a stranding event.

Short-range sonar systems have a pulse repetition rate consistent with the water depth and comparable vertical and horizontal beam width (mostly pencil beams).

Sound exposure of sonar systems

The exposure of sonar systems is estimated by:

$$RL = SL - TL$$

where

RL is the received level
SL is the transmitted source level
TL is the propagation or transmission loss from source to receiver

SOUND SOURCE LEVEL

The sound source level is defined as the pressure level that would be measured at a reference distance of 1 m from an ideal point source radiating the same sound intensity as the actual source. It is a purely theoretical value. In underwater applications, the source level is typically expressed as dB//1 µPa@1m.

Very close to the sound source, however, the so-called near field, the sound intensity does not follow simple relations as it is generated by an extended surface. The total sound intensity can be measured properly and described by a single number only at a certain distance. The maximum sound pressure level is also only measured in the axis of the transmit beam pattern.

For example, the SURTASS LFA consists of an array of 18 sound sources. While it is correct to use 240 dB//1 µPa@1m as the maximum source level of the whole source array for long-range applications, the maximum received level close to the source array may not exceed 215 dB//1 µPa@1m, which is the source level of a single source, as stated in the SURTASS LFA OEIS (Johnson, 2001).

In practice, the theoretical value of the source level will be measured at distances large enough to exclude near-field effects, but close enough to calculate the propagation loss between the reference and actual distance.

SOUND PROPAGATION

An understanding of sound propagation is crucial to the performance assessment of long-range sonar systems and consequently also required for the evaluation of the exposure of marine life to sound.

In general, propagation loss is composed of losses due to distribution of energy (spreading loss), absorption of energy in the water column, and loss as a consequence of interaction with the boundary.

The spreading loss reflects the principle of energy conservation and depends only on the sound speed gradient in the ocean (Snell's law). This does not imply that the spreading loss may be easily estimated. Under very specific circumstances (constant sound speed for all depth and range), the following formula is valid for the transmission loss TL in dB:

$$TL = 20\log R + 60 + \alpha R \qquad R < R_0$$

$$TL = 20\log(R_0) + 60 + 10\log\frac{R}{R_0} + \alpha R + \gamma R \qquad R \geq R_0$$

All ranges R are in km (note the 60 dB constant) and R_0 is the critical range where the spreading changes from dominantly spherical to mainly cylindrical. This value depends on the actual sound-speed profile and is typically proportional to the width of the channel in which the sound energy is propagating.

α is the absorption coefficient and describes the energy loss along the acoustic path. The absorption is frequency dependent and varies in sea water from 0.001 dB/km @ 0.1 kHz to 30 dB/km @ 100 kHz. (Urick, 1983).

For low frequencies and short ranges, the effect of absorption may be neglected. At large ranges, however, transmission loss due to absorption becomes significant. For example, we get an additional loss of 90 dB for 1 kHz and a range of 2500 km.

γ is a loss factor representing the sound leakage out of the sound channel. This value may be significant when the sound interacts with the bottom. Urick (1983) gives a value for Baltic Sea bottom absorption in the order of 0.5 dB/km, that is, we get an additional loss of 90 dB at a range of 180 km.

In general, sound absorption or channel leakage will provide an upper limit to the distance of sound propagation.

In most cases of the real ocean situations, the above characterisation of the transmission loss is too simplistic. The sound speed profile is usually sufficiently complicated that, for real applications, transmission loss is measured or estimated with mathematical models which take into account not only the actual sound speed measurements but also complex bottom parameters. At reasonably close ranges, however, sound propagation is in close agreement with spherical spreading.

SOUND IMPACT ASSESSMENT

The knowledge of the received level or signal access is not sufficient to estimate the impact of sound exposure on marine mammals. It is necessary to include the biological significance of the sound on the ensonified species, which is expected to depend also on frequency, bandwidth, signal duration, and on the activity in which the animal is found (resting, foraging, etc). Richardson *et al.* (1990) suggest that biological significance depends on:

- Area affected *versus* available habitat
- Auditory interference by masking
- Behavioural disruption
- Habituation *versus* continued responsiveness
- Long-term exposure
- Cumulative exposure

In view of the pathological findings of the beaked whale mass strandings, one should add to this list:

- Recovery from acoustically introduced traumas
- Co-operative reaction

The biological significance of sonar impacts and responses to sonar sound should be quantified in the same way as sound propagation is expressed, by a number. It may not be possible to address all relevant topics conclusively, but without being quantified (scientifically or politically), they may not be useful for risk assessment.

RISK ASSESSMENT

The final assessment of acoustic risk is the responsibility of the decision-makers. To facilitate the assessment process, in which the risk is related to competing requirements and politically weighted, it would be useful to base the assessment on a well-defined risk assessment procedure, which also allows quantification of the residual risk. To reduce this residual risk further, special, on-scene, risk mitigation tools could and should be developed. This risk assessment procedure should be comprehensive and must include the assessment of biological significance. The procedure should also be robust enough to allow minor uncertainties in the knowledge applied.

OPEN QUESTIONS

Tactical mid-frequency (1-10 kHz) sonar has been used by navies during the last two decades all over the world. So why have so few mass stranding of beaked whales been reported? The following reasons are put forward:

- Lack of temporal-spatial coincidence
- Interaction more often, but
  - no stranding occurred
  - no stranding observed

Is sound directly or indirectly the cause of the stranding?

- Trauma due to sound impact
- Trauma due to reaction to sound

Which characteristics in the sonar sound are causal to stranding?

- Sound pressure
- Signal waveform (type, frequency, bandwidth, duration)
- Signal usage (repetition rate, operational context)

Is there a gradual interaction or a sudden onset of mass stranding?

- Is there a linear relationship between cause and effect?
- Do animals panic when disturbed by sound?

REFERENCES

D'Amico, A. (editor). 1998. *Summary Record SACLANTCEN Bioacoustic Panel*. La Spezia, Italy, 15-17 June 1998.

Degollada, E., Arbelo, M., André, M., Blanco, A. and Fernández, A. 2003. Prelimary ear analysis report of the 2002 Canary Island Ziphius mass stranding. Pp. 60-61. *In:* Abstracts, 17th Confrerence of the European Cetacean Society , Las Palmas de Gran Canaria, 9-13 March 2003. 285pp..

Evans D.L. and England G.R. 2001. *Joint Interim Report Bahamas Marine Mammal Stranding Event of 15-16 March 2000*. Unpublished Report. 61pp. Available at www.nmfs.noaa.gov/prot_res/overview/Interim_Bahamas_Report.pdf.

Evans D.L. 2002. *Report of the Workshop on Acoustic Resonance as a Source of Tissue Trauma in Cetaceans*. 24-25 April 2002, Silver Spring, MD..Unpublished Report..

Freitas L. (this volume). The stranding of three Cuvier's beaked whales *Ziphius cavirostris* in the Madeiran Archipelago – May 2000.

Johnson J.S. 2001. *Final Overseas Environmental Impact Statement and Environmental Impact Statement for SURTASS LFA Sonar*. Unpublished Report.

Ketten D. 2003. Presentation at Workshop on Active Sonar and Cetaceans, European Cetacean Society's 17th Annual Conference, Las Palmas, Gran Canaria, Spain, 8th March 2003.

Richardson W.J. , Greene, C.R., Malme, C.I. and Thomson, D.H. 1995. *Marine Mammals and Noise.* Academic Press, San Diego, CA.

Urick R. 1983. *Principles of Underwater Sound*. McGraw-Hill, NY.

THE FIRST MASS STRANDING THAT WAS ASSOCIATED WITH THE USE OF ACTIVE SONAR (KYPARISSIAKOS GULF, GREECE, 1996)

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INTRODUCTION The Greek Seas occupy the northern part of the eastern Mediterranean and are characterised by a very long, highly irregular coastline and a rich geomorphology (Stergiou *et al*., 1997). The depressions and the deep trenches that surround Greece (Fig. 1) create appropriate habitats for deep diving cetaceans close to the coasts.

The Cuvier's beaked whale *Ziphius cavirostris* is the only ziphiid regularly present in the Mediterranean Sea (Notarbartolo di Sciara, 2002). Both strandings and sightings recorded during the last decade have shown clearly that the Greek Seas are an important area for this species (Frantzis *et al*., in press). The yearly average of Cuvier's beaked whale strandings in Greece is 5.6 individuals (95% C.L. = 2.78) for the decade 1990-99 (the mass stranding of May 1996 excluded). Although underestimated (because no official stranding network was established in Greece before 1992), this number is significantly higher than the respective average for each of the three northern countries of the west and central Mediterranean (Spain 1.9, France 0.2, Italy 2.6), and higher (although not significantly) than their sum. Most of the strandings that occurred in Greece were recorded along the Hellenic Trench, which runs all around the west and south Greece, and marks the limits of the European continental shelf with steep underwater relief. Surveys conducted along the Hellenic Trench confirmed that Cuvier's beaked whales are abundant (Frantzis *et al*., in press).

The mass stranding of Cuvier's beaked whales presented in this work was the first to be associated with the use of active sonar. It took place in Kyparissiakos Gulf (Frantzis, 1998), which is also part of the Hellenic Trench. It is a long sandy beach in the west coast of the Peloponnese (Fig. 1). Mass strandings involving beaked whales had repeatedly coincided with the proximity of military manoeuvres in the recent past in the Canary Islands (Vonk and Martin, 1989; Simmonds and Lopez-Jurado, 1991); however, no data regarding the nature of the military activity and the possible use of active sonar that was taking place are available.

THE MASS STRANDING During the first hours of the morning of 12 May 1996, Cuvier's beaked whales started to strand alive in many different locations of Kyparissiakos Gulf. The strandings went on until the afternoon of 13 May. A few more specimens (4-5) were reported as stranded and rescued, entangled and rescued, or swimming very close to the coasts during the next three days. However, only one of those reports could be confirmed. Twelve whales have been recorded in total on the 12^{th} and 13^{th} May. Those whales were spread along 38.2 km of coast and were separated by a mean distance of 3.5 km (SD = 2.8, n = 11) (Fig. 1).

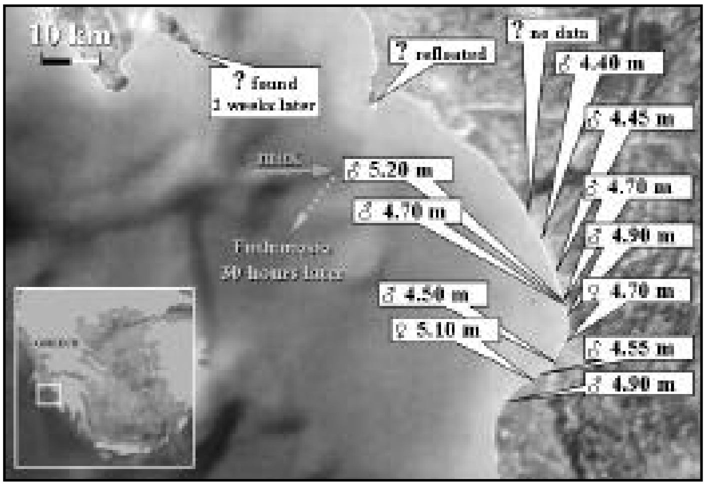

Fig. 1. Position, sex and total length of the 14 Cuvier's beaked whales that were recorded during, or shortly after the mass stranding of 12 and 13 May 1996 in Kyparisiakos Gulf, Greece

Another whale stranded on 16 May and was driven back to the open sea. Two weeks later, one more animal was found decomposing on a remote beach of the neighbouring Zakynthos Island, 57 km away from the closest stranding on the mainland. We had the opportunity to observe, measure, and sample 11 whales. Nine of them were immature males with no erupted teeth and two were females (Fig. 1). The recorded spread of the stranded animals in location and time was atypical, as whales usually mass-strand at the same place and at the same time. The term "atypical mass stranding" has been proposed for the recorded strandings as opposed to typical mass strandings known mainly from pilot whales and false killer whales (Geraci and Lounsbury, 1993).

Necropsies of eight stranded animals were carried out, but no apparent abnormalities or wounds were found. These necropsies were limited to basic external examination and sampling of stomach contents, blood, and skin. No ears were collected; no entire organs or histological samples were conserved because of many problems related to permits, lack of facilities and means, and lack of relevant knowledge and trained specialists. A recent re-examination of old photos of the mass stranding showed that the eyes of (at least) four individuals were bleeding. These animals had been photographed soon after their death. Stomach contents had variable quantities of squid remains (like beaks and ocular lenses) from three different squid species. Many of them contained cephalopod flesh, indicating that recent feeding had taken place.

The following year (October 1997), several strange strandings of Cuvier's beaked whales were recorded in the Ionian Sea, once more spread along several kilometres of coast. The northern stranding position was slightly north of Lefkada Island (some 80 nautical miles north of Kyparissiakos Gulf) and the southern was in south Zakynthos Island (Fig. 2). At least nine Cuvier's beaked whales stranded within a period of about ten days. Two more whales were reported to accompany one of the stranded animals. However, no photographic documents exist to confirm these reports. At least one of the stranded animals was alive when stranded on the 1st October. According to the state of decomposition of the whales that were found dead, the strandings should have started by the last days of September 1997. Once more there was military activity in the area. Unfortunately, no precise data regarding this activity have become available until today. This is the reason why this second atypical mass stranding of Cuvier's beaked whales in the Greek Ionian Sea has remained largely unreported.

THE CAUSE All available information regarding the conditions associated with the mass stranding of May 1996 was gathered, and many potential causes were listed and examined. The most important of them were: major pollution events, important tectonic activity, unusual geochemical/physical/meteorological events, magnetic anomalies in the area, epizootics, and conventional military exercises. However, none of the potential causes listed above coincided in time with the mass stranding or could explain its characteristics (see also NATO-Saclantcen, 1998, which came to the same conclusion). Several months after the mass stranding, I found a warning to mariners issued by the Greek Hydrographic Service, which provided significant information relevant to its cause. This warning (586 of 1996) was stating that 'sound-detecting system trials' were being performed by the NATO research vessel *Alliance* from 24:00 on 11 May to 24:00 on 15 May - a period that encompassed the mass stranding. The officially declared area where the sea trials had been carried out enclosed all the co-ordinates of the stranding points. The tests performed were for Low Frequency Active Sonar (LFAS), a system that introduces very high levels of low and medium frequency sound into the marine environment to detect quiet diesel and nuclear submarines. Detailed information regarding the time schedule, the runs (Fig. 3), and the specific sound characteristics of the transmissions became unclassified and available through NATO-Saclantcent by the fall of 1998 (NATO-Saclantcen, 1998). The Alliance was using high power active sonar, transmitting simultaneously to both low (450-700 Hz) and medium (2.8-3.3 kHz) frequencies, at a maximum output of 228 dB re 1 μPa @ 1 m, which enables long detection ranges.

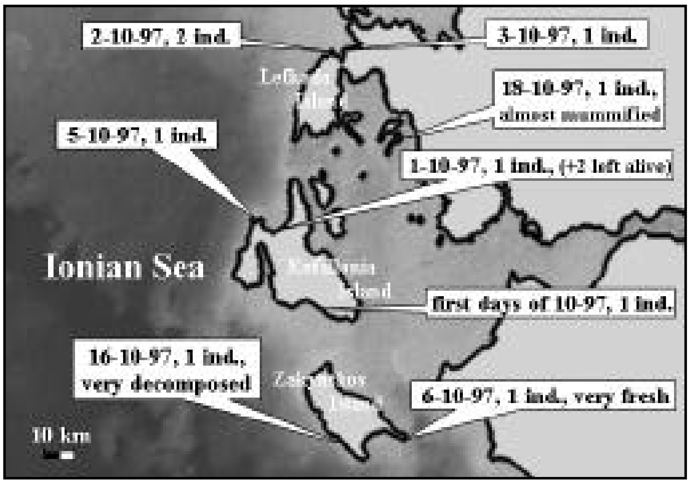

Fig. 2. Date of discovery, number of individuals, and carcass state for the Cuvier's beaked whales that stranded in the east Ionian Sea by the end of September - beginning of October 1997.

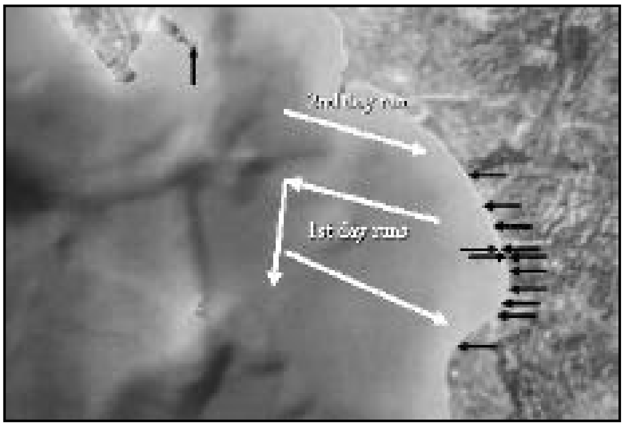

Fig. 3. Runs of the first and second day of the LFAS tests (12 and 13 May 1996) according to NATO-Saclantcen (1998). The black arrows indicate the stranding positions of the whales during the same days, plus the position of the whale found in Zakynthos Island

DISCUSSION Research on LFAS began by NATO in 1981 (NATO-Saclantcen, 1993), and a statement on its environmental impact was formally initiated in July 1996 by the US Navy. The adverse effects of low and mid-frequency sound on whales had been poorly studied (Richardson and Würsig, 1997) by the time the mass stranding occurred in Kyparissiakos Gulf. However, many specialists had warned that at high levels, as occurs with LFAS, they could be dramatic (see relevant discussions on LFAS in MARMAM list in 1996). Like all ziphiids, the Cuvier's beaked whale is a deep-diving, pelagic cetacean that rarely mass-strands (Heyning, 1989). Only seven strandings of more than four individuals had been recorded from 1963 to 1996 worldwide - the individuals on these occasions numbering 5, 6, 6, 10, 12, 15 and 19 (Frantzis, 1998). On most of these clearly extremely rare occasions, mass strandings showed atypical characteristics unlike those that occur with other whales. This suggests that the cause should have a large synchronous spatial extent and a sudden onset. Such characteristics are shown by sound in the ocean. Cetaceans, and particularly the deep-diving whales, were known to be especially affected by low and mid-frequency anthropogenic sound, even at quite low received levels (Watkins *et al*., 1985; Finley *et al*., 1990; Finley and Greene, 1993; Bowles *et al*., 1994; Richardson and Würsig, 1997), and it is worth noting that the first atypical mass stranding of ziphiids was recorded in 1963 (Tortonese, 1963), i.e. at the time that the use of a new generation of powerful mid-frequency tactical sonars became widely deployed (Balcomb and Claridge, 2001). In addition, the proximity of military manoeuvres had already been suspected of causing three previous atypical mass strandings of Cuvier's beaked whales, spread over wide areas of the Canary Islands (Vonk and Martin, 1989; Simmonds and Lopez-Jurado, 1991).

Although the available data in 1996 could not directly prove that the use of active sonars caused the mass stranding in Kyparissiakos Gulf, all evidence clearly pointed to the LFAS tests. The main arguments and the supporting evidence are listed below:

- At least 12 of the 14 animals stranded alive in a completely atypical way.
- The robust condition of the stranded animals plus the stomach content analyses were not consistent with pathogenic causes (which anyway are not known to provoke atypical mass strandings).
- No unusual environmental events occurred before or during the stranding (e.g. tectonic activity, magnetic anomalies, geophysical or geochemical events, meteorological events etc.).

- The stranding characteristics suggested a cause with large synchronous spatial extent and sudden onset (i.e. those shown by sound in the ocean).
- Loud, low and mid-frequency sound was already known to have an impact upon deep-diving cetaceans.
- And most importantly, the probability for the two events (i.e. the LFAS tests and the mass starnding) to coincide in time and location, while being independent, was extremely low. In other words if we consider the 16.5-year period before the mass stranding (1981 was chosen arbitrarily because this was the year that NATO started to experiment on LFAS, and we are sure that no mass stranding, nor other tests of LFAS had occurred in the area since that year), the probability of a mass stranding occurring for other reasons during the period of the LFAS tests (i.e. from the 12th to the 15th of May 1996 instead of any other day) is less than 0.07%

Today, after the repeated mass strandings that followed the Greek case with identical characteristics and always in close association with naval exercises and use of military active sonar in the Bahamas (Balcomb and Claridge, 2001), Madeira, and Canary Islands (see this volume), there is little doubt in the scientific community regarding the cause of the mass stranding in Kyparissiakos Gulf. If the precautionary principle had been applied shortly after the analysis of the data related to the Greek case, and active sonar tests had been stopped, the most recent mass strandings would have been avoided.

The Cuvier's beaked whale stranding history of Kyparissiakos Gulf (Fig. 4) shows that although no mass strandings had been recorded before 12 May 1996, the strandings of this species were not rare. The average stranding rate was 0.88 individual/half year (SD = 0.99, n = 8). After the mass stranding of May 1996, the stranding rate was reduced to less than one-third of what it was before the mass stranding (0.25 individual/half year, SD = 0.45, n = 12). This is an alarming result, which is in accordance with what has been observed in the Bahamas after the multi-species mass stranding of March 2000: previously photo-identified and re-sighted beaked whales were not sighted again after the mass stranding (Balcomb and Claridge, 2001). These results indicate that the damage could be significantly higher than the death of the stranded whales. Many others may have left the area or may have died in the deep offshore waters.

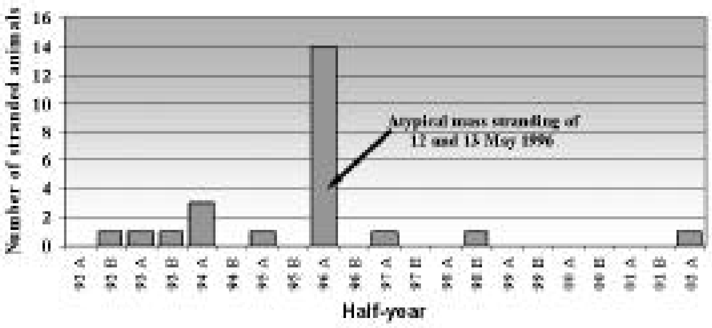

Fig. 4:. The stranding history of Kyparissiakos Gulf regarding Cuvier's beaked whales from 1992 to 2002

The present workshop, as well as the exponentially increasing number of studies regarding beaked whales indicate that there is a high level of interest in the scientific community regarding the serious problem of the use of high power active sonars in the oceans, and a lot of effort is dedicated in finding solutions. The recognition of the problem, which is now unanimous, is an important first step. The various interesting theories regarding the mechanisms through which sound sends the animals ashore are also very useful in an effort to mitigate the problems. However this significant progress is not able to stop further loss of cetaceans and cetacean habitats, if not accompanied by the proper decisions. The scientific community does not need to witness further mass strandings linked to naval exercises in order to advance its knowledge. There are enough data to show that the most reasonable decision is to stop all dangerous, powerful sonar activities in the ocean. Cetologists prefer to have the opportunity to observe and study the beaked whales and all other cetacean species alive and free ranging in their habitats rather than lying dead on a beach.

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REFERENCES

Balcomb, K. C. III and Claridge, D. E. 2001. A mass stranding of cetaceans caused by naval sonar in the Bahamas. *Bahamas J. Sci*., 5: 1-12.

Bowles, A.E., Smultea, M., Würsig, B., DeMaster, D. P. and Palka, D. 1994. Relative abundance and behaviour of marine mammals exposed to transmissions from the Heard Island Feasibility Test. *J. Acoust. Soc. Am*., 96: 2469–2484.

Finley, K. J. and Greene, C. R. 1993. Long-range responses of belugas and narwhals to ice-breaking ships in the Northwest Passage. Abstracts of the 26th ASA Meeting, 4-8 October 1993, Denver. 4aAB4.

Finley, K. J., Miller, G. W., Davis, R.A. and Greene, C. R. 1990. Reactions of belugas, *Delphinapterus leucas*, and narwhals, *Monodon monoceros*, to ice-breaking ships in the Canadian high arctic. *Can. Bull. Fish. Aquatic Sci*., 224: 97-117.

Frantzis, A. 1998. Does acoustic testing strand whales? *Nature*, Lond., 392: 29.

Frantzis, A., Alexiadou, P., Paximadis, G., Politi, E., Gannier, A. and Corsini-Foka, M. (in press). Current knowledge on the cetacean fauna of the Greek Seas. *J. Cetacean Res. Manage.*

Geraci, J. R. and Lounsbury, V. J. 1993. *Marine Mammals Ashore. A Field Guide for Strandings.* Texas A&M Sea Grant Publication, Galveston, Texas. 305pp.

Heyning, J. E. 1989. Cuvier's Beaked Whale *Ziphius cavirostris* G. Cuvier, 1823. Pp. 289-308. In *Handbook of Marine Mammals* Vol. 4 (Eds. S. H. Ridgeway and R. J. Harrisson). Academic Press, London. 442pp.

NATO-Saclantcen 1993. *Endeavour and Achievement*. NATO–SACLANT Undersea Research Centre, La Spezia, Italy. 37pp.

NATO-Saclantcen, 1998. *Report of the SACLANTCEN Bioacoustic Panel and SACLANTCEN Marine Mammal Environmental Policy and Mitigation Procedures Panel*, La Spezia, 15-19 June 1998. NATO-Saclantcen, La Spezia. 4 chapters+Annexes A-KK.

Notarbartolo di Sciara, G. 2002. III – Cetacean species occurring in the Mediterranean and Black Seas, Pp. 6-26. In *Cetaceans of the Mediterranean and Black Seas: state of knowledge and conservation strategies.* (Ed. G. Notarbartolo di Sciara). Document ACCOBAMS/MOP1/Inf.6, presented to the first meeting of ACCOBAMS partners, February 2002, Monaco. 219pp.

Richardson, W. J. and Würsig, B. 1997. Influences of man-made noise and other human actions on cetacean behaviour. *Mar. Fresh. Behav. Physiol.* 29: 183–209.

Simmonds, M. P. and Lopez-Jurado, L. F. 1991. Whales and the military. *Nature* (Lond.), 351: 448.

Stergiou, K.I., Christou, E.D., Georgopoulos, D., Zenetos, A. and Souvermezoglou, C. 1997. The Hellenic Seas: physics, chemistry, biology and fisheries. *Oceanogr. Mar. Biol., Ann. Rev.*, 35: 415-538.

Tortonese, E. 1963. Insolita scomparsade cetacei (*Ziphius cavirostris* G. Cuv.) nel golfo di Genova. *Natura*, 54: 120-122.

Vonk, R. and Martin, V. 1989. Goose beaked whales *Ziphius cavirostris* mass strandings in the Canary Islands. Pp. 73-77. In: *European Research on Cetaceans - 3*, Proc. 3rd Ann. Conf. ECS, La Rochelle, 24-26 February, 1989 (Eds. P.G.H. Evans and C. Smeenk). European Cetacean Society, Lieden, Holland. 150pp.

Watkins, W. A., Moore, K.E. and Tyack, P. 1985. Sperm whale acoustic behaviours in the Southeast Caribbean. *Cetology*, 49: 1–15.

CRANIAL TRAUMA IN BEAKED WHALES

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INTRODUCTION Beaked whales (Ziphiidae) are a ubiquitous but poorly understood group of marine mammals. Our knowledge of them has been limited largely to off-shore sightings, surface observations, and gross measurements, often from poorly preserved animals. Historically, they are more frequently found as single stranded animals and most species rarely mass strand. For a very few species, well-preserved material is available but much of it has not been dissected nor employed in experimental work because of the rarity of specimens. Playback experiments in free-ranging animals have also been difficult to achieve, and there is to date no published, clearly verified vocalisation data for any beaked whale species (Wartzok and Ketten, 1999). We therefore know relatively little about ziphiid behaviour or physiology in general, and virtually nothing of their use of sound or hearing abilities.

Recent mass strandings of beaked whales in Greece, the Bahama Islands, Madeira, and the Canary Islands suggest that beaked whales - and particularly Cuvier's beaked whale (*Ziphius cavirostris*), are prone to stranding following exposure to high intensity impulse noise, particularly mid-frequency sonar. Beaked whale mass strandings are notable because, unlike pilot whales and white-sided dolphins, these animals do not live in large social groups and do not commonly mass strand. One of the difficulties of reviewing stranding statistics on beaked whales historically is that species identification is difficult. Cuvier's beaked whales have been reported to mass strand more frequently than other beaked whale species, but they are relatively rare world wide, and only two prior mass stranding events of beaked whales have been reported for the Bahamas in the last 150 years.

Each of the above noted strandings coincided with a U.S. Navy, NATO/SACLANT, or European naval exercise that involved ships utilising tactical mid-frequency sonars. These events have generated considerable concern that sonars instigated the strandings and may have directly or indirectly caused the deaths and traumas found in the beached whales. Clearly, there is an acute need to understand whether sonar was a direct or indirect agent in the injuries to these whales, the precise mechanism behind the traumas that were found, and the nature and extent of potential impacts from man made sounds, particularly from sonar and impulse noise, on these elusive animals.

To that end, organised retrospective investigations are being conducted for each of these strandings. Full details of the Bahamian stranding and results of subsequent related studies may be obtained from the report on this event available at the following website:

www.nmfs.noaa.gov/prot_res/overview/Interim_Bahamas_Report.pdf

This paper summarises the stranding and results from the radiological examinations and necropsies of the whales that died in the Bahamian stranding event of March, 2000, and discusses the potential mechanisms of traumas based on the pathologies observed. Multiple researchers and pathologists are involved in determining the findings in these cases. The final consensus report is in preparation and the data presented here is not to be considered binding or final. The findings reported in this paper represent primarily the findings by the senior author at this time and should not be construed to represent views of NOAA Fisheries or any other investigator. Final conclusions will be released by NOAA Fisheries in the report expected in spring 2004.

BAHAMIAN STRANDING EVENT SUMMARY On 15 and 16 March 2000, 17 cetaceans were reported stranded along a 240 km arc in the Northeast and Northwest Providence Channels of the Bahamas Islands. The strandings, with the exception of one animal, were spread along the western shores of three islands (Grand Bahama, Abaco, and North Eleuthera) and comprised four species distributed as follows: ten Cuvier's beaked whales (*Ziphius cavirostris*), three Blainville's beaked whales (*Mesoplodon densirostris*), two unidentified beaked whales, one spotted dolphin (*Stenella frontalis*), and two minke whales (*Balaenoptera acutorostrata*). Seven of these animals died, including five Cuvier's beaked whales, one Blainville's beaked whale, and one spotted dolphin. The remaining ten live animals were successfully pushed into deeper water or swam away and did not restrand, however, the longer term fate of these animals is unknown at this time. Based on the condition and location of each of the stranded animals in this event, it is likely that all animals stranded within a narrow time frame on the morning of 15 March. Strandings were first noted at the southern end of the channels and reports proceeded northwest throughout the following 36 hours. The spotted dolphin and minke whales stranded in areas well separated from the beaked whales. Both minke whales came to shore alive and returned to deeper water on their own. Because these two animals were not examined in any way, no definitive statements can be made about the cause of their stranding or whether they sustained any subtle injuries in common with the beaked whales.

SHIP MOVEMENTS AND ACOUSTIC MODELLING

Commander in Chief of the U.S. Atlantic Fleet prepared a report (Evans and England, 2001) which described in detail the timing and courses of U.S. Navy ships in the Northeast and Northwest Providence Channels on March 15, 2000. Numerous ships transited from the southeast to the northwest in generally the same pattern as the strandings were discovered. Five ships used their main frame active sonar in the channels during the time of interest. Two ships operated the tactical mid-frequency sonar designated AN/SQS-53C and two operated sonar designated AN/SQS-56. During the 16-hour period in which the ships transited the channel using sonar, each ship pinged its sonar approximately every 24 seconds with pings from nearby ships staggered in time so as not to coincide. Because the ships did not operate at the same frequencies, and because the ships with the same frequency sonars did not operate in the same temporal and spatial proximity, there is little likelihood of increased sound pressure levels from multiple simultaneous pings.

GROSS NECROPSY RESULTS The post-mortem condition of the seven animals that died ranged from fresh dead to advanced decomposition. Six of the seven mortalities were necropsied to the fullest extent possible. Only three of these animals, one Cuvier's beaked whale, one Blainville's beaked whale, and the spotted dolphin, were sufficiently fresh to provide gross and histo-pathology results for most of the available tissues (albeit there was post-mortem autolysis noted in all of the beaked whale tissues).

The spotted dolphin was the only animal stranding on the eastern shore of the islands. The necropsy of this animal revealed chronic, systemic, debilitating disease in multiple organ systems.

It did not have any of the trauma elements found in the beaked whales that died. Based on the location of the animal and the clear evidence of long term disease typical of many stranded animals, it was concluded that the spotted dolphin in this event was a coincidental stranding and its beaching was unrelated to the mass stranding event of the beaked whales that same day.

The remaining six animals that died were all Cuvier's and Blainville's beaked whales. One was severely decomposed and was only partially necropsied. The other five were fully necropsied, and heads of two of the animals were examined radiologically. All five animals examined were in good body condition, and none showed evidence of debilitating infectious disease, ship strike, blunt contact trauma, or fisheries related injuries. Three of the beaked whales had small amounts of ingesta in the stomach. Similar to findings in many stranded cetaceans, distinct band lesions - consistent with stress, were found in histological examinations of the heart muscle. Similar common stranding-related lesions were found in the spleen, liver, and kidney. These pathologies are consistent with death from cardiovascular collapse due to extreme physiologic stress associated with the physical stranding; *i.e*., hyperthermia, high endogenous catecholamine release, and shock.

CRANIAL NECROPSY RESULTS Whole heads and ears obtained as post-mortem specimens from the strandings listed above were examined first by computerised tomography (CT scanning) to assess tissue conditions and gross pathology of the head and particularly of the brain and peripheral auditory system. Measurements of pathological blood deposits and three-dimensional reconstructions of the heads and ears were obtained from the scan data and images. Four ears from two animals were re-examined after extraction of the ear complex by ultra-high resolution, 100 micron section CT scan imaging and light microscopy. These results were compared with data from single stranded animals of the same species that were collected under the NMFS stranding response efforts in the United States from 2000-03. The chief objective of the study was to determine the nature and extent of the physiological impacts these animals sustained, and to determine whether impacts in the presence of sonar are different than those found in other stranded animals.

The scan and necropsy analyses of single stranded animals show that beaked whales have ear structures in common with most odontocetes, but some significant differences were found in ear and airway anatomy compared with other marine mammals.

General beaked whale scans reveal an exceptional ear anatomy (Ketten, 1998). Beaked whales have a fundamentally odontoid temporal bone, but there is an auxiliary bony element at the Eustachian tube aperture (Fig. 1). This sesamoid shaped bone has a flexible synostotic joint. It attaches to the tube and appears to act as a strut to prevent closure. The periotic is also partly fixed to the squamosal, like that of the physeterids but less substantially than in mysticetes. The inner ear is classically odontoid with one notable exception: the vestibular divisions are remarkably well developed. The vestibule is large and bulbous, and the vestibular nerve trunks appear to represent well over the conventional 5% of the VIIIth nerve common in other cetaceans. Hearing ranges vary with each species; however, all beaked whales have conventional odontocete adaptations for good ultrasonic hearing. The lower frequency capacity is heavily species dependent. Ganglion counts are considered incomplete at this time, as the majority of specimens have spotty losses coincident with trauma and age induced hearing loss.

CASE RESULTS: BAHAMIAN STRANDED BEAKED WHALE STUDIES

Ears and intact heads were examined from the animals noted above that were considered to be in adequately fresh condition to warrant full analyses. The heads were examined by 0.1 to 3 mm section CT imaging as described and by gross necropsy. Ears from some additional animals were scanned also after extraction. To date, six of the extracted ears have been scanned, histologically processed, and examined.

In no animal was there evidence of profound or near-field blast damage, but in all three of the fresher heads, there is evidence of *in vivo* cranial trauma. This evidence consisted of intra-cochlear (IC) and temporal region subarachnoid haemorrhages (SAH) with lateral ventricular clots (LVH). In simpler terms, there are deposits of blood within some of the inner ear chambers and in at least two animals, there was haemorrhaging in a discrete region of the fluid spaces surrounding the brain (Fig. 1). These pathologies were first observed in the CT scans and subsequently confirmed by gross dissection.

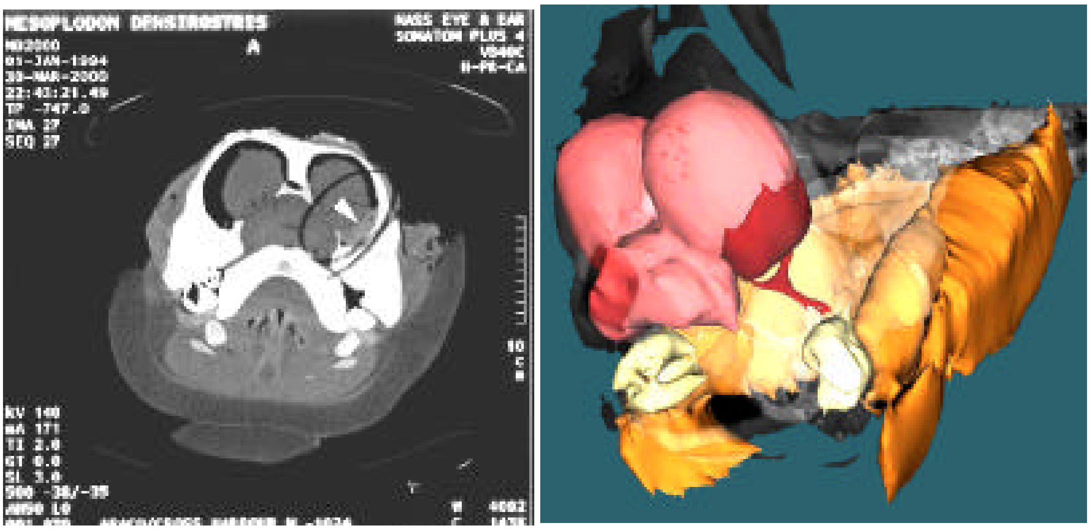

Fig. 1. Left: A 2D CT scan 3 mm slice transaxial image at the temporal lobe level of a Blainville's beaked whale. The arrow and circle indicate a subarachnoid haemorrhage in this region. Fresh blood is also visible in the internal auditory canal. The head was partially flensed during the original field dissection, hence the lack of soft tissue on the dorsal surface of the head. Right: A 3D reconstruction demonstrates the distribution of blood (red) in the fluid space around the brain (pink), and its path along the internal auditory canal leading to the ear bones (white) and the jaw fats (yellow).

CONCLUSIONS The number and coincidence of the strandings combined with these necropsy findings, and with the fact that these strandings appear to be dominated or exclusively beaked whales, suggest a species dependent related trauma. The patchy patterning of blood in the *Ziphius* and *Mesoplodon* ears indicates that the inner ear membranous partitions and major nerves were intact and that the internal auditory canal and cochlear aqueduct were conduits for blood movement between the cranial and inner ear spaces. The presence of blood in only restricted intracranial spaces and the intact inner ear membranes are not consistent with simple post-mortem pooling. Indiscriminate post-mortem pooling is generally greater on the side down on beaching, and occurs throughout the whole ear because normal ear tissues that divide the inner ear are lost through post-mortem necrosis, and blood collects preferentially in dependent areas. The patterning of the haemorrhages therefore suggests the ear was structurally intact and the animals were alive at the time of injury.

Findings in the poorly preserved specimens are consistent with those in the fresher animals, but are not strong data nor conclusive, because of the animals' poor condition. Observations are consistent for all animals examined to the extent that bloody effusions were found in and near the ears, and there were no indications of ship strike or other large, direct impacts. However, in the three poorest specimens, we cannot rule out post-mortem migration and deposition of blood in the auditory areas.

There are several important implications from these observations. First, the level of intracochlear blood and haemorrhage in these animals is consistent with a transient, intense event. Second, the observed damage does not necessarily indicate permanent hearing loss or acute, direct mortality. While similar lesions in humans can be painful, humans with similar auditory system haemorrhage and animals with similar experimentally induced lesions in lab studies typically regain hearing that may be impaired by the event (hearing loss is transient). In some cases there is often no significant hearing loss reported at all.

The actual observed cause of death in these animals was the physical consequences of stranding, including hyperthermia, suffocation, cardiovascular collapse, shock, and blood loss from external wounds from coral cuts, shark attack, etc. Therefore, the cause of the cranial trauma *per se* was not immediately lethal in these animals, but it may be an important contributory, or even the causal, factor for the strandings. Even if the auditory damage evident in the necropsied animals were recuperable in terrestrial animals, it is still important to analyse it carefully, to determine its cause, and to identify potential mitigation measures since it is likely to have played a significant role, perhaps by initiating the strandings.

Based on current medical and experimental data, the haemorrhagic patterns observed in these animals are found in the following etiologies in other mammals (*n.b.*: order not significant): concussive acoustic trauma from blasts or intense impulse events, barotrauma, direct or contact concussive trauma (head blows with or without fracture), auditory concussion from non-impulse source, sonic booms, spontaneous subarachnoid haemorrhage and hyperemia (bleeding into the cranial fluid spaces), vestibular atelactasis (vestibular collapse accompanied by sudden vertigo and nausea), intraoperative birth trauma (canal squeeze and forceps use), and diathetic (haemorrhage enhancing) disease.

There was no evidence or reports of explosions or underwater blasts in the vicinity or near the time of these strandings. Direct or concussive trauma can be ruled out because there were no surface marks, fractures, or contusions that would accompany blunt trauma. The number, temporal coincidence, and age of the animals stranding make birth trauma and random spontaneous haemorrhage unlikely candidates for a cause. Diathetic disease? In humans, diseases related to subarachnoid and intracochlear haemorrhages include several diseases or conditions; e.g., haemophilia (rarely), Wegener's granulomatosis, and leukaemia. Were any of these diseases present, there should be confirming evidence in the body tissue histological analyses. It is also possible that beaked whales have some diathetic condition that is for them a normal state but makes them particularly fragile to impulse traumas. As with the disease case, looking for symptoms of such a condition should certainly be a priority in the necropsy analyses for beaked whales in this, and in other, stranding cases. Vestibular? A hyper-responsive vestibular system, particularly for lower frequency signals, is certainly an important possibility for beaked whales, considering that they have a better developed vestibular system and Eustachian tube than most cetaceans. Lastly, of course, intense impulsive sources, shock waves, and sources that mimic pressure characteristics of sonic booms are possible and clearly warrant careful consideration. It is important to note, however, that the traumas described do not constitute classic acoustic trauma which would involve sudden and definitive damage to the cochlear duct components of the inner ear and possibly to the middle ear tissues, the ossicles, and the tympanic membrane

In summary, the findings in the beaked whale heads examined to date are that haemorrhages were found in the inner ears and some cranial spaces. These pathologies are consistent with trauma that may have compromised hearing but was not immediately lethal. Other related observations include haemorrhages and contusions in the jaw fats and mandibles in some of the animals. The pattern of damage is consistent with several causes, including indirect acoustic effects, diathetic fragility, vestibular sensitivity, and behavioural responses. None of these can be ruled out at this point, and it should be borne in mind that all may represent a contributory element.

Because the strandings coincided both temporally and geographically with a large scale naval exercise involving tactical mid-range frequency sonar, coupled with the nature of the physiological impacts found in the dead animals, and given the absence of any other exceptional or intense acoustic events, the investigation team concluded that the sound field created by the combination of ocean state, topography, and the use of multiple tactical mid-range frequency sonars during the exercise, was an important factor in the stranding event.

The sonars were employed in a complex environment that included the presence of a strong surface duct, unusual underwater bathymetry, intensive use of multiple sonar units, a constricted channel with limited egress, and the presence of beaked whales that appear to be particularly sensitive to the disturbance to the normal environment that the exercise produced. The investigation concluded that the cause of this stranding event was the synergism of these factors. It is not yet clear if any one element, such as frequency, intensity, or the anomalously robust sound field stretching over tens of kilometres, or all, were critical factors. Combinations of factors different from this set may be more or less likely to precipitate strandings. We do know that similar strandings in other areas that involve beaked whales and military activity, have some features in common, but a careful comparative physical analysis is not yet available. To date, there have not been any strandings linked to single mid-range sonar use nor to low frequency sonars. Therefore it is critical that all parameters for which we have data, including the environmental as well as the physiology and pathology results, be examined carefully and in concert, to accurately determine the mechanisms behind this event.

FUTURE RESEARCH The short-term goals of this project were completed; however, it raised several issues that warrant further investigation, particularly hearing range, sound reception, and tissue resonance modelling. More comprehensive light and electron microscopy data on the ears of these species would allow us to determine their hearing ranges and to analyse the sub-structure and conformation of vestibular, middle, and inner ear complexes. Equally important, the availability of whole heads in several museum collections, coupled with scanning analyses, would provide the necessary measurements to determine cranial and Eustachian tube resonances. Given the most recent developments in imaging and segmentation, it is now feasible to consider whole head FEM analyses that would provide high confidence functional simulations of specific frequency range responses in these animals, that are likely to be the keys to acoustic effects observed to date.

This work was supported jointly by the Office of Naval Research and by NOAA Fisheries. Scanning was preformed with the co-operation of Mass. Eye and Ear Infirmary, at the Imaging facility of WHOI, and at clinical facilities in Madeira through arrangements by Dr. Luis Freitas. D. Claridge, K. Balcomb, A. Bater, whilst L. Freitas provided assistance in access and preservation of key specimens. AFIP and Dr Ruth Ewing of NMFS provided histological diagnoses of tissues from the trauma and non-trauma cases.

REFERENCES

Evans, D.L. and England, G.R. 2001. *Joint Interim Report Bahamas Marine Mammal Stranding Event of 15-16 March 2000*. Unpublished Report. 61pp.

Ketten, D.R. 1998. Marine Mammal Hearing and Acoustic Trauma: Basic Mechanisms, Marine Adaptations, and Beaked Whale Anomalies. Pp. 2/21, 2/63-78. In: *Report of the Bioacoustics Panel, NATO/SACLANT* (Eds. A. D'Amico and W. Verboom). Unpublished Report.

Wartzok, D. and Ketten, D.R. 1999. Sensory Biology. Pp. 117-175. In: *Marine Mammals*. (Eds. J. Twiss and J. Reynolds), Vol. 1, Smithsonian Institution Press, Washington DC, USA.

THE STRANDING OF THREE CUVIER'S BEAKED WHALES *ZIPHIUS CAVIROSTRIS* IN MADEIRA ARCHIPELAGO – MAY 2000

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INTRODUCTION In May 2000, three Cuvier's beaked whales (*Ziphius cavirostris*) stranded in Madeira archipelago. The stranding of individual beaked whales is a rare event in the archipelago, making these three strandings in such a short period, unique, so far.

Madeira archipelago is located 400 km off the north-west of the African Continent at an average latitude of 32º 46' and longitude of 16º 46'. The archipelago includes Madeira, Porto Santo, and Desertas Islands, forming a cluster, and further south, the Selvagens Islands.

Its marine environment is characterised by oceanic oligotrophic waters influenced by the south-going branches of Gulf Stream Current, namely the Azores current and the Canaries current, as shown in Figure 1 (Anonymous, 1979). Being an oceanic archipelago, its bottom topography is characterised by steep slopes coming from the abyssal plain (average 3000 to 4000 m deep) almost to the surface. Between Madeira Island and Porto Santo Island, there is a deep-water channel going down to nearly to 3000 m deep (Fig. 2).

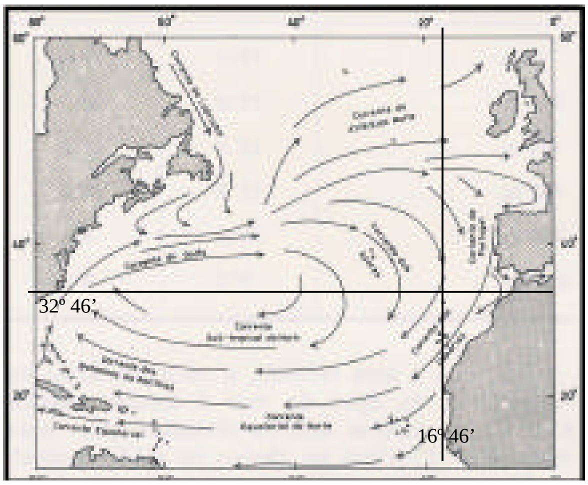

Fig. 1. General surface currents of the North Atlantic which influence Madeira archipelago (Anon, 1979)

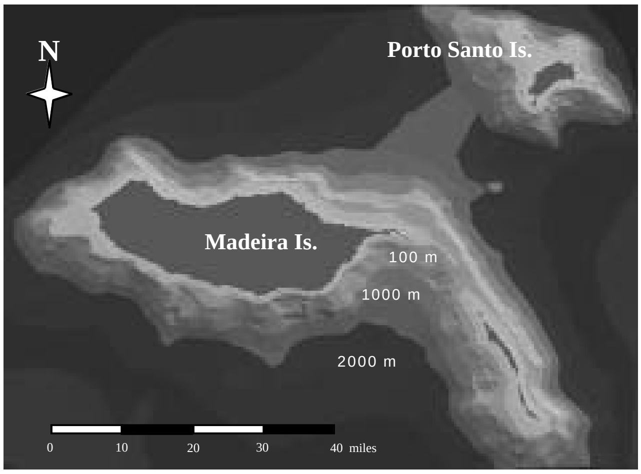

Fig. 2. Madeira archipelago (excluding Selvagens Islands) bottom topography

The presence of beaked whales in Madeira archipelago waters was registered for the first time in 1917, with a stranding of a Blainville beaked whale, *Mesoplodon densirostris* (de Blainville, 1817) in Porto Santo Island (Harmer, 1924). In 1941 a Sowerby's beaked whale, *Mesoplodon bidens*, was hunted south-east of Madeira Island (Maul and Sergeant, 1977).

With the organisation of a stranding network in the 1990s, there was an increased interest and awareness towards these animals, and probably as a result, more strandings of beaked whales were noted and registered. In 1998, another Blainville beaked whale stranded in Porto Santo Island, and in 1992 and 1999, two Cuvier's beaked whales stranded, the first in Porto Moniz and the second north of Caniçal, Madeira Island (Fig. 3). All strandings were of single individuals.

At the same time, a sighting network was also organised by the Whale Museum, which allowed the recording of several opportunistic sightings of beaked whales, especially around Funchal Harbour where there is more maritime traffic and, thus, a better coverage (Fig. 4).

In 2000, the Whale Museum started a project for the conservation of cetaceans in Madeira archipelago. The project included systematic sea and aerial surveys around the archipelago, especially around Madeira, Porto Santo, and Desertas Islands up to the 2500 m contour, between the years 2001 and 2003. Seven beaked whales were sighted around the Islands, two of which were confirmed as Cuvier's beaked whales (Fig. 4). This project also continued the effort conducted previously on strandings, with improvements, however, on the ability to study cetacean pathologies and determine causes of death.

Over a period of five days, between 10th and 14th May 2000, three Cuvier's beaked whales stranded: two in Porto Santo Island and one in the north-east coast of Madeira Island (Fig. 5 and Table 1). This stranding sequence was unusual when compared with the historical records of single strandings events of beaked whales in Madeira archipelago.

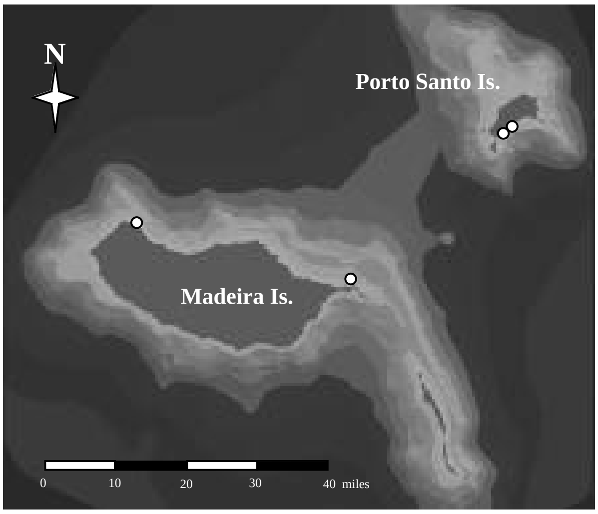

Fig. 3. Location of the recorded strandings of beaked whales in Madeira archipelago before the year 2000

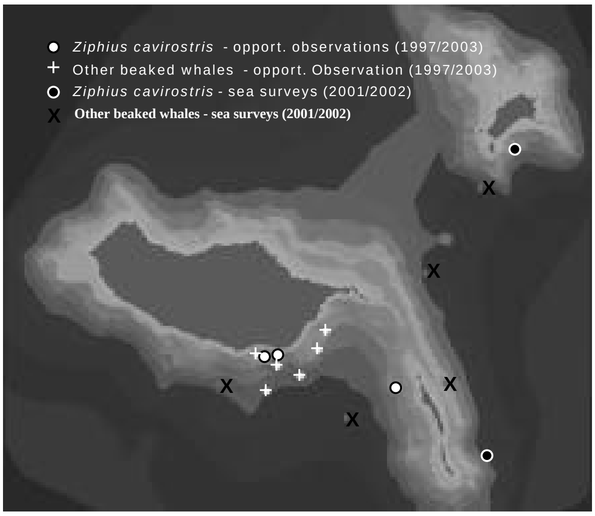

Fig. 4. Map of all the recorded sightings reported to the Whale Museum between 1997 and 2002

MATERIALS AND METHODS The first Cuvier's beaked whale stranded on the 10th May 2000 (stranding code AR.O.00.2) on the 8 km sandy beach, along the south coast of Porto Santo Island (Fig. 5). This animal was handled with an excavator and transported by truck to the local garbage dumping site by Porto Santo Municipality services. The post-mortem examination was performed on the 11th May by the Whale Museum team working on the stranding network. The animal stayed approximately 24 hours dry at ambient temperature. An external and internal gross examination was conducted, and samples from the different organs were collected for histopathology and microbiology. The stomach contents and parasites were collected for studies on the ecology and biology of these animals. It was not possible to preserve the head for further studies due to logistic problems. The remains of the animal including the head were buried in dumping site for future recovery of the skeleton.

The second animal (stranding code AR.O.00.3) was found on the north-east side of Porto Santo Island (Fig. 5) on the 13th May, stranded on a rocky platform close to a pebble beach protected by a barrier of rock outcrops. On the 14th May, the animal was towed afloat by the Whale Museum team to a sandy beach south of the stranding site, where the post-mortem examination was conducted. It was moderately decomposed, the body swollen and smelly, indicating it had died a few days before. The animal was examined externally and internally, and only samples for histopathology were collected because of the body and organs condition. The histopathological samples were preserved at low temperatures (4º C) during transport for the Madeira Government Veterinarian laboratory, which made the analysis. On this occasion, it was possible to collect and transport the head back to Madeira where it was preserved frozen at -20ºC for later examination.

The third animal (stranding code AR.O.00.4) was reported on the 27th May, and examined on the stranding site on the 30th May. According to local people, the animal had stranded on 14th May, and was burned some days after in an attempt to eliminate the smell exhaled by the corpses in decomposition. The skull was collected for examination and integration in the Whale Museum collection.

RESULTS AND DISCUSSION The results from the post-mortem gross exam, histopathology and microbiology findings for the stranded animals are presented in Table 2.

Table 1. Compared information on the animals stranded, as well as, dates and locations of those strandings

Stranding code:	**AR.O.00.2**	**AR.O.00.3**	**AR.O.00.4**
Date of death:	2000-05-09/10	<2000-05-11	Undetermined
Animal found:	2000-05-10	2000-05-13	2000-05-14
Stranding location:	Praia do Porto Santo, South coast of Porto Santo Island	Praia da Cana, Northeast Porto Santo Island	Rocha do Navio, Northeast of Madeira Island
Necropsy date:	2000-05-11	2000-05-14	2000-05-30
Necropsy location:	Local garbage dumping site	Sandy beach, East Coast of Porto Santo Island	Rocha do Navio (external examination)
Body condition:	Code 3	Code 3	-------------------
Animal length:	380 cm	410 cm	430 cm (estimated)
Age:	Sub-adult	Sub-adult	Undetermined
Sex:	male	Female	Female

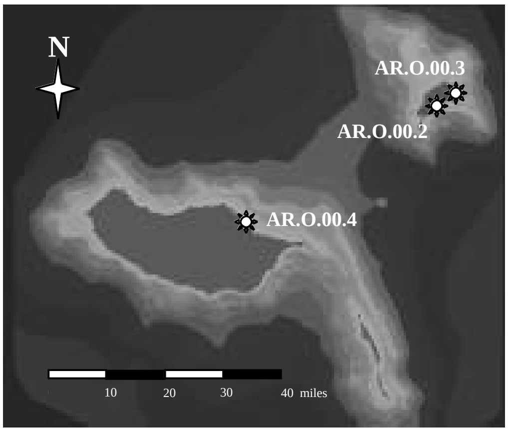

Fig. 5. Location of the three Cuvier's beaked whales stranded in May 2000 in Madeira archipelago

Fig. 6. External exam of one of the Cuvier's beaked whales stranded in May 2000

The first whale stranded (AR.O.00.2) showed several marks and wounds on the skin, in some cases going deep into the blubber, which were made by an excavator handling the animal and by the transport from the stranding site to the local dumping site (Table 2). The left side of the animal showed different areas of abrased skin, which may have been caused while the animal was stranded on the beach, by the movement of the animal, and by waves and tide. Besides the haematoma observed in the ventral area, no marks or wounds of other origin or of unknown origin were observed. Internally, this animal presented a pleural haemorrhage, the lungs with normal appearance, as well as the other organs. At the microscopic level, localised pneumonia lesions were found on the right and left lungs, which could not justify the death of the animal. The microbiological findings did not indicate the presence of any pathogenic agents in the different organs, with the exception of *Vibrio damsela* in the lungs, and five different bacteria strains found in the cardiac blood. The presence of these bacteria in the cardiac blood is most probably the result of contamination during collection of blood sample from the animal in the garbage dumping site.

Table 2. Results from the post-mortem exams performed to the three animals

Stranding code:	**AR.O.00.2**	**AR.O.00.3**	**AR.O.00.4**
External exam findings	· Several marks and wounds · Left side of the body abrased · Haematoma present at ventral area · Eye haemorrhages	· left side of the body abrased · Right side presented several superficial wounds and scratches · Haematoma present at the · pectoral fin area · Eye haemorrhages	· Animal set on fire by local residents · Absence of lower jaw (removed according to local, at sea people before stranding)
Internal exam findings	· Pleural haemorrhage · swollen pulmonary lymphatic nodes · lungs with normal appearance · other organs with normal · appearance · presence of parasites in the kidneys	· Pleural haemorrhage · small purulent nodules in a localized area of the lungs · presence of parasites in the lungs · other organs in decomposition (autolyse)	
Histopathology findings	· left lung with localized pneumonia lesions · right lung with edema and congestion, as well as, localized pneumonia lesions · liver congested · kidneys with hemorrhagic congestion	• lungs with pneumonia lesions • for the other organs no histopathological exams conclusive	
Microbiology findings	· lungs with *Vibrio damsela* · cardiac blood sample – *5 bacteria strains found* · other organs – no pathogen agents found	· no samples taken due to the state of organs decomposition	

The second stranded animal (AR.O.00.3) did not show marks or wounds - only the left side showing abrasion from contact with rocks at the stranding site and haematoma at the pectoral fin area. Internally, it had, as AR.O.00.2, pleural haemorrhaging and small purulent nodules in a localised area of the lungs. The histopathology confirmed pneumonia lesions in that area. For the remaining organs, neither the gross exam nor the histopathology was conclusive, due to the state of decomposition of those organs. The head of the animal was preserved and examined in September 2000 by Dr. Darlene Ketten (Ketten, 2003).

On the 9th May 2000, NATO naval exercises started around Porto Santo Island, involving one aircraft carrier, three submarines, and more than 40 surface vessels, including war vessels, logistic vessels, and landing cratt. The Whale Museum team observed military exercises whilst going to Porto Santo Island by ferry to perform the necropsy on the first stranded animal, namely anti-submarine warfare (helicopters launching sonobuoys). The military manoeuvres finished on the 14th of May according to local press.

The stranding of individual beaked whales is a rare event in Madeira archipelago according to the historical records. A multiple stranding had never been recorded until the episode in May 2000. Although not seen very frequently, beaked whales, including Cuvier's beaked whale, are present in Madeira waters and, with more effort, an increasing number of animals have been sighted. In the past ten years, two strandings of Cuvier's beaked whale have been recorded for which we have a good indication of causes of death: one killed intentionally by man (shot or harpooned) and the other possibly collided with a ship.

In May 2000, over a short period of a few days (10-14 May 2000) three Cuvier's beaked whales stranded. No consistent evidence from the post-mortem examinations was found to justify the strandings, and clearly link them together. However, for the two animals for which it was possible to conduct an external and internal examination, several common points were found: haematoma present at the ventral area, suggesting live strandings; pleural haemorrhaging; and eye haemorrhages. The first stranded animal (AR.O.00.2), besides the pleural haemorrhages, presented lung congestion and kidney hemorrhagic congestion, which is consistent with findings in multiple stranded beaked whales in other areas (D. Ketten, *pers. comm.*). Finally, while these strandings were occurring, there were NATO naval exercises taking place, including surface vessels and submarines, around Porto Santo Island.

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REFERENCES

Anonymous. 1979. *Roteiro do Arquipélago da Madeira e Ilhas Selvagens*. Instituto Hidrográfico, Lisboa, Portugal.

Harmer, S.F. 1924. On *Mesoplodon* and other Beaked Whales. *Proceedings of the Zoological Society of London*, XXXVI: 541 – 587.

Maul, G.E. and Sergeant, D.E. 1977. New Cetacean Records from Madeira. *Bocagiana*, 43: 1-8.

MASS STRANDINGS OF BEAKED WHALES IN THE CANARY ISLANDS

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INTRODUCTION Members of the family Ziphiidae are amongst the least known of marine mammals due to their oceanic habits and cryptic behaviour. In addition, the available data suggests that their populations are not abundant. Most of the information regarding their natural history comes from the study of a low number of stranded specimens. Mass strandings of the family are rare (Erdman, 1962; Erdman *et al*., 1973; Galbreath,. 1963; Martin *et al*., 1990a, b; Rosario-Delestre *et al*., 1998; Van Bree and Kristensen, 1974; Viale, 1975), and over recent years they have called the attention of conservationists and researchers due to their possible connection with Naval exercises (Frantzis, 1998; Simmonds & Lopez-Jurado, 1991).

On the morning of the 24th September 2002, a mass stranding of beaked whales occurred on the islands of Fuerteventura and Lanzarote, Canary Islands (Spain), whilst some naval exercises NEOTAPON 2002 were being held in nearby waters. Due to circumstances, the number of animals involved, and the special difficulties, various people and institutions set in motion a plan to try and rescue the greatest possible number of animals. Right from the beginning the priorities were :

1. Help to refloat live animals.
2. Locate and preserve dead animals on the coast.
3. Carry out necropsies to determine the causes of death and gather biological information.

The current document presents the circumstances and the preliminary results of this stranding, the species and number of animals involved, the acquisition of biological data and other relevant aspects. Likewise, it makes a synthesis of similar events occurred in the Archipelago over recent years.

DESCRIPTION OF THE EVENT OF THE 24TH SEPTEMBER 2002

On the 24th September, at least 14 cetaceans stranded on the islands of Fuerteventura and Lanzarote. The special development of the event, and the number and species involved were as follows: five animals were found dead on the coast (four in Fuerteventura and one in Lanzarote), three were found alive and subsequently died, from which one was taken by the sea. Finally, six specimens were returned to the sea (including one Gervais' beaked whale *M. europaeus*) and another was seen near the coast by an emergency helicopter. Finally, on the 25th September, two Cuvier's beaked whales *Z. cavirostris* appeared (one in Fuerteventura and another one in Lanzarote), and on the 26th September, two other specimens of the same species (one in Fuerteventura and another in Lanzarote). An undetermined decomposed specimen was seen floating in the north of Fuerteventura, but it could not be recovered. It is likely that the animals seen on subsequent days were those that were returned to the sea on the 24th September. From the specimens that were refloated on the 24th, there was an adult male Cuvier's beaked whale and a Gervais' beaked whale. Between the 24th and 27th September, a total of eleven dead specimens were recovered and studied belonging to three species: Cuvier's beaked whale (n=9), Blainville's beaked whale (n=1), and Gervais' beaked whale (n=1).

In connection with the circumstances, all the animals appeared at late dawn. Those that were alive were disoriented, making them easy to handle them on the coast. In fact, the lesions that they possessed consisted of scratches and in no case had they broken jaws or damage to their faces, which is common in other types of strandings, despite finding some of the specimens on the rocks. The specimen of Gervais' beaked whale did not strand and was found dead floating a few metres away from the coast.

Specimens from the 24th September underwent a necropsy by members of the Veterinary University of Las Palmas, Gran Canaria (pathological information) as well as by the Society for the Study of Cetaceans of the Canaries Archipelago (biological information). The same happened with specimens from subsequent days which, based on their autolytic status, must have died on the 24th September. The complete stomachs of the six animals of the 24th September 2002 were collected and frozen for subsequent analysis. The stomach of the remaining specimens was collected *in situ*, and its contents were fixed with 70% alcohol. Except for one animal, whales had a stomach content which was fresh to moderately digested, indicating that they had recently been eating. One of the specimens was thin, with a high number of stomach nematodes. Another one had a piece of cloth of 80 x 100 cm. All specimens of Cuvier's beaked whale had the nematode *Crassicauda sp* in their kidneys, although this can be considered normal for the species. To date, *Crassicauda sp* shows a prevalence of 100% in the Cuvier's beaked whales stranded in the Canaries.

An adult male Cuvier's beaked whale which appeared on the morning of the 25th September in the island of Lanzarote, was partially eaten by a shark, especially the jaws and melon, in addition to the tail stock. The head is a rare location for bites from predators in the dead bodies of floating cetaceans, specially in specimens which are so fresh, and therefore it is likely that the presence of haemorrhages in the oral cavity and /or blowhole had resulted in this. It is interesting that in the event of 1985 (see below), the live cetaceans were followed by sharks to shore.

Other cases that have occurred in the Canary Islands

Eight previous cases of beaked whale strandings in the Canary Islands are known to share similarities with this one; at least six coincide in time with naval exercises, one has some indications, and for the remaining cases, no information has been found. Of these, five were mass strandings, two involved two animals and one a single individual. From the mass strandings, four were multi-specific, involving two to three species. In one of the multi-species events there was a couple of pygmy sperm whales (*Kogia breviceps*). In all cases we had difficulties in knowing the number and composition of the stranded animals due to a combination of circumstances and therefore the animals specified below are not the ones which stranded but those which could be studied. A decisive factor was that the animals remained stranded in coves and inhabited coast stretches that had to be surveyed, others were returned to the sea and subsequently appeared in other areas of the coast which caused great confusion. The cases which occurred in the Canaries were the following:

1. 8th February 1985. Mass stranding of 10-12 animals along the south-east coast of Fuerteventura. Species involved: Cuvier's beaked whale and Gervais' beaked whale. Coincides with naval exercises.

2. 1st June 1986. Stranding of five animals on the north-east coast of Lanzarote. It was possible to study only two specimens. Species involved: three Cuvier's beaked whale, one Gervais' beaked whale, and one undetermined.

3. 4th July 1987. Stranding of three Gervais' beaked whale on the north-east coast of Lanzarote.

4. November 1987. Two Cuvier's beaked whales stranded on the north-east coast of Lanzarote.

5. 25th and 26th November 1988. Stranding of three Cuvier's beaked whales and one northern bottlenose whale *Hyperoodon ampullatus* on the south-east coast of the island of Fuerteventura. At the same time, two pygmy sperm whales appeared on the north-east coast of Lanzarote. Coincides with naval exercises "FLOTA 88".

6. 19th October 1989. Three Gervais' beaked whales, two Blainville's beaked whales and at least 15 specimens of Cuvier's beaked whale stranded on the east coast of Fuerteventura. The specimens were found in an advanced state of decomposition. This stranding coincided with naval exercises CANAREX 89.

7. 11th December 1991. Two Cuvier's beaked whales stranded in Tazacorte, La Palma, following the sinking of the boat "Churruca" during the development of naval exercises "SINKES 91" in the area.

8. 5th June 1991. The dead floating body of one Cuvier's beaked whale was found off Santa Cruz de La Palma, island of La Palma ($28^0$40'60''N; $17^0$45'90''W). Coincides with naval exercises "OCEAN SAFARI 91".

CONCLUSIONS The overall analysis of the event of the 24th September 2002 and of other similar strandings which have occurred in the islands share various common elements. There is a clear coincidence in time and space between naval exercises carried out in the Canary Archipelago over recent decades and mass strandings of members from the family Ziphiidae.

Except for one case, the common species is Cuvier's beaked whale *Z. cavirostris,* which is in agreement with other similar events occurring in other regions. Within each species, a strong segregation is seen according to sex and size. For example, most of the Cuvier's beaked whales that stranded on the 24th September 2002 were sub-adults. In none of the cases described above was the presence of calves or dependent animals detected. In all cases, the majority of the animals stranded during dawn and early morning. Except for three individuals, the animals had exceptionally fresh stomach contents, with remains from cephalopods and crustaceans which were virtually intact, together with partially digested remains, which shows that they had been recently feeding. The fact that it simultaneously affected various species with different habits and use of habitat within the family Ziphiidae, seems to suggest that the factor responsible is connected with a characteristic which is shared by all the members of the family.

The spatial development of the strandings suggests that the event affects all the species and/or animals within a specific area, and probably there is a relationship between the density of specimens in the area and the number of stranded animals. In this sense, it is interesting to highlight that those events with higher numbers of stranded animals took place in the autumn, the time of the year when most strandings of Cuvier's beaked whales are detected in the Canary Islands (V. Martín, unpublished data). Possible interactions between naval exercises and strandings may be missed in cases of individual strandings, such as in the case of La Palma. For this reason, we are currently re-evaluating the strandings of these species over recent years in the Canaries as well as their circumstances.

REFERENCES

Erdman, D.S. 1962. Stranding of a beaked whale, *Ziphius cavirostris*, on the south coast of Puerto Rico. *Journal of Mammalogy*, 43: 276-277.

Erdman, D.S., Harms, J. and Marcial-Flores, M. 1973. Cetacean records from the northeastern Caribbean region. St. Augustine, Florida: *Cetology* (Biol. Syst.), 17: 1-14.

Frantzis, A. and Cebrian, D. 1998. A rare, atypical mass stranding of Cuvier´s beaked whales: cause and implications for the species' biology. Pp. 332-335. In: *European Research on Cetaceans -12*. Proc. 12th Ann. Conf. ECS, Monaco, 20-24 Jan, 1998. (Eds. P.G.H. Evans and E.C.M. Parsons). European Cetacean Society, Valencia, Spain. 436pp.

Galbreath, E. 1963. Three beaked whales stranded on the Midways Islands, Central Pacific Ocean, *Journal of Mammalogy*, 44: 422-423.

Martín, V., Vonk, R., Escorza, S. and Montero, R. 1990. Records of Gervais´ beaked whale *Mesoplodon europaeus* on the Canary Islands. P. 95. In: *European Research on Cetaceans – 4.* Proc. 4th Ann. Conf. ECS, Palma de Mallorca, Spain, 2-4 Mar, 1990. (Eds. P.G.H. Evans, A. Aguilar and C. Smeenk). European Cetacean Society, Cambridge, UK. 140pp.

Rosario-Delestre, J.R. and Mignucci-Giannoni, A.A. 1998. Epizootic and herd strandings of goosebeak whales in the Caribbean. P. 116. In: *Abstracts*, the World Marine Mammal Science Conference, Monaco, 20-24 Jan 1998. 160pp.

Simmonds, M.P. and Lopez-Jurado, L.P. 1991. Whales and military. *Nature* (Lond.), 351: 48.

Van Bree, P.J. and Kristensen, I. 1974. On the intriguing stranding of four Cuvier´s beaked whales, *Ziphius cavirostris* G. Cuvier, 1823, on the Lesser Antillean Island of Bonaire. *Bijdr. tot de Dierk.*, 44: 235-238.

Viale, D. 1975. Whalebone whales (rorquals) and toothed whales observed in the western Mediterranean. *International Council for the Exploration of the Sea CM* 1975/N: 15.

Vonk, R. and Martín, V. 1988. First list of odontocetes from the Canary Islands. Pp. 31-36. In: *European Research on Cetaceans – 2*. Proc. 2nd Ann. Conf. ECS, Troía, Portugal, 5-7 Feb, 1988. (Ed. P.G.H. Evans). European Cetacean Society, Lisboa, Portugal. 119pp.

Vonk, R. and Martín, V. 1989. Goose-beaked whales (*Ziphius cavirostris*) mass strandings in the Canary Islands. Pp. 73-77. In: *European Research on Cetaceans – 3*. Proc. 3rd Ann. Conf. ECS, La Rochelle, France, 24-26 Feb, 1989. (Eds. P.G.H. Evans and C. Smeenk). European Cetacean Society, Leiden, The Netherlands. 132pp

PATHOLOGICAL FINDINGS IN STRANDED BEAKED WHALES DURING THE NAVAL MILITARY MANOEUVRES NEAR THE CANARY ISLANDS

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A recent mass stranding of beaked whales in Canary Islands, following naval military exercises ("Neo-Tapon 2002") on 24th September 2002, has raised new social, environmental, and scientific concerns of a possible relationship between anthropogenic sonic activities and stranding and death of marine mammals (Simmonds and Lopez-Jurado, 1991; Frantzis, 1998; Balcomb and Claridge, 2001; Evans and England, 2002).

Our group was requested by the Canary Islands Regional Government to perform a pathological study, as complete as possible, in order to try to achieve a diagnosis that could contribute to understand the beaching and death of the beaked whales.

Necropsy of ten animals was performed by first examining and sampling internal viscera, and preserving the heads at 4^{o}C and shipping to Gran Canaria. The head dissections were then completed in our department. Tissues taken from all the necropsied cetaceans were processed for routine light microscopy.

The macroscopic studies of organs and tissues did not demonstrate inflammatory or neoplastic processes. No traumatic lesions physically caused by ships, fishing activities, or other blunt trauma were observed. The amount of gastric content, its freshness and digestive status indicated that the period between the onset of illness and death was short.

Macroscopically, some external findings were noticed, notably the presence of blood around the eyes and especially in the oral cavity.

Once the heads were dissected, we noted that all the fresh animals showed haemorrhages of varying sizes and distribution along the acoustic fat, reaching massive proportions in the head (Fig. 1).

We also recorded some possible non-specific findings, such as haemorrhages in the sclera of the eyes in some animals, either fresh or partially autolytic ones. The corresponding histological results showed undamaged connective tissue together with extensive haemorrhages on the surface of the sclera.

A macroscopical view of three heads (two fresh and one partially autolytic) revealed focal haemorrhages in the dura mater membrane, and a large amount of blood in the subarachnoid space around the cranial spinal cord, in both fresh and autolytic cases.

After opening the dura mater, a generalised congestion of the brain blood vessels could be seen in all fresh animals, whilst close to the surface, multifocal subarachnoid haemorrhages were detected. Additionally, in those tissues that were fresh, the presence of empty spaces and bubbles inside the vessels made them prominent at the surface.

In the sections of the brain, the main findings were multifocal petechial haemorrhages located mainly in the white matter. Furthermore, the choroid plexus showed congestion, haemorrhages, and in some animals, small blood clots inside the lateral cerebral ventriculi. On the other hand, all the lungs presented general diffuse congestion, some subpleural haemorrhages, and alveolar edema in both fresh and autolytic cases.

The kidneys were enlarged, with marked vascular congestion and haemorrhages in the capsular and interstitial areas. All the kidneys presented granulomatous parasitic nephritis due to nematodes of *Crassicauda* species.

The haemorrhagic areas observed macroscopically in the acoustic fat were also demonstrated histologically, with extensive amounts of red cell infiltrating the fat tissue.

For processing the air bone tissues, we have had the collaboration of Eduardo Degollada for histological sectioning of the cochlear. The most significant microscopical observation found has been acute Wallerian degeneration of the vestibulo-cochlear nerve, characterised by granular degeneration and the presence of active macrophage-like cells in the affected areas, a process that can occur hours after injury. Other frequent observations in the three processed fresh animals include the presence of haemorrhages in the perineurum or the nerve.

The corresponding histological observation of the subarachnoid haemorrhages were clearly seen, in a laminar type, with the same morphology as described in humans. In the brainstem and around the cranial spinal cord, severe haemorrhage was observed in perivascular spaces of congested, mid-sized vessels and around the nerves.

In addition, perivascular haemorrhages and perivascular edema affected the white matter of most of the animals, with the same distribution and anatomical pattern as in humans suffering decompression sickness.

Proteinaceous, perivascular edema, cerebral spogiosis, and ischemic necrosis of the cortex were frequently found in all of the fresh brains.

Reactive gliosis, especially neuron satellitosis, was evident in the central nervous system of the stranded beaked whales. Such cell changes take place in a few hours after vascular hypoxia.

All the studied lungs showed a general congestion and severe diffuse alveolar edema with red cells into the alveoli.

Microscopically, the kidneys presented capsular and subcapsular haemorrhages as well as a general congestion. The autolytic animals had the same haemorrhagic pattern as did the fresh kidneys.

At present, we can conclude that the beaked whales had a morphological diagnosis of Severe Disseminated Microvascular Haemorrhage, characterised by the lesions previously mentioned.

Having made this diagnosis, the second aim of the study was to determine which mechanism or mechanisms could be responsible for the Disseminated Microvascular Haemorrhage. To answer this question, and taking into account similar clinico-pathological findings described in human forensic pathology, we established the hypothesis that fat embolism could be the pathogenic mechanism responsible for inducing such haemorrhages in the microvascular system.

To test this hypothesis, we used frozen samples and two histochemical standard fat stainings. They were Oil Red O and Sudan Black B (see Figs. 2 & 3). Positive and negative controls were properly used.

Fat emboli were demonstrated in the beaked whale lungs using both techniques. All the lungs showed numerous fat emboli in the septal areas with the same shape and pattern as in humans suffering this syndrome (Fig. 3).

We have also analysed other organs, such as the cerebral choroid plexus, auditory plexus and connective tissues surrounding the medula and optic nerve. They showed positive fat globules, but some care needed to be taken with these organs, as they have interstitial fat.

Another important target organ of fat emboli in human beings is the kidney. In our cases, many globular intravascular fat emboli were demonstrated using both techniques.

Other organs such as lymph nodes presented vacuoles in the sinuses and reabsorption of blood (representing an *in vivo* process) as were lymph nodes of the head. Using Oil Red, this organ was full of lipid globlets. In the partially autolytic beaked whale, the spleen was full of fat globules detected using the same histochemical technique.

In conclusion, our findings indicate that a decompression-like sickness (Knight, 1996) was responsible for the mass stranding. The lesions of this syndrome were characterised by severe disseminated microvascular haemorrhages localised in vital organs including the brain, kidneys, and lungs and specialised acoustic organs of the whales. The type of injury and pattern of lesions were caused by widespread, fat emboli histochemically demonstrable by Oil Red O and Sudan Black B techniques applied to frozen tissue samples. Fat embolism would support the published hypothesis (Crum and Mao, 1996; Houser *et al*., 2001) of the involvement of sonic sonar signals generated during the naval exercises in the development of intravascular bubbles in nitrogen-supersaturated whale tissues, as an initiating factor in the patho-physiological process. Once the whales became stranded due to the "bends", death due to cardiovascular collapse followed. The present study demonstrates, for the first time, that well adapted, diving, marine mammals are susceptible to a decompression-like sickness, a new pathological entity to be described in cetaceans.

REFERENCES

Simmonds, M.P. and L.F. Lopez-Jurado. 1991. Whales and the Military. *Nature* (Lond.), 51: 448.

Frantzis, A. 1998. Does acoustic testing strand whales? *Nature* (Lond.), 329: 29.

Balcomb, K.C. III and Claridge, D.E. 2001. A mass stranding of cetaceans caused by naval sonar in the Bahamas. *Bahamas Journal of Science*, 2: 2-12.

Evans D.L. and England G.R. 2001. *Joint Interim Report Bahamas Marine Mammal Stranding Event of 15-16 March 2000*. Unpublished Report. 61pp. Available at www.nmfs.noaa.gov/prot_res/overview/Interim_Bahamas_Report.pdf.

Knight, B. 1996. *Forensic Pathology*. 2nd Edition. Arnold and Oxford University Press.

Crum, L. and Mao, Y. 1996. Acoustically enhanced bubble growth at low frequencies and its implications for human diver and marine mammal safety. *Journal of the Acoustical Society of America*, 99: 2898-2907.

Houser, D.S., Howard, R and Ridgway, S. 2001. Can diving-induced tissue nitrogen supersaturation increase the chance of acoustically driven bubble growth in marine mammals? *Journal of Theoretical Biology*, 213: 183-195.

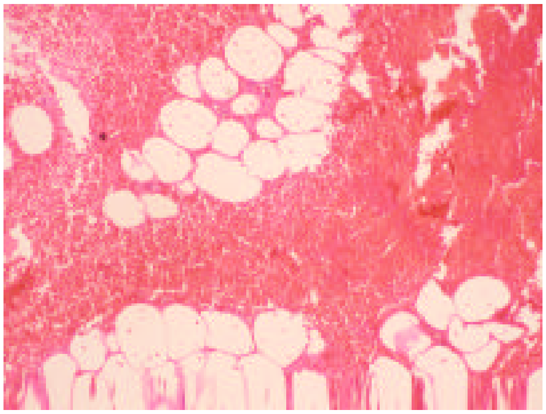

Fig. 1. Severe haemorrhage in the acoustic fat of a stranded beaked whale (Haematoxylin-eosine technique)

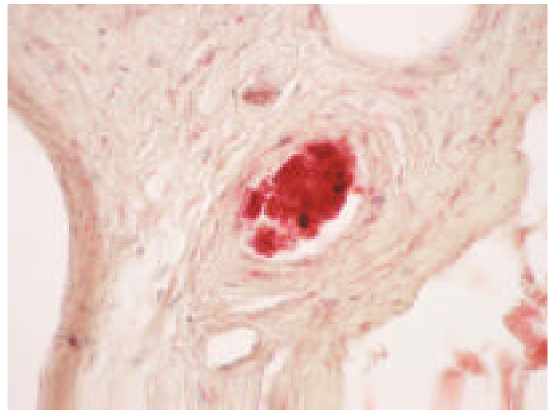

Fig. 2. Intravascular fat emboli in a portal vessel in the liver of a beaked whale (Oil Red technique)

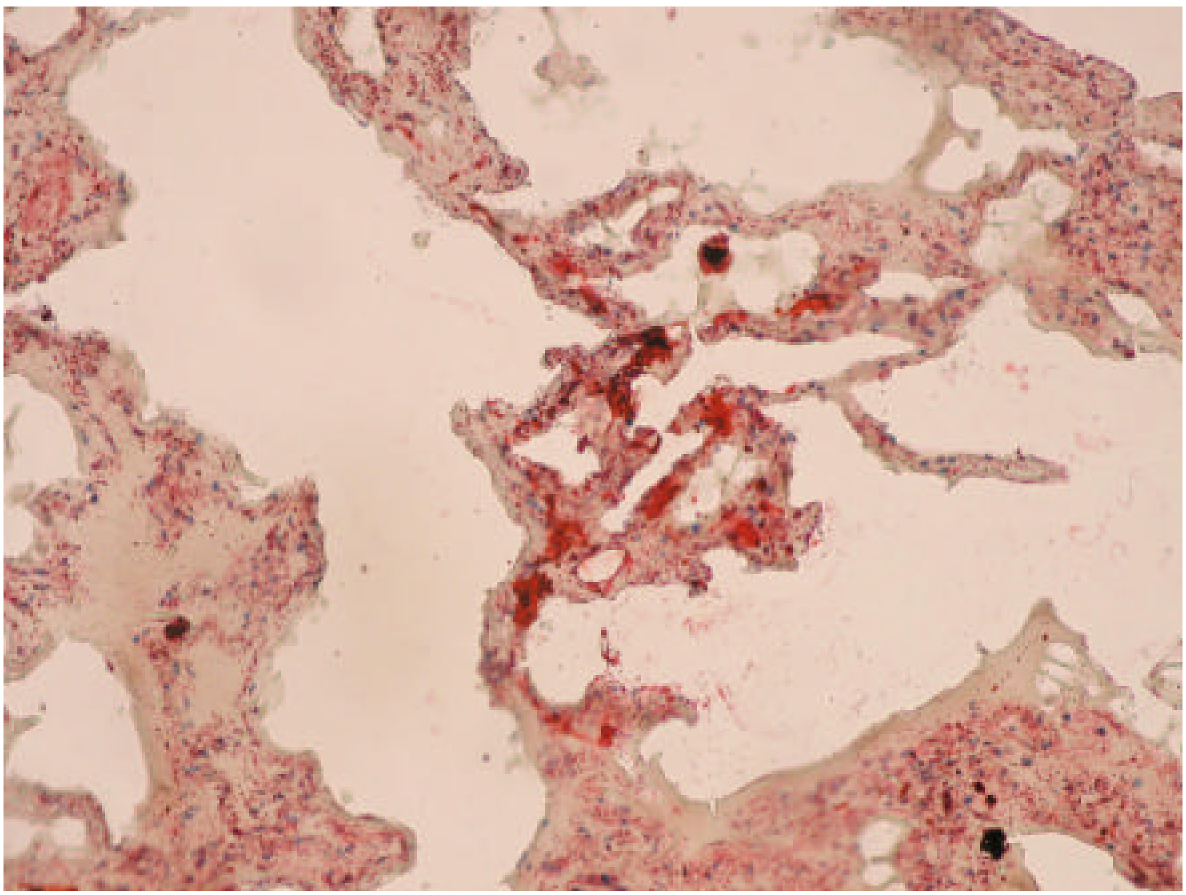

Fig. 3. Intravascular fat emboli in the interalveolar septa in the lung of a beaked whale (Oil Red technique)

SPERM WHALE SONAR RIVALS TACTICAL SONAR WITH SOURCE LEVELS AT 235 DB

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Tactical, mid-frequency range sonars have in a number of cases been the alleged cause of mass stranding events of cetaceans, notably beaked whales (Frantzis, 1998, Evans and England, 2001). A physiological mechanism for the debilitation of the ensonified animals has yet to be agreed upon, but resonances in air cavities, rectified diffusion of gas, and acoustic traumas have all been suggested. Common to these mechanisms is that the magnitude of the effect will be related to the intensity, or energy, of the sonar signal. The introduction of powerful sonar signals to the seas is regarded as a man-made, un-natural phenomenon, and for good reasons. However, new data on sperm whale sonar show that sonars of similar intensities are likely to have been around for millions of years, apparently without observed, damaging effects on fellow cetaceans. A comparison of the properties of signals from tactical sonar and sperm whale sonar therefore may be helpful in sorting out signal properties with and without a potential for causing sonar-mediated mass stranding, and thus also as a guide to designing mitigating measures.

Table 1 Properties of sonar signals from sperm whales and tactical sonars

SONAR →	**SPERM WHALE**	**AN/SQS-56**	**AN/SQS-53C**
SOURCE LEVEL, dB re 1 μPa	235	223	235(+)
PING DURATION, ms	0.1	500	500
PING ENERGY, dB re 1 μPa^2*s	196	221	233
REP-RATE, PINGS/s	1	0.125	0.125
DUTY CYCLE, %	0.01	6.2	4 - 8
FREQUENCY, kHz	5 - 20	6.8, 7.5, 8.2	2.6, 3.3
SPECTRUM TYPE	Broad band	Narrow band	Narrow band
DIRECTIONALITY, half-power, half-angle, degrees	4	360 x 30	120 x 40

The properties of signals from sperm whale sonar from new recordings off Andenes, Norway (Møhl *et al.*, 2003), and those from tactical sonars (from the Joint Interim Report on the Bahamas 2000 mass stranding event, Evans & England, 2001), are extracted in Table 1. Notably, source level *per se*, the most frequently assumed parameter for debilitating mechanisms, is not much different. The level experienced by the ensonified animal will depend more on the distance to the sonar than on the minor differences in source level. Ping energy is 30 to 40 dB higher in the tactical sonars. This may be significant, but the difference corresponds to a change in distance by a factor of 30 to 100. This means that the ensonified animal will receive the same sonic energy from a sperm whale click at 10 m as from a sonar ping at 300 to 1000 m, i.e. at realistic distances. Ping duration is much lower in the sperm whale, and ping-rate somewhat higher, the effective values being confounded by reverberation, the likely presence of more than one ship, and by the variability of the click rate of the whale. Duty cycle (ping duration * rep-rate) is orders of magnitude higher in the tactical sonars, and this difference may be significant. The whale sonar and the tactical sonars are using the same part of the spectrum, but the whale uses broad-band pulses, while tactical sonars use narrow-band pulses. This difference may also be important. A conspicuous difference is directionality: the whale sonar has a narrow, pencil-beam shaped radiation pattern, while the tactical sonars have omni-directional or wide angled radiation patterns. The beam of the SQS-56 can be thought of as a disk of sound 30 degrees tall vertically, with the upper bound at the surface, but extending equally in all directions around the ship.

From the vantage point of an ensonified animal, the two kinds of sonars will appear quite different. The likelihood of being ‘hit’ by an on-axis sperm whale click is low and, furthermore, chances of being hit several times by consecutive clicks are also low (unless the sperm whale deliberately is targeting the ensonified animal). In contrast, the pings of tactical sonars will hit the ensonified animal at each ping, as long as the animal is within the disk of sound described above. The shortest route of escape is to go down below the disk of sound. The theoretical ‘acoustic sanctuary’ in the pressure release zone adjacent to the surface (due to the Lloyd mirror effect) is only of some significance at frequencies lower than that of tactical sonars and only in calm seas (Richardson *et al*., 1995). Complete relief from the sonar signals, however, could be obtained, if the beaked whales performed spy-hopping (keeping their heads above the water), a behaviour known from several odontocete species (Carwardine, 1995). This conspicuous behaviour has not been reported from beaked whales in connection with sonar exercises.

While the data in Table 1 do not lead to clear conclusions about the mechanism of sonar mediated mass stranding, they do tend to reduce the likelihood of proposals of sonically induced physiological mechanisms. Instead, a hypothesis of sonically triggered, behavioural mechanisms is consistent with the observations. Since different species of whales react differently to man made disturbances (Richardson *et al*., 1995), behavioural mechanisms have the additional potential of explaining why a particular group of cetaceans, the beaked whales, are predominantly affected. Making the speculative assumption that beaked whales react in panic, trying to escape the persistent ensonification of tactical sonars, their best option appears to be to get down below the disk of sound, reducing the time spent at the surface to the minimum required for a single exchange of the respiratory gases. This will compromise recovery from deep dives and cause a number of secondary, detrimental physiological effects (asphyxia, super-saturation, potentially leading to embolism, see Fernández, A., this volume).

A test of this hypothesis would be to track diving, beaked whales during sonar exercises. Depending on the outcome, mitigating measures during sonar exercises, such as silent periods of sufficient duration for dive recovery, may then be considered.

REFERENCES

Carwardine, M. 1995. *Whales, Dolphins and Porpoises*. Dorling Kindersley, London. 256 pp.

Frantzis, A. 1998. Does acoustic testing strand whales? *Nature* (London), 392: 29.

Richardson, W.J., Greene, C.R., Malme, C.I. and Thompson, D.I. 1995. *Marine Mammals and Noise.* Academic Press, London. 576 pp.

Evans, D. L. and England, G. R. 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

Møhl, B., Wahlberg, M., Madsen, P.T., Heerfordt, A. and Lund, A. 2003. The mono-pulse nature of sperm whale clicks. *Journal of the Acoustical Society of America* (in press).

CAN CONTROLLED EXPOSURE EXPERIMENTS BE USED TO HELP DETERMINE SAFE EXPOSURE FOR BEAKED WHALES? –TOOLS AND TECHNIQUES FOR QUANTIFYING THE RESPONSES OF WHALES TO SOUND

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There has been growing concern over strandings of deep-diving beaked whales, as is evidenced by this special workshop. Recent strandings of beaked whales have been reported in the Bahamas, Greece, and Canary Islands. These strandings have been associated with naval manoeuvres, and involve an unusual pattern in which >10 whales strand over tens of km within a few hours. Some of the stranded whales show signs of recent injuries, of a sort that have been associated with exposure to intense acoustic stimuli, among a variety of other causes (Evans and England, 2001). This pattern suggests that the sounds of naval sonars may be involved in the strandings. "Post-mortems" of these kinds of stranding can help identify problems or correlations. However, they seldom can relate exposure to risk, because the location of whales before the strandings is impossible to reconstruct. One first order question is what caused the strandings -- what is the chain of events and responses that lead to the risk of stranding? The first potential link in this chain is the question of what kinds and levels of sounds might cause the observed injuries. This is best studied with acoustic modelling using careful anatomical measurements from dead animals. If exposure to sonar sounds is involved in the strandings, we need to determine which features of the sounds pose the risk. This may suggest possible changes in sounds to be used for these sonars. Whether changes are made or not, the basic question critical to protecting marine mammals from these risks is: what exposures are safe? This question can only be answered directly by experiments to study responses of marine mammals to controlled exposures of noise. These controlled exposure experiments should be limited to sound exposures thought to be very unlikely to pose any risk to the subject, but rather to confirm that the exposures thought to be safe are indeed safe.

While strandings can provide a front line for detecting unexpected new problems for marine mammals, there are serious problems with using poorly controlled naturalistic observations as more than an early warning system. The exposure at the animal can seldom be accurately measured or estimated. It is difficult to structure observations to assess how response may vary with exposure. Simple reporting of uncontrolled observations provides little additional information to assess biological significance of any reactions observed. In terms of estimating the prevalence of the problem, there is an inherent bias in stranded animals available for study. There is simply no way to determine how many animals exposed to the sounds showed no reaction. In addition, it is difficult to assess the statistical power of the study when no reactions are observed. This is particularly exacerbated when we do not have systematic data on exposure available, either during the times of the stranding, or at other times when strandings are not observed.

There is a developing consensus that controlled exposures are the best way to study short-term behavioural reactions to noise. The basic protocol involves selecting the subject prior to exposure to minimise chances that the subject will be biased for probability of response. These experiments cannot prove whether animals react in general; rather they must use a specific protocol to test for specific kinds of reaction related to adverse impact. In order for each individual to serve as its own control, behaviour must be measured pre-, during, and post- exposure. These experiments should be designed to monitor behavioural reactions in ecologically valid settings at sea. It is essential to avoid exposures high enough for risk of injury. Controlled exposure experiments should be designed in a conservative series starting at low exposure levels, and only increasing the exposure level after evaluation of reactions indicates low risk.

Controlled exposure experiments have been conducted with marine mammals since the early 1980s. For example, avoidance reactions of gray whales migrating past the central California coast were studied in Jan, March 1983, 1984, and Jan 1997 (Malme *et al.*, 1984). This is a particularly good setting for observing whales from shore; one can pinpoint the location of each whale surfacing with a theodolite, and plot tracks of whales (Fig 1.) The behaviour of migrating whales is very predictable; this makes it easy to test for reactions.

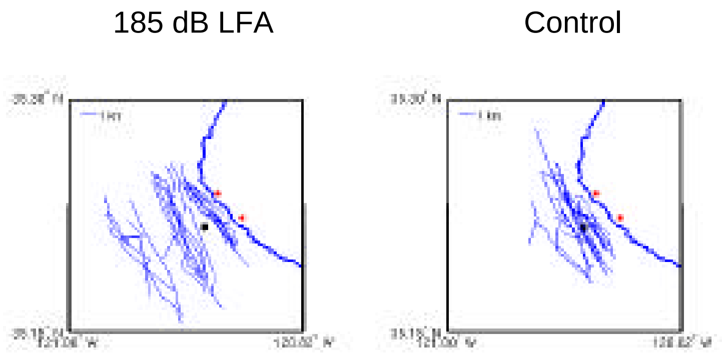


Fig. 1. Tracks of gray whales migrating past a sound source indicated by the black square

As can be seen, there is a gap around the sound source on the left as the whales avoid exposure to this low frequency source at a source level of 185 dB re 1 µPa at 1 m. The received level of sound at which half the whales avoided exposure was 135 dB re 1 µPa. This relationship between dosage and response is very helpful for modelling the reactions of these whales to specific exposure scenarios.

This situation where whales surface every few minutes as they swim along the coast makes it unusually easy to track their responses. For most marine mammals, especially deep divers, new technological solutions are required to track their behaviour throughout their dives. We have developed an acoustic recording tag to solve the following problems:

- Improve our understanding of functions and costs of behaviours in order to infer biological significance of behavioural disruption
- Develop a dose : response technique to measure received level of stimulus at whale while also measuring behavioural and physiological responses

- 3.3 GByte FLASH memory
- Pitch, roll, heading to ± 2°
- Depth to ± 0.3m
- Audio 90 to 190 dB re 1 uPa
- 16.5 hours at 96kHz
- Two suction cups
- Pump / Release
- Rechargeable battery
- Infra-red offload (4Mbps)

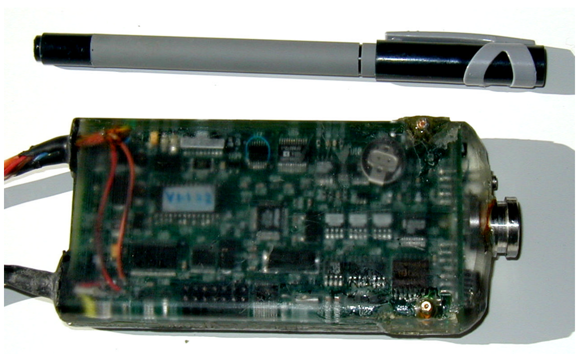


Fig. 2. Photo and features of the digital acoustic recording tag

We have deployed this tag for several field seasons with right whales and sperm whales (Johnson and Tyack, 2003). The tag has proved capable of detecting subtle responses to sound, including orientation, fluke beats and vocal responses. The right whale research has focused on risk factors for vessel collision. Right whales show clear responses to conspecific vocalisations (Fig. 3), but we have detected no such reactions to experimental or uncontrolled vessel approaches (Nowacek *et al*., 2004).

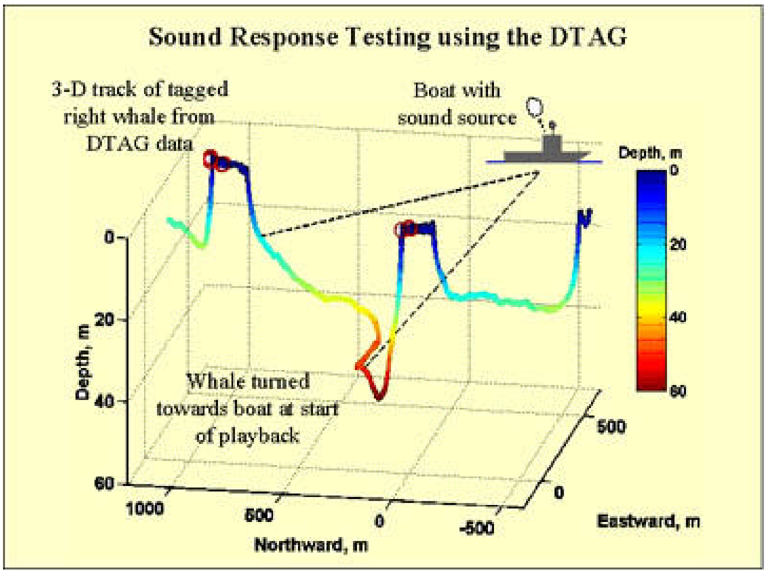
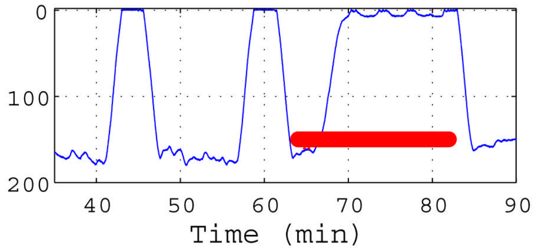


Fig. 3. Right whale at 50 m depth during a dive turns toward sound source at start of playback of a vocalisation recorded from right whale social groups. This kind of response at depth would have been invisible in visual observations of surfacing.

Given this lack of reaction to ships, Nowacek *et al.* (2004) developed an alerting stimulus as a control for comparison purposes. As soon as most right whales heard this control stimulus, they swam at high speed to the surface, and then at high speed along the surface until the sound stopped, whereupon they resumed normal foraging dives. These responses were observed for received levels of the alert stimulus ranging from 133–148 dB re 1 µPa. The fluke rate during the rapid surfacing was significantly higher than during other ascents.

The alert sound was an 18-minute exposure consisting of three, 2-minute signals played sequentially three times over. The three signals had a 60% duty cycle and consisted of (i) alternating 1 sec pure tones at 500 and 850 Hz, (ii) a 2 sec logarithmic down-sweep from 4500 to 500 Hz, and (iii) a pair of low-high (1500 & 2000 Hz) sine wave tones amplitude modulated at 120 Hz and each 1 sec long. The right side of Figure 4 illustrates each of the individual signals that made up the playback stimuli. The timing in this illustration is not accurate – the individual signals are presented back-to-back for efficiency of display.



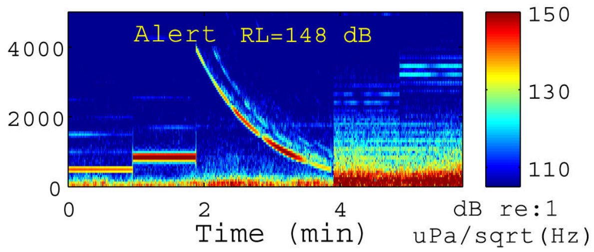


Fig. 4. Left: Rapid surfacing reaction of N. Atlantic right whale exposed to alarm stimulus illustrated on the right. As soon as the whale heard the alarm stimulus, it swam to the surface and continued swimming on the surface until the sound playback stopped. Right: Illustration of the alert/alarm stimuli used in the right whale playbacks. The figure plots individual sounds back to back, that were actually presented at 60% duty cycle in the playback stimulus. These signals were extracted from a tag recording on a right whale during one of the playback experiments.

These responses illustrate how a short-term CEE can define a strong short-term response to sound that may impose greater risks during longer or more intense exposure.

It is more challenging to attempt to attach tags to fast moving beaked whales and there are few sites where beaked whales are regularly studied. We are developing two field sites to study beaked whales and to learn how to tag them. We are working with a group of biologists who have been able to identify individual Cuvier's beaked whales (*Ziphius cavirostris*) using natural markings from tooth scrapes. It has proved possible to sight beaked whales on most days when the weather is calm. We have successfully attached a Dtag to a Cuvier's beaked whale on one occasion for one full 17-minute dive to 450 m (Fig. 5). No sounds likely to be vocalisations of *Ziphius* were recorded during this dive, with a sampling rate of 32 kHz that could record sounds up to 16 kHz.

These baseline field studies need to continue for us to learn how to increase the success rate of tag attachment per approach and to attach tags for durations of several hours. We have modified the tag to record much higher bandwidths, in case *Ziphius* produces narrow band pulses above 100 kHz, as do *Kogia* and *Phocoena*. Once we learn how *Ziphius* uses sound, and learn more about their diving behaviour, we should reach a point where we will be ready to plan CEEs with this species.

Fig. 5. Attaching a Dtag to a Cuvier's beaked whale using a hand-held pole. The tag stayed on for one full dive, and came off after the whale surfaced.

The design features of CEEs to *Ziphius* will be challenging. These experiments must help to demonstrate safe sound exposures, while not posing a risk to the subjects. Planning these experiments will require workshops with input from a broad range of disciplines and points of view, emphasising how to focus the science best on the most critical policy issues. Our ability to conduct safe playbacks to the highly endangered right whales makes us optimistic that it is possible to design CEEs to safely detect strong behavioural response, and to explore which acoustic features of stimuli trigger the responses. These kinds of experiment offer great promise to define what acoustic features pose the greatest risk, and what exposures are safe. We hope that this can play a role in comparing effects of low-, mid-, and high-frequency sonar signals, in the possible redesign of sonar signals to reduce the risk, and to set standards for safe exposure levels.

REFERENCES

Evans, D. L. and England G. R. 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*

Johnson, M. and Tyack, P.L. 2003. A Digital Acoustic Recording Tag for Measuring the Response of Wild Marine Mammals to Sound. *IEEE Journal of Oceanic Engineering,* 28: 3-12.

Malme, C.I., Miles, P.R., Clark, C.W.. Tyack, P. and Bird, J.E. 1984. *Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behaviour. Phase II: January 1984 migratio*n. Bolt Beranek and Newman Report No. 5586 submitted to Minerals Management Service, U. S. Dept. of the Interior.

Nowacek, D., Johnson, M., and Tyack, P. 2004. North Atlantic right whales (*Eubalaena glacialis*) ignore ships but respond to alarm stimuli. *Proc. R. Soc. B.*, 271: 227-231.

MEASURING HEARING WITH AUDITORY BRAINSTEM RESPONSES

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INTRODUCTION: BEHAVIOURAL HEARING MEASUREMENTS Anthropogenic, or man-made, noise is generally increasing in the oceans (Ocean Studies Board, 2003) and recent reports indicate that cetaceans are beaching correlated with anthropogenic noise. There are a number of sources for ocean noise including: (1) dredging and construction, (2) aircraft, ships and boats including oil tankers, (3) oil and gas surveys, drilling and production, (4) geophysical surveys (airguns, sleeve exploders and gas guns etc), fish-finding and naval sonars, (5) explosions, (6) military exercises, and (7) ocean science studies (seismology, acoustic propagation, acoustic tomography, acoustic thermometry) (Richardson *et al*., 1995). Cetaceans, particularly odontocetes, have evolved superb abilities to receive and process acoustic information (Nachtigall *et al*., 2000) and are therefore very adapted to using sound in the sea for a variety of basic biological functions including echolocation for finding food (Benoit-Bird and Au, 2003) at night.

Despite the effort to understand odontocete cetacean hearing that has been going on since 1965 (Johnson, 1967) we generally still know little about most species, in fact we only have basic audiograms on 12 (Nachtigall *et al.*, 2001) of the 83 (Rice, 2000) cetacean species. Johnson's initial (1967) audiometric experiments on the Atlantic bottlenose dolphin (*Tursiops truncatus*) provided the first quantitative information on high frequency odontocete hearing and also provided the model for behavioural experiments in odontocetes.

Most of what is known about cetacean hearing has been gathered from behavioural audiogram experiments on trained dolphins or small whales that take a relatively long time, and considerable effort and resources, to complete. The behavioural audiogram is based on what the animal hears and what it is trained to report. Usually the animal is trained to sit quietly in a fixed position and to leave and tap a response ball if a sound is presented and to remain still if no sound is presented. Each time the animal correctly reports that a sound is either present, or not present, it receives a fish reward. The sound is then gradually made quieter across trials until the animal can no longer hear it. At that point the 'direction' is reversed and the sound is increased for a while until the animal once again reports that it hears it. These reversal points are used to determine the behavioural threshold – the point at which the animal just barely hears the sound. Sounds representing a variety of frequencies, or pitches, are presented. When threshold is plotted by frequency, one obtains an audiogram. A summary of odontocete audiograms, taken from Nachtigall *et al.* (2001) is presented in Fig 1.

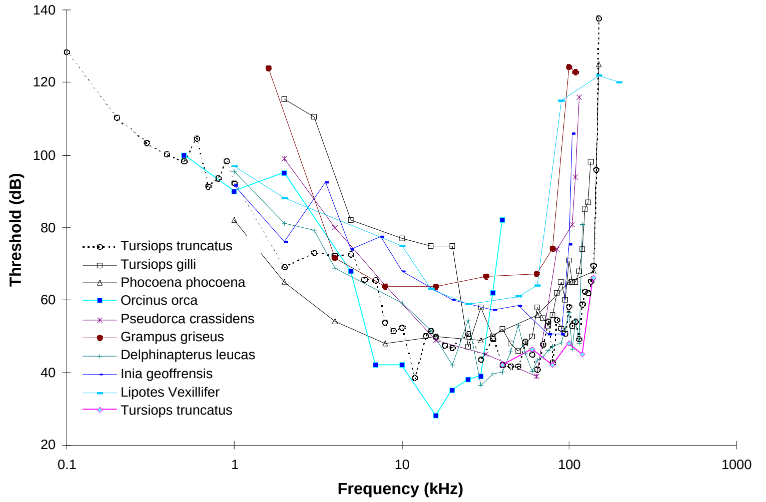

Fig. 1. Odontocete Audiograms from a variety of experiments and species

AUDITORY BRAINSTEM RESPONSES MEASURING HEARING While behaviourally measured audiograms will remain as the primary method for measuring hearing because they actually depend on the report of an animal's experience at hearing something, recent developments in audiometry using auditory brainstem responses have added a new procedure for measuring hearing. Basically an auditory brainstem response (ABR) is a way to measure what an animal hears through the detection and recording of electrical impulses in the lower portion of the brain that occur in response to sound.

Two developments in the measurement techniques for recording ABRs made them satisfactory for use with marine mammals: (1) they can be collected from the surface of the skin using human EEG sensors placed within soft latex rubber suction cups, and (2) acoustic signals comparable in length to behavioural audiogram signals can be presented and ABRs measured using envelope following responses (EFR) which is a rhythmic burst of ABRs to amplitude modulated acoustic stimuli (Dolphin *et al.*, 1995, Supin *et al*., 1995). These same procedures can now also be used to readily test the hearing of newborn human babies (Stoeckert, 2003).

ABR audiograms comparable to behavioural audiograms can be obtained from dolphins by training them to sit still in the water and wear two suction cup sensors, one on the head behind the blowhole and the other on the back. A tone of a particular frequency is played into the water and that tone is amplitude modulated (simply meaning that it rapidly and smoothly changes from loud to quiet). The rate of that change is easily followed by the dolphin's brain so that it can change 1000 times per second and that modulation rate can be observed in the dolphin's brain wave patterns. Relatively loud sounds produce relatively large (in microvolts) ABRs while relatively quiet sounds produce small ABRs. If the animal cannot hear the sound, the modulation rate of the sound will not be observed in the animal's brain waves.

The amplitude modulated sound and the EFRs to those various levels of sound are pictured in Fig 2. In more technical terms, the amplitude modulation rate is set at 1000 Hz, and the overall amplitude of the signal is varied. The EFR is averaged across trials and the signals analysed with a fast Fourier transform. The Fourier-spectrum peaks centre on the modulation rate and the height of the peaks varies with amplitude of the signal. The linear regression of the peak amplitudes is calculated, and the point at which the regression line crosses zero is considered as the threshold, as shown in Fig. 3.

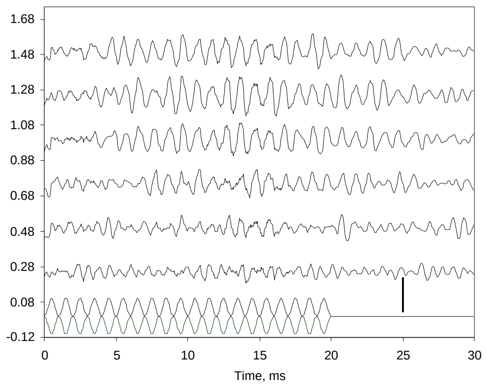

Fig. 2. Amplitude modulated acoustic stimulus (bottom) and brainwave responses to various acoustic amplitudes

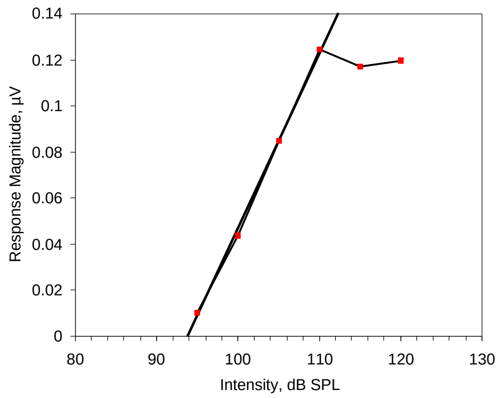

Fig. 3. Peak EFR level at various acoustic amplitudes with threshold at the zero cross-over point determined by linear regression

Measuring hearing using ABRs has proved valuable to testing hearing in a number of circumstances (Supin *et al*., 2001) where longer-term behavioural work was impossible. Popov and Klishin (1998) examined the hearing of a stranded common dolphin while under medical care, while Andre *et al*. (2003) recently found that a stranded striped dolphin undergoing rehabilitation following stranding was essentially deaf. In both of these circumstances the dolphins were under medical treatment following stranding. We recently had the opportunity to attempt to measure the hearing of a stranded infant sperm whale undergoing rehabilitation (Moehl *et al*., 2003), but unfortunately the animal expired of causes unrelated to our attempts before we could complete the audiometric measures. The ABR procedure is generally a very fast, safe and effective way to examine the hearing of most cetaceans that have so far been examined. Almost all of them have been odontocetes with large brains, but many odontocetes including the beaked whales have yet to be tested. The ABR hearing tests would be important for both diagnostic procedures to test whether or not a stranded animal had damaged hearing and also for the acquisition of new knowledge to know what a particular species hears. Hopefully the procedures may some day be used to test the hearing of the larger mysticete whales, but the distance from brain to skin surface make this a more challenging task.

Given the importance of the current emphasis on the effects of underwater sound on marine mammals, and the relative paucity of information on the hearing of a great number of cetacean species, an emphasis on the development of new techniques to measure hearing in whales and dolphins seems reasonable. ABRs can be taken in captive animal laboratories with trained animals, in rehabilitation facilities with animals that are under medical care and recovering, and perhaps at some point in the future with free-swimming animals with appropriate tags temporarily attached.

REFERENCES

Andre, M., Supin, A.Ya, Delory, E., Kamminga, C., Degollada, E., and Alonso, J.M. 2003. Evidence of deafness in a striped dolphin, *Stenella coeruleoalba. Aquatic Mammals*, 29(1): 3-8.

Benoit-Bird, K.J. and Au, W.W.L. 2003. Prey dynamics affect foraging by a pelagic predator (*Stenella longirostris*) over a range of spatial and temporal scales. *Behavioural Ecology and Sociobiology,* 53: 364-373.

Dolphin, W.F., Au, W.W.L., Nachtigall, P.E. and Pawloski, J.L. 1995. Modulation rate transfer functions to low frequency carriers by three species of cetaceans. *Journal of Comparative Physiology* A, 177: 235-245.

Johnson, C.S. 1967. Sound Detection Thresholds in Marine Mammals. Pp. 247-260. In: Tavolga, W. (ed) *Marine BioAcoustics*. Pergamon Press, New York.

Nachtigall, P.E., Lemonds, D.W., and Roitblat, H. L. 2000. Psychoacoustic Studies of Whale and Dolphin Hearing. Pp. 330-364. In: Au, W.W.L, Popper, A.N. and Fay R.J. (eds) *Hearing By Whales*. Springer-Verlag, New York.

Møhl, B., Madsen, P.T., Wahlberg, M. Au, W.W.L., Nachtigall, P.E. and Ridgway, S.H. 2003. Sound transmission in the spermaceti complex of a recently expired sperm whale calf. *Journal of the Acoustical Society of America. Acoustics Research Letters Online* (4)1: 19-24.

Ocean Studies Board. 2003. *Ocean Noise and Marine Mammals*. National Research Council, Washington D.C. USA 192pp.

Popov, V.V., and Klishin, V.O 1998. EEG study of hearing in the common dolphin. *Aquatic Mammals*, 24: 13-21.

Rice, D.W. 1998. *Marine Mammals of the World*. The Society for Marine Mammalogy, Lawrence Kansas USA, 231pp.

Richardson, W.J., Greene, C.R., Malme, C.I. and Thomson, D.H. 1995. *Marine Mammals and Noise*. Academic Press: San Diego. 576pp.

Stoeckert, J.A. 2003. Personal Communication. Director, House Ear Institute, Los Angeles California, USA.

Supin, A. Ya, and Popov, V.V. 1995. Envelope following response and modulation transfer function in the dolphin's auditory system. *Hearing Research*, 92: 38-46.

Supin, A.Ya., Popov, V.V., and Mass, A.M. 2001. *The Sensory Physiology of Aquatic Mammals*. Kluwer Academic Publishers, Boston. 332 pp.

PASSIVE ACOUSTIC TOOLS FOR THE IMPLEMENTATION OF ACOUSTIC RISK MITIGATION POLICIES

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INTRODUCTION The effect of anthropogenic noise on the marine environment is a serious concern for scientists (Richardson *et al*., 1995; Nascetti *et al*., 1997; D'Amico, 1998; Frantzis, 1998; AA.VV, 2003) and has gained the attention of public opinion. To reduce the impact of high power underwater sound sources, Acoustic Risk Mitigation Policies have been drawn up and are currently under implementation. Basically, ARMP are aimed at preserving particularly populated areas and critical habitats, and at reducing or stopping emissions if animals are within a defined distance.

Among tested approaches, passive acoustics has shown to be an efficient tool to (a) expand knowledge about marine mammal distribution in space and time (i.e. with surveys), (b) characterise biological and artificial sources, (c) evaluate effects of sound exposure on animals' behaviour, and (d) monitor, detect, locate and track vocalising animals within, or approaching, a sound exposure area.

Passive acoustics can continuously work regardless of weather, visibility, daylight or night. Sounds efficiently propagating in the water are received from great distances, and all detections can be proved with recordings.

Currently available signal detection and storage equipment allow weeks of recordings from multiple sensors (Pavan *et al*., 2001; Priano *et al*., in press). On the other hand, no tools are available for effortless cataloguing of acoustic events, nor for specific signal automatic recognition. Moreover, no definitive methods exist to predict or determine, with high confidence, whether marine mammals are present in a given area or not. In particular, passive acoustics may fail in detecting animals whose vocalisations (class of emissions, emission rates and cycles) are not well known or completely unknown.

To get an overall picture of an area it is thus very important to integrate more methods including visual sightings, aerial surveys and any new technology aimed at detecting surfacing and diving animals (infrared detection, radar detection, low power active sonars).

Many "Dual Use" experiments, even if they have offered excellent results in the low frequency band, have clearly shown that specific equipment packages are needed to satisfy mitigation peculiarities. Expanded bandwidth, very low self noise, easy to use interfaces, optimised for rapidly time-varying signals, are the striking points of the required ARMP tools.

The CIBRA Workstation Since 1999, CIBRA has been co-operating with SACLANT Undersea Research Centre in the SOLMAR project (Sound, Oceanography and Living Marine Resources). The project is aimed at developing Marine Mammals Risk Mitigation policies (MMRM) for NATO Navies and at defining and testing the required tools and protocols. To support this project, a PC based Sound Analysis Workstation was designed, assembled and extensively tested in SIRENA cruises organized by SACLANT (Figs. 1-3). It offers an affordable and flexible tool for wide-band acoustic detection and monitoring. Based on bioacoustic analysis experiences started in the 80s', it was redesigned and updated to match underwater bioacoustics and acoustical oceanography needs (Pavan *et al*., 1997; Pavan *et al*., 2001; Priano *et al*., in press).

Custom-made wideband sensors and arrays feed the analysis system with signals describing the acoustic environment. Arrays operating at different depths (Fig. 1), signals gathered by a sensor network (i.e. sonobuoys), and wideband beam-forming are the explored hardware solutions to get improved, multichannel detection capabilities.

Extended bandwidth is required to preserve ultrasonic signals, including echolocation clicks, that are usually not detected with audio equipment (Fig. 4). Detecting signals whose energy is mostly in the ultrasonic range maximises detection abilities at short range, i.e. within the most sensitive area for MMRM policies. Experience shows that ultrasonic signals can often be the only signals revealing the presence of animals at short range.

Based on the same multi-year experience, an observation protocol has been developed to deal with the circadian patterns of vocalising animals. By continuous monitoring, 24hours/day, it is possible to reveal the presence of animals sporadically vocalising. Also, continuous monitoring while performing sonar emissions, or other possibly invasive actions, is required to detect acoustic responses of animals or any change in vocalising behaviour.

The Workstation is carefully assembled with off-the-shelf components deriving from both high-end audio and industrial signal acquisition; the basic configuration has 8 input channels with 48 kHz bandwidth per channel. Advanced configurations offer up to 12 channels at 96 kHz and up to 400 kHz on a single channel.

The tested sensors configuration consists of a two channel towed array (Fig. 2), designed in 1993 (Pavan and Borsani, 1997), characterised by very low self-noise and 45 kHz bandwidth, and other arrays with assorted sensors ranging up to 300 kHz in frequency (Cetacean Research Technology). A compact array that provides more than 100 kHz bandwidth, with beamforming capabilities up to 20 kHz, is going to be assembled.

The software and the user interface were designed to return easy interaction, real-time feedback and reliability. The software set provides hard-disk recording, together with real-time high-resolution spectrographic and beamformer display. GPS and navigation data logging, operator-based acoustic classification logger, GIS file output as well as acoustic file analysis and post-processing (Fig. 3, 4 and 5) are included. The workstation can provide uninterrupted high resolution monitoring and recording for days. When based on a laptop PC, the system can be installed and operated from small platforms.

To offer continuous recording for days or weeks, required in wide area surveys, signals can be recorded on almost any fast digital storage system. Files are organised in user defined time cuts, georeferenced by automatic GPS logging. Navigation data and georeferenced acoustic events, categorised by trained operators, and can be sent to a GIS for a nearly-real-time mapping (Manghi *et al.*, a, in press). The workstation returns an immediate summary of the underwater acoustic environment.

Maps showing where and when each sound category was detected can be easily plotted (Fig. 5). Useful during the surveys, to get a picture of the detections, this tool reduces the post processing time. The tables and maps of acoustic contacts can be used as an index to focus the post-processing on those slots and areas containing interesting data. Matching these GIS data with environmental parameters, either derived by remote sensing or oceanographic models, offers exciting possibilities in the study of the distribution of animals.

The described system was tested during SIRENA cruises on the NR/V Alliance (SACLANTCEN CD27/99; CD41/00; CD53/01; CD60/02). The cruises were aimed at performing acoustic experiments and a combined visual and acoustic survey in the Ligurian Sea, Italy. In Sirena 00-01-02, more than 700 hours of passive acoustic monitoring and recording were carried out with wideband towed arrays during 54 research days. State of the art maps of marine mammal distribution resulted from this work (work in progress).

The analysis, based on sound categories detected in 1 minute time slots, show that dolphin vocalisations have a clear diel cycle with higher activity at night: in Sirena 02 (Fig. 6), in the sunset-sunrise interval, slots with detections were up to 80%, four times more than in daylight hours; the same interval contained 84.5% of the slots with “nacchere”, a peculiar category of dolphin vocalisations.

Resulting data clearly show that to get a real picture of the presence of dolphins in an area, it is important to investigate on a complete diel cycle. Based on acoustic detections, dolphins, mostly represented by striped dolphins (a pelagic species), were distributed throughout the entire study area. The comparison with sightings shows that the acoustic approach outperformed the visual one; in the specific environment and context of the Ligurian basin, dolphin sightings averaged less than 0.4 per hour.

CONCLUSIONS A multi-sensor approach allows one to monitor many frequencies and depths at once. Large bandwidth allows one to detect ultrasonic signals, including echolocation clicks, that cannot be detected with traditional audio equipment and which can be the only signals revealing the presence of animals. Silent animals, or species whose repertoires are unknown, require this surveillance to be integrated with other approaches including visual sightings, aerial surveys, and any new technology aimed at detecting surfacing and diving.

To make Acoustic Risk Mitigation Policies, Rapid Environmental Assessment and (bio)acoustic research easy, efficient and affordable it is important to rely on:

- compact, easy to use packages including a wideband towed array connected to a wide-band real-time analysis system with possibly beam-forming capabilities
- analysis workstations to monitor multiple sensors at the same time
- a quiet platform
- trained, skilled and motivated operators following tested protocols
- operator based and computer assisted detection tools to provide acoustic classification and early alerting
- 24h/day monitoring to provide reliable data for assessing animals’ presence and distribution
- tools to integrate navigation data, sightings, acoustic detections and oceanographic data into a GIS
- an integrated multidisciplinary approach.

The software package and the equipment developed at CIBRA proved to be a flexible and useful tool for both research and mitigation purposes. The sound analysis software can be downloaded from the CIBRA website.

ACKNOWLEDGEMENTS Project carried out within the SACLANT Undersea Research Center's SOLMAR Project with ONR Grants N00014-99-1-0709 and N00014-02-1-0333. The development of the first CIBRA wideband array was granted by the Italian Ministry of the Environment in 1993. We wish to thank the Italian Navy and Adm. Dino Nascetti for the support given to our activities since 1995; Angela D'Amico, Mike Carron and Nicola Portunato for their precious, friendly support during SACLANT U.R.C. activities.

REFERENCES

AA.VV. 2003. *Ocean Noise and Marine Mammals*. The National Academies Press, Washington. 206pp.

D'Amico, A. (Editor), 1998. Saclantcen Bioacoustics Panel. *Saclantcen Report* M-133.

Frantzis, A., 1998. Does acoustic testing strand whales? *Nature* (Lond.), 392:28.

Manghi, M., Pavan, G., Fossati, C., Priano, M., Mapping and analyzing acoustic surveys' results: a GIS approach. *European Research on Cetaceans,* 16: in press (a)

Manghi, M., Fossati, C., Pavan, G., Priano, M., Diel occurrence of characteristic acoustic emission in feeding striped dolphins. *European Research on Cetaceans*, 17: in press (b)

Nascetti, P., Perazzi, A., Hastrup, O., 1997. An investigation of the interaction between active sonar operations and marine mammals. *European Research on Cetaceans*, 10: 61-67.

Pavan, G. and Borsani, J.F. 1997. Bioacoustic research on cetaceans in the Mediterranean Sea. *Mar. Fresh. Behav. Physiol*., 30: 99-123.

Pavan, G., Priano, M., Manghi, M., and Fossati, C. 1997. Software tools for real-time IPI measurements on sperm whale sounds. *Proc. I.O.A., Univ. Of Loughborough, UK,* 19 (9): 157-164.

Pavan, G., Fossati, C., Manghi, M., and Priano, M. Nacchere: an acoustic behaviour of striped dolphins. *European Research on Cetaceans*, 17: in press.

Pavan, G., Manghi, M., and Fossati, C., 2001. Software and hardware sound analysis tools for field work. *Proc. 2nd Symposium on Underwater Bio-sonar and Bioacoustic Systems. Proc. I.O.A., Vol. 23 (part 4):* 175-183.

Priano, M., Pavan, G., Manghi, M., Fossati, C., Sound analysis workstation for the implementation of acoustic risk mitigation policies. *European research on Cetaceans*, 17: in press.

Richardson, W.J., Greene, C.R. Jr., Malme, C.I., Thomson, D.H., 1995. *Marine mammals and noise*. Academic Press, London. 546pp..

SACLANTCEN CD27, 1999. SIRENA 99 Report. SACLANT Undersea Research Centre, Viale San Bartolomeo 400, 19138 La Spezia, Italy.

SACLANTCEN CD41, 2000. SIRENA 00 Report. SACLANT Undersea Research Centre, Viale San Bartolomeo 400, 19138 La Spezia, Italy.

SACLANTCEN CD53, 2001. SIRENA 01 Report. SACLANT Undersea Research Centre, Viale San Bartolomeo 400, 19138 La Spezia, Italy.

SACLANTCEN CD60, 2002. SIRENA 02 Report. SACLANT Undersea Research Centre, Viale San Bartolomeo 400, 19138 La Spezia, Italy.

WEB REFERENCES

CIBRA http://www.unipv.it/cibra
ONR http://www.onr.navy.mil
SOLMAR http://solmar.saclantc.nato.int

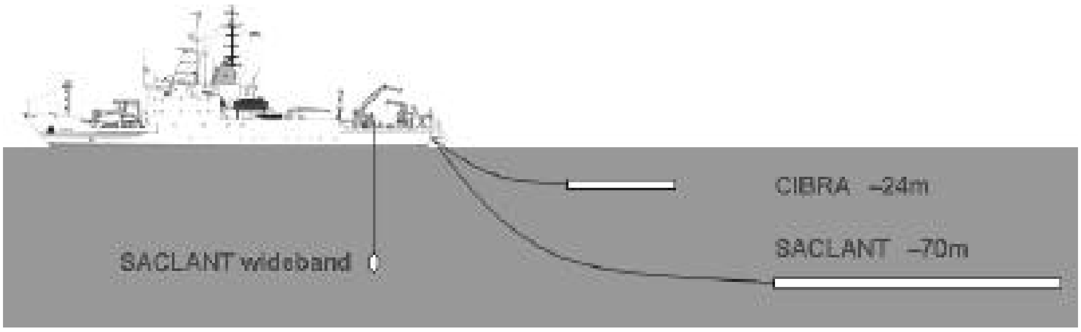

Fig. 1. Multi-sensor configuration allows to maximise detection capabilities. During Sirena 2002 research cruise, two wide-band arrays were towed at different depths. A wideband hydrophone was used in stationary monitoring stations. Sonobuoys were also deployed when cruising at high speed.

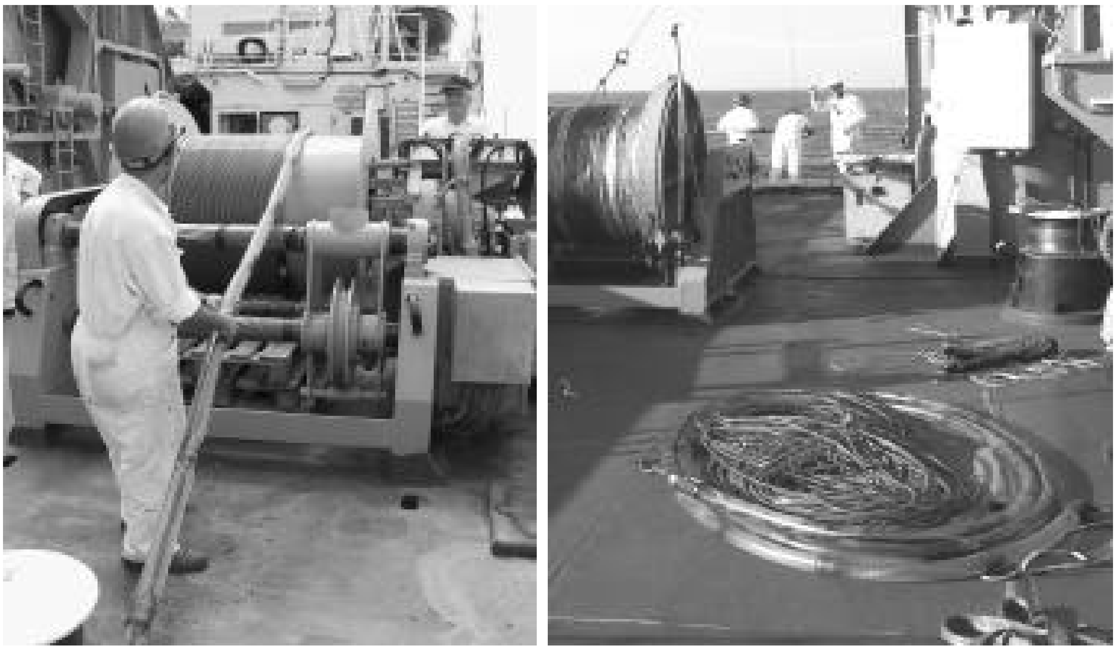

Fig. 2. CIBRA arrays were designed to fit the needs of bioacoustic research in the field. They can be used with a small winch, though they can be easily moved, deployed and recovered by hand as well.

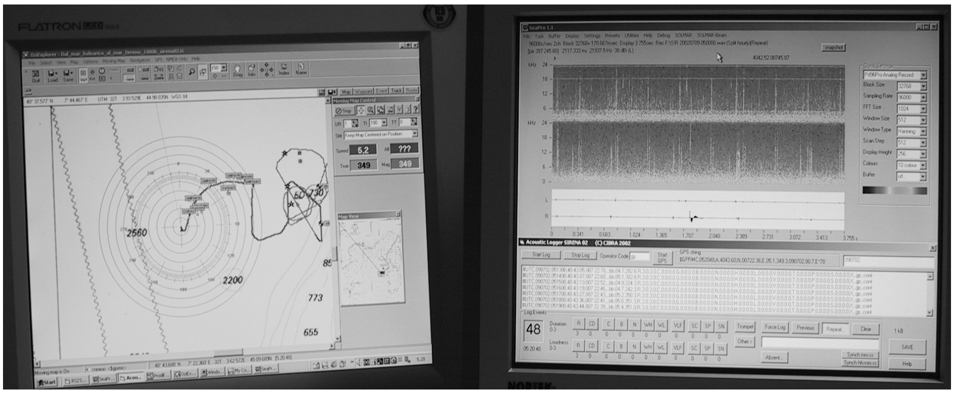

Fig. 3. While listening and observing real-time spectrograms, researchers classify received signals 24h/day and fill a log with 1 minute time slots. Each slot is geo-referenced, allowing a direct link to a GIS for acoustic mapping. On a dual screen system, recording, analysis, display and GIS plotting can be performed at the same time.

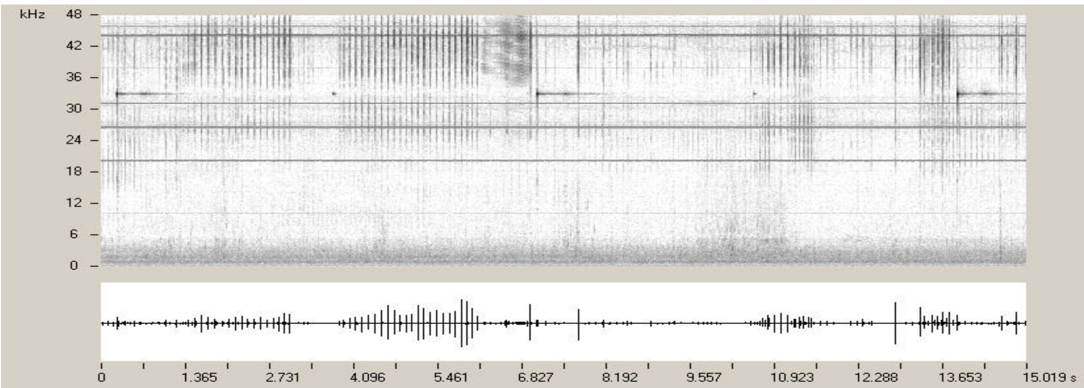

Fig. 4. Spectrogram of dolphin clicks whose energy is above 20 kHz (horizontal lines are due to electrical interferences; traces at 33 kHz are due to the ship's echosounder).

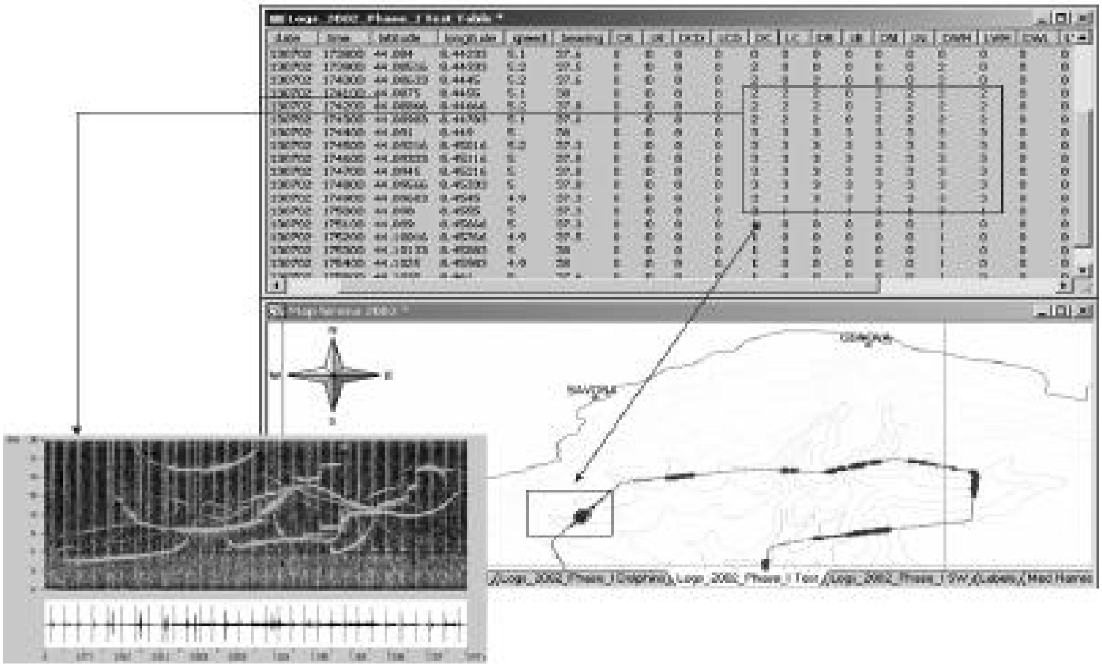

Fig. 5. Acoustic contacts can be plotted on a GIS in real-time to give a complete picture of the acoustic activity in an area. Furthermore, the acoustic logging with 1 minute time resolution becomes an index to recordings for making easy and quick the post-processing of the data.

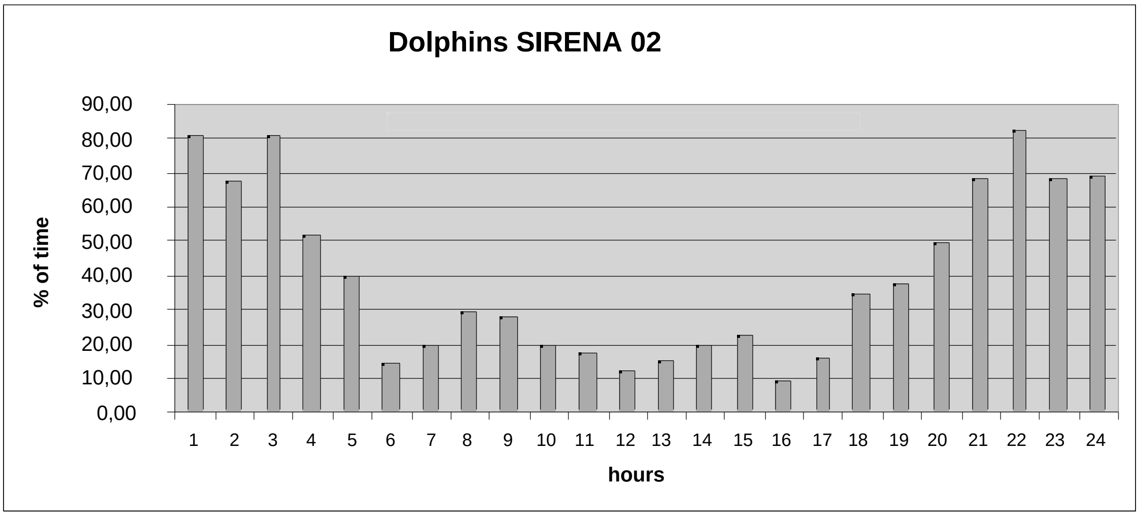

Fig. 6. Detection rates of dolphin vocalisations *vs* time of day. The white bar shows the sunrise-sunset interval. Detection rates (Y axis) are computed as % of minutes with positive detections in each hour.

NATO SACLANTCEN MARINE MAMMAL RISK MITIGATION PROGRAMME (SOUND, OCEAN, AND LIVING MARINE RESOURCES)

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BACKGROUND The SOLMAR project was initiated following the recommendations of SACLANTCEN panels on Bioacoustics and Marine Mammal Environmental and Risk Mitigation Procedures, convened (15-19 June 1998)[1] in response to a description of an unusual mass stranding[2] of Cuvier's beaked whales, *Ziphius cavirostris*, in Kyparissiakos Gulf, Greece. A more complete history of this can be found in the 2001 Annual Report.

Since the incident mentioned above, there have been multiple strandings of *Ziphius cavirostris* in March 2000 during a U.S. exercise in the Bahamas, in Madeira during a NATO naval exercise in May 2000, and again in 2002 during a Spanish led exercise in the Canary Islands.

The earliest stranding recorded for Cuvier's beaked whale is from 1804, but no multiple strandings were reported until 1963. Since then there have been progressively more mass strandings, totalling >20 events. Only recently have tissues been analysed for clues as to the cause of stranding, but about half of the stranding reports mention the presence of surface warships in the area at the time of the strandings.

The accumulating evidence supports the decision made in 1998 by SACLANTCEN to establish an environmental policy to reduce the risk to marine mammals from powerful sonar transmissions, and to establish a research programme[1] with appropriate goals.

The main scientific goals are to develop a cetacean density prediction capability and to develop and evaluate on-site acoustic risk mitigation procedures and tools. These are being accomplished through the collection of relevant ocean characteristics and cetacean presence data and by setting up an integrated Ocean Physical/Biological Information System (OPBIS). This will be followed by the development of a cetacean prediction framework. At the same time specific, carefully controlled acoustic exposure experiments are carried out with cetaceans on an opportunistic basis to investigate the impact that active acoustic devices may or may not have on the animal being studied. Trained visual observers, passive and active sonar, and the use of non-acoustic sensors, such as motion-recording tags, allow the collection of unique data sets designed to help the understanding of the impact, or lack of impact, of sound on cetaceans.

The SACLANTCEN risk mitigation policy is multi-layered. It first requires an environmental scoping study to be performed to determine the possible negative effects of sonar operations on the environment. Then it establishes an exposure level above which risk mitigation must be applied. Depending upon response data, this may differ according to species. For example, sperm whales in the area of the Greek *Ziphius* stranding showed little change in behaviour, suggesting that sperm whales may be less sensitive to that exposure than *Ziphius*.

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[1] SACLANTCEN M-133.
[2] ***Nature,*** **392**, 1998: p.29.
[3] Originally under the direction of Angela D'Amico (presently at SPAWAR Systems Center, San Diego)

Two methods are being developed to reduce the possibility that marine mammals will be exposed to this level. A database of marine mammal distribution is being developed and oceanographic factors are being studied to predict the presence of different species to assist the planners in selecting areas and times least likely to have high densities of sensitive animals during sonar trials.

At sea, observers scan for marine mammals and passive acoustic monitoring is used to listen for animal vocalisations. A low-power whale-finding sonar is being developed to improve the probability of detecting submerged animals that may not be vocalising. Each Sirena cruise attempts to improve visual monitoring, increase the ability to detect animal sounds, and test the whale-finding sonar concept. During 2002, the *Sirena 02* sea trial was conducted to acquire environmental information and to evaluate techniques to (1) determine maximum safe exposure levels for and determination of the signal strength for target sperm whales; (2) continue data acquisition with respect to deep diving cetaceans, in particular sperm whales and Cuvier's beaked whales; and (3) attempt to separate higher frequency dolphin whistles from (possible) similar sounds being made by the Cuvier's beaked whales.

Sirena 02 was the fourth of a series of interdisciplinary measurements in the Ligurian Sea, a deep basin located in the northwestern Mediterranean Sea bounded to the north by the Italian and French Riviera, to the south by the northern coast of Corsica and to the southeast by the shallow water shelf of the Tuscan archipelago. It is open to the Mediterranean Sea along its western boundary. During the sperm whale portion of *Sirena 02,* NRV Alliance transited from the southern Ligurian Sea to the NW coastal region of Sardinia to the Balearic Islands and back along the French littoral to the Gulf of Genoa.

During *Sirena 2002,* three sperm whales were tagged with a compact recording device, to acquire multi-sensor data for better understanding of behaviour during deep diving and when exposed to sonar sound. The animals were simultaneously tracked with a passive sonar system and by a highly experienced visual team from the flying bridge of NRV Alliance.

The most critical research involves testing responses of whales in the exposure range established by policy as safe. The Cuvier's beaked whale is so difficult to sight and so little is known about their vocalisations, that no techniques are available to reconstruct the distribution of these animals prior to a stranding event. Even when it is possible to calculate how sonar sounds propagated before a stranding event, critical information is lacking to determine the association between received levels at the animal and concomitant risk of stranding. Strandings indicate a high level of risk. A risk mitigation threshold should mark a low level of risk. While the beaked whales examined in the Bahamas and Canary Island strandings showed signs of auditory injury, the injuries were of a type from which terrestrial mammals usually recuperate. The animals are thought to have died from the stranding event and not directly from physical damage from an acoustic event. It is not known whether the behavioural events leading to the stranding are triggered by injury or whether adverse behavioural effects could occur at received levels lower than those required to produce injury.

The Centre is committed to investigating the impact of active acoustic devices on the at-risk species. In the case of beaked whales, where there may be a sudden transition to flight, it will be critical to develop experimental protocols to reduce the risk of adverse impact of the experiment. This suggested initially testing CEE on a deep diving marine mammal thought to be at less risk. Sperm whales, *Physeter macrocephalus,* are more common than beaked whales, yet there are no known cases of sperm whale strandings associated with sonar exercises. Initial CEEs, like the one performed on *Sirena 02*, with sperm whales, are designed to test whale responses and the definition of experimental protocols for future work with beaked whales.

NATO and SACLANT Undersea Research Centre will continue to put significant resources into research to gain knowledge of the baseline behaviour of marine mammals, the possible interaction of sonars and marine mammals, and the development of policies and protocols to minimise the risk to these animals during sonar testing and military exercises.

MARINE MAMMAL RISK MITIGATION RULES The primary responsibility of the Marine Mammal Risk Mitigation (MMRM) programme at the SACLANT Undersea Research Centre is to perform research directed toward developing protocols and tools to protect marine mammals during active sonar testing performed by the Centre. The protocol presently in place at the Centre (and reviewed and revised every November) has an influence on similar operating guidelines issued to NATO operational forces when they exercise with their sonars. A sonar trial or test is a tightly controlled experiment, staffed (at sea) by experienced scientists (often with external marine mammal observers). A military exercise normally uses operational military units to simulate a combat situation. Research institutions such as SACLANT Undersea Research Centre usually execute sonar trials and tests. Military exercises can be national, multi-national or NATO. For example, the 1996 Greek strandings seem to be associated with a sonar test performed by SACLANT Undersea Research Centre, thus giving rise to this programme. The September 2002 Canary Islands exercise was a Spanish exercise with other nations participating.

WHOSE RULES? During SACLANT Undersea Research Centre sonar experiments, scientists must adhere strictly to the Centre’s Instruction and Protocol for Human and Marine Mammal Risk Mitigation. When under NATO control, military units must follow NATO protocols and guidelines unless their own nation has stricter rules and protocols or the host nation imposes stricter rules. When not under NATO control, military units must follow their national or host nation’s rules and protocols.

SACLANT UNDERSEA RESEARCH CENTRE ACTIVE SONAR PROTOCOLS All active sonar experiments performed by the Centre or in co-operation with the Centre are governed by strict rules and protocols. A series of steps must be followed prior to any active sonar experiment:

Environmental Scoping Study
- –Previous studies
- –Human swimming or diving
- –Marine Mammal Activity expected
  - »Expected species
  - »Breeding grounds
  - »Seasonal variations
- –Itemise details of high-level sound sources (explosives should be avoided)
- –Avoid wrecks, MM sanctuaries
- –Acoustic modelling to establish safety ranges for divers and marine mammals
- –Consult with internal/external authorities/experts
- –Assess impact of the high-level sound on divers and marine mammals.
- –Determine/confirm visual and acoustic monitoring requirements
- –EES Matrix as part of sea trial test plan.

If multiple ships are involved, ALL must adhere to the same (and strictest) protocol. Rules have been established for the maximum energy to be received by different classes of animals and maximum transmission durations, duty cycles, and maximum cumulative exposure per day are established.

In actuality, stricter rules are almost always imposed, especially if in a region known or suspected to be a habitat of Cuvier’s beaked whales. In all cases, the MMRM programme must be consulted prior to active sonar experiments, and members of the programme advise all experiment designers as to the best way to avoid ensonifying *Ziphius* or other marine mammals with significant levels of sound.

In addition to the Environmental Scoping Study there are other rules that must be followed before active sonars may be activated:

–Trained lookouts must used.
–Aircraft for visual search when available.
–Passive acoustic devices deployed and monitored.
–Listen, look, and record for at least 30 minutes prior to ensonfication. Normally we require this to be increased to 60 minutes.
–Visual and acoustic lookout information recorded using Visual Watch Recording Form
–Ramp-up procedures (If transmissions stop for more than 60 minutes, ramp-up procedures must be repeated)
–During an experiment operations are suspended if divers or MM noted or suspected to be within appropriate safety range.
–If animal is on endangered species list (or is *Ziphius cavirostris*), safety range, as determined from acoustic propagation modelling just prior to the experiment, is automatically doubled.

THE FUTURE OF RESEARCH AT SACLANT UNDERSEA RESEARCH CENTRE

The Centre and NATO have continually increased its support to the MMRM programme. In 2003, there will be three cruises dedicated to this programme. In addition to the *Sirena* and *Zifio* sea trials, project scientists and technicians have been working to improve both the acoustic and visual data handling and analysis systems. The amount of data collected from the 128 hydrophone analog array, the data buoy, the WHOI Dtags, and by the visual team become a processing burden. The new processing systems will make the data collected during *Sirena 03* and subsequent cruises instantly available for analysis.

Early in 2002, the SOLMAR project and the LASW department established a Marine Mammal Crisis Action Team. After the Canary Island strandings in September of 2002 became known, the team followed the draft protocol and reacted in a timely manner to pass pertinent information to the Centre, and NATO authorities. Initial press reporting said that the stranding was caused by a NATO exercise. This turned out to be false, and quickly it was determined that the exercise was Spanish. Nevertheless, the MMRM programme responded to national requests for information. The Canaries strandings have heightened the sensitivity of many navies to the MMRM problem. NATO through the SACLANT Undersea Research Centre’s MMRM programme is advising and establishing joint research programmes with many European nations and the US.

HIGH FREQUENCY MARINE MAMMAL MONITORING ACTIVE SONAR SYSTEM

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INTRODUCTION Active sonar and other anthropogenic sound sources, operating with source levels up to 245 dB (re: 1 micro Pa @ 1 metre), have the potential to harass and/or injure marine mammals. These sources have legitimate uses including location of natural resources and geographic formations, charting of ocean features, and protection of commercial and military maritime assets. Until recently, there were only two methods utilised to ensure that marine mammals were not close enough to these sources to be injured—visual and passive acoustic monitoring. Obvious drawbacks exist with these methods—visual can only be optimally utilised during daylight hours and in relatively good weather and low sea state, and passive acoustics will only detect marine mammals when they are vocalising. What is needed is a 24-hour, all-weather mitigation method. One proven measure is the use of high-frequency sonar (similar to commonly used fish-finder sonars) to ensure that during operations, no marine mammals are within the volume of ocean where their received levels could potentially cause injury.

HIGH FREQUENCY MARINE MAMMAL MONITORING (HF/M3) SONAR The United States Navy developed the High Frequency Marine Mammal Monitoring (HF/M3) sonar system specifically to meet the marine mammal mitigation plan proposed for a new surveillance sonar (DON, 2001). The HF/M3 system is integral with the surveillance sonar, residing at the top of the vertical transmit array. The sonar utilises PC based processing and control and comprises primarily commercial off-the-shelf (COTS) components. The HF/M3 is an active sonar operating in the 30 – 40 kHz frequency range with a source level of 180 to 220 dB (re: 1 micro Pa @ 1 metre). The system utilises four independent transponders mounted on a rotating carousel. Each transponder consists of an omni-directional hydrophone located at the focal point of a parabolic reflector. Table 1 provides the system parameters. (Stein *et al.*, 2001a,b)

Table 1. HF/M3 sonar system parameters

Transmit Frequency	30 to 40 kHz
Nominal Source Level	Variable up to 220 dB re 1 μPa at 1 m
Pulse Length	10 to 40 msec (nominal)
Repetition Rate	3 to 4 sec (nominal)
SL Ramp-up Period	5 minutes
Vertical Beamwidth	10 degree
Horizontal Beamwidth	8 degree
Vertical Steering	± 10 degree
Azimuthal sweep period	45 to 60 seconds
Directivity Index (one-way)	21 dB at 30 kHz 23 dB at 35 kHz 25 dB at 40 kHz
Detection Processing	Matched-Filter, Range-dependent Thresholding

ANALYSIS AND TESTING The system has been tested in numerous field trials, as shown in the Table 2, where its ability to detect marine mammals of various size has been qualitatively verified (Ellison and Stein, 2001).

Table 2. HF/M3 sonar testing

Date	Testing	Location
October 1998	Performance testing of single source/receiver.	Seneca Lake, NY
April 1999	Performance testing using complete prototype.	Baja California
February 2000	Calibration of system.	Seneca Lake, NY
April 2000	Integration with sonar transmit array on R/V *Cory Chouest.* Engineering trials following installation.	Hawaii
May 2000	Performance testing (HF/M3 sonar only) on R/V *Cory Chouest.*	Hawaii
August 2000	Performance testing with controlled bottlenose dolphins.	Southern California
October 2000	Marine mammal mitigation trials.	Adriatic Sea

Analysis and testing of the HF/M3 sonar operating capabilities indicate that this system substantially increases the probability of detecting marine mammals that may pass close enough to the surveillance sonar transmit array to be potentially injured, and provides excellent monitoring capability (particularly for medium to large marine mammals) beyond this zone. Figure 1 shows the single-ping probabilities of the HF/M3 sonar detecting various marine mammals as a function of range. These curves are based on: 1) the *in situ* measured interference (i.e., backscattering and false targets that cause target-like echoes on the sonar) observed during at-sea testing; 2) the *in situ* measured transmission loss (TL) from at-sea testing; and 3) the best available scientific data on marine mammal target strength (i.e., the level at which a marine mammal "reflects" acoustic energy). The single-ping probabilities of detection shows only one facet of the effectiveness of the HF/M3 sonar as a mitigation tool because, in general, any marine mammal that enters the HF/M3 detection zone can be expected to be ensonified multiple times—approximately once every 50 seconds. (Ellison and Stein, 2001)

From Figure 1, it can be seen that for a 2.5-metre (8.2 ft) dolphin, Pd_1 (at 1,000 m/3,281 ft) = 43 percent. Using the formula $Pd_N = 1- (1 - Pd_1)^N$, where N = number of animal ensonifications and Pd_1 = the single-ping probability of detection, it can be seen that for two ensonifications, $Pd_2 = 1 - (.57)^2 = 1 - 0.32 = 68$ percent. For four ensonifications, probability of detection increases to 90 percent, and for five ensonifications, probability of detection approaches 100 percent. (DON, 2001; Ellison and Stein, 2001; Stein *et al.*, 2001a,b)

Probabilities of detection for a stationary whale of 20-metre (65.7-ft) length (e.g., a humpback) at various depths and ranges within the mitigation zone are estimated to be from 98 percent (animal at 1-km [0.54-nm] range and 160-metre [525-ft] depth) to 72 percent (animal at 2-km [1.08-nm] range and 160-metre [525-ft] depth). Outside of the mitigation zone, probability of detection for the same whale is estimated to be 95 percent (animal at 1.5-km [0.81-nm] range and 200-metre [656-ft] depth). Thus, an animal of this size approaching the mitigation zone from any direction would have an extremely high likelihood of being detected before entering the zone. (Ellison and Stein, 2001).

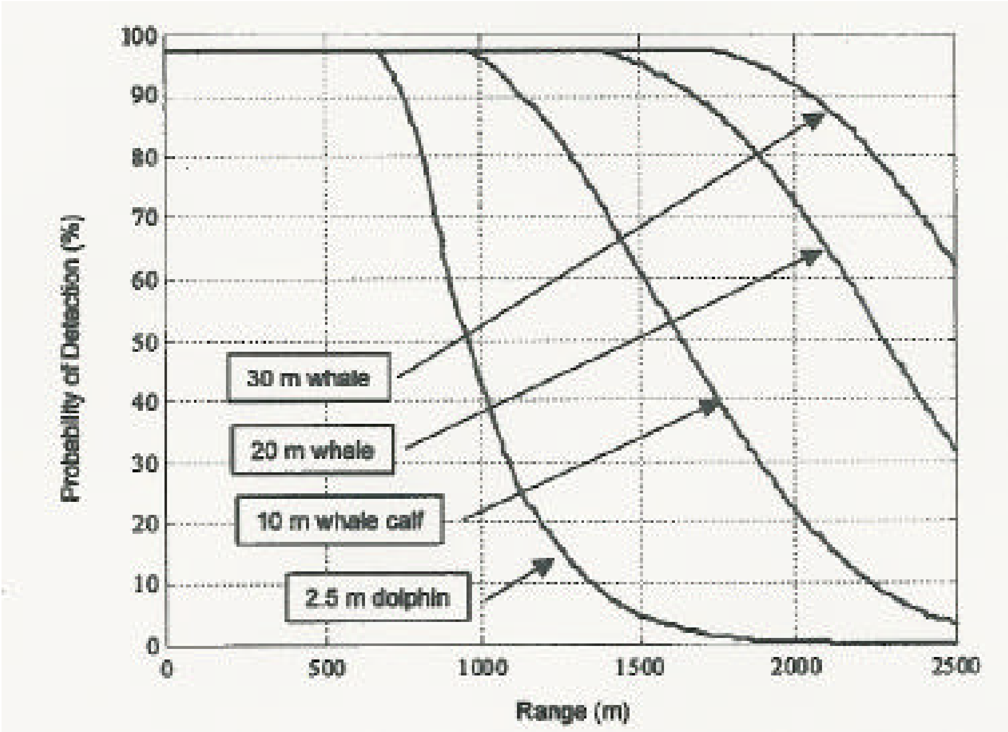

Fig. 1. Probability of detecting (on any given ping) various marine mammals swimming within the search beam of the HF/M3 sonar system

SUMMARY The United States Navy has successfully developed, tested and deployed a high frequency, active sonar system - the HF/M3 Sonar - for the detection of marine mammals, to provide mitigation for the operation of surveillance sonar onboard oceanic research vessels. Aside from its uses as a mitigation measure for active sources, there are ongoing efforts to adapt the HF/M3 sonar for various uses to localise and identify marine mammals in their environment, including whale collision avoidance and use in stock surveys, especially to track and census whales that are underwater.

ACKNOWLEDGEMENTS I wish to thank Dr. Peter Stein of Scientific Solutions Inc. and Dr. William Ellison of Marine Acoustics Inc. for the design, development and successful testing of the HF/M3 sonar.

REFERENCES

Department of the Navy (DON), 2001. *Final Overseas Environmental Impact Statement and Environmental Impact Statement for Surveillance Towed Array Sensor System Low Frequency Active (SURTASS LFA) Sonar*. Chief of Naval Operations. Washington DC. January 2001.

Ellison, W.T., and P.J. Stein. 2001. *SURTASS LFA High Frequency Marine Mammal Monitoring (HF/M3) Sonar: System Description and Test & Evaluation*. Marine Acoustics Inc. and Scientific Solutions Inc.

Stein, P.J., W.T. Ellison, and J.S. Johnson, 2001a. *High Frequency Marine Mammal Mitigation Active Sonar System*, Proceedings of the Oceans 2001 MTS/IEEE Meeting, Honolulu, HI. November 2001.

Stein, P., J. Rudzinsky, M. Birmann, W. Ellison, and J. Johnson. 2001b. *High Frequency Marine Mammal Mitigation Active Sonar System*. Acoustical Society of America Meeting 3-6 Dec 2001. Fort Lauderdale, FL.

MITIGATION MEASURES FOR USE WITH MILITARY SONAR

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I have been asked to address the question of mitigation measures, but one should note that these are generally untested recommendations. There is no history of any navy using these measures and collecting data to show whether they work.

I begin by assuming that the best form of mitigation, doing away with military sonars altogether, is not a viable option. As long as there are hostile nations with submarines, sonar will be used to find them. And some of the areas in which they practice will undoubtedly be beaked whale habitat. It seems unfortunate to me that we now have to balance beaked whale conservation against any other consideration, but this seems to be the world we live in.

Aside from abolishing sonar, the second best option is to operate them with mitigation measures to minimise the harm done to marine mammals. This compromise is probably the best we can do at present.

I will focus my remarks on mitigation for mid-frequency, tactical sonar of the type that was in operation at the time of the Bahamas, Madeira, and Canary Islands beaked whale strandings. These sonars operate at 2-10 kHz with source levels of 235 dB or greater. This technology was introduced 30 years ago and is now used by most navies of the world. They are usually operated with minimal or no mitigation measures, irrespective of the environment in which they are used. Increasingly, this environment involves near-shore areas.

It is premature to suggest mitigation measures for low frequency sonars as a class. Low frequency sonar (100-500 Hz) is either experimental or not yet fully operational in world navies. No known marine mammal strandings have been associated with it, it does not operate near-shore, and the most advanced system, that of the U.S. Navy, uses very good mitigation measures. The problem we know enough about to resolve is mid-frequency sonar and beaked whales.

My recommendation for mitigation measures comes largely from a list that appeared in the "Joint Interim Report of the Bahamas Marine Mammal Stranding, December 2001". Cdr. Paul Stewart of the US Navy and I edited this report and we devised the mitigation measures it contains.

I have paraphrased those measures here to make them more generic. To this list I will add one suggestion that comes from the mitigation measures being used on the US Navy's low frequency sonar. I will conclude by mentioning some of the research that is needed to develop new mitigation measures in the future.

MITIGATION MEASURES FOR SONAR

- The most obvious mitigation measure is to avoid areas where beaked whales are known to concentrate, or to avoid them in the seasons when whales are present. Military sonar exercises are held where submarines could lie in wait for surface ships while being concealed from detection by an acoustically complex environment. Deep, submarine canyons with steep walls are ideal for these so-called "chokepoint" exercises. Unfortunately, such places are often ideal for beaked whales as well. Navies should survey each canyon for beaked whales immediately before each exercise begins. The military could sponsor marine mammal surveys of all chokepoints to be used for sonar operations to determine whether and at what seasons they contain beaked whales.

- The second mitigation measure is to plan sonar operations so as to avoid the confluence of factors, other than beaked whales and submarine canyons that was believed to have contributed to the Bahamas stranding. These include surface ducts that trap sonar signals near the surface, and the use of multiple sonars. Surface ducts tend to form in winter. No one is yet certain of the extent to which they contribute to stranding events. But for now they can generally be predicted so they should be avoided. In terms of sonar, often an SQS-53C sonar is used in combination with an SQS-56 sonar (called a DE 1160 in Europe), and the two sonars ping alternately as often as every 15 seconds, sometimes for hours on end. Multiple pairs of 53C's and 56's may be used in an operation. Planners should avoid this set of factors (that is, beaked whales, submarine canyons, surface ducts, and multiple sonars) until the actual route of tissue damage is known. At that point the mitigation measures could become more sharply focused.

- The following mitigation measures are applied at the scene of an operation. Ships should establish safety zones around the sonars and be prepared to shut down the sonar if animals are detected breaching them. In the near term, navies should use visual observers and passive acoustic detection to locate animals.

- Visual observers and passive acoustic detection both fail to detect all submerged animals. Navies do not yet have, but need to develop, a foolproof method of detecting animals. High frequency sonar is the most promising technology for this purpose. I will return to this point below.

- After a sonar operation has ended, navies need to always conduct surveys for injured animals. These surveys are essential because unless we systematically look for injured animals we will never know which mitigation measures work, and which do not but only seem plausible.

Ramp up, or soft start, which is used as a mitigation measure with airgun arrays, would be of questionable value with sonar operations. In the Bahamas event, and probably others, beaked whales could have heard sonars approaching from a great distance and the increasing received levels would have had the same effect as a ramp up procedure. Nevertheless, animals stranded and some died, suggesting that whales did not vacate the area, which is the purpose of ramp up.

I now come back to the subject of whale-finding sonar, the mitigation measure of the future as I see it. Two different research groups in the U.S. are developing high frequency, low power sonars. They are similar to fish finders except that they look horizontally as well as downward. These sonars have a limited detection range (about 2 km) because the high frequencies they use (20 to 50 kHz) do not propagate well. Their source levels are low (210 dB re 1 micro Pascal) and their pings are brief (40 milliseconds), so the total acoustic energy they produce is too small to cause injury. Any behavioural avoidance they cause among marine mammals is local because of the limited propagation range.

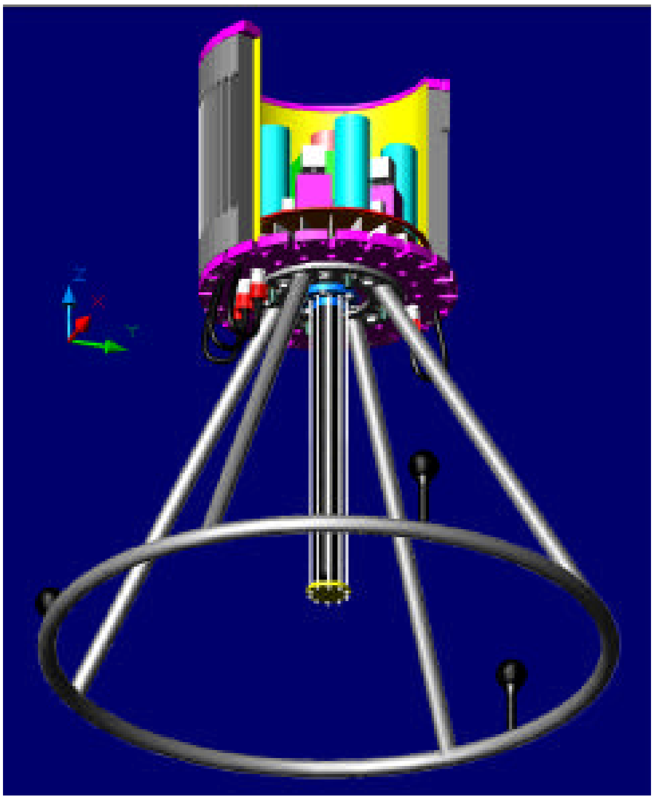
This high frequency sonar, called IMAPS, is a prototype being developed by Scientific Solutions, Inc. It looks both down and horizontally in 360 degrees, and produces a new image every four seconds (Fig. 1). At the time of writing, it had not yet been field tested. The same company made the High Frequency Marine Mammal Monitoring sonar (HFM3) that the U.S. Navy uses as a mitigation measure for its low frequency sonar. In field trials, the HFM3 detected dolphins with great success out to about 2 km. It has been used in operations since early 2003, but no report of its success rate is yet available. HFM3 and IMAPS are alike in signal characteristics but they differ in the way they scan; HFM3 is mechanically steered whereas IMAPS is a phased array (no moving parts). A group at the University of Rhode Island is also developing a high frequency sonar, but I have no current information about it.

Some new method will have to be devised to use high frequency sonar as a mitigation measure for mid-frequency sonar. The main problem is that the ships that carry mid-frequency sonar operate at very great speed, possibly too fast for them to detect whales and react appropriately. A separate survey ship might be needed to scan the operation area beforehand. Clearly research is still needed. But high frequency sonar is the most promising new mitigation tool in a decade, so the effort would be worthwhile.

The mitigation measures I have discussed are fairly generic because we still do not know the mechanism by which beaked whales are affected by mid-frequency military sonar. We do not know which part of the acoustic signal causes the problem, or whether it acts through whale behaviour, physiology, or tissue trauma. Once the mechanism is known it may be possible to manipulate just the implicated variables. Some of the variables occur at the level of the whole operation, such as the number of sonars used, frequency with which pairs ping, and the duration of pinging. Other variables deal with the characteristics of individual sonars, such as source level, rise time, and frequency composition. Until we know the causative mechanism, planners should reduce their total acoustic output to the very minimum that is required to accomplish their mission goals.

We are only beginning to devise effective mitigation measures for navy sonars. As our knowledge increases, we will undoubtedly abandon old mitigation measures and develop new ones. For this process to take place, scientists need to work co-operatively with navies to devise, implement, and evaluate the efficacy of mitigation measures. Navies generally lack the skills to do this on their own.

I began my presentation by stating that we scientists must recognise that the twin needs of beaked whale conservation and national defence must be balanced. I want to close by saying that navies must recognise this same fact and begin to plan their sonar exercises accordingly.



Features

- 20-40 kHz, Max R of 2.5km
- 60 Receivers, electronically steered
- Source level up to 210 dB re µPa @ 1m

Benefits

- Enhanced tracking
- Integrated low-frequency passive detection capability

Fig. 1. IMAPS Integrated Marine mammal Monitoring and Protection System

INSIGHTS INTO THE DETERMINATION OF BEAKED WHALE 'HOTSPOTS' THROUGH THE DEVELOPMENT OF A GLOBAL DATABASE

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INTRODUCTION Beaked whales are the second largest family of the order Cetacea (the whales, dolphins and porpoises) with 21 currently recognised species, and they form one of the three major evolutionary lineages of the sub-order Odontoceti, the toothed whales. One of the biggest problems faced in trying to understand and mitigate potential impacts from human activities on beaked whales is the lack of knowledge about their biology. For this reason, applying traditional approaches to the conservation of large mammals, such as monitoring population sizes or identifying and mitigating specific threats, is problematic. Therefore, it is suggested that such traditional approaches should be augmented by an additional approach, the identification of beaked whale 'hotspots'. The 'hotspot' concept was originally developed to aid in the conservation of terrestrial areas with high levels of biodiversity that are threatened by human activities, and has been used to identify a number of areas of conservation importance around the world based on set criteria (Myers, 1988, 1990). Here, the 'hotspot' concept has been adapted and applied to the problem of beaked whale conservation. Five criteria were used to designate an area as a beaked whale 'hotspot'. The first four of these criteria were based on aspects of beaked whale ecology such as occurrence, distribution and diversity, while the fifth was based on evidence of past interactions between humans and beaked whales. The criteria were:

A. Areas where one, or more, beaked whale species have been regularly recorded at sea.
B. Areas which are used during movements between two or more key areas defined in criteria A.
C. Areas with a high diversity of beaked whales species.
D. Relatively small areas which cover a large portion, or all, of the known range of an individual species or isolated population.
E. Areas where human activities are known to have had an impact on beaked whales in the past.

METHODOLOGY Records on beaked whale occurrence were located from a number of sources including unpublished reports, published sources, unpublished datasets, contacts with local research groups, and privately held records. These records were collated into a single database using a common format and locations for specific records were plotted using ArcView 3.2 GIS software. Data were quality controlled for potential errors such as wrongly entered positions (e.g. sightings which plotted on land, or strandings in the middle of oceans), conflicting information within specific records (e.g. strandings records where measurements greatly exceeded known species maximums), and questionable species identification (e.g. claims of species identity from photographs which did not display recognisable and species unique field marks). If data could not be corrected after the original sources were re-checked, the records were removed from the database and were not used in the subsequent analysis. After the quality control procedure, data were re-plotted and checked against the five criteria above to identify 'hotspot' areas. Finally, the identified 'hotspots' were compared with published and unpublished sources which described additional information about beaked whales in specific areas, but which lacked information about locations of specific beaked whale records. This was done in order to provide further support for identified 'hotspots' and to check that additional 'hotspots' had not been missed. This resulted in a final list of beaked whale 'hotspots', which could be identified based on currently available data.

RESULTS AND DISCUSSION Twenty-two areas were identified from the collated data, which could be designated as beaked whale 'hotspots' based on the above criteria (Table 1). These 'hotspots' range from relatively small and discrete geographic areas, such as the Gully of Nova Scotia, to large regions, such as the Southern Ocean and Antarctica and general diffuse areas such as New Zealand. These differences reflect two factors. First, it reflects the different scales at which research into beaked whales has been conducted in different areas. In the Gully, research has been specifically targeted at studying northern bottlenose whales, the main species found there, while in the Southern Ocean and Antarctica, most data comes from ocean-wide surveys undertaken to calculate the abundance of minke whales within the area. Furthermore, some 'hotspots' are based upon strandings data. Strandings data at best provide only a low resolution view of patterns in beaked whale occurrence. This is due to the fact that animals can travel long distances before stranding, meaning that such data can only be used to identify general areas of occurrence rather than specific locations. Secondly, it reflects differences in beaked whale distribution at different scales and in different oceans. For example, on a broad scale, there is a high abundance of beaked whales throughout the Southern Ocean and Antarctica, whereas, in other locations, beaked whale distribution is related to fine-scale factors with relatively low occurrence outside key areas. For example, in one part of the north-eastern Bahamas, beaked whale distribution is closely tied to the presence of a marine canyon, and few groups are encountered away from this specific location. Further data are required to investigate whether within broad-scale areas there are specific fine-scale localities which beaked whales preferentially utilise within them, and whether such fine-scale areas are part of larger networks of areas of high beaked whale abundance which cover broader scale areas.

Although the definition and identification of beaked whale 'hotspots' will provide a useful tool in assessing and mitigating potential human impacts on beaked whales, it will prove most useful when used in conjunction with a multi-strategy, multi-disciplinary approach to the problems associated with beaked whale conservation. Firstly, the marine environment is a dynamic system with major changes over time. This is less of a problem in terrestrial ecosystems, where large changes in environmental conditions may take decades or centuries to occur rather than over a few years or less, as can occur in marine systems. Therefore, it is possible that 'hotspots' may not be static entities. This will be particularly true of 'hotspots' that cover relatively small areas and are based on fine-scale data, where small geographical shifts in oceanographic condition could result in beaked whales shifting their distribution out of delimited 'hotspots'. This will be less of a problem for larger 'hotspots' where major, region-wide changes in oceanographic conditions would be required to change beaked whale distribution throughout the entire 'hotspot' area. Therefore, 'hotspot' areas need to be monitored for changes in beaked whale distribution, and new or altered patterns of occurrence identified.

Secondly, known human impacts on beaked whales need to be investigated to determine what specific mitigation strategies should be implemented to reduce impacts in 'hotspot' areas. In some cases, such as mass strandings associated with the use of military sonars, it may first be necessary to identify the exact mechanisms behind these impacts before this can be done. This may only be possible if many currently isolated disciplines work together.

Thirdly, the 'hotspots' identified here are only those which can be identified based on the currently available information. It is almost certain that with further research, more areas will be found which fulfil the 'hotspot' criteria. To highlight this, if a similar analysis had been conducted a decade ago based on the data which were available at the time, only eight of these twenty-two 'hotspots' could have been identified. There are two ways which further 'hotspots' can be identified: First, by undertaking dedicated research projects and surveys. Many areas of the world (e.g. eastern tropical Atlantic and South Atlantic) remain unsurveyed for the presence of beaked whale populations or diversity. However, this is very much a long-term measure and will take many years as well as being logistically expensive and difficult. The second method is to use currently available data on the relationship between beaked whale occurrence and oceanographic variables to predict distribution in areas where there is little available information. This is something which can be done in the short-term and has two benefits: The identification of potential beaked whale 'hotspots', where a precautionary approach to reducing human impacts on beaked whales can be used, and the highlighting of areas where beaked whales may occur which can be targeted by researchers to increase our knowledge of their ecology, which, in turn, will improve our abilities to understand and conserve beaked whales.

REFERENCES

Myers, N. 1988. Threatened biotoas: "hot spots" in tropical forests. *The Environmentalist*, 8: 187–208.

Myers, N. 1990. The biodiversity challenge: expanded hot-spots analysis. *The Environmentalist*, 10: 243–256.

Table 1. 'Hotspots' for beaked whales identified using the five criteria outlined in this study

Area in Figure 1	Criteria					Specific Locations Known to be of Importance in Area (Criteria)
	A	B	C	D	E	
1. Atlantic Frontier	Yes	Yes				Northern end of the Rockall Trough, particularly around the eastern end of the Wyville-Thompson Ridge, approximately 59.4°N 007.9°W (A), and the Faroes-Shetland Channel, centred at approximately 61.7°N 003.0°W (A, B).
2. The Bay of Biscay	Yes		Yes			Southern Bay of Biscay around Santander Canyon and long continental shelf edge (A)
3. The Ligurian Sea	Yes					
4. Southern Greece	Yes				Yes	
5. The Azores	Yes		Yes	Yes		Around the island of Pica (A)
6. The Canaries	Yes		Yes		Yes	South of La Gomera (A), south-west of Tenerife between 28.3°N 16.9°W and 28.1°N 16.8°W (A), Fuertoventura and Lanzarote (E)
7. The Gully, Nova Scotia	Yes			Yes		43.5°N to 44.5°N and 058.5°W to 060.0°W (A,D)
8. North-eastern North America Continental Shelf Margins	Yes		Yes			
9. Northern Bahamas	Yes				Yes	Little Abaco Canyon, centred at approximately 26.6°N, 076.9°W (A), southern edge of Little Bahama Bank from 26.6°N 078.5°W to 25.9°N 077.3°W (E).
10. Northern Gulf of Mexico Continental Shelf Margins	Yes					25.9° to 27.6°N and 96.0° to 90.8°W (A), a area bordered by the following co-ordinates: 26.6°N 90.0°W; 27.0°N 90.4°W; 27.7°N 90.6°W; 28.0°N 90.6°W; 29.2°N 87.4°W 28.9°N 87.1°W; 27.7°N 88.0°W (A).
11: Californian Shelf Margins, U.S.A.			Yes	Yes		Waters from 32.9° to 36.6°N (D)
12. Hawaii	Yes					
13. Eastern Tropical Pacific	Yes		Yes			
14. Galapagos	Yes					
15. Maldives	Yes					
16. Japan	Yes	Yes	Yes			
17. The Cook Islands	Md					
18. The Falkland Islands and Tierra del Fuego	Yes		Yes			
19. Indian Ocean Around South Africa	Yes		Yes	Yes		
20. Tasmania and South-western Australia			Yes	Yes		
21. New Zealand			Yes			
22. Southern Oceans and Antarctic Waters	Yes					Antarctic Peninsula from 65.2°S, 066.2°W to 70.3°N, 094.6°W (A).

CONCLUDING REMARKS

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Attention was first drawn to the possible link between the mass stranding of certain cetacean species and military activities in the 1990s, with beaked whale strandings in the Canary Islands (Simmonds, M.P. and L.F. Lopez-Jurado), and in Greece (Frantzis, 1998). Unfortunately, in those cases, there were no opportunities for post-mortem examinations, although as presented here by Alexandros Frantzis for the Greek stranding, the coincidental nature of the incident strongly suggested a relationship. Since then, opportunities for pathological studies have presented themselves at subsequent strandings in the Bahamas (March 2000), Madeira (May 2000), and the Canaries (September 2002). The nature of those events are described here by Luis Freitas, Teri Rowles, and Vidal Martin respectively, with the accompanying pathologies reviewed by Darlene Ketten (Bahamas & Madeira) and Antonio Fernández (Canaries).

The results of post mortem examinations of mass stranded cetaceans, immediately following naval activities using mid-frequency long-range tactical sonar, provide compelling evidence that acoustic trauma from those activities, or at least injuries stimulated by behavioural responses to them, has in some way led to their deaths. Deep-diving medium-sized odontocetes particularly of the family Ziphiidae appear to be the most susceptible, with Cuvier's beaked whale *Ziphius cavirostris* making up more than three-quarters (36/47 animals specifically identified) of the total number of animals recorded stranding in four major incidents (May 1996 – September 2002). Other species for which the military manoeuvres were directly implicated in their deaths have included Blainville's beaked whale *Mesoplodon densirostris* and Gervais' beaked whale *Mesoplodon europaeus*, whilst two minke whales *Balaenoptera acutorostrata* live-stranded in the Bahamas but were successfully re-floated. Previous cetacean mass strandings in the Canaries that were coincident with naval activities included also northern bottlenose whale *Hyperoodon ampullatus* and pygmy sperm whale *Kogia breviceps*. The unusual occurrence of the live stranding of two minke whales raises the possibility that under certain circumstances baleen whales may also be affected.

There was general agreement from all sides on the wish and need for more co-operation between biologists and navies. This can be expressed in two major ways: 1) data transfer between the two parties; and 2) the inclusion of biologists in planning those naval operations where a potential risk exists. Data transfer should be: a) from the navy to biologists – detailed information on protocols adopted at a particular manoeuvre involving active sonar (and the specific tactics being employed, since these vary depending on whether the vessels are involved in detection, tracking, or some other mode), locations, dates, depth and local bathymetry, directionality or direction of the source, and source levels, ping rates, numbers of ships pinging simultaneously, and the total duration over which that ping rate was used, the spectrum of transmissions used (for example are lower frequencies also used that might cause vestibular problems for whales?) as well other sound characteristics; and b) from biologists to the navy – autopsy results, strandings data, data on distribution and abundance, results of tracking to better understand behaviour, and proposals for "experiments" or procedures which may elucidate some of the factors involved. The involvement of biologists as observers in specific naval operations can help avoid unintentional exposure and may help provide information on the behaviour of animals in the area, with acoustic and visual monitoring before, during, and after exposure. The possibility for controlled exposure experiments such as those described by Peter Tyack and Mark Johnson should also be explored further, as well as “in situ” studies of whale hearing, including auditory brainstem response studies as described by Paul Nachtigall and Alexander Supin.

The pathological studies conducted upon beaked whales at three of the four mass strandings all showed widespread haemorrhaging, affecting several organs, but with the micro circulatory systems particularly affected. Head and ear traumas were commonly found, whilst haemorrhaging in the eyes was observed in some specimens from Madeira and the Canaries. It is not known whether such haemorrhaging occurs as a direct response to sonar exposure or subsequently during the beaching process. The presence of fat (and possible gas) emboli associated with haemorrhages and other lesions in all of the beaked whales examined in the Canaries by Antonio Fernandez and presented for the first time in this workshop opens up the possibility that a condition similar to decompression sickness (DCS) may have occurred. Although the lesions in the Canaries-stranded beaked whales are not conclusive proof of a DCS-like condition, they raise the possibility that acoustic exposure can induce physiological damage by a behavioural response (e.g. accelerated ascent rates) to the loud sounds rather than direct acoustic trauma. Another theoretical possibility is that *in vivo* bubble formation in these animals may have been driven by a physical effect of loud sound exposure on bubble precursors by a process such as rectified diffusion (Crum and Mao, 1996; Houser *et al.*, 2001). Although cetaceans have long been thought to be highly resistant or immune to in vivo bubble formation or DCS, gas bubbles and associated acute and chronic lesions have recently been reported in a small number of stranded animals (three Risso's dolphins, three common dolphins, one Blainville's beaked whale, and one harbour porpoise) examined in the UK over the period October 1992 - January 2003 (Jepson *et al*. 2003).

Clearly there is a need to resolve whether in particular situations, deep-diving whales do actually experience a decompression-like sickness either by too rapid vertical movements in an attempt to escape noise within a sound channel, or by other possible mechanisms, or whether there is a direct pathway by which fat embolisms occur. Alternatively, hair cell damage from previous exposure to loud sounds may further cause disorientation and panic.

Factors influencing the level of sound received by a whale need further elucidation. Presently, emphasis is placed on received levels measured in decibels re 1 micropascal and source levels measured at 1 metre range. However, as Bertel Møhl’s contribution demonstrates, overall energy (expressed as dB re 1 μPa^2 s) may be a better measure or guide for possible acoustic damage, and should be taken alongside peak pressure measurements. Contributions from Ed Harland and Walter Zimmer highlight a number of potential variables. It is likely that animals at different ranges from the source will be exposed in different ways. Sound may be trapped within channels in the water column and there is a need to better understand the physical characteristics of the local marine environment in these situations. The omni-directional nature of the active sonar source and inter-pulse interval also influence received levels. Features such as its rise time and frequency composition must also be considered. If whales are endangered by active sonar largely through a behavioural response at depths, then a simple mitigation measure for reducing received levels is to reduce the duty cycle of the sonar. In this context, the behaviour of animals during exposure clearly needs further investigation. A number of the sonar exercises have taken place at night and animals have been reported coming ashore early in the morning. Questions that need to be addressed include whether whales are mainly foraging at particular depths during those activities, and if a sound channel is present, do they behave differently when exposed to the sound if they are below it, within it or above it. This is where the controlled exposure experiments described by Peter Tyack and Mark Johnson are likely to be especially valuable.

An important question that has yet to be answered fully is why should beaked whales apparently be specially vulnerable to active sonar. Is their hearing particularly sensitive to sounds within the frequency range 2-8 kHz? The anatomical studies by Darlene Ketten and co-workers suggest that beaked whales may have a hyper-responsive vestibular system, particularly for lower frequency signals. At present, no audiogram exists for any beaked whale species, and it would be very valuable to undertake an auditory brainstem response study upon a species like Cuvier's beaked whale as described by Paul Nachtigall. Alongside such approaches should be further examination of the head and ear anatomy of beaked whales in relation to other taxa. Work in this direction using CT scans and computer modelling has already been started by Ted Cranford and colleagues (see Cranford *et al*., 2003). Likewise, if sonar signals are eliciting a behavioural response that has repercussions on the formation of fat emboli, then that might explain why deep-diving species such as beaked whales appear to be particularly affected.

It would be unrealistic to expect the world's navies to suspend all military activities involving all use of active sonar. There is an urgent need for research to identify risk factors for beaked whales. This may extend beyond military sonars - the stranding of beaked whales coincident with operation of airguns used for seismic operations (Malakoff, 2002) highlights the need to determine what acoustic exposures are dangerous for beaked whales. Ideally in the long run, this can be used to modify sonars to ensure that sounds produced by humans in the sea pose little or no risk to beaked whales. In the interim, the best approach will be to develop effective mitigation measures. The first obvious one is to try to identify areas for sonar testing far from beaked whales. At the same time, it is important to identify beaked whale habitats and to ensure that sound producers are informed to avoid projecting intense sounds in those areas. Unfortunately, beaked whale distribution and abundance is poorly known, and although we can identify some apparent "hot-spots" (as indicated in Colin Macleod's contribution), there are many parts of the world where information currently is almost entirely lacking. Furthermore, it is likely that the needs of the military will coincide with those of beaked whales - deep submarine canyons with steep walls are favoured by the military for sonar exercises because these are where submarines are better able to conceal themselves, but they also may form suitable habitat for deep-diving beaked whales.

In their reviews of mitigation measures, both Roger Gentry and Mike Carron highlight the need for preliminary surveys of an area before it is used for sonar exercises. Beaked whales spend a large part of their lives away from the surface at depth and so acoustic methods for detection become all the more important. However, so far, beaked whales have proved difficult to routinely detect acoustically. In this context, the wideband passive monitoring approaches being developed by Gianni Pavan and co-workers show promise. Nevertheless, there will always be limitations for those situations when beaked whales are acoustically silent. And here we come to a potential solution that is not so far removed from the problem itself – the use of high-frequency active sonar for whale finding prior to the use of medium-frequency active sonar for submarine finding. Both Joseph Johnson and Roger Gentry describe prototypes that are currently being developed in the United States. The energy source is relatively low power thus minimising potential harm to the whales, whilst maintaining a detection range (1-2 km) that potentially is adequate for effective monitoring. Field-testing under a variety of conditions is now required. Whale-finding sonar needs to be deployed from a slow moving vessel and so will likely require a separate ship for ongoing surveillance, rather than those ones used directly in the military activities.

Research is clearly needed on several different fronts, and for this we come back to the critical need for active co-operation between scientists from a range of disciplines and navies, with appropriate resources made available by governments if we are to achieve our objective of conserving biodiversity, and minimising any harm for living creatures of the marine environment.

REFERENCES

Cranford, T.W., Hock, M., McKenna, M., Wiggins, S., Shadwick, R., Sauter, A., Armsworthy, G., Krysl, P. and Hildebrand, J. 2003. Building an acoustic model of a Cuvier's beaked whale (*Ziphius cavirostris*). P. 23. In: *Conference Guide and Abstracts*, 17th Conference of the European Cetacean Society, Las Palmas de Gran Canaria, 9-13 March 2003. 285pp.

Crum, L. and Mao, Y. 1996. Acoustically enhanced bubble growth at low frequencies and its implications for human diver and marine mammal safety. *Journal of the Acoustical Society of America*, 99: 2898-2907.

Frantzis, A. 1998. Does acoustic testing strand whales? *Nature* (Lond.), 329: 29.

Houser, D.S., Howard, R and Ridgway, S. 2001. Can diving-induced tissue nitrogen supersaturation increase the chance of acoustically driven bubble growth in marine mammals? *Journal of Theoretical Biology*, 213: 183-195.

Jepson, P.D., Arbelo, M., Deaville, R., Patterson, I.A.P., Castro, P., Baker, J.R., Degollada, E., Ross, H.M., Herráez, Pocknell, A.M., Rodriquez, F., Howie, F.E., Espinosa, A., Reid, R.J., Jabert, J.R., Martin, V., Cunningham, A.A., and Fernández, A. 2003. Gas-bubble lesions in stranded cetaceans. *Nature* (Lond.), 425: 575-576.

Malakoff, D. 2002. Suit ties whale deaths to research cruise. *Science*, 298: 722-723.

Simmonds, M.P. and Lopez-Jurado, L.F. 1991. Whales and the Military. *Nature* (Lond.), 51: 448.

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