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The Irish Whale and Dolphin Group

The impact of Multibeam on cetaceans: A review of best practice

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Introduction

The National Parks and Wildlife Service invited the Irish Whale and Dolphin Group (IWDG) to a meeting to discuss the impacts of multibeam sonar on cetaceans. In order to aid discussions, the IWDG carried out a literature and web review of the impacts of multibeam on marine mammals and best practice for mitigation.

The Bathymetric Multibeam Echosounder - SIMRAD EM1002

The state research vessels RV Celtic Explorer and RV Celtic Voyager currently operate the SIMRAD EM1002 multibeam sonar. Bathymetric Sonar EM1002 is a compact, high resolution, multibeam echo sounder that operates at a frequency of 92 to 98 KHz. Multibeam echosounders seep the seabed and the area of esonification is a function of swath width to depth. Swath width is defined by a number of factors including beam angle and depth of water. The vertical resolution of a multibeam echosounder is determined by the pulse length, and the pulse length corresponds with bandwidth in the frequency domain. The SIMRAD EM1002 system operates with one of three different pulse lengths: 0.2, 0.7 and 2 ms. Maximum ping rate is 10/sec (in shallow water) with the ping rate decreasing with increasing water depth. Maximum output using long pulses in 800m water depth is 226 dB re 1 micro Pa.

Multibeam surveys have a footprint on the seabed of up to 7.4 times the water depth and to a width of 1.5º. Such a system, mapping in 1000m of water, would ensonify a moving area 7.4 km by 50m. Multibeam surveys typically work in parallel tracks with some overlap between swaths and move at speeds of up to 12 knots. At this speed, a point 1000m away from the ship would experience sound levels >50% beam strength for <10 seconds.

Table 1. Sound exposure produced by a SIMRAD EM1002 Multibeam (echosounder hull-mounted).

Source	Sound pressure level (dB re 1µPa@1m)	Ping Energy (dB re 1µPa^2*s)	Ping Duration (ms)	Duty Cycle (%)	Peak Freq. (kHz)	Band Width	Directionality
Multibeam	235	218	20	0.4	12	Narrow	Vertical

Multibeam systems generally operate with frequencies above 12kHz with deep water systems below 20kHz. Source levels for the deep water systems are quoted as maximums of 236-238 db re 1 dB re 1 micro Pa. Systems for shallower water are both higher frequency and lower power, down to small systems deployed on launches.

Possible and potential impact of sonar on cetaceans

Sound travels 4.5 times faster in water than in air and low frequency sounds travel farther underwater than high frequency sounds. Multibeam can be defined as Low frequency (<1 kHz), Mid frequency (1-10 kHz) and High Frequency (>10 kHz). The hearing ranges of marine mammals differ from one species to another. Each species has different characteristics and ranges of perception of sound frequencies. The sensitivity of marine mammals depends on their specific audiogram. For example, harbour porpoises are sensitive from 3 kHz to 130 kHz, with peak sensitivity at 125-130 kHz, and bottlenose dolphins from 5-110 kHz, with peak sensitivity at 5 kHz. Common seals are sensitive 4-45 kHz (peak sensitivity at 32 kHz) and grey seals 8-40 kHz. Humans are sensitive only to around 16-18kHz.

High intensity, low and mid-frequency sonar has been implicated in some fatal strandings (Frantiz, 1998). There are many potential impacts of acoustics on cetaceans but most are very difficult to monitor (Table 2).

Table 2: Potential detectable and non-detectable effects of acoustic impacts on cetaceans.

Detectable Effects	Non-Detectable Effects
Respiration rate, Swim speed, Vocalisations, Dive times, Dive depth, Residence time Distribution, Movement relative to sound source	Miscarriage; Birth defects; Changes in mating dynamics; Death rate; Injury; disease; morbidity; Vulnerability to hazards; shipping; fishing nets; Vulnerability to predation; Feeding rate and changes in appetite; Changes in echolocation and navigational abilities; Change in group bonds and coordination (both within and between groups); Change in mother calf bonds; Annoyance; pain; panic; confusion; anxiety and stress; Change in metabolic rate; Lung-gas interface; Change in susceptibility to the "bends"; Cavitation; Tissue shearing due to radiation pressure; Deafness and hearing impairment (temporary or permanent); Change in stranding rates; Changes in population (long term).

Potential impacts on marine mammals may range from physical damage, including temporary and permanent threshold shift (deafness), to perceptual (masking biologically significant noises) and behavioural impacts (temporary or permanent displacement and stress) as well as indirect effects (reduced prey availability). Gordon *et al*. (1998) listed a hierarchy of potential impacts from direct injury to indirect affects:

Physical: Including damage to body tissues, gross damage to ears. Auditory threshold shifts including temporary (TTS) and permanent (PTS). Indirect physical damage can be caused by sound-induced growth of bubbles in body tissues (the 'bends') but this tends to preferentially affect deep diving species.

Perceptual: If the frequencies produced by the sound source overlap with frequencies used for echo-location or communication there is potential for interference and masking of these biologically significant noises.

Behavioural: The greatest potential impact on marine mammals from acoustic surveys is on their behaviour. Displacement of individuals from their preferred feeding, breeding or resting areas may occur. If the impact is great this displacement may be long term or permanent.

Chronic effects: Stress induces physiological effects (increased heart and respiratory rate).

Indirect: These include damage or displacement of prey species and other essential aspects of the life history of marine mammals.

SCAR (2002) recommended a method of assessing the potential risk of acoustic surveys to marine mammals by asking questions and constructing a risk matrix. Questions that should be addressed include:

- Can the equipment physically kill or injure an animal and if so at what range?
- Can the equipment damage an animals hearing and if so over what range?
- Does the use of the equipment affect animal behaviour and over what area?
- Does the behavioural disturbance constitute a threat to populations by changing behaviour at critical times and in critical areas?
- Will a survey affect large numbers of animals, a small important group of animals or will the area be free of most species during the survey?
- Will a survey affect prey species in a way that will increase or decrease their availability to predators?

- What proportion of an area used by animals is affected by the survey?

In practice it can be very difficult to assess the risk of injury as there has been little research carried out to answer these questions directly and most literature available is based on effects on humans.

Auditory thresholds

The best reviews available on auditory thresholds and acoustic surveys were found in Richardson *et al.* (1995), Keevin and Hempen (1997) and Gordon *et al*. (1998). Examples from some of the research findings are presented. This selection is not exhaustive. Conclusions on auditory thresholds resulting in auditory damage in marine mammals are highly speculative due to lack of data.

Crum and Mayo (1996) calculated that exposure of humans or marine mammals to 500 Hz sounds at sound pressure levels of 210 dB re.1 µPa could cause bubble growth to occur and they suggest that this could theoretically induce the ‘bends’ in marine mammals. They considered that this effect was unlikely at sound pressure levels below 190 dB re. 1 µPa. Exposure to noise of sufficiently high intensity causes a reduction in hearing sensitivity. This can be a temporary threshold shift, with recovery after minutes or hours, or a permanent threshold shift with no recovery. Schlundt *et al*. (2000) carried out a comprehensive study involving experiments with five individual bottlenose dolphins and 2 belugas. The hearing threshold of the animals was measured before and after exposure to 1 second tones at 0.4, 3, 10, 20, and 75 kHz. The levels required to cause a 6 dB reduction in sensitivity for these short exposures at these frequencies were between 192 and 201 dB. At 400 Hz, where sensitivity was lowest, no animals showed evidence of threshold shifts. Common dolphins were reported to reduce vocalisation rate at a distance of 1km from a seismic vessel producing sound pressure levels of between 90 and 140 db (Goold, 1996).

Richardson *et al.* (1995) and Gordon *et al.* (1998) noted that damage was more likely and thresholds lower for repeated exposure. They recorded damage from as low as 178 dB re 1 µPa for 100 long pulses, to 24 dB re 1 µPa for a single short pulse. The dominant frequencies of marine seismic surveys and lower frequency echo sounders coincide more or less with the range of frequencies used by baleen whales for communication and other purposes. McCauley *et al.*, (2000) concluded that animals must be able to cope physiologically with their own sounds, concluding that whales can cope with levels of 188-192 Db re 1 µPa. Richardson *et al,* (1995) reviewed literature, which indicated whales react to lower frequency echo sounders, sometimes showing strong avoidance behaviour. Baleen whales seem to react to frequencies up to 28KHz but do not react to pingers, acoustic tags and echo sounders at 36KHz and above. For focused echo sounders, such sound levels will be found in the narrow main lobe immediately below the transducer. Hence the most likely scenario for injury of an animal by acoustic equipment would be if the equipment were turned on full power while the animal was close to it.

Review of studies of best practice

An internet search yielded many results where multibeam technology has been used in seafloor mapping. The following is a description of various studies undertaken internationally where multibeam acoustic technology has been used. Included in each study are mitigation measures followed by each company to minimise the potential risk to marine mammals present in these areas during operations.

Restrictions on the use of multibeam systems in Antarctic waters, decreed by the German Federal Environmental Agency (UBA), September 2003.

The UBA categorized multibeam (MB) operations as minor or transitory impacts to the environment. The biggest concerns of the UBA were the source level of 237 db rel 1µPas@1m and the presumed side-lobes of unknown energy and propagation. The UBA believed that this source level caused a potential risk to harm marine mammals. Continuous

MB-measurements are in Germany only imposed with the following restrictions and limitations:

1. continuous visual (three observers) and acoustical monitoring of the ship's vicinity for the appearance of marine mammals
2. one hour before beginning the MB-survey, a soft start-up with reduced transmission power
3. at night and during bad weather visibility conditions MB-operation is not permitted
4. in the case of appearance of one or more mammals the MB-operation has to be interrupted
5. MB-operations are not permitted within a distance of 5km to the sea-ice and the shelf-ice edge.

The assessment of the impact of multibeam sonar signals on the environment, as performed by the UBA, is based on the theoretical assumption that marine mammals can be ensonified by the fan-shaped sonar beam which could result in a TTS (temporary threshold shift) or PTS (permanent threshold shift) and lead to disorientation and finally to stranding of marine mammals. The statistical probability of crossing a cetacean with a narrow multi-beam fan several times, or even once, is very small. However it cannot be excluded with a 100% probability that a marine mammal could be exposed to such a sonar signal.

Oceanographic Surveys in the Southern Gulf of California

The National Marine Fisheries Service (NMFS) indicated in the Federal Register that multibeam sonar had an anticipated radius of influence significantly less than that for an airgun array (airguns are used to generate high intensity source for seismic surveys). NMFS further stated that marine mammals close enough to be affected by the multibeam sonar would already be affected by the airguns. Therefore, no additional allowance was included for animals that might be affected by the sonar. There was no enhanced impact of using the multibeam when operating it together with the airgun array.

NMFS treated harassment or injury from pulsed sound as a function of total energy received, the actual harassment or injury threshold for multibeam sonar signals would be at a much higher dB level than that for longer duration pulses such as seismic or military sonar signals. As a result, NMFS believed that marine mammals were not likely to be harassed or injured from the multibeam sonar or the sub-bottom profiler.

Impacts of Marine Acoustic Technology on the Antarctic Environment, July 2002, SCAR Ad Hoc Group on the marine acoustic technology and the environment

This working group felt that the evidence available did not justify a ban on seismic surveys or scientific echo sounders in the Antarctic waters. The equipment with the highest risk potential were airgun arrays and low frequency high power transducers with wide beam angles, however the working group recommended that surveys should be examined on a case by case bases and mitigation should be used to reduce the risk to Antarctic wildlife from high power, low frequency sonars. Some mitigation strategies in use include:

1. Use of the minimum source level to achieve the result.
2. Use of "soft starts" whereby power is increased gradually over periods of 20 minutes or more.
3. Care should be taken with survey line lay outs to avoid restricting the ability of cetaceans to avoid the source.
4. Equipment should be shut down if cetaceans are within a distance of the vessel defined by the power source, directionality and propagation characteristics.
5. Surveys should be planned to minimise repeated surveying of area in consecutive years with high-risk equipment.
6. Care should be exercised to minimise impacts in known sensitive areas and times.

The Joint Nature Conservation Committee (JNCC)

JNCC provide a list of guidelines to be followed by anyone planning marine operations that could cause acoustic or physical disturbance to marine mammals in UK waters. JNCC recommend approximately 30 minutes before commencement that observers scan the area for the presence of cetaceans within 500m of the working vessel. Hydrophones and other listening devices may provide additional information on the presence of cetaceans. This is particularly important in poor weather conditions when visual evidence of marine mammals cannot be obtained. Where equipment allows, power should be built up slowly from a low energy start-up over at least 20 minutes to give adequate time for marine mammals to leave the vicinity. Throughout the survey, the lowest practicable power levels should be used.

Table 3: Summary of different areas where Multibeam surveys were carried out and mitigation measures.

Area	Multibeam used and frequency	Potential Impact	Recommended Mitigation	Reference
Gulf of Alaska, Northeastern Pacific	Bathymetric sonar- Em1002, 92-98 KHz.	• Disturbance • Avoidance	• Controlled speed • Course alteration • Vessel based observers to monitor marine mammals in the vicinity.	Federal Register: June 23, 2004 (Vol. 69, No. 120).
Southern Gulf of California		• Disturbance • Avoidance	• Marine mammal observers, surveying the area even during the night using night vision equipment. • soft start.	Federal Register: June 7, 2004 (Vol. 69, No. 109).
Antarctic waters	237 db rel 1µPas@1m	• Disorientation • Stranding • Hearing impairment, TTS (Temporary Threshold Shift).	• continuous visual and acoustic monitoring of the ships vicinity for the appearance of marine mammals. • a soft start with reduced transmission power one hour before beginning the MB-survey. • MB is not permitted at night and during bad visibility conditions. • in the case of appearance of one or more mammals the MB-operation has to be interrupted. • MB is not permitted within 5km of the sea-ice and the shelf ice edge.	German Federal Environmental Agency.
Antarctic	>12KHz <20KHz	• Hearing damage • Disturbance • Avoidance	• Use of the minimum source level to achieve the result. • Use of "soft start" whereby power is increased gradually over periods of 20 minutes or more. • Care should be taken with line layouts to avoid restricting animals' ability to avoid the source. • Equipment should be shut down if cetaceans are within a distance of the vessel defined by the power source, directionality and propagation characteristics. • Surveys should be planned to minimise repeated surveying of area in consecutive years with high risk equipment. • Care should be exercised to minimise impacts in known sensitive areas and times.	SCAR 2002.

IWDG Recommendations

The IWDG suggest the following recommendations should be incorporated into a protocol for all vessels carrying out acoustic surveys in Irish waters (including the entire EEZ):

1. During survey planning, managers should consider the marine mammal species present in the survey area, the proportion of the population contained in the survey area, the range of the species involved, species migratory seasons likely to affected by the survey and the likelihood of a survey representing an acoustic barrier to the movement of cetaceans along a bathymetric feature or across the entrance a feature such as a bay or estuary. Managers also need to consult with relevant marine mammal experts. A risk matrix such as that presented in SCAR (2002) is recommended to facilitate survey design.

2. Any acoustic surveys in marine protected areas (MPAs) should obtain permission from NPWS. Prior to permission being granted the NPWS should ensure such surveys avoid sensitive periods such as calving periods or during important feeding times.

3. The minimum source level to achieve results should be used and frequencies chosen to minimise impacts on marine mammals. Sounds above 50kHz are inaudible to most animals. Continuous noise is likely to be more damaging to marine mammals than pulsed sounds.

4. Marine mammal observers (MMOs) should be present on board the vessel emitting the sound whether produced by multi-beam or an air-gun. The selection and training of MMOs needs to be co-ordinated by a state agency with the state agency deciding which MMO goes on each survey.

5. MMOs should survey the area for presence of cetaceans 30 minutes before the onset of the soft start in waters of 200m or less and 60 minutes before the onset of soft start in waters deeper than 200m, to allow for deep diving species to surface and be detected. The IWDG recommended a minimum distance of 1km between the survey vessel and the nearest cetacean in waters of 200m or less and 2km in water depths exceeding 200m, prior to commencement of the soft start.

6. Soft start should commence after the area around the vessel has been confirmed clear of dolphins for 30/60 minutes. Soft starts should follow JNCC guidelines with maximum sound output being achieved 20 minutes after soft start has commenced in waters less than 200m or 40 minutes after soft start has commenced in waters deeper than 200m, to allow deep diving species extra time to re-surface and leave the survey area.

7. Once the sound source has achieved maximum output the survey need not be halted should cetaceans approach the vessel.

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