PROCEEDINGS OF THE ECS WORKSHOP

NEW MITIGATION METHODS AND EVOLVING ACOUSTIC EXPOSURE GUIDELINES

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Photo by Juliet Vines

Editors:
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Exposure to anthropogenic sound has potentially detrimental effects on marine life. Acknowledging this, various nations have followed the UK example and developed guidelines to minimize the potential impacts of sound producing activities on marine life (especially marine mammals), such as seismic surveys. Many of the mitigation measures included in these guidelines rely heavily upon the detection of marine mammals within a given radius of the sound source. However, current detection methods have limitations surrounding their effectiveness (e.g., Parsons *et al*., 2009; Weir & Dolman, 2007). Other methods presume, without evidence, that marine mammals will respond to increasing sound levels from an approaching source by moving away to avoid high-level exposures.

To review developments in these areas, the Marine Mammal Observer Association (MMOA) and New Zealand's Department of Conservation (DOC) convened a workshop in March 2015, in conjunction with the 29th Annual Conference of the European Cetacean Society in Malta. Entitled "New mitigation methods and evolving acoustic exposure guidelines," the purpose of the workshop was two-fold. The first aim was to cover recent developments in technology and new mitigation methods. The second goal was to look at current methods used in mitigation with a view to improving or enhancing guidelines in New Zealand and elsewhere. For DOC the workshop constituted an information-gathering process to inform their current review of the existing Code of Conduct for Seismic Surveys (DOC, 2013).

The topics ranged across a variety of new and little used technologies and looked at existing mitigation methods and how these may be improved. The first session of the workshop concentrated on new and improved technologies that could be used in mitigation. The second session discussed guidelines for seismic surveys and other activities, as well as the roles new technologies might play in them. Technical presentations detailed the advancing techniques and technologies of passive acoustic monitoring (PAM), active acoustic monitoring (AAM) and thermal imaging, as well as aversive acoustic deterrents. The remaining presentations considered the potential role of multibeam sonar from a seismic operation in a mass stranding of melon-headed whales, a consideration of data collected by marine mammal observers (MMOs) in the UK, with a focus on the effectiveness of soft starts, and a general review of the state of knowledge on the effectiveness of current mitigation measures.

The workshop concluded with an overall discussion that encompassed how these technological developments could be used to improve marine mammal mitigation, how they may be brought into effect and, lastly, how guidelines such as the New Zealand guidelines could be improved.

ACKNOWLEDGEMENTS

The New mitigation methods and evolving acoustic exposure guidelines workshop was partly sponsored by the New Zealand Department of Conservation. Their contributions are gratefully acknowledged.

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2. PAM – METHODS AND PLATFORMS FOR UNDERWATER NOISE SENSING

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ABSTRACT

Passive Acoustic Monitoring (PAM) is an activity that has seen a significant increase in the number of participants over recent years. However, the role of PAM and the means by which it may be achieved is often not fully appreciated. A PAM system has to start off with a hydrophone. Simply listening to the underwater sounds e.g. cetacean vocalisations, impulse noise, background ambient noise, means that much useful work remains undone. In addition, where the data eventually ends up and what may be derived from it depends largely on the mode of platform on which the PAM system has been installed.

The presentation commences with a review of some underwater sounds that are of interest and relevance to the professional PAM practitioner. This is followed by an introduction to a number of metrics by which the sounds may be quantified. The presentation then goes on to discuss a number of PAM-based deployment platforms giving examples of where they have been deployed and indicating the advantages and disadvantages of each. Finally some ideas for future PAM sensor development are floated.

INTRODUCTION

This paper comprises a review of passive acoustic monitoring (PAM) methods that may be deployed in the pursuit of recording noise underwater. It commences with a brief discussion on the types of noise that may be heard underwater – both natural and man-made. It then moves on to summarise the principles of acoustic data acquisition and this is followed by a review of the platforms from which acoustic noise gathering systems may be deployed at sea – ranging from the mundane e.g. a dunking hydrophone, through to the extraordinary e.g. an autonomous underwater vehicle (AUV). A number of hints and tips are peppered throughout the report. These draw on the author's experiences of at-sea acoustic measurements and the noting of which by the interested reader, it is hoped, will lead to more successful deployments in the future.

Sources of underwater noise

The underwater environment is a noisy place: the silent world suggested by Jacques Cousteau in his eponymous 1955 film does not, in reality, exist. The generating mechanisms for underwater noise fall into one of three classes:

- Natural – consisting of weather driven noise such as wind; waves; rain; surf; lightning strikes;
- Biological – consisting of cetacean, pinniped and fish noise amongst others; and
- Man-made – such as shipping; construction e.g. piling and drilling; military; and seismic exploration to give just a very non-exhaustive list.

The sounds themselves may be of short duration and high amplitude such as an explosive blast or a lightning strike; or they may be of long duration such as shipping noise or rain noise. Equally, they might be low frequency in content such as a baleen whale call or high frequency such as a harbour porpoise echolocation click. In each case, however, the noise is generated by a change in pressure over a period of time. Changes in pressure are easily detected using specialised equipment. Starting from first principles, the next section discusses how this property is the starting point of many types of underwater noise recorder.

Principles of acoustic data acquisition

A schematic showing the principles of a noise recording system is shown in Figure 1 where it will be seen that there are a number of key stages in the process.

Fundamentally, a noise is given by a change in pressure which itself may fluctuate continuously over a period of time. A number of materials are sensitive to changes in pressure and subsequently respond by generating a small voltage. Equally, when a voltage is applied to the material, it changes shape in some way. This piezoelectric property is used to effect in a hydrophone, which when exposed to a pressure field such as that generated by a sound source, responds by emitting a voltage of given amplitude. At this stage, the output voltage is analogue in nature, that is, it is continuously varying. In order for this to be used on a modern high speed computer, the signal needs to be converted to a digital format. This is achieved by means of an Analogue-to-Digital Converter (ADC). The ADC is a device that samples part of the input signal then converts that signal into a number which represents the amplitude of the original signal. It is essential that the sampling is carried out in such a way that the salient features of the input signal are well-represented. An example of this is shown in Figure 2.

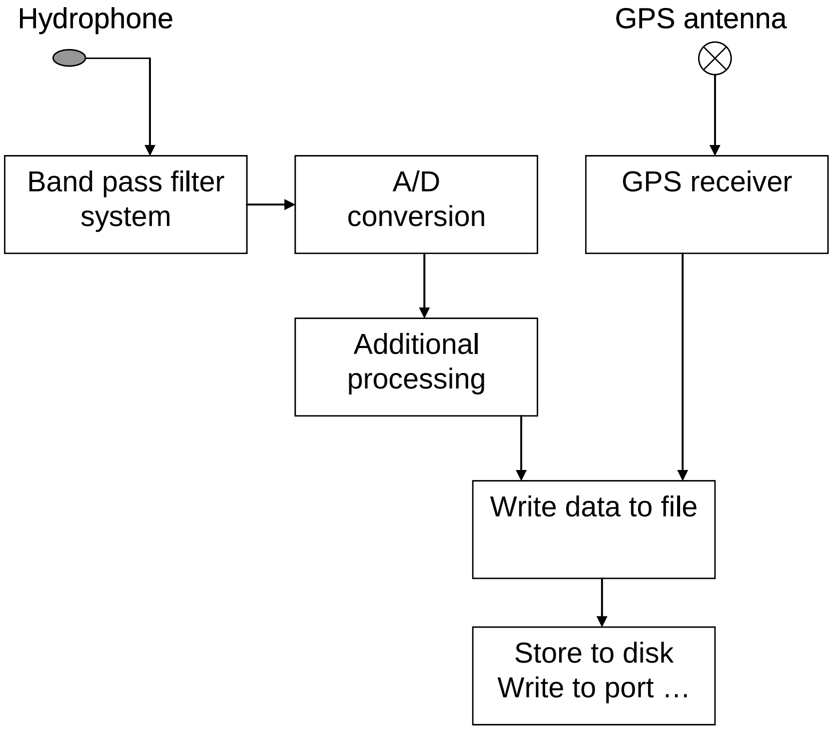


Figure 1. Schematic showing data acquisition structure.

Figure 2 shows a signal undergoing 2-bit sampling. The output signal has 4 levels of quantisation and is, as a result, somewhat blocky in nature. If the signal undergoes 3-bit sampling resulting in 8 levels of quantisation, the digitised signal is slightly more refined in that the errors arising between the original, analogue signal and the processed, digital signal are reduced. In a typical data acquisition system there may be 16-bit sampling allowing a signal to be represented to 65535 levels. The downside of such a process is that it takes time to digitise a signal and more space to store a file consisting of 16-bit signal compared with, say, an 8-bit signal although the relative errors are reduced.

The rate at which the signal is quantised is also an important consideration. The Nyquist Sampling theorem (Shenoi 2005) requires that the digitisation process be undertaken at a frequency at least 2x the highest frequency component in the original signal. In practical terms, suppose it is necessary to digitise a pilot whale whistle having a maximum frequency of 8 kHz, then the digitising needs to be carried out at a frequency of at least 16 kHz in order to ensure that the highest frequency signal components are fully represented.

Once the signal has been digitised then it is ready for additional data processing if required (see Figure 1). Subsequently it may be written to a data file having a given data format structure (digital waveform e.g. .WAV or .MP3; or digital data e.g. unsigned binary, offset binary, 2's complement). At this stage, additional information should be added to the file if possible. This includes GPS time and position data as these allow the user to quickly identify when and where the data was acquired long after the event.

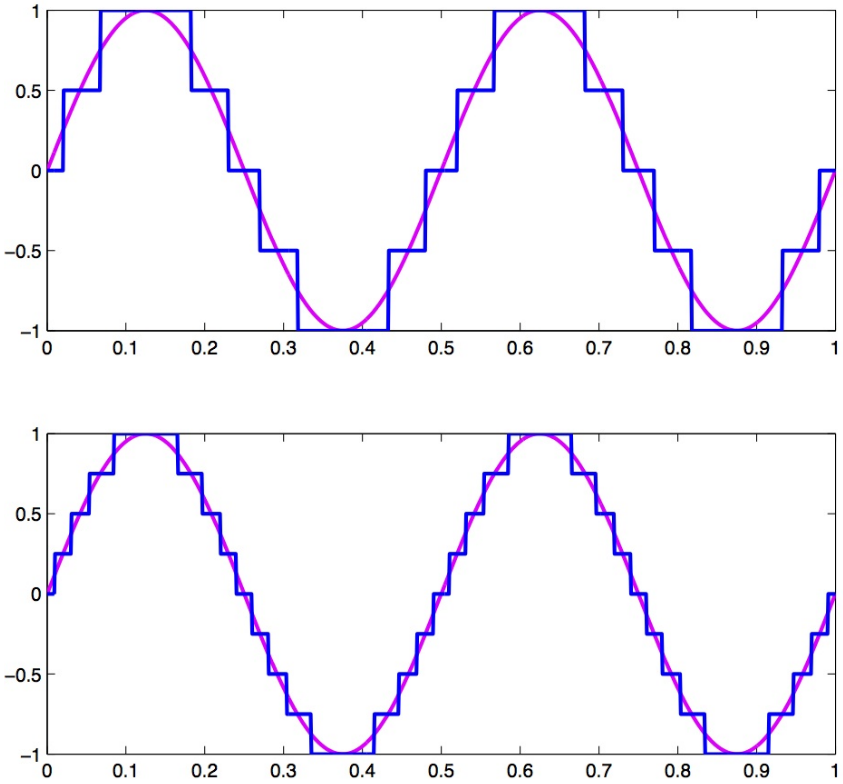


Figure 2. Principles of quantisation: Top 2-bit sampling; bottom 3-bit sampling.

UNDERWATER NOISE GATHERING PLATFORMS

The practical implementation of an acoustic data acquisition system can take a number of forms depending on the user requirement. Each system is discussed briefly below while outlining their advantages and disadvantages where appropriate.

Over-The-Side (OTS) system

Kongsberg developed a bespoke system for internal use. This is known as the Over-The-Side (OTS) system referring to the way the hydrophone is deployed or dunked over the side of a vessel during survey activities at sea.

The OTS system, shown in Figure 3, consists of a research quality hydrophone having a nominal frequency bandwidth of 20 Hz to 90 kHz and a sensitivity of -165 dB re 1 volt/μPa; an amplifier with a user selectable gain in the range 0 – 50 dB; an 18-bit ADC sampling at 500 k samples per second; and a high-end laptop running bespoke acoustic data acquisition software.

Although the Kongsberg OTS system has only one hydrophone, it is quite possible to deploy a number of hydrophones simultaneously and this is especially appropriate if the target noise covers a wide frequency range (such as background noise measurements made over the frequency range 20 Hz to 180 kHz). The system illustrated in Figure 4, shows three hydrophones: the large disc hydrophone at the bottom covers frequencies from 20 Hz to 5 kHz, higher up, the medium frequency hydrophone covers the range 1 kHz to 50 kHz while the high frequency hydrophone responds to frequencies from 10 kHz to 100 kHz. Additionally, a depth sensor was included so it was possible to lower the system to the correct depth instead of having to rely on duct tape at strategically placed intervals on the hydrophone cable. A ballast weight was attached to the system to stop the whole arrangement floating back up to the water surface.

Simply throwing a hydrophone over the side of a vessel is not necessarily the best way to get useful data. Firstly, it is important to ensure that the hydrophone reaches the right depth. This requires having knowledge of both the water depth and the sound speed profile at the survey location.

In shallow water, it is important to get a few metres at least below the water surface otherwise wave or rain noise could drown out the target noise: half water depth is often a good starting position. In deeper water, the structure of the sound speed profile could create shadow zones in the water where the target noise simply is not audible. A relevant navigation chart and an expendable bathythermograph (XBT) or a Conductivity-Temperature-Depth (CTD) probe for determining the oceanographic structure of the sea would be useful in this situation.

The use of a dunking hydrophone, although highly mobile, does present a number of problems that need to be addressed in order that the deployment is ultimately successful. Experience has shown that certain noise artefacts may be generated that pollute the noise record. In particular weather conditions, “wave slap” occurs where waves strike the hull of the survey vessel and are audible through the hydrophone. In addition, flow noise due to the movement of water across the surface of the hydrophone can be pervasive: this can occur due either to the vertical movement of the hydrophone in the water or to the presence of a tidal stream such as is found in e.g. Strangford Lough or Pentland Firth. One solution to these problems is illustrated in Figure 5 which shows a deployment off the west coast of Mainland Orkney at the EMEC site at Billia Croo. The solution to “wave slap” involved paying out a long length of hydrophone cable. The cable was supported by a number of buoy floats (shown in the foreground in Figure 5) while a home-made anti-heave float damped out any vertical movement of the hydrophone in the water. The anti-heave float, shown at mid-range on the right of the picture in Figure 5, was made from a 2 m length of standard PVC drain pipe with blanking caps at both ends and a ballast weight attached to the lower end. The hydrophone cable was suspended from a bungee cable at the lower end and the whole arrangement was allowed to float as far from the survey vessel as the length of the hydrophone cable allowed. Persuading the ship's captain to turn off the engines and allowing the vessel to float on-the-tide reduces the velocity of the hydrophone relative to the water flow. This also addresses the problem of ship's own noise which is picked up by the hydrophone. Drifting unpowered is an effective solution, but only if it is safe to do so and on the understanding that the hydrophone is retrieved immediately and the engines restarted if conditions suddenly deteriorate.

Figure 3. Kongsberg OTS system.

Figure 4. Multiple hydrophone configuration.

Figure 5. Paying out a hydrophone to overcome platform related noise.

Remote Undersea Noise Evaluation System (RUNES)

If measurements over a long time period are required, then it is not practical to use the manually-deployed system discussed above. The Remote Undersea Noise Evaluation System (RUNES) shown in Figure 6 was developed by Kongsberg as part of a requirement to monitor background noise levels over extended periods in the Moray Firth, Scotland prior to a seismic survey. With the resident populations of harbour porpoises amongst others, it was known to be an environmentally sensitive area. As part of the Consenting Process as regulated by the UK Department of Environment and Climate Change, it was required to monitor underwater background noise levels before any activity took place. RUNES was developed in response to this requirement. An outline specification is given in Table 1.

RUNES is designed to be lowered onto the seafloor with the aid of a winch or A-frame fitted to a suitable vessel, and may remain on deployment for periods up to 7 weeks at a time. The underwater background noise is recorded using one of a number of different sampling schedules. For the Moray Firth deployment, a schedule of 1 minute on and 59 minutes off was chosen. The data is written to the on-board Solid State Drive (SSD) and this process continues until the end of the deployment period. The unit is then lifted off the seabed and returned to the laboratory where the data is downloaded and processed according to the client's requirement.

Figure 6. The Remote Undersea Noise Evaluation System (RUNES).

Table 1. RUNES specifications.

Component	
Frequency range	50 Hz to 250 kHz
Hydrophones	2
Deployment period	Up to 7 weeks
Sampling schedule	Variable
Data storage	256 Gbytes Solid State Drive
Dimensions	1 m diameter x 0.5 m high
Weight	100 kg (in air)
Max operating depth	500 m

A typical example of the output data, given in Figure 7 shows the temporal variation in background noise levels during a noise survey off the Isle of Lewis, Scotland (Ward and Needham 2014). The unweighted noise levels show that background noise varied between 105 dB re 1 μPa and 124 dB re 1 μPa. The fluctuating noise levels were attributed to changing weather conditions over the deployment period.

It is also possible to estimate the auditory response to the background noise by various species of marine mammals using the M-weighting groups introduced by Southall et al (2007). This technique requires that marine mammals are divided into a number of functional groupings based on their hearing capability.

Hence Mlf represents those cetaceans whose optimal hearing is at the lower frequencies – this group consists of the baleen whales such as the minke, fin and blue; Mmf covers cetaceans whose auditory range lies over the mid-range of frequencies and this includes the common dolphin, bottlenose dolphin and pilot whale; while Mhf represents the harbour porpoise amongst others whose hearing is optimised at the higher frequencies. Finally, Mpw covers pinnipeds in water, and includes both harbour and grey seals. The technique developed by Southall et al. (2007) was extended to cover a number of species of fish relevant to the survey area and was based on audiograms for herring and dab (Nedwell et al. 2004). The results indicated that Mhf cetaceans are the most sensitive to the whole bandwidth of the underwater noise while dab are the least sensitive.

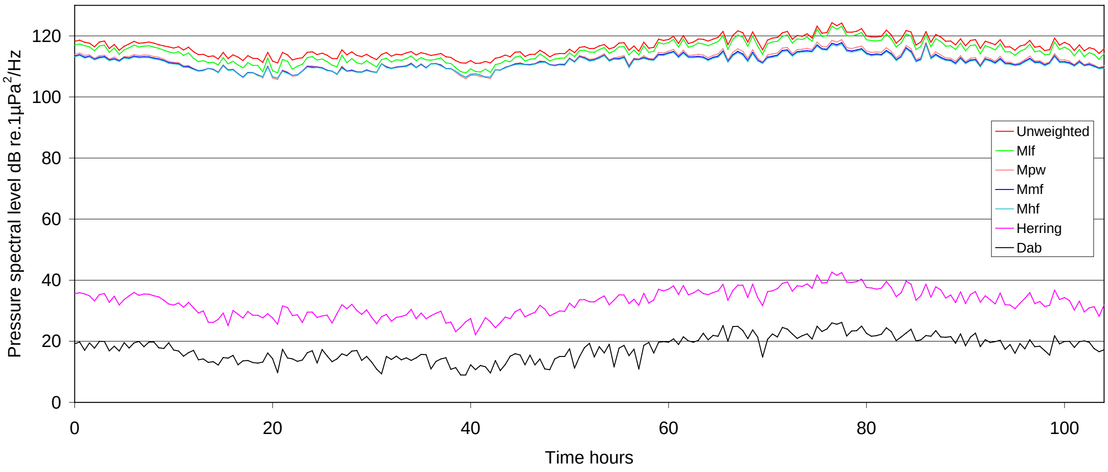


Figure 7. Temporal response of background noise levels recorded by RUNES

Acoustic Monitoring Buoy System (AMBS)

A variant of RUNES was developed and this is known as the Acoustic Monitoring Buoy System (AMBS). The main advantage of this system is that the user does not have to wait until the end of the deployment before the results become known. AMBS, shown in Figure 8 while the specification is given in Table 2, was developed in response to a need by the German regulatory authorities to monitor noise arising from underwater piling for offshore wind farms. The German Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie - BSH) set levels on the sound that is emitted into the underwater environment during piling operations. It is stipulated that the sound pressure level and the sound exposure level must not exceed 190 dB re 1 μPa and 160 dB re 1 μPa2s respectively at a distance of 750 m from the piling site (BSH 2012).

Figure 8. The Acoustic Monitoring Buoy System (AMBS).

Table 2. AMBS specifications.

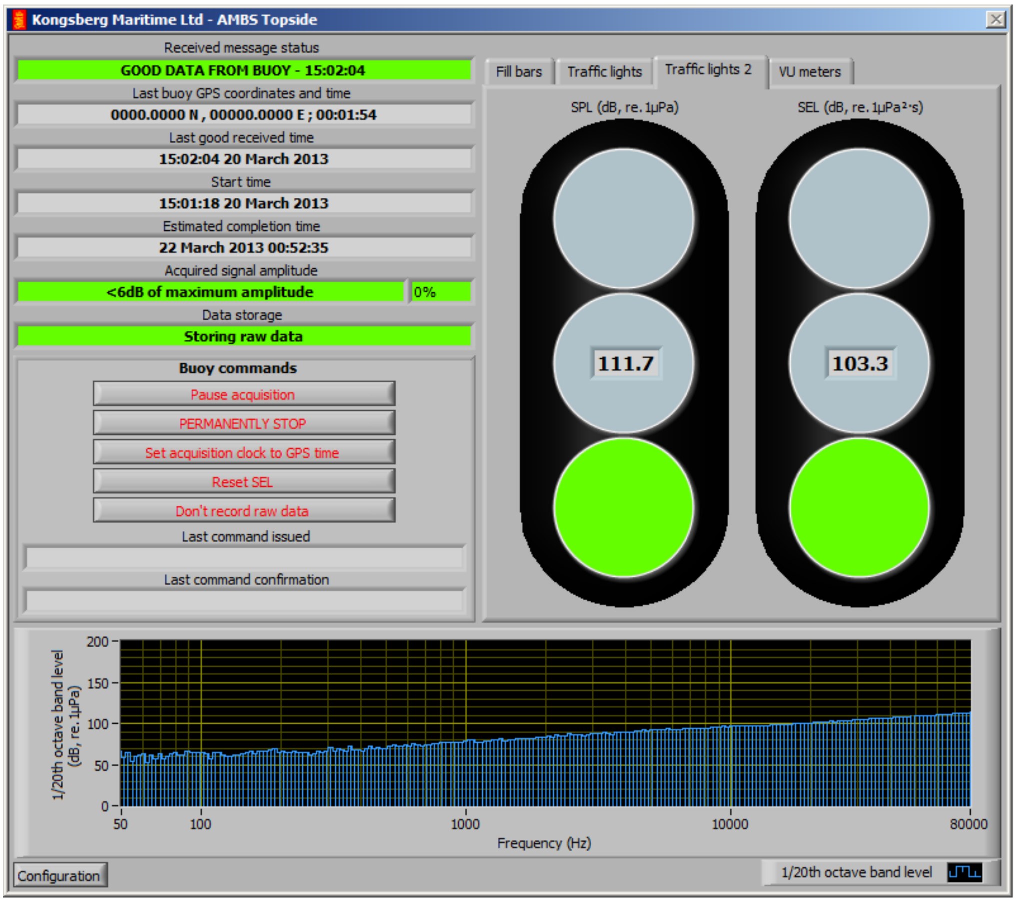
Component	
Frequency range	50 Hz to 80 kHz
Hydrophone	KM S-4009 IS
Sampling	250 kS/sec
Data storage	256 Gbytes
Data link	UHF RF transmission

The hydrophone is connected to the input socket on pelicase A which contain the data acquisition and processing system. This unit is installed on a buoy which is located at a given position relative to the piling site. The system monitors the instantaneous sound pressure level as well as the build-up of sound exposure over time. The levels are compared with preset thresholds that have been set by a regulatory authority and warning signals are issued by the controlling software when the levels are approached or breached. A radio modem transmits data between the buoyside unit and a remote PC (pelicase B) which displays the results in real-time. The separation between the two units may be up to 20 km line-of-sight. Due to bandwidth restrictions on the modem it is not possible to transmit all the data. This is resolved by partitioning the data into 1/3rd octave frequency bins.

A screenshot of the results typically displayed on the remote PC is given in Figure 9. The traffic light system provides a highly visual means of quickly determining the instantaneous Sound Pressure Level and the Sound Exposure Level relative to the BSH thresholds. The levels are indicated by one of three states:

- When piling starts, both lights are green indicating that current noise levels are far from any specified threshold level.
- When one or other lights turn amber, the noise levels are within e.g. 3 dB or 5 dB of the threshold level (this parameter is user-selectable).
- When the lights turn red, the threshold condition has been met and that previously agreed mitigation actions need to commence.

AMBS was used most recently during the construction stage of the Borkum-Riffgrund I offshore wind farm in 2014.


Kongsberg Maritime Ltd - AMBS Topside

Received message status: GOOD DATA FROM BUOY - 15:02:04
Last buoy GPS coordinates and time: 0000.0000 N , 00000.0000 E ; 00:01:54
Last good received time: 15:02:04 20 March 2013
Start time: 15:01:18 20 March 2013
Estimated completion time: 22 March 2013 00:52:35
Acquired signal amplitude: <6dB of maximum amplitude 0%
Data storage: Storing raw data
Last command issued:
Last command confirmation:
SPL (dB, re. 1µPa): 111.7
SEL (dB, re. 1µPa²·s): 103.3

Figure 9. AMBS software screenshot

Seaglider

Seaglider (Figure 10) is an autonomous underwater vehicle (AUV) around 2 m long and 0.4 m diameter, developed for continuous, long term measurement of oceanographic parameters[1]. A typical sensor fit includes acoustic Doppler current profiler (ADCP), and packages to monitor conductivity and temperature, acoustic backscatter and dissolved oxygen. Propulsion is based on changes in buoyancy and wing trim in order to control forward motion while the vehicle attitude is controlled using adjustable ballast. The Seaglider moves through the water in a saw-tooth like pattern along a pre-defined transect sampling en-route. When it surfaces, it transmits collected data and receives commands via satellite telemetry. The main advantage of this platform is that missions can last up to 10 months in duration and cover large areas.

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[1] http://www.km.kongsberg.com

The latest version of Seaglider has been fitted with a PAM module the specification of which is given in Table 3. This configuration has been deployed twice so far, once in the Mediterranean Sea[2] and once off the coast of south-west Ireland[3]. During the latter mission, initial results indicate that vocalisations from a number of marine mammals were captured by the PAM system

Figure 10. Seaglider – The PAM module is fitted in the rear instrument section and the hydrophone is adjacent to one of the dorsal fins

Table 3. Specification of PAM module fitted to Seaglider

Component	
WISPR soundcard[4]	2-input channels, up to 125 kSamples per second
Frequency range	2 Hz to 50 kHz
Hydrophone	HTI-92-WB
Sensitivity	-145 to -185 dB re 1 volt /□Pa
Data storage	Compact flash cards – currently up to 256 GB capacity

CONCLUDING REMARKS

This review paper commenced with an outline of the fundamentals of acoustic data acquisition and was followed by a brief discussion of the different types of platforms on which a passive acoustic monitoring capability may be mounted. It is noted that each system has its advantages and disadvantages and it is important to select a platform that is appropriate to the mission objectives.

The importance of checking noise data while still out in the field cannot be overstressed. It is vital to perform QA checks on data in real-time if possible and to reject any datasets that may be unsuitable. Leaving it until personnel and equipment have returned to the lab is leaving it too late.

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[2] http://ueaglider.uea.ac.uk/DIVES/index.php - Mission 21

[3] http://ueaglider.uea.ac.uk/DIVES/index.php - Mission 22

[4] Embedded Ocean Systems Inc. http://embeddedocean.com/passive-acoustics-2/wispr-v1-0/

As a final note, it is essential that the underwater noise practitioner has the ability to work on-the-fly when conditions are dynamic. The author can confirm that practical skills in rope-work are essential (Figure 4) in order to prevent important equipment suddenly becoming irretrievable.

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3. FINAL REPORT OF THE INDEPENDENT SCIENTIFIC REVIEW PANEL INVESTIGATING POTENTIAL CONTRIBUTING FACTORS TO A 2008 MASS STRANDING OF MELON HEADED WHALES (PEPONOCEPHALA ELECTRA) IN ANTSOHIHY, MADAGASCAR

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EXECUTIVE SUMMARY[5]

A highly unusual event involving the long-term displacement and mass stranding of approximately 100 melon-headed whales (*Peponocephala electra*) occurred in May-June 2008 in the Loza Lagoon system in northwest Madagascar. This typically open-ocean cetacean species had never previously nor since been reported in this shallow tidal estuarine system, nor in any other in Madagascar, although previous strandings of this species in embayments have been documented. A coordinated effort was organized for response to live animals, and to collect information through physical samples from stranded animals and a structured interview process. This mass stranding response involved local officials and citizens, conservation organizations, oil and gas exploration companies working in the area, and international marine mammal experts. Despite the remote location of the stranding event and the challenging logistics of operations, field efforts were mounted within days and a significant amount of information about the stranding event was collected.

After several years, a formalized process for investigating the known facts associated with this event was established through a partnership among many of the organizations involved in the mass stranding response effort, the International Whaling Commission (IWC), and U.S. federal agencies with relevant expertise and interest in the event; this process was undertaken in direct communication with the government of Madagascar. An Independent Scientific Review Panel (ISRP) reviewed all available information provided by responders and those analysing the events. Following a face-face meeting of the ISRP with information providers, all potential primary or secondary contributing factors to

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[5] This Executive Summary is reproduced here from the original report, Southall et al. (2013), with all appropriate permissions.

this atypical mass stranding were considered relative to all available information given to the ISRP.

The extent to which causality may be unequivocally determined here is limited by: (1) the remote and harsh conditions of the stranding area; (2) the time required to mount the stranding response and investigation; (3) the time that has passed since the event; (4) the fact that the location and behavioral state of the animals just prior to the first known observations of them within the lagoon system is unknown; and (5) limited information on the type and nature of behavioral responses of melon-headed whales to multi-beam echosounders.

There is no unequivocal and easily identifiable single cause of this event, such as those that have been implicated in previous marine mammal mortalities (e.g., entanglement, vessel strike, identified disease) or mass stranding events (e.g., weather, extreme tidal events, predator presence, anthropogenic noise). Based on information provided to the ISRP these animals apparently entered the bay on 30 May 2008 following some initial triggering event, following which at least 75 mortalities resulted over the following weeks, ultimately as a result of multiple secondary factors (e.g., emaciation, dehydration, sun exposure) related to their being out of their normal habitat for such an extended period. In such a stranding scenario where the initial response may be behavioral, but the ultimate cause of mortality relates to being out of typical habitat (of which there are a growing number of examples discussed in the report), there may not be clear forensic evidence of causality. Assessing such situations inherently requires some subjective assessment by experts of the weight of the evidence regarding the temporal and spatial association with some potential disturbance and the stranding event, as well as a science-based approach to systematically consider all possible primary or secondary contributing factors (as in Southall et al., 2006; Jepson et al., 2013; Wright et al., 2013).

While aspects of this event will remain unknown, the ISRP systematically excluded or deemed highly unlikely nearly all potential reasons for the animals leaving their typical pelagic habitat and entering the Loza Lagoon (an extremely atypical area for this species). This included the use of seismic airguns in an offshore seismic survey several days after the whales were already in the lagoon system, which was originally speculated to have played some role but in the view of the ISRP clearly did not. The exception was a high-power 12 kHz multi-beam echosounder system (MBES) operated intermittently by a survey vessel moving in a directed manner down the shelf-break the day before the event, to an area ~65 km offshore from the first known stranding location. The ISRP deemed this MBES use to be the most plausible and likely behavioral trigger for the animals initially entering the lagoon system. This conclusion is based on:

Very close temporal and spatial association and directed movement of the MBES survey with the stranding event. The MBES vessel moved in a directed manner transmitting sounds that would have been clearly audible over many hundreds of square kilometers of melon-headed whale deep-water habitat areas (and extending into some shallower waters along the shelf break) from 0544 until 1230 local time on 29 May and then intermittently in a concentrated offshore area (located ~65 km from the mouth of the lagoon) between 1456 and 1931 on 29 May; these preceded the first known stranding during the day of 30 May and sighting of live animals within the lagoon at 2300 on 30 May.

The unusual nature of this type of stranding event coupled with previous documented apparent behavioral sensitivity in this pelagic species (albeit to other sound types - discussed in more detail below).

The fact that all other possible factors considered were determined by the ISRP to be unlikely causes for the initial behavioral response of animals entering the lagoon system.

This is the first known such marine mammal mass stranding event closely associated with relatively high-frequency mapping sonar systems. However, this alone is not a compelling reason to exclude the potential that the MBES played a role in this event. Earlier such events may have been undetected because detailed inquiries were not conducted, given assumptions that high frequency systems were unlikely to have such effects because of relatively greater sound propagation loss at high frequencies. It is important to note the relatively lower output frequency, higher output power, and complex nature (100+ directional but overlapping sound beams) of the MBES used here relative to most conventional lower-power and often much higher-frequency fish-finding or shallow-water bathymetric mapping systems. Similar MBES systems to the 12 kHz source used in this case are in fact commonly used in hydrographic surveys around the world over large areas without such events being previously documented. In fact, a very similar MBES system was apparently used in a survey in the general area (and particularly the Mahajanga harbor area to the south) for some period during April and early-mid May 2008. This in fact could have played some contributing factor by sensitizing animals in the vicinity to such sources, but information on where and how this system was used was unavailable despite efforts to obtain it.

There may well be a very low probability that the operation of such sources will induce marine mammal strandings - animals may simply avoid them or even ignore them most of the time. In this case, environmental, social, or some other confluence of factors (e.g., shoreward-directed surface currents and elevated chlorophyll levels in the area preceding the stranding) may have meant that this group of whales was oriented relative to the directional movement of the transmitting vessel in such a way that an avoidance response caused animals to move into an unfamiliar and unsafe out-of-habitat area. It is important to note that, especially for odontocete cetaceans that hear well in the 10-100 kHz range where ambient noise is typically quite low, high-power active sonars operating in this range may in fact be more easily audible and have potential effects over larger areas than lower-frequency systems that have more typically been considered in terms of anthropogenic noise threats. The potential for behavioral responses and indirect injury or mortality from the use of similar MBES systems should be considered in future environmental assessments, operational planning, and regulatory decisions.

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4. THE USE OF MULTI-BEAM IN MAINE MAMMAL RESEARCH AND MITIGATION; PITFALLS AND POSSIBILITIES

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SUMMARY

Multibeam sonar is increasingly being considered as a behavioural research tool to identify and track marine mammals underwater; for example, Nottestad et al (2002) used a 95kHz multibeam sonar to measure the behaviour of fin whales foraging on herring schools, Benoit-Bird & Au (2003a) used sonar to integrate the behaviour of spinner dolphins and their prey, and Benoit-Bird & Au (2003b) used sonar to locate and track spinner dolphins in the water column in Hawaii. Regulators and industry are also now considering using sonar for mitigation purposes around areas of commercial value such as aquaculture facilities, or potentially high risk activities such as tidal turbines, munitions detonations, and industrial developments such as pile driving or seismic surveys. Multibeam sonar has a number of technical features that make it attractive for tracking marine mammals including its ability to detect non-vocal species, to provide locations and movements of individuals with a high temporal and spatial resolution, and to provide a permanent data record of the animal behaviour. However, most marine mammals rely on sound to navigate, and for detecting prey, and there is the potential that the acoustic signals of sonar could cause behavioural responses. For example, we carried out behavioural response tests with grey seals to two sonar systems (200 and 375 kHz systems). Results showed that both systems had significant effects on the seals behavior; when the 200 kHz sonar was active, seals spent significantly more time hauled out and, although seals remained swimming during operation of the 375 kHz sonar, they were distributed further from the sonar. The results illustrate that although peak sonar frequencies may be above marine mammal hearing ranges, high levels of sound can be produced within their hearing ranges that elicit behavioural responses. We described the implications of these results for the use of sonar as a behavioural research tool, and discussed the pros and cons of multibeam sonar for mitigation purposes.

5. EXPLORING THE THERMAL LIMITS OF AUTOMATIC WHALE DETECTION

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ABSTRACT

Growing concerns, that aquatic noise produced during naval exercises and offshore seismic surveys may be harmful to marine mammals, have led an increasing number of regulating agencies to request mitigation measures when issuing permits for such surveys in their nations' EEZ. The most common measure is to implement a "marine mammal watch", a team of observers that scans the ship's environs for signs of presence of marine mammals to trigger a shutdown of the hydroacoustic source when marine mammals are entering a predefined exclusion zone.

Marine mammal observers usually scan the ship's environs for whales using binoculars or the naked eye. Sightings mostly rely on spotting a whale's blow, which might rise to a height of several meters but is visible for a few seconds only. Hence, in combination with the whales' prolonged dives, sighting opportunities are rare, which, in addition to the limited field of view and finite attention span of human observers, renders this method personnel-intensive and difficult, even during fair weather and daytime. During darkness it is not feasible. Our long-term goal is to overcome these difficulties and to develop a reliable, automatic whale detection system for the full range of oceanic environmental conditions (wind, sea surface temperature) and species. To this end, we developed a ship-based thermal imaging system for automated marine mammal detection, consisting of an actively stabilized, spinning IR camera and an algorithm that detects whale blows on the basis of their thermal signature. So far, this technology has been tailored to and tested under cold (SST < 10°C) water conditions only, as this is where the technology was expected to perform best.

Here we present our latest results in adapting this technology to warmer environments and testing its performance. We operated our IR based whale detection system during the northward humpback whale migration, which occurs annually rather close to shore near North Stradbroke Island, Queensland, Australia. Based on the collected data, we calculated detection functions for different environmental conditions and marine mammal cues. This data will allow to scale the laws of thermal imaging based marine mammal detection.

6. AVERSIVE SOUND MITIGATION TO REDUCE THE RISK OF DAMAGE TO MARINE MAMMALS

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SUMMARY

For those situations where potentially damaging/harmful activities such as pile driving and explosive detonation, are unavoidable, there is a clear need for effective mitigation. For animals which are difficult to detect at sea, such as pinnipeds and small cetaceans the only sensible option is to move those vulnerable animals out of the “Danger Area” before that activity begins. As marine mammals are highly dependent on acoustics for sensing their environment and as sound propagates well underwater, the use of aversive sounds for this purpose seems promising. There are few refuges at sea for air-breathing marine mammals so avoidance is likely to be a common anti-predator strategy for marine mammals. A review of the literature is encouraging: it provides many examples of marine mammals moving away from various sound sources.

A factor which may reduce the effectiveness of aversive sounds in both marine mammals and terrestrial animals is habituation or the development of tolerance: animals cease to respond to initially aversive signals which have not been reinforced by unpleasant conditioning stimuli. This is unlikely to be a concern for this application however because aversive signals will only need to be used for short time periods and will often be linked with unpleasant stimuli, such as pile driving. This consideration does point to the desirability of using signals that animals are unlikely to be routinely exposed to in their normal lives however.

For regulators to be able to rely on aversive sounds, their effectiveness in field conditions needs to be rigorously tested. Work in this area has begun with two species. Bioconsult have conducted and published the results from a series of trials with harbour porpoises exposed to an ADD made by Lofitech. They showed high levels of exclusion out to ranges of ~7km.

We have begun to carry out controlled exposure trails with seals using a new real time UHF telemetry system. Trails with the same Lofitech ADD and with killer whale calls will be described. These are revealing responses at ranges which are shorter (~1-2km) but which should still be useful for many applications.

Aversive sound mitigation could provided a methodology which is both more effective than approaches that rely on detection and very much easier and less expensive to apply. The technique could be effective in reducing risk of damage at relatively short range but, like conventional mitigation, it does nothing to

address problems of disturbance and displacement from actives such as pile driving.

7. REMOTE PASSIVE ACOUSTIC MONITORING (RPAM): LISTENING FOR WHALES AND DOLPHINS FROM THE SAFETY OF LAND

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INTRODUCTION

Regulatory requirements for effective noise mitigation have increased – particularly for the protection of whales and dolphins. It has become standard practice for several industry sectors to have Marine Mammal Observers (MMOs) and Passive Acoustic Monitoring (PAM). Personnel dedicated to monitoring, visually and acoustically, to ensure that animals are not in the close vicinity of an active sound source. These requirements necessitate more environmental specialists going offshore, increasing safety risks and costs.

Remote Passive Acoustic Monitoring (RPAM) is a new technology that enables the acoustic monitoring of marine mammals from an onshore location. Acoustic data is transferred, in real time, via satellite link from an at-sea PAM system. From anywhere in the world, a RPAM operator can detect, listen to, and track vocalising whales and dolphins – potentially reducing the number of operators at sea.

This technology, critical for the offshore Industry such as marine seismic exploration, offers a clear added value by providing a high quality and cost-effective real time mitigation solution. In addition, RPAM can be readily applied to academic research, civil engineering projects, baseline studies and environmental education programs

A POTENTIAL END TO PAM OPERATORS OFFSHORE?

Running operations from shore has the potential to reduce the number of people required at sea. At the same time, RPAM is able to reduce logistical challenges and increase cost effectiveness. The most significant benefit though is reducing Health and Safety (HSE) risk. There is the possibility, in the near future, that RPAM could completely reduce the need for offshore PAM personnel. However, for now, it is more likely to fulfil an expert supporting role.

Regulatory requirements in several areas of the world stipulate more than one PAM operator; yet the pool of experienced operators is small. There is also tremendous pressure on physical bunk space on-board seismic vessels. In these instances, RPAM can play a significant role in ensuring the highest levels of environmental protection and regulatory compliance.

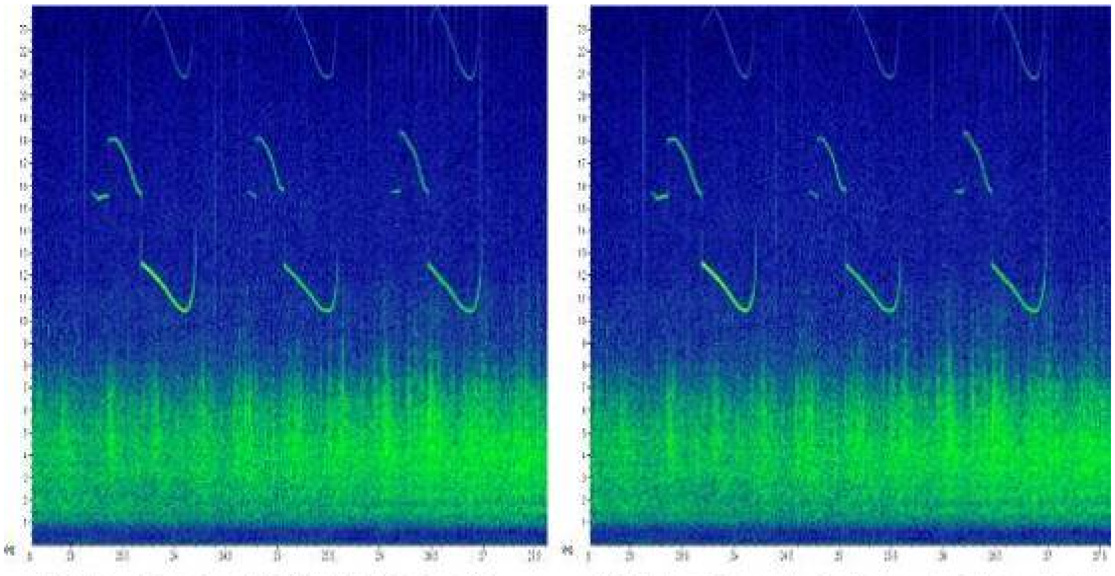
ONBOARD AND REMOTE PAM OPERATORS WORKING TOGETHER

Remote PAM is conducted simultaneously with a local PAM operator on-board the vessel. The operators can communicate continuously with the remote operator via instant messaging, or simply by using a direct telephone link. The PAM operator role is a multi-skilled one. It requires both biological knowledge and technical ability – as well as the competence and attitude needed for working offshore. With expertise on technical and biological matters available at the shore base, the offshore operator benefits significantly from the support the RPAM operator can offer.

RPAM FOR MITIGATION

RPAM is particularly useful for mitigation. The approach of having additional expertise has already proved vital in ensuring robust decisions are made for shutdowns to seismic industry operations.

Delays and shut-downs to industry operations are costly and must be evidence based. The critical need is to establish whether an animal has entered the mitigation zone around the seismic source – not an easy task. With RPAM, there is no longer the need for a lone operator on-board the vessel to take sole responsibility for high-pressure decisions (Figure 1).



PAM detection of a dolphin in Gulf of Mexico, USA

RPAM detection made simultaneously in Devon, UK

Figure 1. A dolphin whistle detected at sea in the USA (left) and simultaneously on land in the UK (right).

Additionally, without RPAM support, the on-board operator, in some countries, may have to continuously monitor for a full 12 hour shift - without breaks.

Fatigue inevitably affects concentration levels. Remote operators on land allow flexible shift patterns to remove such problems completely. Furthermore, any on-board technical problems or even illness of the operator can readily be covered by RPAM.

Multiple Access

The provision of live support for technical troubleshooting is a further asset. If the problem cannot be fixed by either onboard or remote operators, the signal can be patched to more experienced technical experts – wherever they may be. Viewing the same signal and listening to the same audio, the problem can be diagnosed and the on-board operator can be talked through how to resolve as swiftly as possible. Furthermore, if required, the live PAM feed can be directly accessed by the client.

How RPAM works

The technical set-up for Remote PAM was first pioneered in 2013. It has been evolving and improving ever since. Today, in addition to the conventional PAM system onboard, a twin processing unit streams the low frequency (LF: 20-19,000Hz) audio signal via the existing vessel VLAN by secure connection. The twin processing unit also independently runs PAMGuard, which can be accessed independently and viewed by remote desktop software, for the high frequency (HF: 19-200,000Hz) data.

This enables the real-time monitoring of both the LF and HF PAM signal at the RPAM station, which can be situated anywhere in the world with a robust internet connection (Figure 2). Alternatively, when closer to shore, the system can directly be operated over radio link.

Robust Connection

To gain a simple assessment of how well RPAM performs against the PAM onboard, we subtract the amount of RPAM "loss" from the total available PAM signal. This connectivity rate has improved as RPAM has developed and projects now consistently deliver rates of 95%.

In all of the projects, the technical and operational performance of RPAM is closely monitored and assessed. All instances of "loss" to RPAM connectivity are recorded, whether high frequency or low frequency. RPAM connectivity loss only amounts to a tiny percentage of the overall monitoring effort (Figure 3). Never the less, to keep improving the RPAM system we investigate each instance of connectivity loss.

A key lesson learned has been the choice of satellite and bandwidth provision to suit the specific project. On-board physical obstructions may also affect the signal and may vary by the vessel heading, pitch and roll. Additionally, periods of intense solar activity occasionally has an effect on satellite communications. With these lessons learned the connection to RPAM is now robust and consistent.

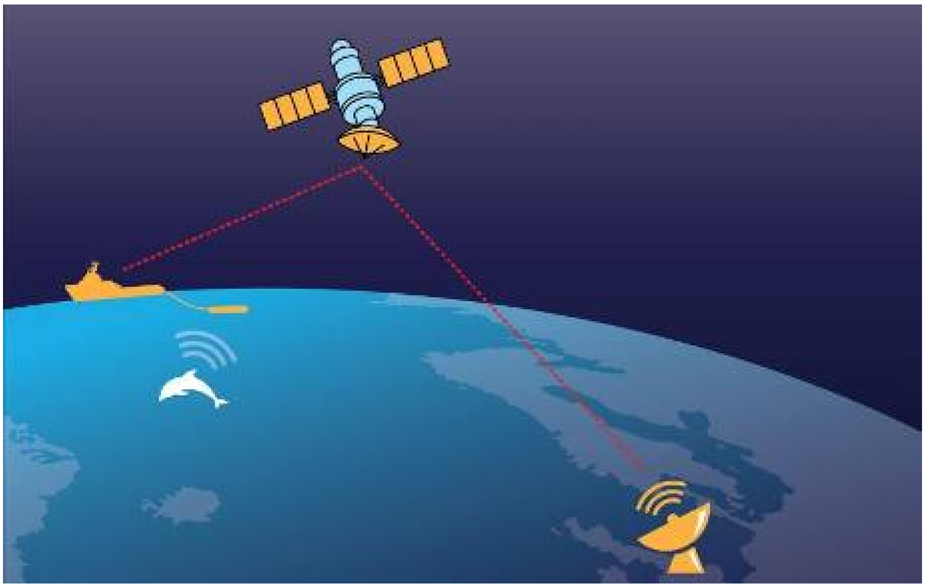


Figure 2. Schematic of RPAM. Acoustic signal from at sea operations is transmitted by satellite - in real-time - to an onshore base.

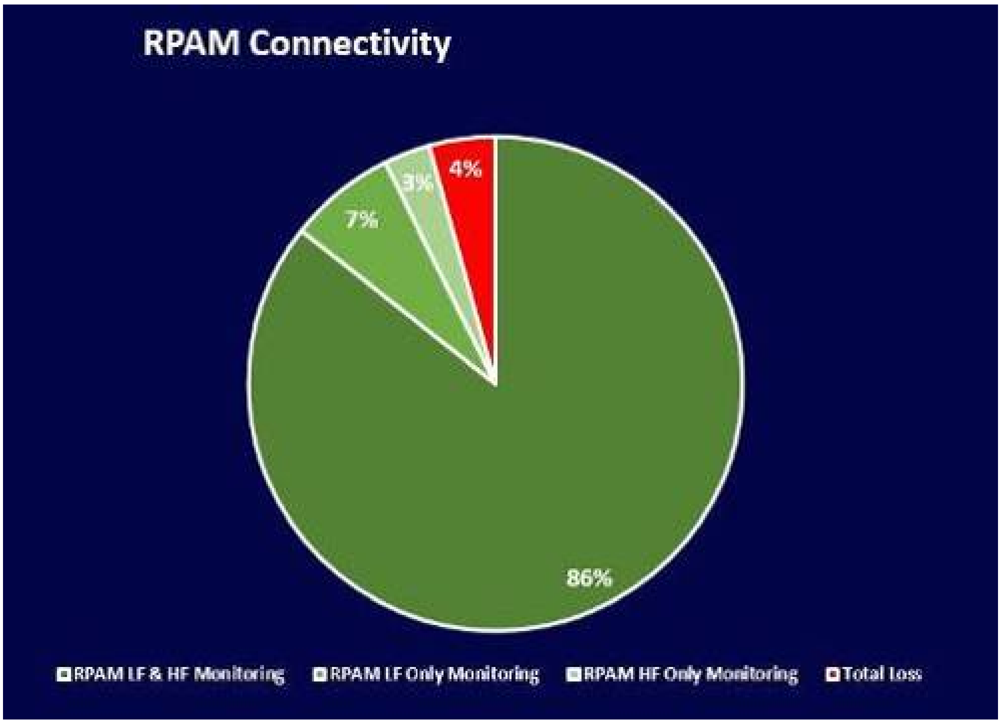


Figure 3. RPAM Connectivity. Instances of RPAM “loss” subtracted from the available PAM signal.

REMOTE FUTURE

With ever greater need for high quality environmental mitigation for anthropogenic sound, Remote PAM has great potential. Like any innovative technique it needs to prove itself. Seiche have now completed over 12,000 hours of Remote Passive Acoustic Monitoring (RPAM) from projects off Australia, South Africa, Malaysia, the US Gulf of Mexico, Canada and Trinidad & Tobago. At the latest count, 943 real time acoustic detections of marine mammals have now been recorded – from the safety of onshore offices - many miles from their actual location in the ocean.–Maintaining connectivity levels of 95%, providing timely onshore personnel rotation and live support will help it to gain regulatory approval and further allow a direct mitigation role.

The role of RPAM as a platform for training and support is already up and running. In several parts of the world there is a growing requirement for local personnel – yet the existing pool of available expert PAM operators is still extremely small. As this trend continues, the ability of RPAM to provide live support to those in the field may prove particularly valuable.

This pioneering technique of listening for whales and dolphins from the safety of land may soon become perfectly normal practice.

ACKNOWLEDGEMENTS

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8. SIGNAL PROCESSING AND ANALYSIS: DETECTION, CLASSIFICATION, LOCALISATION AND RELIABILITY

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SUMMARY

The purpose of Passive Acoustic Monitoring is generally to Detect, Classify and Localise sounds from a variety of marine mammal species in near real time. The wide variety and variability of marine mammal call types combined with a highly variable noise field means that the success of a PAM system will vary considerably by species and by installation. This presentation introduces some of the basic DCL techniques and discusses factors which are likely to affect their performance. While computerised DCL methods form an essential component of a modern PAM system, human observers will continue to form an essential part of any monitoring system except in the most simple of circumstances.

9. QUIETSEA™ MARINE MAMMAL MONITORING SYSTEM

Christophe L'Her (presenter during ECS conference)[1] and Laurent Guerineau (author of abstract)[1]

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INTRODUCTION

Over the years, there has been a growing number of regulatory agencies requiring or encouraging the use of Passive Acoustic Monitoring (PAM) for real time detection and localization of marine mammals within the Exclusion Zone (EZ) in order to minimize the potential environmental impact from marine seismic sources.

The Exclusion Zone, usually defined as the radius around the seismic sources within which mitigation measures, such as seismic source shutdown, are implemented is generally set at 500m. Current PAM systems are typically comprised of a dedicated towed array containing several hydrophones, an onboard signal conditioning and data acquisition device, all of which is connected to a dedicated computing system.

Although the potential value of Passive Acoustic Monitoring as a real time mitigation tool has been recognized by most regulatory agencies, the currently available PAM systems, while well suited for research and scientific use, are limited as a tool for marine seismic surveys.

Figure 1. PAM towed array entanglement with lead-in

On the acquisition vessel, the management of a dedicated PAM towed array poses safety concerns for operators during the deployment and retrieval phases. The current PAM systems also greatly increase the risk of entanglement with lead-ins and streamers (see Figure 1), which increases the likelihood of unnecessary down-time and equipment replacement costs for the seismic contractor.

PAM towed arrays are usually deployed a few hundred meters from the back deck of the seismic vessel. The boat-induced noise masks the vocalization of marine mammals and the vessel wash acts as an acoustic barrier, both of which hinder the system's ability to detect cetaceans.

Commercially available PAM systems typically rely on a single linear antenna containing a limited number of hydrophones, which leads to several restrictions in terms of system performance:

- Limited forward detection/localization performance, which is a direction of particular interest, and the inability to solve the port/starboard localization ambiguity.
- The limited number of hydrophones may not provide enough information for localization in some cases, and does not offer any redundancy in case of hydrophone malfunction.
- The use of a single antenna results in operational downtime during night time in case of entanglement. Indeed, PAM being the only mammal monitoring tool available at night as Marine Mammal Observers cannot operate; its unavailability leads contractors to wait until day time to resume operations.
- Towed arrays don't provide any QC status concerning their state of health, elevating the risk of operating a malfunctioning system.
- Poor low frequency response, which may exclude some whale species from being identified through acoustic monitoring.

Current PAM system software is not intuitive, making it cumbersome to configure and operate:

- Expert PAM operators are required for configuration and operation as there are no standard software settings for optimal results. System performance is inconsistent and highly dependent on the skills, ability and experience of the operator.
- Expert skills are required to analyze the data, confirm acoustic detections, reject false alarms, provide range estimates, etc. This subjective interpretation is operator-dependent and results in inconsistent, unreliable performance.

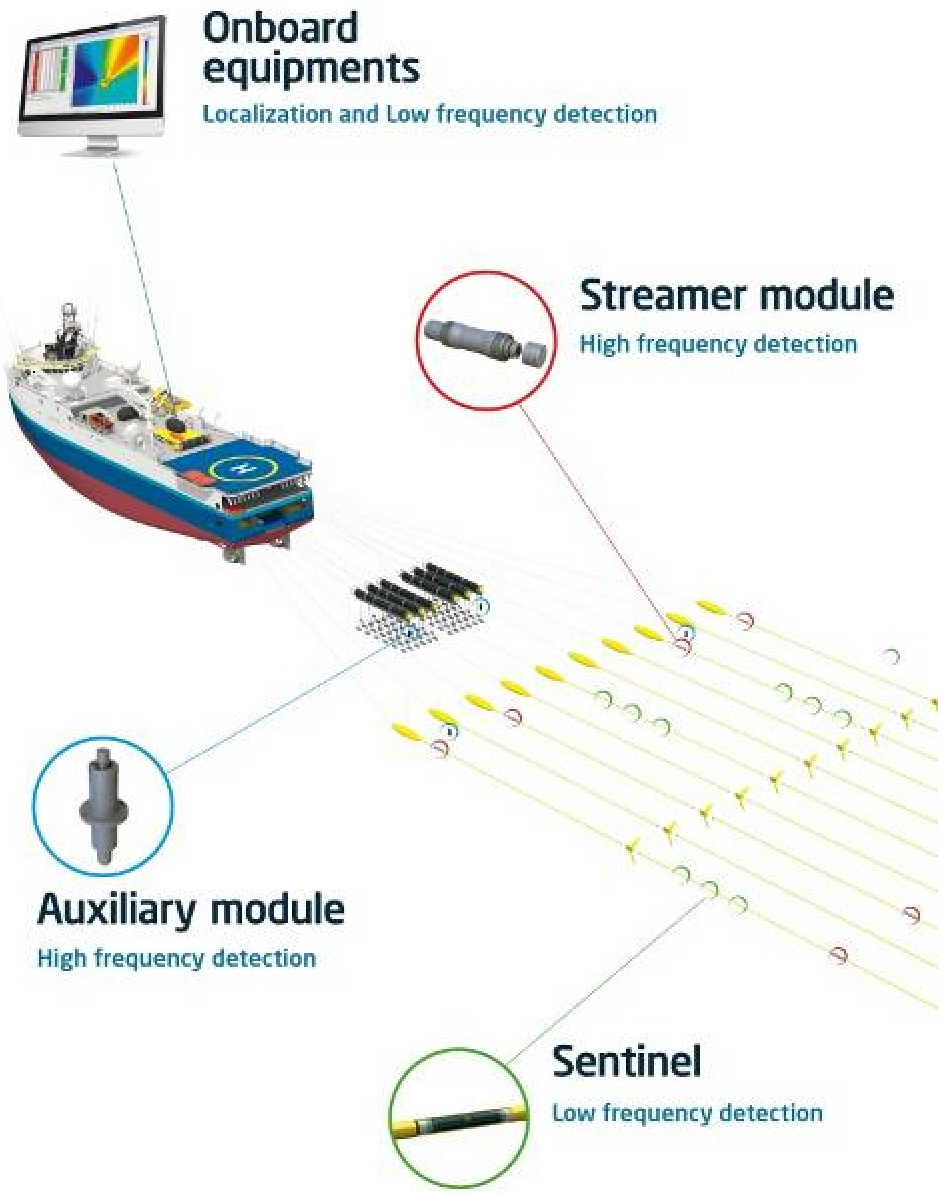


Figure 2. QuietSea insea architecture

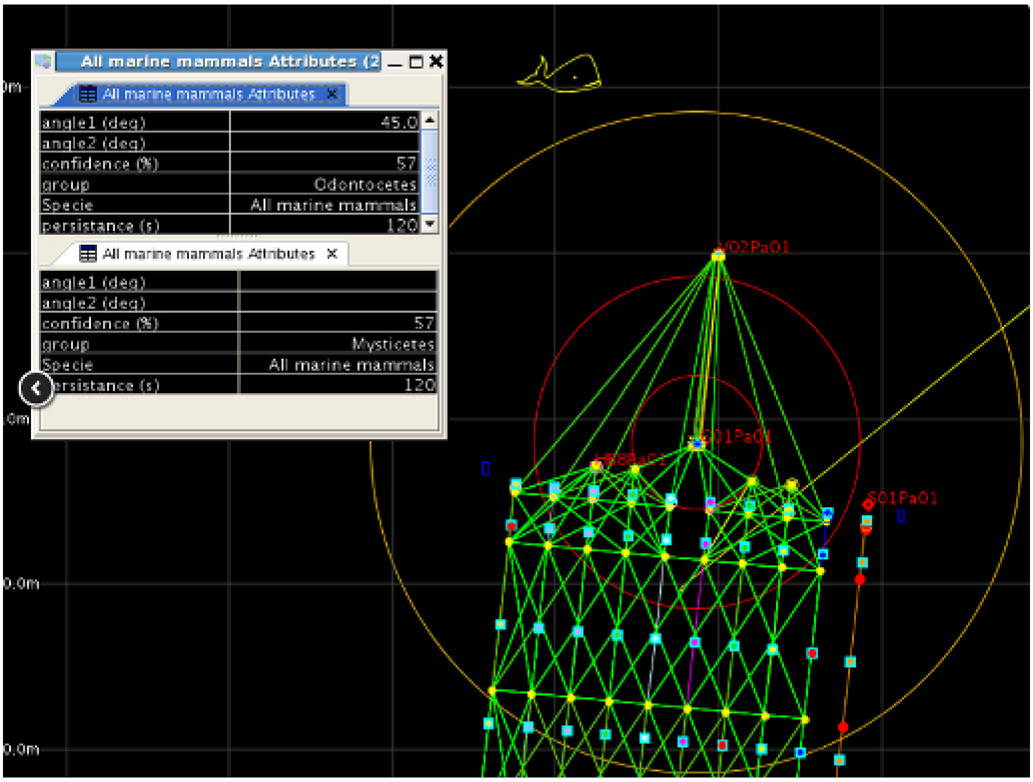
QUIETSEA

QuietSea, the new fully integrated Passive Acoustic Monitoring system from Sercel overcomes many of the limitations of current PAM systems.

Designed to fully integrate with the Seal 428 seismic acquisition system, SeaProNav navigation system, and incorporated in the Sentinel® streamer (see Figure 2), QuietSea offers numerous benefits to seismic contractors.

By eliminating the need for deployment of separate PAM antennas at sea, the QuietSea system mitigates the possibility of accidents during deployment, retrieval and operation, thus significantly reducing the possibility of downtime and possible equipment replacement costs.

In addition, the bidirectional communication with the navigation software, coupled with the network of broadband in-sea modules seamlessly integrated within the Sentinel® streamers, provides improved cetacean localization accuracy and real time reporting of detected events for faster decision making (see Figure 3).



angle1 (deg)	45.0
angle2 (deg)	
confidence (%)	57
group	Odontocetes
Specie	All marine mammals
persistance (s)	120

angle1 (deg)	
angle2 (deg)	
confidence (%)	57
group	Mysticetes
Specie	All marine mammals
ersistance (s)	120

Figure 3. SeaProNav display showing Exclusion Zones and localized cetacean.

<u>QuietSea offers an enhanced monitoring of the Exclusion Zone… and beyond</u>

Thanks to the very low noise Sercel Sentinel® hydrophones, QuietSea utilizes up to 512 sensors to monitor baleen whales, such as Blue whales, down to 10Hz.

Additionally, numerous broadband hydrophones seamlessly integrated within the Sentinel® streamers and placed in strategic positions (on streamer heads, outside the vessel wash and close to the center of EZ) constitute a large, redundant 2D array that provides good detection and localization of baleen and toothed whales, regardless of the listening direction.

QuietSea relies on advanced automated detection and localization algorithms which drastically decrease the false alarm rate, delivering truly objective, consistent and reliable information for decision making, regardless of the skills, ability or experience of the operator.

The QuietSea GUI is intuitive and user-friendly, with minimal settings, relying on self-adjusted software parameters to deliver stable performance across various environments.

The rugged and reliable in sea modules are based on a field proven design, with built-in Quality Control capability that allows QuietSea to assess the health of the hydrophones as well as the detection performance of the modules.

QuietSea provides seismic contractors with a reliable PAM system optimizing the control of their environmental footprint.

CONCLUSION

In marine acquisition, Passive Acoustic Monitoring is recognized as a promising tool to complement current mitigation measures during geophysical surveys, but has yet to realize its full potential.

QuietSea integrated Passive Acoustic Monitoring system addresses most of the limitations encountered in today’s PAM systems, making it the most intuitive PAM system available for marine seismic surveys.

By carefully balancing both the expectations of the regulatory agencies and the operational constraints of the seismic contractor, QuietSea will help Passive Acoustic Monitoring gain the wide acceptance it deserves among the marine seismic industry while actively contributing to the reduction of the environmental footprint of marine seismic surveys.

10. WESTERNGECO WHALEWATCHER

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INTRODUCTION

WhaleWatcher™ is a new tool for passive acoustic monitoring of marine mammals using the seismic spread. The system is a tool to assist the Marine Mammal Observer (MMO) in detecting and localizing mammals in the vicinity of the seismic source. The system will be run by the seismic observers onboard.

WhaleWatcher utilizes the seismic single sensor hydrophone data (0.5 kHz sampling rate) and the positioning hydrophone data (8 kHz sampling rate) from the Q-Marine seismic spread. It listens to the hydrophone recordings and tries to detect and localize sound sources in the sea potentially originated from marine mammals. The detections are then verified either by visual observations, or by QC tools available within WhaleWatcher. Overview of the WhaleWatcher system is shown in Figure 1.

The Q-Marine enabled mammal monitoring has several unique features:

- Using existing streamer hydrophones – no added equipment needed
- No interference with the seismic operation
- Fully configurable aperture for optimized signal processing and whale detection
- The mammal detections are presented in navigation displays – ship-wide
- The sensor count and aperture give excellent performance in low SNR environments
- High resolution bearing and accurate mammal localization are achieved

The system is split into a low-frequency part using the seismic hydrophones, and a high-frequency part using the positioning hydrophones. In combination these two systems span most of the frequency band of the whale calls.

Low-frequency system

Seismic data are characterized by high noise levels at lower frequencies due to streamer vibrations, vessel noise, wave action and others. To achieve sufficient signal-to-noise ratio, it is necessary to take advantage of the large aperture and large number of sensors of the seismic streamer. Beamforming, implemented as frequency-wavenumber (f-k) estimation is used for this purpose.

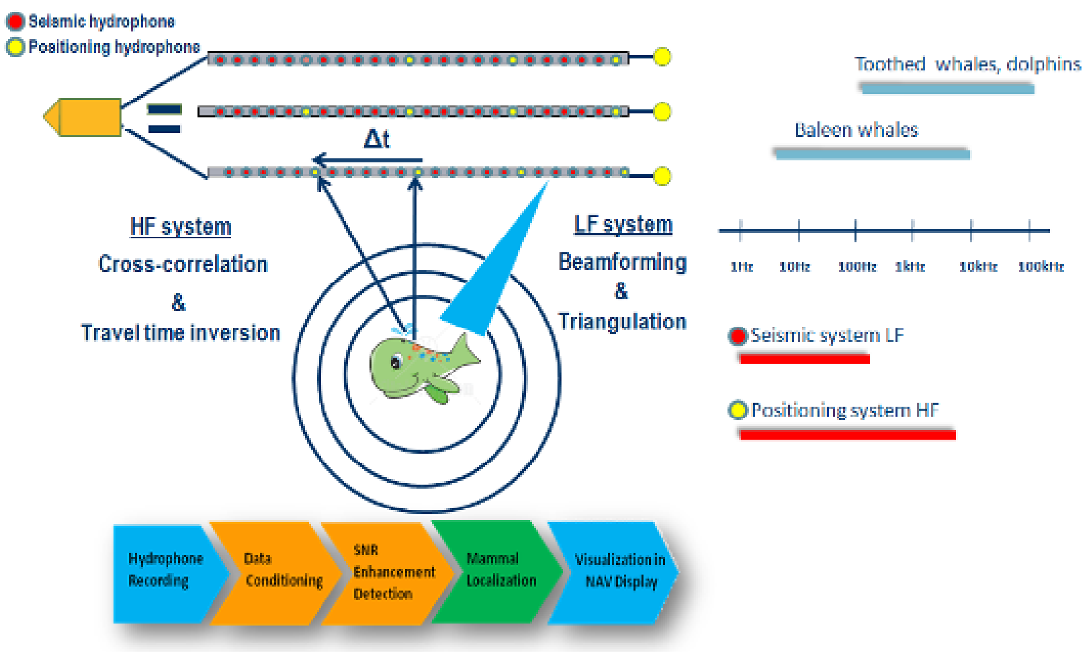

Figure 1. Diagram of the WhaleWatcher system.

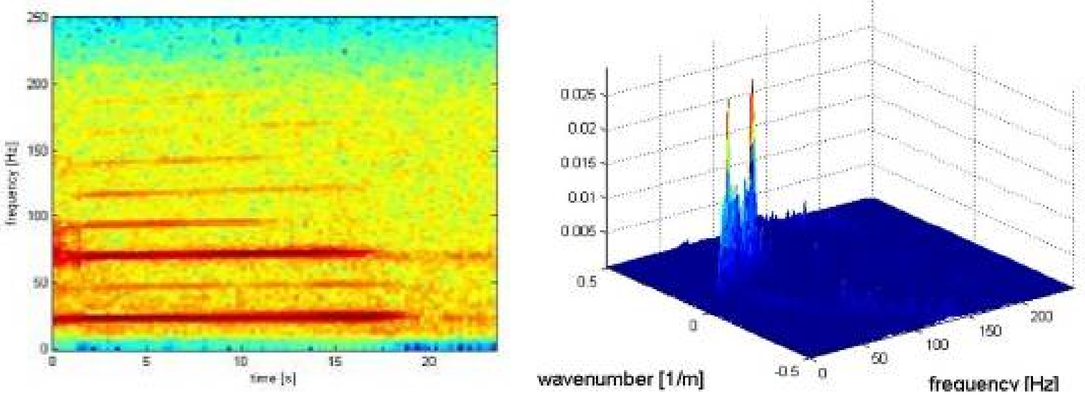

Figure 2. The left panel shows a pygmy blue whale call with two main harmonics at 23 Hz and 70 Hz. The right panel shows the f-k spectrum of the whale call.

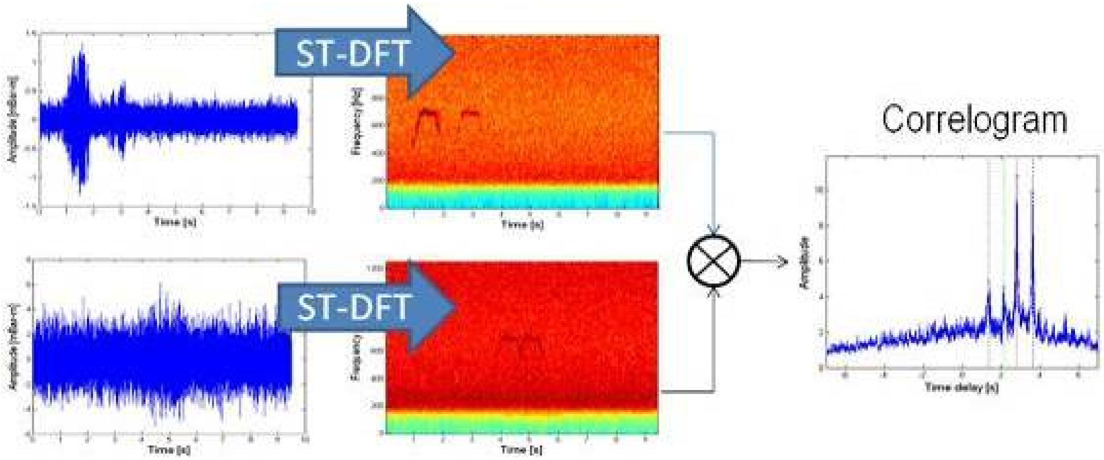

Figure 3. Two traces with humpback whale calls (left) are transformed to spectrograms (middle) using short-term Fourier transforms. The spectrograms are correlated to produce a correlogram (right), from where time differences of arrivals can be estimate.

High-frequency system

For the high-frequency part of the system, the hydrophones are spaced too far apart for beamforming. However, the higher-frequency bands are less affected by noise, and we are not as dependent on large array gain. Instead, cross-correlation of hydrophone traces is used to enhance the signal-to-noise ratio. The detection part consists of picking the peaks of the correlograms and assigning them to different arrival paths. The extracted observations are the high-frequency data processing for detecting marine mammals. The records from separate hydrophones are converted to time-frequency plots, using short-time Fourier transforms. These spectrograms are then correlated to detect similar signals on the hydrophones. The peak locations give the relative travel times used for inversion in the localization step. Whale calls detected by the low and high frequency part of the system are shown in Figures 2 and 3.

Visualization

The detections from the low- and high-frequency systems are displayed in the Vessel Tracking System (VTS) which is available ship wide (Figure 4).

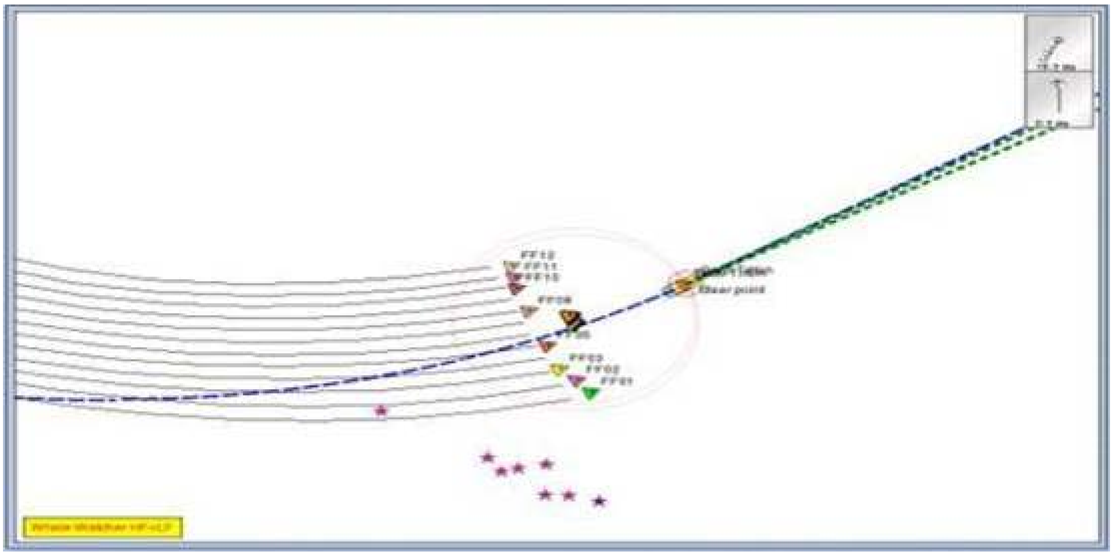

Figure 4. WhaleWatcher localization display.

QC tools

WhaleWatcher may detect any point-acoustic source in the sea. The system automatically applies filters to take away some of the unwanted detections, for instance noise coming from the vessel itself, but still the detections need to be verified prior to establishing that this is actually a whale.

Once the WhaleWatcher system reports detection, the MMO on the bridge can use the estimated location of the whale to try to get a visual confirmation. If it is during periods of low visibility, e.g. at night, or there is no spot of marine mammal from the MMO, the observers can revert to the WhaleWatcher QC plots. Currently, the WhaleWatcher system provides two types of QC plot, one is FK plots from each subsection of streamers for the low frequency processing, and the other is spectrogram plots for all the channels used for high frequency processing (Figure 5).

The observers are trained to use these QC plots to determine whether the detection is a whale or not by looking for consistent signal across several hydrophones or subsections, and by comparisons with QC plots from the shots just prior to or after the detection was made.

The key advantage of the system is the huge aperture and large number of closely spaced point receiver hydrophones, and the capabilities have been verified in the field world-wide.

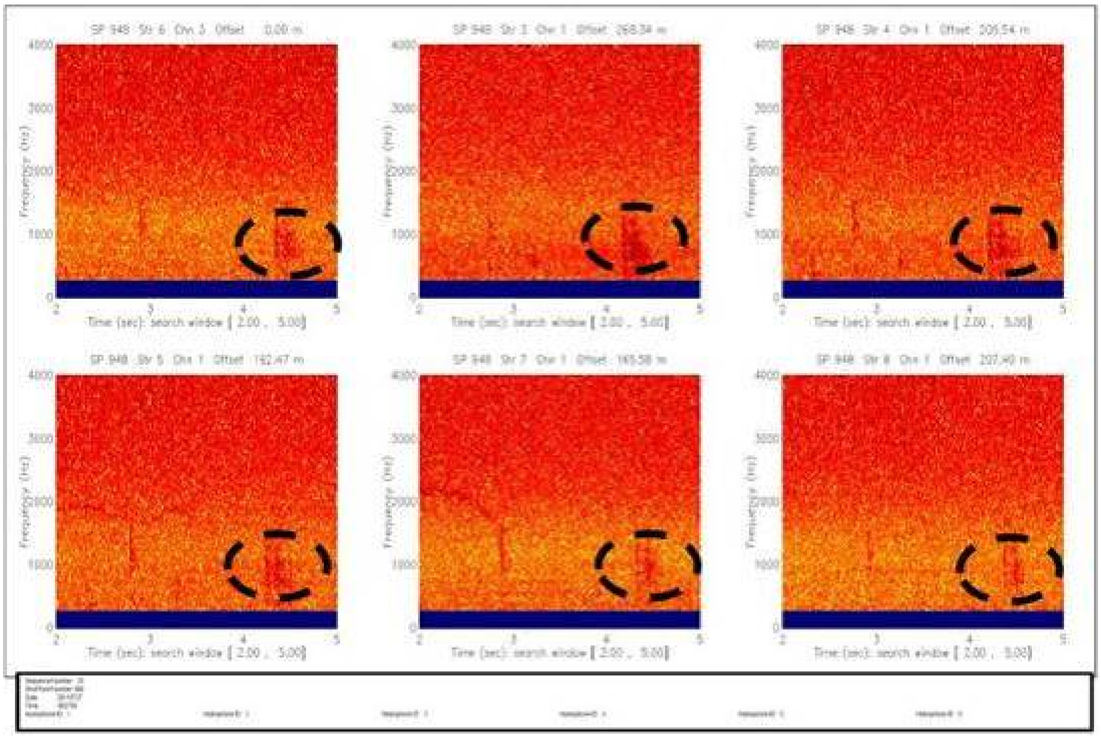

Figure 5. High frequency whale detection QC plot.

11. DEPLOYING PORPOISE ALERTING DEVICE (PAL) IN BALTIC AND NORTH SEA GILLNET FISHERIES

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SUMMARY

Annually, large numbers of harbour porpoises (*Phocoena phocoena*) perish in gillnets as unintended bycatch. Conventional deterrents such as pingers may lead to habituation, habitat exclusion and noise pollution. The novel Porpoise Alarm (PAL) alerts the animals in the vicinity of nets by increasing their acoustic awareness (Culik *et al*. 2015) without deterring them, thereby effectively mitigating by-catch.

The fisheries version PALfi (Figure 1) produces 3 synthetic porpoise-like alerting signals per Minute. Each upsweep chirp has a duration of 1.3 s and consist of 700 clicks (SL 151db ± 2dB p-p re 1µPa at 1 m; centre frequency 133 kHz ± 0,5kHz). PALfi are attached to the headrope of gillnets and spaced 200 m apart. Like most pinger types, PALfi are directional and all have to be attached facing the same direction to avoid acoustic "holes".

Figure 1. PALfi attached to gillnet floatline.

The majority of by-catches occurred in control nets without PAL (c.f. text for details).

Between September 10, 2013 and November 6, 2014 we deployed and re-deployed a total of 524 PALfi in German and Danish gillnet fisheries in the Baltic and North Sea (Figure 2), each for a duration of approximately 45 days (corresponding to the safe battery autonomy of the experimental prototype). Simultaneously to nets equipped with PALfi, approx. the same number of standard nets were set and served as controls. Details of fishing operations were reported by the fishermen via protocols and for many trips additionally monitored by on-board video-equipment or scientific observers.

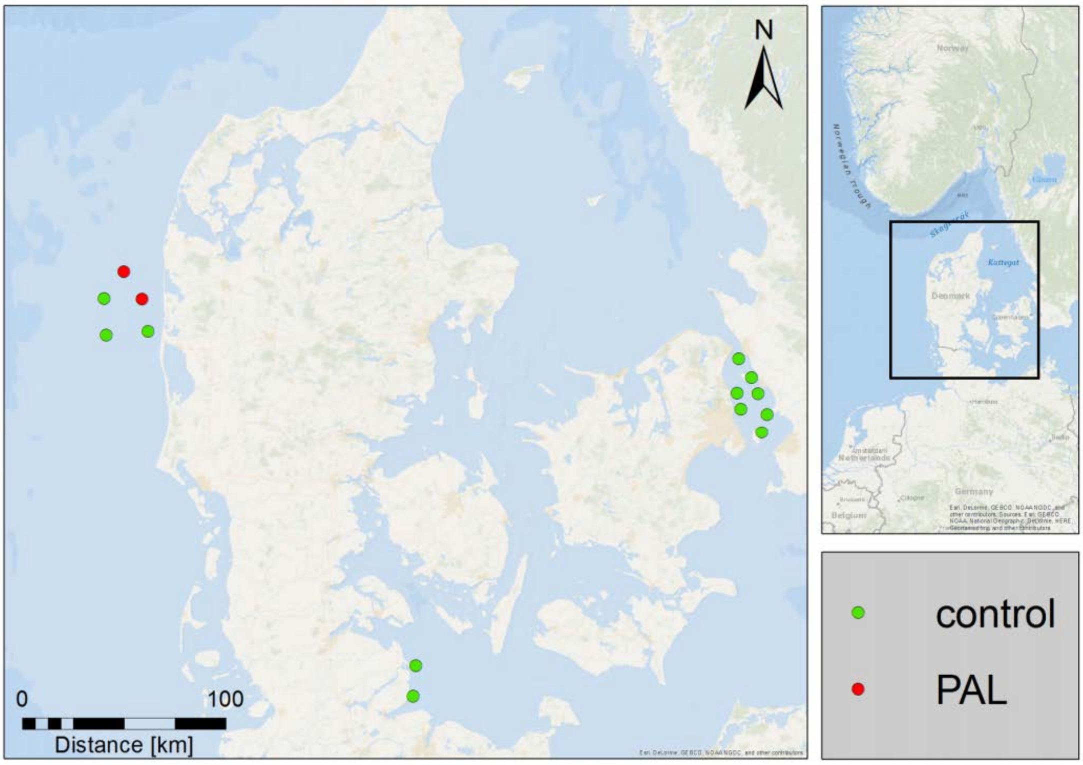

Figure 2. 2014 tests of PALfi against unequipped nets in Baltic and North Sea fisheries.

A total of 14 porpoise by-catch events were reported during the 14 month field test: 12 in control and 2 in PAL nets (p= 0.006, binominal test). In the Baltic, 9 porpoises were reported from control and 0 from PAL-equipped nets (p=0.002). In the North Sea, 3 porpoises were reported from control and 2 from PAL-equipped nets (p=0.5).

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12. MARINE MAMMAL OBSERVATIONS DURING SEISMIC SURVEYS IN UK WATERS: EFFECTIVENESS OF THE SOFT START PROCEDURE AND GENERAL OBSERVATIONS ON IMPLEMENTATION OF THE GUIDELINES

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EXECUTIVE SUMMARY

Data from Marine Mammal Observer (MMO) reports from UK and adjacent waters between 1994 and 2010 were examined to assess the effects of seismic operations on marine mammals (Stone 2015a) and compliance with the JNCC guidelines (Stone 2015b). Data were examined for any specific response to the soft start procedure (Stone 2015a), as well as examining overall trends in compliance and implementation of the guidelines (Stone 2015b), comprising analysis of data from both visual and passive acoustic monitoring (PAM).

There was evidence that the soft start procedure may be an effective mitigation measure, with overall detection rates of cetaceans during the soft start being significantly lower than when the airguns were not firing. On surveys with 'large arrays' (airgun volume of 500 cubic inches or more), more cetaceans were observed demonstrating avoidance behaviour (e.g. avoiding or travelling away from the survey vessel) during the soft start than at any other time.

Analysis of compliance and implementation of the guidelines highlighted that visual monitoring overall was more effective than PAM at detecting marine mammals and noted potential areas of improvement for both PAM technology as well as PAM operators. Examples of where the seismic guidelines could be improved included for example, strengthening and clarifying some of the existing mitigation measures, guidance on the use of PAM and further training elements for both MMO and PAM operators to ensure the guidelines are fully implemented.

Full details of these studies can be found in the JNCC published reports referenced below.

ACKNOWLEDGEMENTS

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Soderstrom, Sarah Dacre and Julie Cook (Department of Energy & Climate Change (DECC)) provided comments on previous versions of the manuscripts.

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13. ACHIEVING UNDERWATER NOISE REGULATION THROUGH AN ECOSYSTEM BASED APPROACH: THE "MEDITERRANEAN STRATEGY ON UNDERWATER NOISE MONITORING"

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INTRODUCTION

In the framework of the Mediterranean Action Plan of the United Nations Environment Program (UNEP/MAP), the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) defines pollution as follows: "Pollution" means the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results, or is likely to result, in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of seawater and reduction of amenities (article 2-a). Today, underwater noise is identified as the most widespread and pervasive form of anthropogenic energy with respect to light and other electromagnetic fields, heat and radioactive energy (Dekeling *et al*., 2013a). Therefore, initiatives aiming at addressing pollution from anthropogenic energy are currently focused on underwater noise. In this regard, the Contracting Parties to the Barcelona Convention are considering the issue of underwater noise pollution under the ongoing implementation of the Ecosystems Approach process (EcAp, Decision 17/6).

In order to assess the environmental status of the Mediterranean, eleven Ecological Objectives (EOs), and respective operational objectives and indicators have been agreed through Decision 20/4 during the 17th Meeting of Contracting Parties (COP 17). In line with the Marine Strategy Framework Directive of the European Union (2008/56/EC), the overarching principle of the EcAp is the achievement of the Good Environmental Status (GES). According to the definition contained in the Decision 20/4, GES related to EO11 is achieved when noise from human activities causes no significant impact on marine and coastal ecosystems. In this context, the Agreement on the Conservation of Cetaceans of the Black Sea, the Mediterranean Sea and the contiguous Atlantic area (ACCOBAMS), in accordance with the Secretariat of the UNEP/MAP, launched a study to develop a basin-wide strategy for underwater noise monitoring in the Mediterranean. The present paper outlines the main elements of the Mediterranean strategy on underwater noise monitoring.

UNDERWATER NOISE IN THE MEDITERRANEAN SEA

The Mediterranean basin is an almost enclosed sea area highly exploited by humans. Some features belonging specifically to the Mediterranean region need to be taken into account while addressing underwater noise and its impact on the marine environment, such as the presence of highly sensitive and/or endangered species, the heavy human development of the coastal region and the high concentration of cumulative pressures in many areas.

It has been demonstrated that naval exercises involving the use of mid-frequency active sonars caused several mass stranding events of Cuvier's beaked whales along the coasts of the Mediterranean Sea and in other sea areas at least during the last 20 years (e.g. Frantzis, 1998; Fernandez *et al*., 2004; Martin *et al*., 2004; Podestà *et al*., 2006; Agardy *et al*., 2007; Filadelfo *et al*., 2009). The correlation between noise and strandings has not been identified with any other anthropogenic noise source, although this cannot be ruled out for the case of geophysical surveys (e.g. Southall *et al*., 2013; Castellote and Llorens 2013). There is concern however that such anthropogenic noise sources may play a role in increasing stress on marine fauna (Rolland *et al*., 2012). A relationship between noise and cetacean reactions has been identified also for ship noise and beaked whales (Aguilar de Soto *et al*., 2006; Pirotta *et al*., 2012). Finally, based on recent IUCN assessments, several cetacean species are experiencing a decreasing population trend, e.g. the bottlenose dolphin and the sperm whale (Notarbartolo di Sciara *et al*., 2012; Bearzi *et al*., 2012). In this context, a proposal for a basin-wide regulation of underwater noise is developed by ACCOBAMS taking into account the potential impact of noise on sensitive and representative cetaceans of the Mediterranean Sea, i.e. the fin whale (*Balaenoptera physalus*), the sperm whale (*Physeter macrocephalus*) and the Cuvier's beaked whale (*Ziphius cavirostris*).

THE CHOICE OF INDICATORS FOR MONITORING AND ASSESSING ANTHROPOGENIC UNDERWATER NOISE

In order to be in coherence with the Marine Strategy Framework Directive of the European Union (MSFD) and to harmonise measures, ACCOBAMS noise experts propose to use the guidance for implementing the Descriptor 11 (D11) of the MSFD (Dekeling *et al*., 2013) as the basis for developing a monitoring and assessment strategy (and thus indicators) for the Mediterranean Sea. In this regards, two indicators are used addressing low and mid frequency impulsive noise and low frequency continuous noise.

IMPULSIVE NOISE INDICATOR

Taking the UNEP/MAP COP17 definition (2012), the indicator for impulsive noise is defined as follows: Proportion of days and geographical distribution where loud, low and mid-frequency impulsive sounds exceed levels that are likely to entail significant impact on marine animals.

In order to be in coherence with the definition given for D11, impulsive sounds are to be interpreted as source levels of anthropogenic sound sources. Further, ACCOBAMS noise experts propose to adapt the definition used for D11 concerning the meaning of “significant impact” as used in the indicator definition, as follows: severe and/or sustained and/or long-term avoidance of an area, and/or disruption of acoustic behaviour, i.e. stop calling or stop clicking.

Implementing this indicator can be achieved through the establishment by Contracting Parties of a register of maritime activities that use impulsive noise sources. Thus, based on the available knowledge on the acoustic biology/ecology of fin whales and Cuvier’s beaked whales, ACCOBAMS noise experts propose to set up the register including two different lists of human activities at sea, one for low-frequency impulsive noise sources, and one for mid-frequency impulsive noise sources. The former addresses the sensitivity range of the fin whale, and since significant impact caused by impulsive noise may occur at very long ranges (Borsani *et al.*, 2008; Castellote *et al.*, 2012), it is recommended that all activities using low frequency impulsive noise sources be included in the register, regardless of their source level. The latter list addresses the sensitivity range of sperm whales and Cuvier’s beaked whales, which have been identified to be highly sensitive to mid-frequencies (e.g. Aguilar de Soto *et al.*, 2006; Weir, 2008). As mid-frequency sounds travel less far than low frequency sounds, it is considered that not all mid frequency noise sources represent a potential danger. Thus, the list uses a threshold system as a condition for inclusion in the register. In summary, activities using low frequency impulsive noise sources to be considered for inclusion in the register are the following:

- Low frequency military sonar (LFA)
- Geophysical surveys (both commercial and scientific, using any source like airguns, sparkers, sub-bottom profilers, etc.)
- At sea or shore based detonations
- At sea or on shore pile driving (only for "assisted press-in systems" which include all types of piston-based hammers)

Activities using mid frequency noise sources to be considered for inclusion in the register in case of threshold exceedance are the following:

- Mid frequency military sonar: SL > 176 dB re: 1 µPa m
- Mid frequency acoustic deterrent: SL > 176 dB re: 1 µPa m
- Other non-pulse sound source: SL > 176 dB re: 1 µPa m
- Other pulse sound source SLE > 186 dB re: 1 μPa^2 m^2 s

Levels used as threshold follow the recommendations given in part II of the last report from TSG Noise (Dekeling *et al.*, 2013), and have been identified through a literature review of available dose-response studies. However, recent research suggests that beaked whales may respond to lower noise levels than those identified by TSG Noise (Deruiter *et al.*, 2013), and hence regular updates are needed as soon as new data become available. In order to establish the register, for each of the above activities, the basic information required to derive the number of days in which activities using impulsive sources occur in an area, is:

- Position data (geographic position: lat/long)
- Period of operation (start – end)
- Source Level dB re: 1µPa rms at 1m
- Number of hours of activity per day
- Duty cycle (ON/OFF ratio) or % of time ON
- Frequency range
- Source level (for mid-frequency sources)

Concerning the temporal scale, ACCOBAMS noise experts recommend using 1 year as a basis for monitoring impulsive noise, in coherence with Descriptor 11 of the MSFD. Hence, the indicator addresses the number of days within 1 year in which activities generating impulsive sounds take place. With regard to spatial management, a grid size of 20 x 20 km is proposed based on a study conducted on Cuvier's beaked whale management in the Mediterranean Sea (Azzellino *et al.*, 2011). This grid size would enable assessment of the potential habitat loss for beaked whales.

AMBIENT NOISE INDICATOR

UNEP/MAP COP17 (2012) define the indicator for ambient noise as follows: Trends in continuous low frequency sounds with the use of models as appropriate. However, using a threshold appears as a better option for the objectives of the UNEP/MAP with respect to monitoring trends. Therefore, ACCOBAMS noise experts propose to simplify the definition of the ambient noise indicator as follows: Levels of continuous low frequency sound with the use of models as appropriate.

Monitoring ambient noise means looking at noise levels and at their changes in time. This can be achieved through in-situ measurements as well as with the use of models and mapping techniques. ACCOBAMS noise experts recommend to use both methods as they are complementary in terms of result quality. Measurement devices should be sited according to a range of requirements and needs:

- Monitoring in both high traffic and low traffic areas, also searching and including spots where noise levels are supposed to be the lowest
- Balancing costs and effectiveness. In this regard, existing oceanographic stations (e.g. EMSO/INFN/INGV networks (Favali *et al.*, 2013) should be used for noise monitoring along with other oceanographic variables already being monitored
- Considering local topography and bathymetry effects (e.g. monitoring near pronounced coastal landscapes or islands/archipelagos)
- Avoiding sources of interference. Locations close to other sound producing sources that might interfere with measurements e.g. oil and gas exploration or offshore construction activities. Furthermore, deep monitoring stations, either autonomous or cabled, should be used whenever possible in order to limit the influence of surface and sub-surface noise.
- Taking into account cetacean habitats. Monitoring station should be primarily located in important cetacean habitats, e.g. as identified by ACCOBAMS (see Fig. 1)

ACCOBAMS noise experts propose to monitor ambient noise in selected low frequency third-octave bands:

- 20 Hz, based on the potential masking effect of ambient noise on fin whale calls (Watkins, 1981)
- 63 Hz, based on the frequency bands where noise from shipping is most likely to dominate over other sources according to Tasker *et al*. (2010)
- 125 Hz, based on frequency bands where noise from shipping is most likely to dominate over other sources according to Tasker *et al*. (2010)
- 250 Hz, based on frequency bands where noise from shipping is most likely to dominate over other sources according to Mediterranean data (Castellote, 2009; Pulvirenti *et al.*, 2014)
- 500 Hz, based on frequency bands where noise from shipping is most likely to dominate over other sources according to Mediterranean data (Castellote, 2009; Pulvirenti *et al.*, 2014)
- 2000 Hz, based on the potential masking effect of ambient noise on sperm whale clicks (Madsen et al., 2002)

The metric recommended for calculating ambient noise levels for D11 is the annual average of the squared sound pressure (or annual mean SPL) in third octave bands expressed as a level in decibels, in units of dB re: 1 µPa. Such a metric can be adopted for the ambient noise indicator of the EO11. However, ACCOBAMS noise experts consider that a finer temporal resolution is needed to better monitor seasonal departure from GES and hence the use of percent exceedance levels is necessary. Assuming that the strongest seasonal effect on ambient noise during a year is recreational craft occurring from June to September (4 out of 12 months), the L33.3 index, i.e. 33.3% Exceedance Level, is proposed as second metric, to be used together with annual mean SPL.

Figure 1. Areas of special importance for cetaceans in the ACCOBAMS area (ACCOBAMS Resolution 4.15, 2010).

APPROACHES FOR THE ACHIEVEMENT AND MAINTENANCE OF GES

Taking into account the basic concepts for developing the present monitoring strategy, the best option appear to be the use of thresholds for both impulsive and ambient noise. Considering the impulsive noise indicator, two thresholds are actually required, i.e. the number of days over a year and the number of cells over the 20 x 20 km grid, while one threshold expressed dB re 1μPa (rms) is needed for the ambient noise indicator. As little knowledge exists on baseline values for both indicators, ACCOBAMS has planned to work on dedicated research projects aimed at providing the necessary baseline information to identify thresholds to be used for GES assessment. Finally, by analogy with human environments, the “acoustic comfort” is a useful concept that can be recalled with a view to attain the good environmental status. Research effort aimed at defining acoustic comfort for marine mammals (and other marine creatures) are very likely to help in defining and/or updating thresholds needed for implementing EO11.

CONCLUSION

This paper outlines the main elements of the Mediterranean strategy on underwater noise monitoring. This strategy was developed to meet the needs of the Ecosystems Approach (EcAp) initiative undertaken within the UNEP/MAP. The basis for such strategy was the guidance for the implementation of the Descriptor 11 of the MSFD and therefore two indicators are proposed addressing space-time distribution of impulsive noise sources and levels of continuous noise through the use of measurements and models. The proposed strategy on noise monitoring recommends several adaptations for the Mediterranean case. Particularly, both indicators are more closely related to the acoustic biology of key marine mammal species of the Mediterranean which are known to be sensitive to noise, i.e. the fin whale, the sperm whale and the Cuvier's beaked whale. The proposed monitoring strategy represents a further important progress towards an effective and widely agreed regulation of underwater noise at a regional scale. Last but not least, scientific research is encouraged to better understand the biological and behavioural responses to disturbance at different levels and spatio-temporal scales.

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14. ASSESSING THE MITIGATION ZONE – NOISE MODELLING AND ACOUSTIC GROUND TRUTHING IN NEW ZEALAND

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ABSTRACT

Globally the need to monitor noise from anthropogenic activities is increasing in line with local legislative requirements. These activities include pile driving, shipping, and seismic noise among others. In New Zealand, under the 2013 Code there is a requirement to perform a desktop sound transmission loss modelling study as well as *in situ* acoustic ground-truthing during seismic survey operations, where activities are planned in or close to Areas of Ecological Importance or Marine Mammal Sanctuaries. Noise modelling is a requirement of the Marine Mammal Impact Assessment (MMIA) and aims to predict the received sound levels at various distances taking into account the specific airgun array configuration as well as environmental conditions within the survey area. Ground-truthing is undertaken in order to compare the actual noise levels of the sound source used during the survey with those predicted by sound transmission loss modelling. The 2013 Code defines the behavioural threshold for species of concern and other marine mammals as being a Sound Exposure Level (SEL) exceeding 171 dB re 1 μPa2s at distances corresponding to the relevant mitigation zones for Species of Concern and other marine mammals, and the injury threshold as being an SEL exceeding 186 dB re 1 μPa2s at a distance of 200 m. Gardline's experience of undertaking both desktop based modelling and field based ground-truthing has shown that the results of these two approaches often vary, depicting different distances for corresponding SELs. More specifically, during a recent case study (utilising a geophysical seismic survey performed in Pegasus Basin) the results of the ground-truthing show noise decays below both the behavioural and injury thresholds at distances far less than those predicted by the sound transmission loss modelling. This suggests that in this case the present mitigation zones as stated in the 2013 Code are very precautionary and more than adequate in the protection of Species of Concern. This raises questions over the accuracy of noise modelling methods, the value of ground-truthing and clearly indicates a need to improve modelling to a level that predicts more reliable results, as well as the need to develop standardised methods and criteria used across the industry.

INTRODUCTION

The 2013 *Code of Conduct for Minimising Acoustic Disturbance to Marine Mammals from Seismic Operations* superseded the original 2012 Code of Conduct which first came into effect on 1st August 2012. The Code is the result of an extensive consultation process and represents one of the most comprehensive programs of mitigation measures aimed at protecting New Zealand's diverse marine mammal populations.

The 2013 Code outlines the requirements for planning and conducting seismic survey operations in New Zealand waters and is a stipulation of permitted activities under the EEZ Act 2012. The 2013 Code includes the compilation of a project specific Marine Mammal Impact Assessment (MMIA) which must be submitted to the Department of Conservation and Director-General.

A fundamental component of the MMIA is ensuring that the sound levels and propagation of the seismic source is understood and that the mitigation zones outlined within the 2013 Code are effective to protect the species identified to be present within the survey area. Should Sound Exposure Levels (SEL) exceed 171 dB re: 1 µPa2s at any of the relevant mitigation zones for Species of Concern or 186 dB re: 1 µPa2s at 200m then the mitigation zones should be extended or acoustic source should be reduce to avoid injury or disturbance to marine mammals. Modelling is particularly important where activities are planned in Areas of Ecological Importance (AEI) or designated Marine Mammal Sanctuaries (MMS). In these areas Sound Transmission Loss Modeling must be conducted and included in the MMIA and results collaborated through ground-truthing during the survey.

Anadarko New Zealand Company conducted seismic operations within the Pegasus Basin (Figure 1) from February to June 2014. The survey utilised 3600 cu in airguns throughout the 2D seismic survey to collect ~4500 line km of seismic data. The Pegasus Basin is within an AEI and lies within 10 km at its closest point to Clifford and Cloudy Bay MMS and as such Sound Transmission Loss Modelling and ground-truthing was conducted in line with the 2013 Code.

METHODS

Sound Transmission Loss Modelling was conducted utilising a RAMGeo model and environmental data collected from the field. Modelling revealed standard mitigation zones as per the 2013 Code to be effective for the purpose of seismic operations.

The 2013 Code requires ground-truthing of the Sound Transmission Loss Modelling to be conducted 'by appropriate means'. Traditionally in New Zealand, sound levels have been collected using the seismic streamers however globally alternative methods have been adopted. Such alternative methods utilises static hydrophones moored at set locations on the site and sail past methods using hydrophones from a dedicated survey vessel. This method and results are outlined.

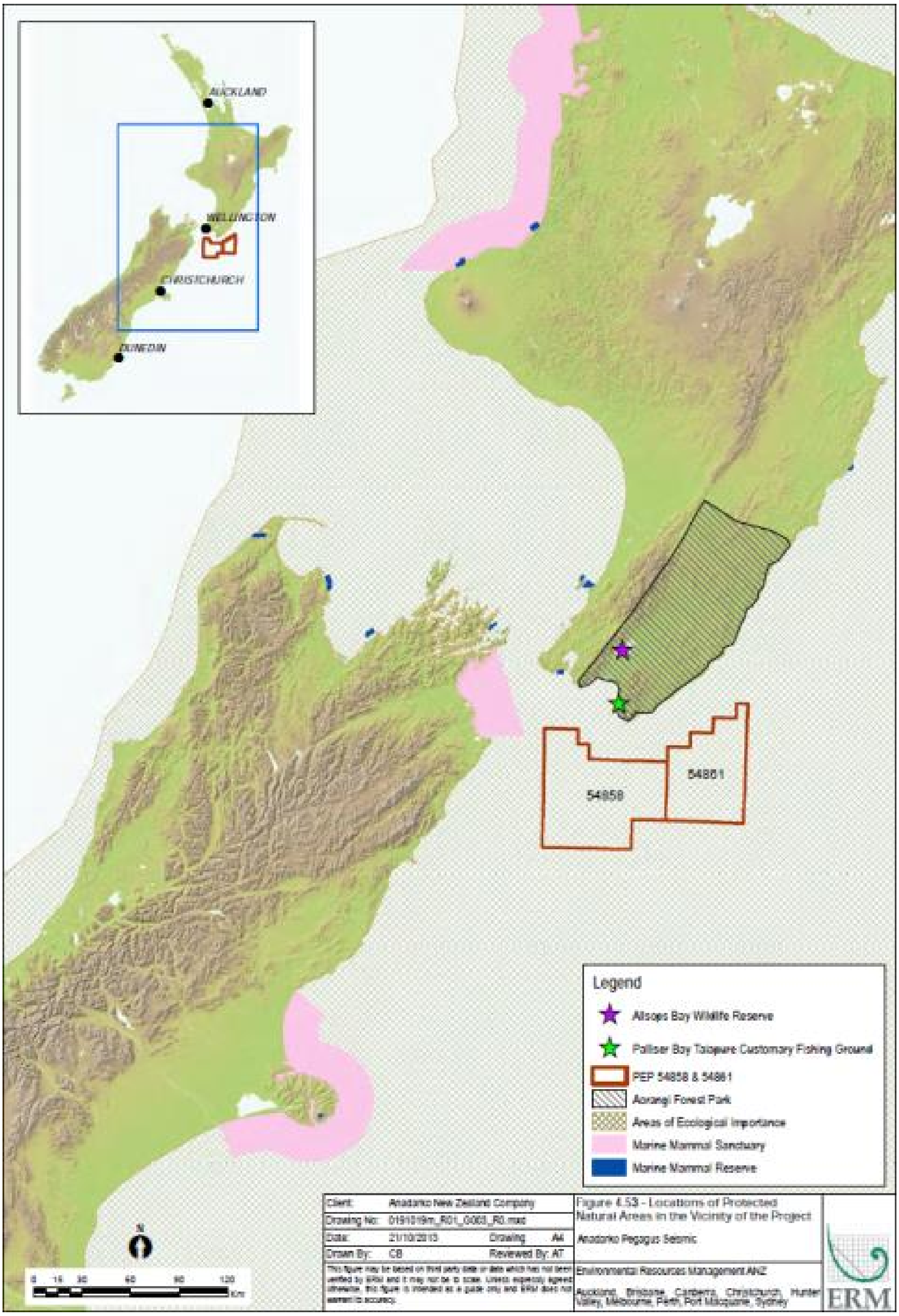
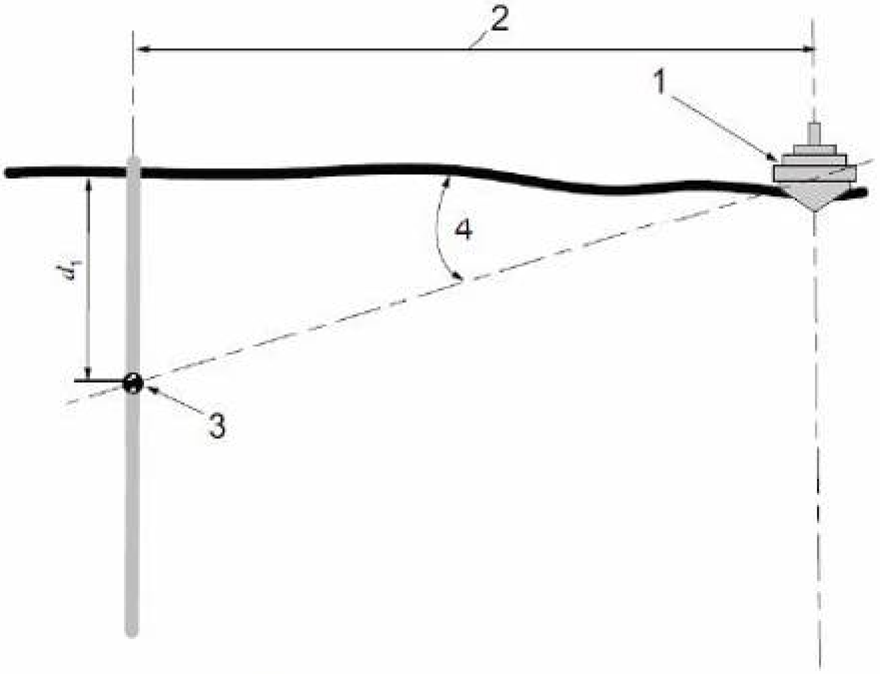


Figure 1. Survey area located south of the Cook Strait, southeast of Wellington.

The sail past technique followed methods outlined in ISO/PAS 17208-1:2012 (Figure 2) and uses dedicated hydrophones to monitor the full frequency range of 1Hz to 120kHz of operational noise with limited interference from background noise.

Moored monitoring used Autonomous Recording Units (ARUs) to monitor sound propagation vertically within the water column.



$d_1 = d_{CPA}\tan(20°)$. Use actual angle (4).

d_{CPA} = 100 m or one overall ship length, whichever is the greater.

ISO/PAS 17208-1:2012, ACOUSTICS — QUANTITIES AND PROCEDURES FOR DESCRIPTION AND MEASUREMENT OF UNDERWATER SOUND FROM SHIPS — PART 1: GENERAL REQUIREMENTS FOR MEASUREMENTS IN DEEP WATER.

Figure 2. General requirements for acoustic measurements in deep water following ISO/PAS 17208-1:2012 sail past methods.

Data was analysed to extract Sound Exposure Level (SEL), zero-to-peak and peak-to-peak Sound Pressure level (SPL), Root Mean Square (RMS) SPL, estimated energy level and peak pressure of airgun source, un-weighted received source levels, prediction of impact zones, cumulative exposure for marine mammals and a comparison with predicted impact ranges.

RESULTS

A total of 228hrs and 58 minutes of noise data was collected from the moored monitoring and sail past methods revealing background and airgun noise levels (Figure 3).

The highest airgun array noise was measured at a distance of 100 m from the airgun array (195.84 dB re: 1μPa^2 zero-to-peak and 200.32 dB re: 1μPa^2 peak-to-peak SPL and SEL of 165.80 dB re: 1μPa^{2}s). Received levels were back propagated to estimate the maximum source level to be 246.86 dB re: 1μPa^{2}m zero-to-peak, 251.34 dB re: 1μPa^{2}m^2 peak-to-peak SPL at 50 Hz and an un-weighted SEL at TOB (one-third octave band) of 216.82 dB re: 1μPa^{2}m^{2}s.

Impact ranges were assessed for low, medium and high frequency cetaceans and pinnipeds in water groups as noted in Southall et al. (2007) for both injury and behavioural disturbance using propagation loss modelling of seven different transects across this site (Figures 4 and 5).

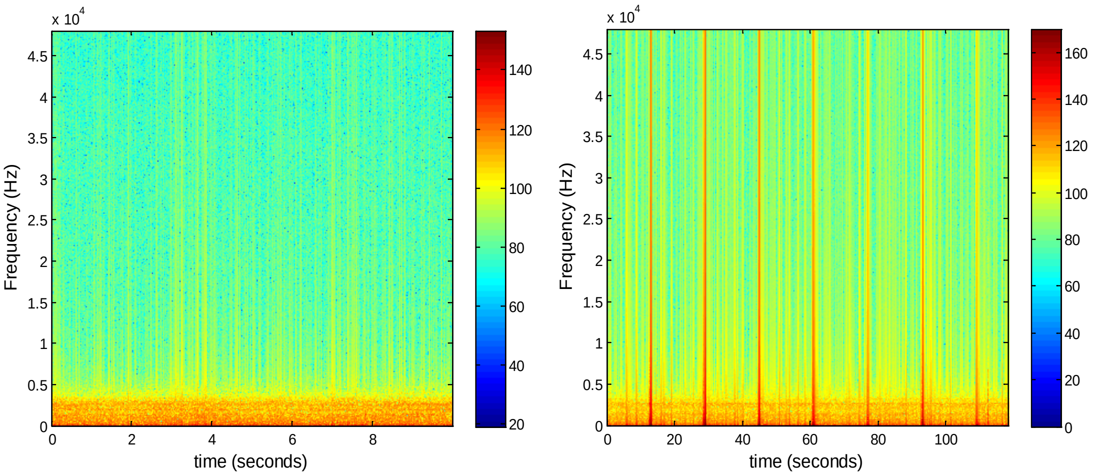


Figure 3. Spectograms showing background noise 1000 m from Clifford and Cloudy Bay MMS (left) and airgun noise at 4300 m from vessel (right).

Table 1. Comparison table of predicted injury and behavioural impact ranges for marine mammal groups as defined by Southall *et al.* (2007).

Species Group	Injury impact range (m)		Behavioural impact range (m)		Mitigation Zone (m)
	MMIA predictions	Ground-Truthing	MMIA predictions	Ground-Truthing	
High Frequency Cetaceans	<100	< 20	400	< 30	1000 - 1500
Mid Frequency Cetaceans	<100	< 20	500	< 30	200 - 1500
Low Frequency Cetaceans	300	< 20	1000	< 55	1000 - 1500
Pinnipeds in water	200	< 40	750	< 60	200

Figure 4. Propagation loss modelled across set transect lines.

CONCLUSIONS

Results of the underwater acoustic ground-truthing survey of seismic activities in the Pegasus Basin are displayed in Table 1 and revealed impact ranges to be between 3 and 50 times lower than those predicted in the MMIA and confirmed that the mitigation zones radius were more than effective and raises the following questions:

1. Is ground-truthing a cost effective requirement if they show mitigation zones to be more than precautionary.
2. Should sound source modelling be more accurate

This study poses the above questions and recommends that further comparisons of modelled and ground-truthed field data be made in order to assess and improve the quality of modelling used within the MMIAs

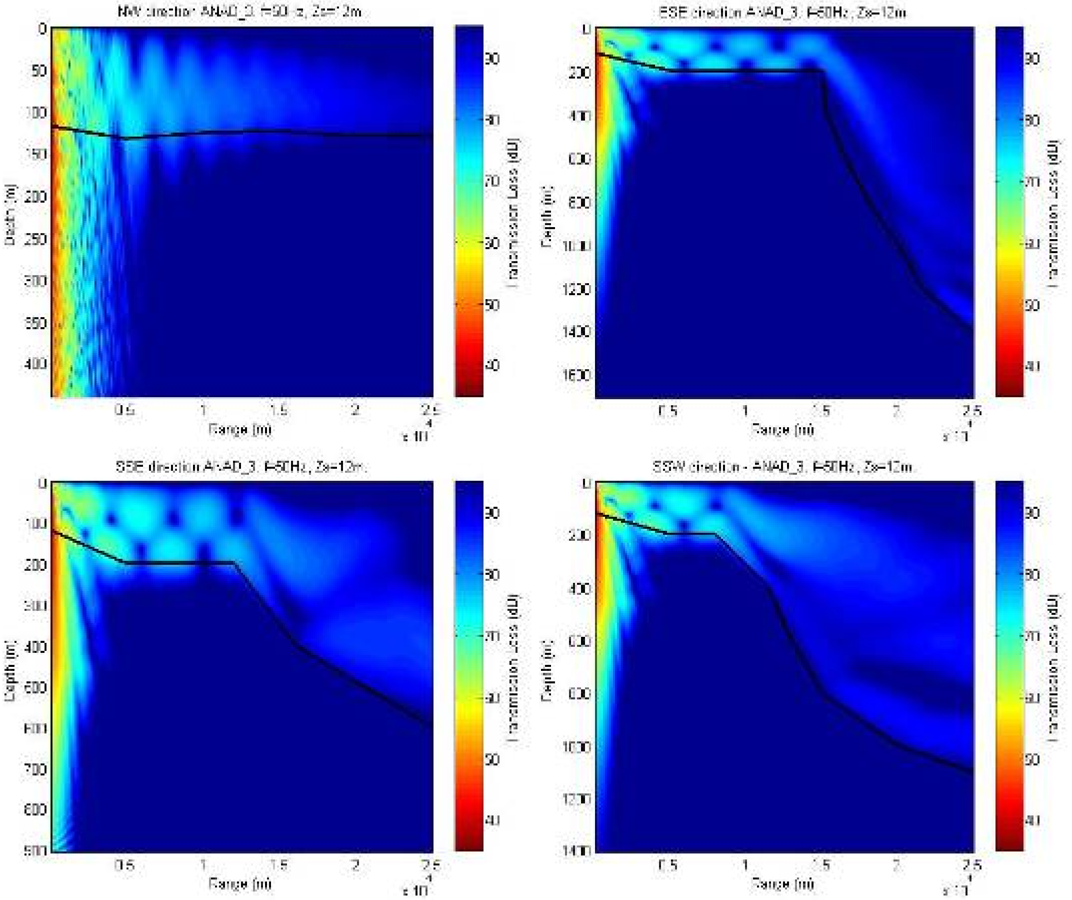


Figure 5. Propogation loss using RAMGeo showing effect of bathymetry along select transect lines shown in Figure 4 (NW, ESE, SSE, SSW).

ACKNOWLEDGEMENTS

Thank you to Anadarko for the use of the data collected during their Pegasus Basin Marine Seismic Survey.

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15. ACOUSTIC EXPOSURE GUIDELINES

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SUMMARY

Recognising the potential for intense acoustic exposures to have detrimental impacts on marine mammals and other marine life, the U.K.'s Joint Nature Conservation Committee 1998 guidelines for minimising acoustic impacts from seismic surveys on marine mammals were a global milestone (JNCC, 1998). Covering both planning and operations, they included various measures for reducing the potential for damaging hearing – an appropriate focus at the time. Many other nations have adopted similar guidelines, with many taking their lead from the JNCC's document. However, since their introduction, there has been a steep rise in the information available about the various impacts of acoustic exposures on marine life. As a result, many guidelines have been criticised for not keeping pace with these developments (see Wright, 2014, for a review). General criticism surrounds the many untested assumptions upon which such guidelines are based, as well as their limited ability to address non-hearing impacts. Moreover, these guidelines often define a minimum technology standard that is somewhat counter-productive to the inclusion of new technologies that might improve effectiveness. The various tools incorporated into current guidelines all have various limits to their effectiveness. Furthermore, prescriptive requirements often exclude the use of new technologies. These issues hinder the applicability of such guidelines to wider management frameworks and must be addressed to allow them to remain relevant and useful in the future.

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16. INCORPORATING NEW TECHNOLOGIES INTO ACOUSTIC EXPOSURE GUIDELINES: A DISCUSSION

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INTRODUCTION

Following the presentations, workshop participants were asked to provide opinions on the possible mechanisms that could be implemented to facilitate incorporation of new technologies into acoustic exposure guidelines that currently prescribe the use of marine mammal observers (MMOs) and passive acoustic monitoring (PAM) only. The ensuing discussion quickly expanded to consideration of the effectiveness of existing mitigation methods and technologies, such as MMOs and PAM, as well as the need for adequate data collection and the extraction of useful information from mitigation reports. Finally, some more fundamental issues with the underlying principles of mitigation protocols were raised. The following is a summary of the discussions and a list of key points as determined by the workshop organisers.

PERFORMANCE STANDARDS

New mitigation methods and technologies are being developed rapidly and it is clear that technology is way ahead of the regulations. There was clear agreement among workshop participants that regulators should not be recommending the use of any one system over another, although it could be argued that current guidelines requiring just MMOs and PAM are doing just this. Instead, guidelines are in need of a mechanism for testing and introducing new mitigation technologies as supplements or alternatives to current detection efforts. This could be achieved through the use of performance standards.

Performance standards need to be matched to the specific task, and perhaps one of the most important factors to consider is the species to be detected. For example, methods for detecting harbour porpoise vary greatly from those used to detect baleen whales (e.g., Gillespie, 2015). Accordingly, it may be necessary to establish some minimum detection criteria for each particular species (or groups of species) for testing new technologies, which could initially be simultaneously deployed with PAM and MMOs.

Regardless of what particular standard should be used, there was general agreement that species-specific performance standards may be more manageable than species-specific guidelines for each technology, as the number of systems and variations is increasing to unwieldy levels. However, some element of regional specific "certification" might also be required, as some detection technologies (such as infrared) function very differently under different temperature conditions (e.g., Zitterbart & Boebel, 2015). Other factors affecting detection rates include sea state, fog, time of day (e.g., day vs. night), noise conditions, etc. Strategic environmental impact assessments will likely be needed to consider all the various combinations of species and operating location in any effort to determining the best equipment for use.

During the discussion session it was noted that there may currently be some ongoing work to create a PAM Standard that might form a useful basis for a wider performance standard. Additionally, some of the presentations described suitable methodologies for evaluating effectiveness of new detection technologies that might prove to be useful for also assessing the drop-off in effectiveness with, for example, changing sightability conditions (e.g., deteriorating weather). Such information would allow us to estimate how many animals will be missed and potentially exposed to sound levels deemed to cause behavioural reactions or even harm, due to the fact that they remained undetected.

Mitigation methodologies are only part of the solution, however, as it would still need to be determined what the various detection criteria are within the performance standards. There are also questions surrounding whether or not MMOs and PAM systems (including their operators) should be held to the same performance standards. Alternatively, MMO detection rates could be used as the standard, although there is currently no formal standardisation of how a MMO performs their observation duties. For instance, there is no standardisation for the position of observers on any given vessel, although this particular example is partly due to ship-to-ship variations. Other considerations that would need to be standardised include scan protocols, equipment (e.g., binoculars), available distractions (e.g., mobile phones), duration of shift (a particular concern in areas that experience (near) 24-hour daylight in summer) and the point in the shift at which any comparisons with the performance standards are made. It was noted that the value of fresh observers and regular shift changes for maintaining MMO alertness, and thus effectiveness, cannot be understated.

Such considerations mean that even current mitigation methods would benefit from more research into their limitations and effectiveness, suggesting perhaps that they too should be compared against any set of adopted performance standards. It was suggested that one standard (or target) for detection rates might be those achieved during research activities, as scientists work hard to maximise the number of sightings in order to increase the accuracy and extent of their datasets.

Another suggestion was that the "standard" should be a nil detection rate and that each detection system (or combination thereof) could be measured by the extent to which it improves the situation. However, others noted that standards might need to consider the trade-off between the improvement in raw performance in terms of detection rates or exposure reduction and the additional financial investment. For example, some promising technologies such as thermal imaging may be (at least at present) prohibitively expensive. Similarly, some (but by no means all) seismic vessels are so loud that they can render the use of PAM impossible, meaning that detection rates could be drastically improved by implementing several quiet ship technologies. While several are too expensive to be commercially viable, modifications improving the efficiency of hull-propeller pairings can relatively inexpensively (at time of build) result in both a quieter and more efficient vessel. Nonetheless, the benefits in terms of improved PAM detection rates of any additional costs that are not offset by efficiency might need to be demonstrated.

For the same reason, regulators may need to be cautious about simply requiring any new detection technology as additional to the current MMO and PAM standard, unless there is a considerable increase in detections. New technologies could supplement and eventually replace the current mitigation standards in some situations, if they are more suitable. Though, at present completely replacing MMOs was highly discouraged, and this in turn, again raises the issue of performance standards.

In addition to meeting performance standards, additional concerns were expressed over the use of aversive sounds in mitigation. This was due to the additional noise they introduce to the marine environment that could either have the potential to exclude animals from (large) portions of their habitat, or give managers a false sense of security should habituation/tolerance prevail. Accordingly, the active acoustic mitigation sources and their consequences would need to be thoroughly tested prior to widespread implementation through mitigation guidelines.

PAM- AND MMO-SUPPORTED MITIGATION ZONES

PAM (like other mitigation measures, including MMOs) is a combination of the operator and the equipment in use. In addition to the above mentioned difficulties in detecting the target species, training and experience (in terms of quality as well as duration) both play a role. Any training for operating PAM and other systems needs to include at least some elements of equipment troubleshooting, unless guidelines require that a technician is also on board – which is unlikely given the additional expense that it would entail. One option would be to require that crew already tasked with technical/engineering roles related to acoustic equipment are given training in maintenance of PAM gear. Alternatively, accredited courses can be offered on PAM (etc.) system maintenance as well as operation and guidelines. There should also be a push within the MMO / PAM industry for greater prospects in terms of continuous professional development to encourage existing observers/operators to stay in the industry and (further) develop relevant skill sets.

However, the question remains about how the MMO / PAM industry, the oil and gas industry, and regulators deal with bad observers and operators. Requirements for pre-training qualifications and/or experience (such as field research with marine mammals) would be helpful in reducing the number of bad observers, but unlikely to eliminate them entirely. Professional development issues may be addressed, at least partly, through a stepped training system. For example, a training scheme based around course modules where a general course in MMO/PAM comes with the pre-requisite of a certain amount of field experience, followed by courses that address implementation of regionally specific guidelines. Other subsequent key course modules could include equipment competence and full maintenance courses (especially for PAM systems). However, no requirements or regulations can fully consider the differences in observer motivation that might come into play during operations: are they really interested in being at sea and seeing and protecting the animals; or are they just in it for the money?

The responsibility for employing experienced and effective observers ultimately lies with the operator and/or the consultancy group. However, despite the fact that an operators' licence may be on the line, there is no immediate economic driver for these entities to ensure that a 'good' job is done. In fact, there are economic benefits linked to low detection rates, especially in areas where shut downs are required. One suggestion was to reframe the regulatory context to provide incentives for greater detection rates. Perhaps these could be limits to allowable (high-level) exposure counts, which would reward efforts to detect animals before they enter the exclusion zone, for instance. This could be associated with penalties for exceeding such allowances (which should cost more than the use of suitable technologies). Alternatively, some sort of certification/seal system for low-exposure rates could be implemented. Another tactic might be that night-time activities are only permitted in situations where the suite of detection technologies has been deemed above some level of effectiveness. This is already the case in some situations when a working PAM system is required for night-time activities, even though its effectiveness has yet to be determined.

As mentioned above, there remains a fundamental need for the effectiveness of PAM to be studied. In areas where there are different species present, especially if they have different levels of protection, it is necessary to have a good indication of how often the PAM system is able to accurately identify which species it is detecting. More generally, PAM usefulness is seriously compromised when: (a) animals are not vocalising; (b) the system or system settings are inadequate or inappropriate for the task at hand; or (c) when noise from the seismic vessel itself interferes with the system. The latter issue might merit issuing noise-limits on night-time start up. In any case, hydrophone placement and location needs to be considered and perhaps standardised within guidelines. Twin arrays may prove useful in addressing the issue of noise, as well as improve localisation of detections. Another option is to utilise the streamers themselves: which seems like an obvious solution, although there has been little movement in this area due to a lack of financial interest and/or incentive. However, there have been some recent developments in this area, as demonstrated by the two presentations on this topic at the workshop (L'Her, 2015; Svendsen, 2015). Challenges to more widespread implementation include the need to improve the detection capabilities for various target species, as well as the current cost and various proprietary restrictions. It was also noted that this would place the hydrophones behind the source, increasing distance to the leading edge and potentially reducing detections in that area – multiple deployments might be optimal.

BEYOND TRADITIONAL SEISMIC SURVEYS

Workshop participants noted that not all elements of typical guidelines can be applied to all seismic surveys. For example, soft starts may not be suitable for vertical profiling / borehole seismic surveys, as these may involve longer duty cycles that could create a different exposure profile that might be more problematic than more traditional survey shooting cycles. It may also be necessary to extend seismic-style guidelines for other sound sources (e.g., multibeam sonars), as Ireland is already doing for near-shore (in and within 1.5 km of bays and estuaries) waters (despite the fact that the lowest frequency multibeam sonars with the highest source levels will be active offshore). The UK already has some more generalised guidelines that do focus on deep water. Again, not all mitigation options would be transferable from seismic surveys to other sources. For example, soft starts may not be an option for some sources, such as multibeams. In this case it might be possible to alter duty cycles for similar effect, but this would represent a new mitigation technique that would need to be individually assessed for effectiveness. The suggestion was made that effort could be made to produce a custom-built ramp-up that could be used across all sound sources (including military sonar) so that the properties could be specifically tailored to the task at hand and to make demonstrations of effectiveness less onerous.

In any case, multi-source operations may require more planning and various mitigation technologies to effectively limit impacts. Overlapping sound production with different sources (e.g., airguns, multibeam sonar, pingers, chirpers, sparkers, etc.) is likely to complicate assessments of impact, by producing sounds at different frequencies and generating heightened potential for masking and other consequences for marine life. The resulting cumulative exposure may induce cumulative impacts not accurately represented by assessments of the most prevalent source alone. In contrast, certain sources may pale in comparison to others when they are used at the same time. Additionally, other factors may be more important than raw source levels. For example, multibeam levels may be less important than survey design in combination with local topography/bathymetry.

Given the various different sound sources and the many unknowns in terms of mitigation effectiveness for each one, it was suggested that the German approach to managing pile driving (e.g., setting a sound exposure level of 160 dB re 1µPa^{2}s or the peak sound pressure level of 190 dB re 1µPa as a threshold at 750 m from a source) might be a useful model for seismic surveys and other sources in general. Such a model might also inspire development of more directional airguns and other seismic sound sources, an area of development that has seen little improvement due in part to lack of acknowledgment, but also incentive. Similar issues have held back efforts to reduce sound produced at unnecessary frequencies, the impacts of which on the activities of many species may be overlooked in 'favour' of consideration of the impacts of the higher-level low frequencies.

COLLECTION AND USE OF MITIGATION DATA

At present the majority of mitigation reports are woefully inadequate. This is due in part to the fact that regulators have not known the right questions to ask and this is particularly evident with PAM reporting. PAM reports should include much more information about the system itself than is currently required, as well as its use throughout the survey, in terms of capabilities and settings, frequencies recorded/displayed, efforts and online times, etc. For example, extended periods without PAM detections, especially at night, could be accompanied by an explanation for why this might be the case – perhaps there was a support vessel near the equipment increasing noise levels for the system. Another useful addition would be noise levels at times of sighting/changes in behaviour/etc. for a better analysis and understanding. The date and results of the last hydrophone calibration would also be useful. Similarly, MMOs should be required to find a position that is high up with a good view of the mitigation zone, and to report any restrictions on viewing 360 degrees to facilitate effective use of sightings data.

Regardless of the limitations, better use of the existing MMO and PAM record data is needed. A certain amount of quality control (QC) will be required as the completeness and accuracy of the record varies greatly, and even in the best situations human error remains a factor. Furthermore, the various uses of this data need to be carefully assessed to determine if they are appropriate. For example, the data may, in some locations, represent a high proportion of sightings records and should be incorporated into species assessments and analyses of baseline data, acknowledging the various caveats.

However, the abilities of observers to detect animals, both visually and acoustically, may often be influenced by the animals' behavioural responses to the seismic operation itself. Detection rates may thus be affected by behavioural responses to human activities. . For example, recent acoustic studies of bowhead whales (*Balaena mysticetus*) in the Beaufort Sea suggest that this population varies their calling behaviour in areas ensonified by seismic sounds (Blackwell et al. 2013, 2015). Blackwell et al. (2013) initially discovered that bowhead whale calling rates dropped significantly at sites where the median received sound levels from airgun pluses were 116-129 dB re 1µPa rms, compared to calling rates that remained unchanged at sites further from airguns where median received levels were 99-108 dB re 1µPa rms. However Blackwell et al. (2015) subsequently determined that bowhead whales exhibit a two-fold reaction to airgun sounds. Initially, as soon as airgun sounds became audible, bowhead whales increased their calling rates. However, once cumulative sound exposure level exceeded ~127 dB re 1µPa 2-s the whale's calling rates began to decrease until they became virtually silent at exposure levels above ~160 dB re 1µPa 2-s (Blackwell et al. 2015).

Similarly, animals may be changing their behaviour at distances too large to be observable from the seismic vessels resulting in lower visual detection probabilities, as is also the case with bowhead whales (Robertson et al. 2013, *in press*). Such changes to acoustic and diving behaviours may thus be (wrongly) interpreted as avoidance, or simply that the animals are not present in the area at all. Consequently, avoidance and many other more subtle behavioural responses to oncoming seismic vessels may be very hard to detect in the visual and acoustic data as they may have already occurred at distances beyond detection and are thus almost certainly under-represented. Data mining efforts taking this into account may thus be quite an effort, requiring reasonable resource allocation.

Although regulators hold the data and would thus be responsible for their appropriate use, the financial burden could be shifted to industry through either mandated or voluntary cost-recovery mechanisms. Similarly, the cost of effective stranding recovery and necropsy could also be transferred to industry. It was noted that this has been the case recently in New Zealand: if there are strandings in the vicinity during the seismic surveys the necropsies are paid for by the oil company. (Note: DOC's experience here suggests that regulators might act as intermediates through a cost-recovery mechanism, rather than have industry pay for strandings directly to avoid public perception problems.) Finally, while it is important to have the right information in the reports, it is also important to realise that this will not solve any problems, simply improve our knowledge about how big the problems are.

BACK TO BASICS

It was noted that all of the current mitigation efforts are centred on reducing damage to hearing and other physical impacts. Despite titles to the contrary, none of them actually address disturbance. This may be partly because there is no currently working definition for what constitutes a “disturbed” animal. One way to address this is through better (and early) planning with a good amount of baseline data: a combination that remains a critical, but often overlooked, mitigation tool.

CONCLUSION

Current mitigation efforts are centred on reducing damage to marine mammal hearing and physical impacts, but offer little in terms of reducing disturbance. This is complicated as there does not appear to be a working definition for what constitutes a “disturbed” animal; an issue that may need to be addressed before mitigation effectiveness can be assessed.

What is clear is that mitigation efforts and specifically guidelines require much work surrounding the testing and introduction of new detection and mitigation technologies. However it is important that regulators do not favour one particular system over another – something that is arguably already a common occurrence as regulators rely only on the use of MMOs and PAM systems for marine mammal mitigation at present. The development of performance standards against which all mitigation efforts could be tested would allow for operators and regulators to effectively and objectively assess different methods and choose those that are most appropriate to the project. Such standards would need to be matched to specific tasks (e.g., detecting certain species in a given region under certain environmental conditions, etc.) and should be applied to the current MMO and PAM methods as well as new technologies.

Performance standards may also be the key to addressing the likely need to extend seismic-style guidelines to new source technologies (e.g., vibroseis), as well as other anthropogenic sound sources (e.g. multibeam sonar). It was suggested that exposure threshold-based approaches (e.g., German threshold of 160 dB re 1μPa^{2}s/190 dB re 1μPa at 750 m for piledriving) might be a very useful tool for easing regulation of source-mitigation pairings and driving technological development. In the interim, adaption of current guidelines to these sources would still offer some level of protection for marine mammals in comparison to the current total absence. However, it should be recognized that not all mitigation options would be transferable. There would also be issues with attempting to adapt provisions relating to planning, modelling and mitigating multi-source operations in current guidelines to multi-source operations.

To date there has been little assessment of the effectiveness of commonly applied MMO and PAM mitigation methods and therefore there are no specific standards to which these mitigation approaches are held, yet both have known limitations. For example, PAM settings and the deployment location of both MMOs and PAM equipment can seriously impact detection rates and thus also mitigation effectiveness, suggesting that better regulation, recording and reporting are required. For example, there is a clear need for minimum standards in terms of qualifications and experience of MMOs and PAM operators, their equipment, and mitigation/data collection protocols. Better data collection and reporting protocols would allow regulators more opportunities to assess the effectiveness of different PAM systems and settings, as well as the effectiveness of MMO-based mitigation compared to PAM-based (or other alternative) mitigation. With this in mind, individuals working in this field should also be encouraged to be continuously improving on any minimum standards.

Differences in reporting quality have made it very difficult for regulators to take full advantage of the data collected by MMOs and PAM operators. The JNCC (as reported on during the workshop) recently published a new summary of their MMO and PAM reports. However, they still faced issues surrounding limited data availability. While acknowledging all the above-mentioned limitations as caveats, MMO and PAM data can provide information on the effectiveness of these mitigation methods, as well as on the distribution of marine mammal species. The latter is particularly important when seismic activity takes place in regions where there is little scientific research. Some examples of occasions when MMO data have been used for scientific publications include de Boer (2010a, b,c), Koski et al. (2008, 2009), Weir (2006a,b; 2008a,b; 2010; 2011), Weir and Coles (2007), Weir et al. (2007; 2008; 2010; 2011; 2012). However, it must be noted that the majority of these simply present new species records or discuss overt behaviours (including responses to the seismic survey), rather than representing a thorough analysis of MMO effectiveness. This is likely a consequence of the investments involved, both in terms of time and money, which supports the argument for encouraging industry to help cover the costs of such data analyses, as well as costs associated with stranding recovery and necropsies. Industry representatives present at the workshop stressed their keen interest in seeing more done with MMO and PAM data in all possible directions, but acknowledged that the current issues surrounding the state of MMO and PAM data often make meaningful analyses challenging.

As mentioned above, this lack of fully-analysed data makes it very hard for regulators to assess the effectiveness of commonly used (and thus also developing) detection technologies. However, many regulatory agencies are also simply not requiring the collection of the right data necessary for answering the various outstanding questions. Accordingly, it is hard or even impossible to usefully apply reported data to future management decisions. Addressing this mis-match would be of particular importance for supporting any decisions pertaining to the development and deployment of aversive sounds. Any such devices or mitigation systems would need thorough testing prior to deployment given the potential issues involved with both long-term successes and failures.

Effective mitigation should be the overarching goal of both regulators and industry, whether it is achieved through the use of traditional MMO and PAM methods or new mitigation technologies. However, there is often very little economic incentive for determining which methods are the most effective, implementing the most effective mitigation methods, or developing more effective mitigation tools. As mentioned above, the mitigation guidelines for the various sound sources used in geological research, military exercises and by industry typically are specific and prescriptive, limiting the use of new mitigation methods and thus actually acting as a disincentive to the design of more effective mitigation methods.

Finally, workshop participants acknowledged that the current focus on the use of PAM and other detection technologies may be partly responsible for better planning with good baseline data languishing as an often-overlooked mitigation tool, despite its likely importance. Performance standards, such as exposure threshold-based approaches, may help draw attention back to these options, while offering a mechanism and incentive for the introduction of both new source and mitigations technologies that effectively reduce the impact of anthropogenic sound on marine mammals.

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APPENDIX 1: LIST OF WORKSHOP PARTICIPANTS

Participant	Affiliation
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Andrew Wright	NZ DOC / George Mason University
Daniel Zitterbart	Alfred-Wegener Institute

APPENDIX 2: WORKSHOP PROGRAMME

New mitigation methods and Evolving acoustic exposure guidelines

New Zealand Department of Conservation in association with the MMOA.

21 March 2015

Workshop Schedule and Abstract Book

Noise measurement

09:15 – 09:40 *Peter Ward, Kongsberg Maritime Ltd*
PAM: Methods and Platforms for Underwater Noise Sensing

Multi-beam

09:40 – 10:05 *Paul Jepson, Zoological Society of London*
Final report of the Independent Scientific Review Panel investigating potential contributing factors to a 2008 mass stranding of melon-headed whales (*Peponocephala electra*) in Antsohihy, Madagascar

10:05 – 10:30 *Gordon Hastie, SMRU, St Andrews University*
The use of multi-beam in marine mammal research and mitigation; pitfalls and possibilities

-------------------------------------- Break 10:30-10:50 ------------------------------------

Thermal Imaging

10:50 – 11:15 Daniel Zitterbart, Alfred-Wegener Institute
Exploring the Thermal limits of Automatic Whale detection

Acoustic deterrents

11:15 – 11:40 *Jonathan Gordon, SMRU, St. Andrews University*
Aversive Sound Mitigation to Reduce the Risk of Damage to Marine Mammals

Passive Acoustic Monitoring

11:40 – 12:05 *Phil Johnston, Seiche Instruments*
Remote Passive Acoustic Monitoring (RPAM) for Mitigation

12:05 – 12:30 *Doug Gillespie, SMRU, St. Andrews University*
Signal processing and analysis: detection, classification, localization and reliability

-- Lunch Break --

Passive Acoustic Monitoring Continued…..

13:30 – 13:55 *Christophe L'Her, Sercel*
QuietSea new PAM system.

13:55 – 14:20 *Morten Svendsen, Western Geco*
Whalewatcher: new PAM system

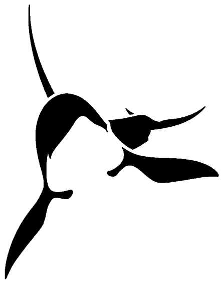
Acoustic Exposure Guidelines

14:20 – 14:45 *Karen Hall, JNCC*
Analysis of MMO data and soft starts.

14:45 – 15:10 *Andrew Wright, George Mason University*
Effectiveness of current guidelines.

------------------------------- Break & Poster Session 15:10-15:40 -----------------------

15:40 – 17:00 Open discussion on guidelines effectiveness and how they might be improved based on information presented.



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