Incorporating new mitigation technologies into guidelines for seismic surveys and other underwater acoustic activities: producing performance standards

Report of the workshop held at the 21st Biennial Conference of the Society for Marine Mammalogy, as part of the 2015–2016 Seismic Code of Conduct review process

Sponsored by the New Zealand Department of Conservation in collaboration with the

Marine Mammal Observer Association

Wild Earth foundation
fundación Tierra Salvaje

New Zealand Government

Department of Conservation
Te Papa Atawhai

Publishing information:

Cite as: Wright, A.; Robertson, F.; Cosentino, A.M. (eds) 2016: Incorporating new mitigation technologies into guidelines for seismic surveys and other underwater acoustic activities: Producing performance standards. Marine Species and Threats, Department of Conservation, Wellington, New Zealand. 27 p.

Authors: Wright, A.; Robertson, F.; Cosentino, A.M. (eds)
Published by: Marine Species and Threats
Department of Conservation, National Office
PO Box 10420, Wellington 6143
Marine@DOC.govt.nz

ISBN: 978-1-98-851409-3

Cover photo: nocturnal detection on an infrared monitoring system of a humpback whale off Kauai, Hawai'i.
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Preface: Background to the workshop

The review of the Code

In 2012 the Department of Conservation (DOC) developed a voluntary Code of Conduct for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations (the Code), following discussions with international and domestic stakeholders representing industry, operators, observers and marine scientists. The Code, and its supporting reference document, aims to provide effective, practical measures to minimise the acoustic disturbance of marine mammals during seismic surveys. It was updated slightly in 2013 after being incorporated by reference into the Exclusive Economic Zone and Continental Shelf (Environment Effects – Permitted Activities) Regulations 2013 (the EEZ Regulations – see SR2013/283).

At the time of implementation, DOC committed to the Code being reviewed after three years. Accordingly, the review of the 2013 Code began in July 2015, with a request for feedback from numerous stakeholders (the Seismic Code Review Group; SCRG). In August 2015, this feedback was combined with that obtained during the three years since implementation.

The workshop

This workshop was held in conjunction with the 21st Biennial Conference of the Society for Marine Mammalogy. Over 50 individuals attended the workshop and participants identified with a wide variety of sectors, including academia, industry, non-profit organisations, government, marine mammal observers (MMO) and passive acoustic monitoring (PAM) operators. At least two students and six members of the Marine Mammal Observer Association (MMOA) also participated in the workshop.

Topics and discussions were divided into two main categories: performance standards for source techniques, and performance standards for mitigation techniques. There were seven presentations in total and each section was followed by a general discussion around the ideas and issues raised. This report provides a summary of both the presentations and discussions held over the course of the workshop.

Part 1: Introduction

1. Future-proofing New Zealand's Code of Conduct: performance standards for seismic survey mitigation

Andrew J. Wright, New Zealand Department of Conservation

The presentation began with a brief outline of the process and progress of the ongoing review of New Zealand's *Code of Conduct for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations* (the Code). The presentation then outlined the desire of many stakeholders (including DOC) to future-proof the Code for the introduction of new methodologies and technologies, rather than maintain the current focus on only airguns, MMOs and PAM. This would require:

- Identifying and implementing mechanisms to make the Code less prescriptively limited to certain detection or source technologies
- Possibly incentivising the use of additional (and/or more effective) means for monitoring and minimising disturbance of marine mammals

The current review of the Code aims primarily to improve operational and technical elements in small working groups. However, achieving the goal of future-proofing requires wider discussions to properly consider new management approaches more suited to larger workshops with more diverse participants. Accordingly, DOC and the MMOA (with the support of Mel Cosentino of the Wild Earth Foundation) co-hosted a workshop in Malta in March 2015, in association with the European Cetacean Society conference (Wright and Robertson 2015). This initial workshop considered emerging improvements in marine mammal detection techniques and technologies, and concluded that these advancements need to reach some sort of performance standard before being implemented in the field.

To further discuss the performance standards concept, DOC and the MMOA again paired to host the present workshop (also with Mel Cosentino's support). This second workshop focused specifically on two areas that might form the basis of performance standards in New Zealand and elsewhere:

1) Regulatory approaches to source management that can be applied across source technologies
2) Current approaches to assess detection technology effectiveness

The presentation concluded with questions on the potential introduction of new techniques in the Code, to guide discussion later in the workshop.

1.1. References

Wright, A.J.; Robertson, F.C. (eds) 2015: New mitigation methods and evolving acoustics exposure guidelines. Report from the European Cetacean Society Conference Workshop, St. Julian, Malta, *European Cetacean Society Special Publication Series No. 59*, 74 p. Available from: http://www.mmo-association.org/images/ECS_SpecPub59_SeismicMit_Final.pdf.

Part 2: Performance standards for source techniques

2. Performance targets: the German experience

Mirjam Mueller, German Environment Agency

The German Environmental Agency (UBA), the largest environmental agency in Germany, conducts over 100 varied research projects a year. Although there is limited seismic survey work in German waters there has been substantial development using pile-driving, for example, in wind farm construction.

The Federal Nature Conservation Act (BNatschG) forms the legal basis for protection of individual marine mammals in Germany. The BNatschG includes protections for: a) injury that encompass any impairment of a protected animal's physical integrity on an individual level; and b) disturbance that impairs the conservation status of a local population.

In practice, 'injury' (as defined in the Sound Protection Concept of the German Federal Environment Ministry (BMUB)) includes temporary impairment, which is considered to include temporary threshold shifts (TTS). These protections were implemented through maximum noise requirements of 160 dB re: 1uPa s^2 single impulse SEL, 190 dB p-p SPL at 750 m[1], which would limit disturbance (at 140 dB) to within 8 km of a pile-driving site (5 km @145 dB; 3 km @150 dB).

These requirements aim to not only prevent injury or death, but also to prevent significant disturbance, defined in this context as a:

- Temporary habitat loss of more than 10% of the Exclusive Economic Zone (EEZ) area disturbed by noise between September and April
- Loss of over 1% of the main area of harbour porpoise concentration or Natura 2000 sites between May and August

Conveniently, these measures also provide a way to account for the cumulative effects of other activities in the affected area.

Initially introduced as a reference value for the wind farm permitting process in 2004, the technology was not then available to achieve the stated threshold sound levels at 750 m. By 2008 the first permit was issued with the limits as obligatory thresholds. The period until 2010 was an interim phase where operators were given leeway to refine the technologies to better meet the standards. By 2011 operators could meet the standards more consistently, and the thresholds became more concrete. However it was not until 2014 that advanced noise reduction systems made reliable adherence to the thresholds possible.

[1] Concept for the Protection of Harbour Porpoises from Sound (available at http://www.ascobans.org/sites/default/files/document/AC21_Inf_3.2.2.a_German_Sound_Protection_Concept.pdf).

This success was possible due to the defined thresholds, and a consistent dialogue between regulators and industry throughout the process. This allowed industry to develop the necessary technologies without regulatory barriers hindering its activities. This was supported by:

- Targeted environmental research and comprehensive monitoring (initially three years of baseline data, but more recently relaxed due to building datasets) before and during construction events
- Detailed daily reporting that allowed for both project-to-project adjustments, and adjustments to projects in progress

The few seismic surveys in German waters currently use more standard mitigation techniques. However, source reduction, and the use of vibroseismic technologies, is being seriously considered.

3. Performance targets: the Danish and Greenlandic experiences

Jakob Tougaard, Aarhus University, Denmark

This talk presented information both for pile-driving and seismic activities. It should be noted that these quite different noise sources are used in two different countries (Denmark and Greenland, respectively), with different socioeconomic conditions and local regulations.

3.1. Seismic surveys – Greenland

Although a part of the Kingdom of Denmark, Greenland is not part of the European Union (EU) – so the Habitats Directive does not apply in its waters.[2] In fact, Greenland has its own autonomous government. Despite an extensive coastline, Greenland has yet to experience much industrial activity in its waters. Greenland is keen to find oil, and develop the industry to support a drive for complete independence from Denmark. However, the population remains very protective of its natural resources, especially fishing. Consequently, several areas considered particularly sensitive have at least seasonal restrictions for certain anthropogenic activities.

Greenland receives advice from the Danish Centre for Energy and Environment[3], and comments from the public (including through public hearings) and NGOs. Permissions to conduct seismic surveys are granted by the Greenlandic Government (Naalakkersuisut) based on the scientific impact assessment. Notably, cumulative impacts aggregated across multiple surveys need to be assessed and included in the Environmental Impact Assessment (EIA). This requires common noise models, and the coordination of activities – which in turn obliges companies to notify their intentions early. Decisions on permitting in cases where the environmental impact is considered non-negligible are made at the political level. Regardless, licensees pay a fee that goes partially to a common fund used for environmental studies (strategic impact studies).

This comprehensive process still occurs with incomplete knowledge: we know that hearing damage and changes in behaviour occur, but we do not know the possible long-term consequences of these for animal health and viability, at individual or population levels. Likewise, very little is known about how to reduce the impact: although source levels can be reduced it is not clear, for example, if it is better to have four surveys run concurrently or sequentially. Accordingly, permits also need monitoring to better inform the next EIA and mitigation requirements. If risk (with limited information) is accepted, there is an obligation to improve the situation for the next time.

3.2. Pile-driving – Denmark

In 2014 Denmark commissioned a working group to discuss pile-driving in the context of various EU directives, particularly the Marine Strategy Framework Directive (MSFD).[4]

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2 See http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm for more information.

3 Part of Aarhus University.

4 See http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm for more information.

The MSFD requires range states to maintain good conservation status, which includes a descriptor for noise. Denmark also has animal welfare obligations to avoid permanent threshold shifts (PTS).

Regarding the protected harbour porpoise, we know noise can induce behavioural responses in this species, which may affect its long-term survival in several ways:

1) Startle responses (if, for example, they lead to bycatch/stranding)
2) Avoidance
3) Disturbance/attraction

The latter two reduce time available for key life activities such as feeding and nursing, thus generating individually small, but cumulatively important, impacts on survival. Calculating these cumulative impacts is not an easy task: noise derived from driving one pile might not be significant, but 100 piles per year for three or four years may become substantial. However, uncertainties are huge and there is no scientific consensus on thresholds for behavioural effects.

Hearing damage, on the other hand, is a lot easier to assess as critical levels can be determined to avoid PTS due to pile-driving. It is up to the company how they wish to meet the target defined by the exposure model – they are free to choose whatever mitigation method they prefer, as long as it is documented to be effective.

In theory, the whole process should be driven by a political goal (eg an 'acceptable' level of increased mortality). Then the energetic consequences, for example of various reactions, can be calculated to estimate a population-level effect (eg x% increase in mortality). The models used for these estimates can (in principle, but not yet in practice) then account for population density and local environmental conditions to assess mortality until the criteria are matched. Some threshold-at-distance criteria can then be determined (eg y dB SEL at z m distance).

4. Discussion: performance standards for source techniques

4.1. The focus for standards

It was noted that TTS and PTS only constitute part of the cumulative impact of noise, and that such considerations still typically only focus on marine mammals. However, the potential exists for noise to have wider impact across entire marine ecosystems that are generally not being considered. For New Zealand, the focus might be more on disturbance. Although disturbance may be just as important as TTS/PTS, we still have little idea how to expand from just managing to TTS and PTS. For example, how do you deal with humpbacks that come within a couple of metres of a construction site? Or how do you incorporate other issues, such as indigenous whaling?

The Netherlands Organisation for Applied Scientific Research (TNO) has been using the population consequences of disturbance (PCoD) model as a guideline to look at the cumulative effects of pile-driving in their waters. As the animals move between borders, TNO found it necessary to look at other countries where the animals occur. Considering the cumulative impact of pile-driving with other noise sources over the construction period, it estimated a decline in the harbour porpoise population of 24%.[5] While workshop participants generally agreed that models are the way forward, they warned that the large uncertainties present mean that these numbers must be treated with the appropriate caution.

Workshop participants also favoured a more species-specific and frequency-based approach – although this would require a lot of data. It was also agreed that:

- Harmonics (not just central frequencies) must also be considered
- Animal reactions increasingly seem to result from a combination of noise and presence of a given activity

Participants advised caution over heavy reliance on any comparative assessments of 'take' (representing lethal and/or non-lethal human-animal interactions, depending on the relevant presiding legislation), given the large uncertainties involved – especially with new and untested technologies. However, the point was made that not all legal frameworks are tied to take assessments, so this might only be an issue for regulators in the USA.

4.2. Source reduction

Various technologies for source mitigation were mentioned, such as the eSource airgun (with lower sound levels at 'higher' frequencies) and vibroseis technology, with lower overall instantaneous sound levels but near-continuous sound production. Participants also discussed the unsuccessful experiments with moving bubble curtains, acknowledging the huge technical difficulties involved.

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[5] https://www.noordzeeloket.nl/en/Images/Framework%20for%20assessing%20ecological%20and%20cumulative%20effects%20of%20offshore%20wind%20farms%20-%20Cumulative%20effects%20of%20impulsive%20underwater%20sound%20on%20marine%20mammals_4646.pdf

Participants discussed how alternative source technologies could be introduced into a set of guidelines focused on current airguns. There was general agreement a threshold-at-distance-based approach (eg as used in Germany and Denmark) was the most viable option at present. When asked for their opinion, operators and regulators immediately noted that this approach had worked well in Germany, given that the companies could were allowed to adapt to the thresholds over a 10-year period.

4.3. Developing appropriate target levels

Regarding the development and future use of appropriate target levels, it was noted that most criteria to date have focused primarily on injury, however defined. Despite this, there is increasing attention on other impacts of noise, and the Germans specifically considered 'disturbance' areas when setting their pile-driving criteria.

It was suggested that, with a minimum of distribution data, it should be possible to qualitatively (if not quantitatively) assess potential habitat availability and overlap, similar to the German approach. Attendees generally agreed this was appropriate – although it might not be possible at present for most species in New Zealand (except maybe Māui dolphin) due to data deficiencies. This approach would also facilitate cumulative impact assessments across different human activities, as it would allow estimates of total habitat loss over space and time. However, it was noted that such assessments should consider habitat quality as well as quantity. Specifically, it is not desirable to displace a species like the Māui dolphin into areas where intensive fishing activity increases bycatch risks.

Despite the implementation challenges, no participant objected to a threshold-at-distance approach to establishing goal-orientated management of seismic sources. There were no alternatives proposed.

Part 3: Performance standards for detection techniques

5. Behavioural reactions to human activities influence observer detectability

Frances Robertson, Marine Mammal Observer Association and Marine Mammal Research Unit, University of British Columbia

This presentation discussed the influence of whale behavioural reactions (to human activities) on the detectability of those whales by observers, and suggested that the effectiveness of many mitigation methods depends directly on detection. This is a concern because marine mammals are generally very difficult to detect.

5.1. Factors influencing the detection of a marine mammal

Factors such as distance to the animal(s), sighting conditions, observer experience and the species itself all influence the detectability of a marine mammal. Both visual and acoustic detection rates depend on perception and availability. Observers are susceptible to perception bias – they miss an animal that could have been seen or heard because (for example) it was too far away, the sighting conditions were poor, or the observer was inexperienced. But an animal's surface and dive behaviour also influences an observer's ability to detect it (eg a whale can only be seen at the surface).

However, the effect of an animal's surface and dive behaviour (in terms of its availability to be seen) can be accounted for with quantitative measures of these behaviours, and platform and survey-specific factors. It is then possible to investigate how availability changes between different activities and circumstances – such as feeding, travelling or socialising, or by age group. Dive and surfacing behaviour can also be used to investigate how whales respond to human activities and ultimately how variations in the availability of marine mammals affect our ability to detect them.

5.2. Studying disturbance effects on bowhead whales' availability

5.2.1. Visual availability

There have been very few studies of how animal availability for visual detection is affected by human activities. This is partly because there is limited paired behavioural data – collected both in the presence of a potential disturbance, and when the population is considered undisturbed. One population where this has been investigated is the Bering Chukchi Beaufort bowhead whales (*Balaena mysticetus*). These are among the best-studied marine mammals in terms of the effects of seismic survey activities. Numerous visual and acoustic studies since the late 1970s (which investigated bowhead whale behavioural responses to seismic surveys and other industry-related activities) have created great opportunities to study the effect of these behavioural changes on our ability to detect the whales themselves.

To date only the bowhead whales' availability for detection by aerial observers has been studied. Robertson et al. (2016) incorporated bowhead behavioural responses to seismic operations into a spatial density model; they used distance-sampling methodology to investigate how variations in the whales' availability influences analyses of marine mammal density and distribution in the vicinity of seismic operations. Regulators may need these estimates so operators can gauge how many whales may have been exposed to seismic sounds.

Analyses of bowhead whale surface, respiration and dive-behaviour data showed that bowheads change their behaviour when exposed to seismic operations. In general, their surfacing durations are shorter and they breathe fewer times during a surfacing, resulting in less total time spent at the surface. This finding was particularly apparent in the autumn and when whales were travelling. These behaviour changes affect observers' ability to visually detect whales, and Robertson's study showed that bowhead whales have a lower detection probability in areas ensonified by seismic sounds.

Robertson et al. (in press) demonstrated how density analyses are influenced by whale behavioural reactions, by comparing predicted bowhead densities from analyses where the whales' behavioural reactions to seismic operations were accounted for, to analyses where only undisturbed whale behaviours were accounted for. Analyses that do not account for behavioural changes result in density underestimation, and therefore also underestimate the numbers of whales exposed to airgun activity. Actual whale numbers in areas ensonified by seismic activities may be as much as 68% higher than previously estimated by studies that used undisturbed whales.

5.2.2. Acoustic availability

Bowhead whales also vary their acoustic behaviour in the presence of seismic operations, thus influencing their acoustic detectability. Blackwell et al. (2015) have determined two behavioural response thresholds for bowhead whales exposed to seismic survey-related sounds. By analysing whale calls collected by directional acoustic recorders (DASAR) deployments along the coast of the Alaskan Beaufort Sea during industry operations, the authors found that whales initially increased their calling rates as soon as airgun sounds became audible. Calling rates then plateaued, and as the cumulative sound exposure level exceeded ~127 dB re 1µPa^2-s whales reduced their calling rates until the cumulative sound exposure level rose above ~160 dB re 1µPa^2-s – at which time the whales ceased calling altogether.

5.2.3. Reductions in availability are not reductions in presence

The results of the Robertson et al. (2016) study also provide strong evidence that (at least in some seasons) whales do not appear to move offshore, or avoid seismic operations, to the extent previously assumed. Rather it appears at least some whales remain in ensonified areas. This is particularly the case for feeding bowhead whales, which show high levels of tolerance to seismic activities and therefore are likely exposing themselves to potentially high sound levels.

5.2.4. Conclusions

Changes in whale behaviour clearly affect our ability to detect them – at least during aerial observations. If changes in behaviour are not accounted for, the number of whales in the vicinity of seismic operations may be underestimated by up to 68%. The results of this work should set a precedent and encourage similar studies on other species, which may respond to acoustic exposures in a similar way. Understanding animals' behavioural responses improves our ability to better understand the effects, and assess the effectiveness, of mitigation methods.

5.3. References

Blackwell, S.B.; Nations, C.S.; McDonald, T.L.; Thode, A.M.; Mathias, D.; Kim, K.H.; Greene, Jr., C.R.; Macrander, A.M. 2015: Effects of airgun sounds on bowhead whale calling rates: evidence for two behavioral thresholds. *PLoS ONE*. 10(6): e0125720. Doi:10.1371/journal.pone.0125720

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Robertson, F.C.; Koski, W.R.; Trites, A.W. 2016: Behavioral responses affect distribution of bowhead whales in the vicinity of seismic operations. *Marine Ecological Progress Series 549*: 243–262. doi:10.3354/meps11665

6. Methods for evaluating observer effectiveness

Stephanie L. Watwood, Jene Nissen, Julie Rivers, Chip Johnson, U.S. Navy
Len Thomas, Centre for Research into Ecological and Environmental Modelling, University of St. Andrews

This presentation outlined the efforts by the U.S. Navy to assess the relative forward-detection effectiveness at 200, 500 and 1,000 m of U.S. Navy sailors deployed as marine mammal lookouts (LOs) vs experienced marine mammal observers (MMOs). Although results are still pending additional data, the methodology used has been formalised (but not necessarily finalised), allowing it to be presented. The study is driven by the Navy interest in evaluating effectiveness of visual mitigation efforts.

Navy observer teams consist of two dedicated LOs with binoculars, bigeyes and a headset to communicate with the bridge crew, and three watch officers on the bridge who can also look for marine mammals. During the study, the LOs are unaware of the experimental setup. The MMO team consists of four MMOs, one on each side of the bridge, one data recorder on the bridge and one roaming liaison to facilitate communication between the MMOs and the Navy observer team.

The study protocol is designed so that when the MMOs first detect the animal(s), a 'trial' begins. The MMOs then discretely relay sighting information to the data recorder, without cuing LOs. The MMOs must also take random pictures and make random team communications to desensitise LOs and reduce possible sightings cues for them. The MMOs then watch for (and record) subsequent detection by the LOs. The trial ends when the animal is seen by the LO, passes the beam, or if the MMOs lose sight of the animal.

The subsequent data analysis will include consideration of shallow-diving/deep-diving behavioural states. To test the model, many assumptions had to be made due to the limited available data, resulting in some assumptions being unrealistic (assumptions will be refined as more data are collected). Separate LO and MMO 2D (forward and perpendicular) detection functions are then used to assess the likelihood of detection. The ultimate goal is to determine the 'sneak-up probability': the probability of animals approaching a vessel undetected.

Currently, full statistical analysis is limited by fairly low sighting rates. Another limitation surrounds the difficulty for LOs and MMOs to determine the species sighted, as the ships do not deviate to gather this information. Furthermore, although most data are from one class of vessel, other ships have different MMO/LO heights/configurations. Finally, there is a standard Navy marine species observer training for LOs. MMO training and capabilities may vary.

7. Towards a mitigation performance metric – thermal imaging detection of whales as a model system

Daniel Zitterbart, Woods Hole Oceanographic Institute, USA; Alfred Wegener Institute, Germany; University of Erlangen-Nürnberg, Germany

7.1. How do we compare effectiveness of disparate detection methods?

Any mitigation focusing on direct immediate injury reduction relies on finding the animal. The question is how best to do this. Although we will always need someone to decide whether the observation is true or not, the tools at their disposal may vary. The simplest solution may appear to be to use all available technologies, but cost and logistics make this impractical. We therefore need to find ways to quantify and compare performance in any given set of conditions.

Thermal imaging (IR) has been undergoing trials at various locations around the world for about seven years. The system scans for thermal signatures that match possible 'blowish events' (ie automatically detected events that meet the criteria for being a blow) then present these to an operator for consideration. It is independent of daylight, although reflections of the sun on the water surface can cause more false positives during daytime.

However, the question remains of how to compare effectiveness of MMOs and IR. It is clear that a direct comparison cannot be made with cues (as opposed to using encounters). This works well when both detections are visual (eg when comparing IR to MMOs), but the approach may not be able to effectively compare visual and acoustic cues.

7.2. A metric to compare methods

A better approach is to ask what the appropriate methods are for the species we are monitoring, in the given environment. To answer this, we need to quantify each method individually before comparing them. This requires a metric, such as a detection function. Specifically, we are interested in the ability of a method to detect an animal before it enters the mitigation area: the 'in-time detectability' (ie the inverse of the above-mentioned 'sneak-up probability'). This is slightly more complicated, as cue-based detection functions may be angularly dependent (eg PAM at back, MMOs at front) and the ship is moving forward, influencing the pre-exclusion zone detection area (with exclusion-zone entry potential).

Another issue surrounds the ground-truthing data – how many whales are undetected. However, IR is perfect to test this as there are already many data sets, and it is possible to narrow the detection field post-hoc to artificially sub-sample. It is also possible to assess when IR can detect a whale *when seen* by the MMO to give a confirmed hit detection function. Once the detection function (for each environmental condition set) is created, the model can be modified to include different species, vessel and whale speeds, etc and assess their influences.

Thus, the process should be:

1) Selecting project area
2) Developing an optimal detection function from available tools
3) Estimating in-time detectability rates for the various species present

Such an IR system currently costs several hundred thousand dollars, which limits the general use of the technology within the seismic industry at present. The cost is likely to fall, however, increasing its availability and use in the future.

8. Seeing clearly: ensuring full visibility for MMOs in bowhead whale aggregation areas in the Canadian Beaufort Sea, 2007–2015

Lois Harwood, Department of Fisheries and Oceans, Canada
Amanda Joynt, University of Waterloo, Canada

Each spring, most bowhead whales of the Bering-Chukchi-Beaufort population migrate to the south-eastern Beaufort Sea where they form aggregations during late summer in Canadian waters. Studies using ship and aerial platforms in the 1980s and 2000s showed these aggregations tend to form in shallow shelf waters of the Beaufort Sea during August and September. More recent satellite telemetry studies have reaffirmed these distribution patterns, and allowed inference that the whales spend (on average) 59% of their time feeding, and within relatively localised areas (<15% of all habitats which they travelled through). This tendency of bowhead whales to aggregate is used by managers as part of the evolving strategy to mitigate effects of seismic noise on this species. Disturbance or displacement of bowhead whales from aggregation areas may have energetic consequences for the population.

8.1. A new mitigation strategy

Since 2006, seismic operators in the Canadian Beaufort Sea have worked closely with Fisheries and Oceans Canada (DFO) to develop a mitigation regime specific to the area, species and operational situation. This involves more restrictive measures where and when bowhead whales aggregate, and has allowed for seismic surveying to be conducted in the Arctic where the operational season is short. The mitigation strategy also includes changes to the size of the safety zone specific to the bathymetry and substrates in different areas of the Beaufort Sea, with safety zones ranging from 500 m to 2.5 km.

Recognising the propensity of bowheads to aggregate, a region-specific mitigation plan was developed and implemented that took into account:

- The ineffectiveness of marine mammal observer (MMO) surveillance in darkness (which ranges from 4 to 20 out of 24 hr over the year)
- Obstructed visibility (eg fog, approximately 10% of the time)
- High sea states (exceeds Beaufort 4, 25–40% of the time)

The plan, which began in 2006, involves the determination of the size and location of bowhead whale aggregation areas prior to the start of the seismic (open water) season. When operators conduct seismic surveys within these specific areas, seismic operations can only be initiated during times of full safety zone (SZ) visibility (eg no fog, daylight, MMO assessment of sea state), and must be stopped if conditions deteriorate to the extent that visibility in the SZ is compromised. The aggregation areas are determined as early as possible within the same season, a process led by the regulating authority.

Shutdowns during the 2007–2010 period mainly occurred within the defined bowhead aggregation areas because the MMOs could see the whales clearly, reliably and consistently there.

9. Low visibility, real-time monitoring techniques review

Jim Theriault, Ocean Environmental Consulting

This presentation outlined the ongoing effort by a consortium to assess the various technologies available for detecting marine mammals in low-visibility conditions. These technologies include PAM, active acoustic monitoring (AAM), infrared (IR), radio detection and ranging (RADAR), light detection and ranging (LIDAR), spectral camera systems – except IR – and satellite. Determining a consistently objective way to evaluate the relative value of distinctly different detection methods was the primary challenge. Variables considered for each technology in different conditions included: weather, animal behaviour and physiology, and observer abilities.

Other concerns included operational conditions – such as practical (including cost) and regulatory constraints – and where animals need to be detected. Regulators often present this area as a circle around the source, but ship movements mean the area is not really circular. Other considerations were the ability of a method to identify species (given the variable extent of protection zones for different species in certain regions), and the need for (near) real-time detection to support mitigation actions.

The ultimate evaluation methodology considered which combination of detection methods maximises the overall detection performance in a given set of conditions, for the best use of money and bunk space. The approach set out to assess the strengths, weaknesses, advantages and disadvantages (SWAD) (instead of a SWOT analysis[6]). External factors were categorised to provide a means to compare relative strengths and weaknesses of the different technologies across different situations, while expert elicitation was used to assess distance-related effectiveness of each technology at given ranges.[7] Whenever a disadvantage is identified, something else must be found to counteract it.

9.1. References

Aspinall, W. 2010: A route towards more tractable expert advice. *Nature 463*: 294–295.

Martin et al. 2012: Eliciting Expert Knowledge in Conservation Science. *Conservation Biology 26*, No. 1, 29–38. © 2011 Society for Conservation Biology, DOI: 10.1111/j.1523-1739.2011.01806.x.

[6] Strengths, weaknesses, opportunities, threats.

[7] 'Expert elicitation' is a structured process for deriving carefully reasoned, quantitative judgements from experts about uncertain quantities. For more details see Aspinall 2010; Martin et al. 2012).

10. Anthropogenic noise and marine mammals: assessing real-time monitoring

Laura Marshall, Centre for Research into Ecological and Environmental Modelling, University of St. Andrews[8]

Current levels of noise in the marine environment are ten times higher than they were just a few decades ago (Hildebrand 2004). Shipping, seismic exploration, underwater explosions, military activities and acoustic deterrent devices have increased both the level of background noise and the frequency with which acoustic pulses are generated. Anthropogenic noise may affect marine mammals in several ways: physiological damage (Richardson et al. 1995), changes in behaviour (eg Miller et al. 2000; Morton and Symonds 2002; Lusseau et al. 2009) or masking of important sounds (Weilgart 2007), such as those used for communication, navigation and feeding. This study considers the potential risk of physiological damage to marine mammal hearing. When exposed to noise, an animal may suffer a temporary threshold shift (TTS) when fatigue of the cochlear hair cells leads to a temporary decrease in hearing sensitivity at certain frequencies (Nordman et al. 2000). More severe or repeated noise exposure may cause permanent damage or death to some of the cochlear hair cells, resulting in a permanent threshold shift (PTS).

This study tested the effectiveness of real-time monitoring for marine mammal presence around a sound source. We compared the cumulative sound exposure level (cumSEL) and the associated risks of TTS and PTS (a) at the time the animal was detected within the 'action zone', to (b) those at the end of the simulation. The action zone was an area out to a set distance from the sound source; if an animal was detected in the area, sound production would cease. Animal movement around the sound source was simulated in three dimensions; each time an animal surfaced they had a chance of being observed by the real-time monitoring system, based on their distance from the vessel/sound source.

The probability that each animal would have suffered a TTS or PTS at the time it was observed represents the unavoidable sound exposure risk prior to detection. The additional risk of TTS or PTS accumulated between detection and the end of the exercise represents the potential risk-reduction by using real-time monitoring.

10.1. References

Hildebrand, J. 2004: Sources of anthropogenic sound in the marine environment. Background report for the U.S. Marine Mammal Commission and U.K. Joint Nature Conservation Committee International Workshop: Policy on Sound and Marine Mammals, 28–30 September 2004, London, England. 16 p. Available at: http://www.mmc.gov/wp-content/uploads/hildebrand.pdf.

Lusseau, D.; Bain, D.; Williams, R.; Smith, J. 2009: Vessel traffic disrupts the foraging behaviour of southern resident killer whales *Orcinus orca*. *Endangered Species Research 6*: 211–221.

Miller, P.; Biassoni, N.; Samuels, A.; Tyack, P. 2000: Whale songs lengthen in response to sonar. *Nature 405*: 903.

Morton, A.; Symonds, H. 2002: Displacement of *Orcinus orca* (Linnaeus) by high-amplitude sound in British Columbia, Canada. *Journal of Marine Science 59*: 71–80.

[8] Laura Marshall was unable to attend. This chapter is therefore not a presentation summary, but instead summarises Chapter 4 of her PhD thesis, which was provided to workshop participants before the meeting following removal of commercially-sensitive information.

Nordman, A.; Bohne, B.; Harding, G. 2000: Histopathological differences between temporary and permanent threshold shift. *Hearing Research 139*: 31–41.

Richardson, W.; Greene, C.J.; Malme, C.; and Thomson, D. 1995: Marine Mammals and Noise. Academic Press, New York. 576 p.

Weilgart, L. 2007: The impacts of anthropogenic ocean noise on cetaceans and implications for management. *Canadian Journal of Zoology 85*: 1091–1116.

Thesis reference:

Marshall, L. 2011: Statistical developments for understanding anthropogenic impacts on marine ecosystems. PhD thesis, University of St Andrews, St Andrews.

11. Discussion: performance standards for detection techniques

It was noted that the alternative approach by Laura Marshall (who was unfortunately unable to attend) to assessing effectiveness of mitigation tools focuses on relative decrease in the risk of PTS onset in exposed marine mammals. This approach is detailed in her PhD chapter, circulated to participants prior to the workshop and summarised above (see **Section 10**). Participants were asked to consider that information during the discussions.

11.1. What should the standards consider?

It was suggested that any standards should consider all relevant factors, such as ocean acidification, bottom substrates, etc. Although there was no suggestion of how this should be achieved, it was noted that such factors are typically incorporated into sound propagation models that would be used to assess compliance with any defined acoustic metric. Participants noted that regulators themselves could explore standards for models and other migration elements, with algorithms tested thoroughly.

The discussion moved onto the metrics that should be evaluated for effectiveness, as distinct from performance. Marshall used risk reduction factors, but many attendees were concerned that most people worry about performance rather than effectiveness of their technology. The question is really about how to quantify the mitigation success – understanding that any technology has a downside, either in terms of a distinct limitation or even some negative impact itself.[9] These should be explicitly acknowledged and (if possible) quantified in any mitigation plan, with a discussion of the relevant unknowns. The latter point is crucial for the application of corrections or establishment of decision thresholds for adaptive management in future.

It is not appropriate to simply assume that something works only because it is based on a good idea. One approach would be to set a minimum required achievement level for a given system. For example, regulators could (and should) demand experienced MMOs; but experienced (either in terms of training or background, or both) does not always mean effective – so 'experienced' would need to be defined objectively. It was also noted that there are no detection functions for PAM during seismic operations, and that this is something we could (and should) be doing. This would require a system with localisation capabilities, such as offered by some in-streamer systems, to allow for distance determination. Until this is achieved, we will simply not know if the equipment does what it is supposed to do, in the setup and with the operators that it has in every case.

Whatever the standard to be implemented, DOC and other regulators are encouraged to incentivise better detection rates. There must be some benefit for the operators to detect more animals, or they will focus on the (unwanted) increase risk of shut-downs. It was noted that Aaron Thode and his group are working to come up with standards for towed PAM, which might help obviate this problem in the case of PAM.

[9] Eg active sonar adds more sound.

11.2. Practicality of implementation on the water

It was noted that berth space is always an issue for monitoring, and therefore for mitigation: there is simply not enough room for everyone. However, the argument was made that the industry would have to accommodate the required MMOs where necessary.

11.3. Balancing the need for international consistency against local conditions

It was also noted that there are large differences in the receptiveness of the various parties (eg seismic contractors, operators, individual deck chiefs) to shut-downs and other mitigation measures.[10] This may be partly due to variations in guidelines and shut-down triggers between countries: accordingly, international consistency was encouraged. However, it was noted by way of example that different methods must be used to detect individuals in the Arctic, as the conditions can change rapidly across a wide range. This means that both regulator and operator must be open and flexible. However, the responsibility remains with the MMO and PAM to tell the operator to shut down – unfortunately there are different interpretations on when this should be done, depending on the national guidance in force. This is a priority and needs to be clarified.

11.4. Data is needed to support the standards, but mitigation is the primary concern

One participant suggested the biggest problem is that, although the technology is there to do something species-specific, we don't always have enough information about the biology of these animals to fill in all the risk and detection functions. In some cases, these might even need to be defined for specific populations – for example, due to differences in population status and any variation in the acoustic signals produced. 'Citizen science' might be useful for coastal species, but wouldn't help for lesser-known offshore species.

11.4.1. The mixed value of analysing existing data

Participants agreed that we need to be collecting better data and running better statistics. Despite the need for new data, it was noted that data collected by MMOs in some countries remain unanalysed.[11] If there is access to the raw data, that repository alone should be able to answer some questions about how effective MMOs and PAM are. Attendees noted two good examples of data analysis:

- New Zealand, as demonstrated in the provisional analysis of PAM and MMO data collected under the Code by Blue Planet Marine (BPM: Childerhouse et al. 2016)
- The Chukchi Sea Environmental Studies Program

[10] It was noted that (at least under some regulatory regimes) for every shut-down you have an extra 45 min of noise in the water. Also, it may be possible to impact other animals in other seasons than previously assessed, if shutdowns delay or extend the project enough.

[11] An example is Australia, where data has not been analysed in 20 years.

Attendees also recommended other nations should follow these examples and analyse the observer data they have been collecting.[12]

While data collected from off-survey seismic vessels might be useful, MMOs and PAM operators need to rest to remain effective. The vessels may still be having an effect themselves, preventing the data being considered as true baseline information. Aerial surveys and (large) drones might be helpful in filling in the gaps for these, but it would not immediately help management. It might even be possible to deploy sonar buoys from chaser vessels to get post-vessel-pass data. However, post-processing of video images or acoustic data, together with data integration, synthesis and analysis could be expensive and time-consuming.

These technologies might therefore be better for monitoring rather than mitigation. International collaborations – especially across mutual EEZ boundaries (eg Mexico, USA and Canada) and in high-seas areas – will be necessary and were strongly recommended.

11.4.2. Detection methods should be tailored to mitigation rather than for data collection

Although the need for data collection is extensive, the main purpose of detection technologies on seismic vessels is mitigation. Accordingly, detection methods will need to be tailored specifically for the expected local species, and may also need to vary with due consideration for sanctuaries, hotspots and other important areas.[13] It may also be necessary to consider some level of tolerance for variability in the performance of a technology (including MMOs) across different conditions. Any assessment of detection method effectiveness and performance will therefore need to be qualified by statements of uncertainty (eg through confidence intervals).

11.4.3. The need to outline uncertainty

Another participant noted that not all PAM systems are equal – settings need to be tailored to the animals present, or likely to be present in the general area. Participants cautioned against making sweeping conclusions about the effectiveness of PAM, unless full details of specifications, operator qualifications and other related statistics (eg detection probability) were also reported. Participants generally agreed these details could then be incorporated into impact models and assessments, and recommended that all reporting should include this.

Regardless of these assessments, it was noted that there was limited capacity for adaptive management in the Gulf of Mexico (and potentially elsewhere), due to the large number of seismic surveys taking place there. This makes it hard to plan ahead and efficiently incorporate new data into management decisions.

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[12] It was noted that the UK's Joint Nature Conservation Commission has analysed data collected under their guidelines. However, that data is primarily restricted to pre-start periods for seismic surveys and incorporates inconsistent ramp-up procedures, limiting the potential to generalise the results beyond that situation.

[13] For example, the acceptable false detection rate and missed detection rates (for a technology under a given set of conditions) should vary with the status of species likely to be present in the area.

This topic ended with a recommendation that a workshop be held on the integration, synthesis and analysis of big data from monitoring of seismic surveys and other activities, to move this issue forward. This workshop should involve scientists with diverse expertise, including those not normally involved in discussions of seismic surveys who would bring fresh perspectives (eg in a similar way to those involved in the MOCHA project with the Navy data).

11.5. Improving mitigation capacity

With regard to the different mitigation techniques themselves, it was noted that in-streamer PAM systems could be complemented by additional elements in front of, or under, the airgun array to improve capacity and localisation.[14] Lastly, one participant noted that the limitations with all current detection techniques mean that mitigation zones will not be perfectly maintained. Geographical separation remains the most effective mitigation of seismic impacts to date. This means that protected areas with restrictions on seismic surveys will need to be established to prevent exposure of at least the most sensitive species to dangerous sound levels.

11.6. References

Childerhouse, S.; Douglas, L.; Kennedy, J.; Burns, D. 2016: Analysis of Marine Observer data from New Zealand seismic surveys, in DOC (Ed.): Preliminary Analysis of Marine Observer data from New Zealand seismic surveys. Available at: http://www.doc.govt.nz/Documents/conservation/native-animals/marine-mammals/seismic-code-of-conduct/mmo-prelim-data-analysis-report.pdf.

Wright, A.J.; Robertson, F.C. (eds) 2015: New mitigation methods and evolving acoustics exposure guidelines. Report from the European Cetacean Society Conference Workshop, St. Julian, Malta, European Cetacean Society Special Publication Series No. 59, 74 p. Available from: http://www.mmo-association.org/images/ECS_SpecPub59_SeismicMit_Final.pdf.

[14] Frances Robertson directed participants to the report from the previous workshop.

Part 4: Conclusions

12. Recommendations for producing performance standards

Participants recommended that guidelines for detection technologies should require a three-stage demonstration of effectiveness:

1) Detection function(s) for the methods to be used in combination with the conditions and species likely to be encountered
2) An estimate of performance: how well will the combined methodology detect animals in the required range?
3) Effectiveness: how well will the combined methodology detect animals before they enter the mitigation zone? What is the reduction in the risk of PTS and TTS occurring for the target species?

Workshop participants recommended a threshold-at-distance-based solution for source technologies, and that this should be pursued as part of a more goal-orientated approach to management.

The German approach to incremental implementation – as shown in North Sea wind park regulation – was recommended, as was a 10-year lead time. In the meantime, regulators should make more-informed decisions simply by requesting more information on the capabilities of the proposed detection and source systems, as discussed above.

No objections were raised to these approaches, and the meeting was adjourned.