Agenda Item 4.2	Review of New Information on Threats to Small Cetaceans Underwater Noise
Document Inf.4.2.a	**Special Publication from the ASCOBANS/ACCOBAMS/ECS Workshop on Noise and Environmental Impact Assessments**
Action Requested	• Take note
Submitted by	European Cetacean Society

UNEP ASCOBANS

NOTE:
DELEGATES ARE KINDLY REMINDED
TO BRING THEIR OWN COPIES OF DOCUMENTS TO THE MEETING

PROCEEDINGS OF THE ECS/ASCOBANS/ACCOBAMS JOINT WORKSHOP ON

INTRODUCING NOISE INTO THE MARINE ENVIRONMENT - WHAT ARE THE REQUIREMENTS FOR AN IMPACT ASSESSMENT FOR MARINE MAMMALS?

Held at the
European Cetacean Society's 28th Annual Conference,
Liège, Belgium, 6th April 2014

Editor:
Peter G.H. Evans

ECS SPECIAL PUBLICATION SERIES NO. 58
AUG 2015

Cover Photo: Humpback whale in front of construction barge, Johnstone Strait, BC, July 2014 (Copyright Frank Thomsen)

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Editor:
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CONTENTS

INTRODUCTION TO NOISE ENVIRONMENTAL IMPACT ASSESSMENTS

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The introduction of noise into the marine environment has increasingly caused concern over possible effects upon animal life, particularly marine mammals that depend heavily upon sound for navigation, food finding and communication (Richardson *et al*., 1995; Würsig and Evans, 2001; NRC, 2003, 2005; Nowacek *et al*., 2007; OSPAR, 2009). Noise from anthropogenic sources is a pervasive influence on today's marine environment. It may come from shipping, smaller craft, seismic surveys, pile driving, or sonar, amongst others.

Different groups of marine mammals occupy different acoustic niches. At the very low frequency range (<100 Hz) are some of the larger baleen whales like blue and fin whale; at the low frequency range (100 Hz – 1 kHz) are humpback and right whales; at the mid-frequency range are medium to large odontocetes such as sperm whale, killer whale and pilot whales (1-10 kHz), and the beaked whales like Cuvier's and Blainville's beaked whale (10-20 kHz); and at the high frequency range (>20 kHz) are the smaller dolphins and porpoises. When the sounds of different human activities are superimposed, it is clear that there is significant overlap, for example of seismic airguns and shipping with baleen whales and, to an extent, a number of the toothed whale and dolphin species. The effects upon communication of masking from anthropogenic noise have been demonstrated in a number of species (see, for example, Clark *et al*., 2009; Di Iorio and Clark, 2010; Moore *et al*., 2012; Cerchio *et al*., 2014).

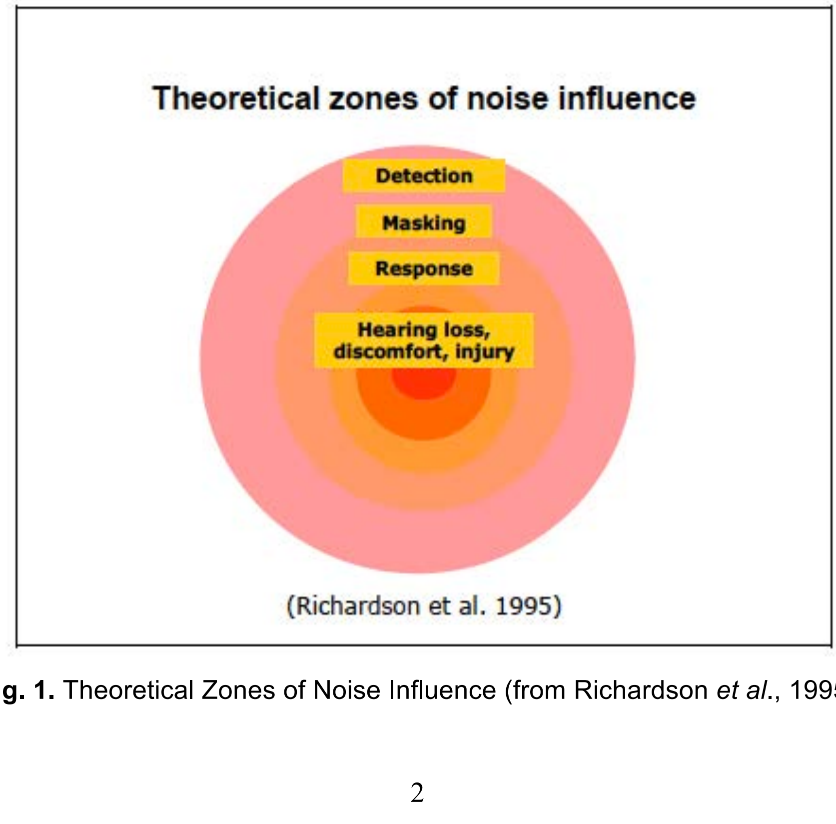

Fig. 1. Theoretical Zones of Noise Influence (from Richardson *et al*., 1995)

Richardson *et al*. (1995) introduced the concept of zones of noise influence, whereby the effects were likely to be dependent upon the distance between the noise source and the receiver (the animal), based upon the fact that as sound spreads, the energy and pressure levels decrease radially with distance (Fig. 1). Thus noise in the ocean may affect marine mammals at close range by causing hearing loss, discomfort or actual injury (often assessed in terms of temporary threshold shift, TTS, or permanent threshold shift (TTS); at greater ranges, it may result in a behavioural response (moving away from the source, changes in dive behaviour, etc); farther away still, it may mask communication, as noted above; and beyond that, the sound may be detected but not have a measurable biological impact. This model has frequently been used in impact assessments where the zones of noise influences are determined based on noise propagation modelling or sound pressure level measurements on the one hand, and information on the hearing capabilities of the species in question on the other (see for example, Madsen *et al*., 2006; Thomsen *et al*., 2006; Southall *et al*., 2007).

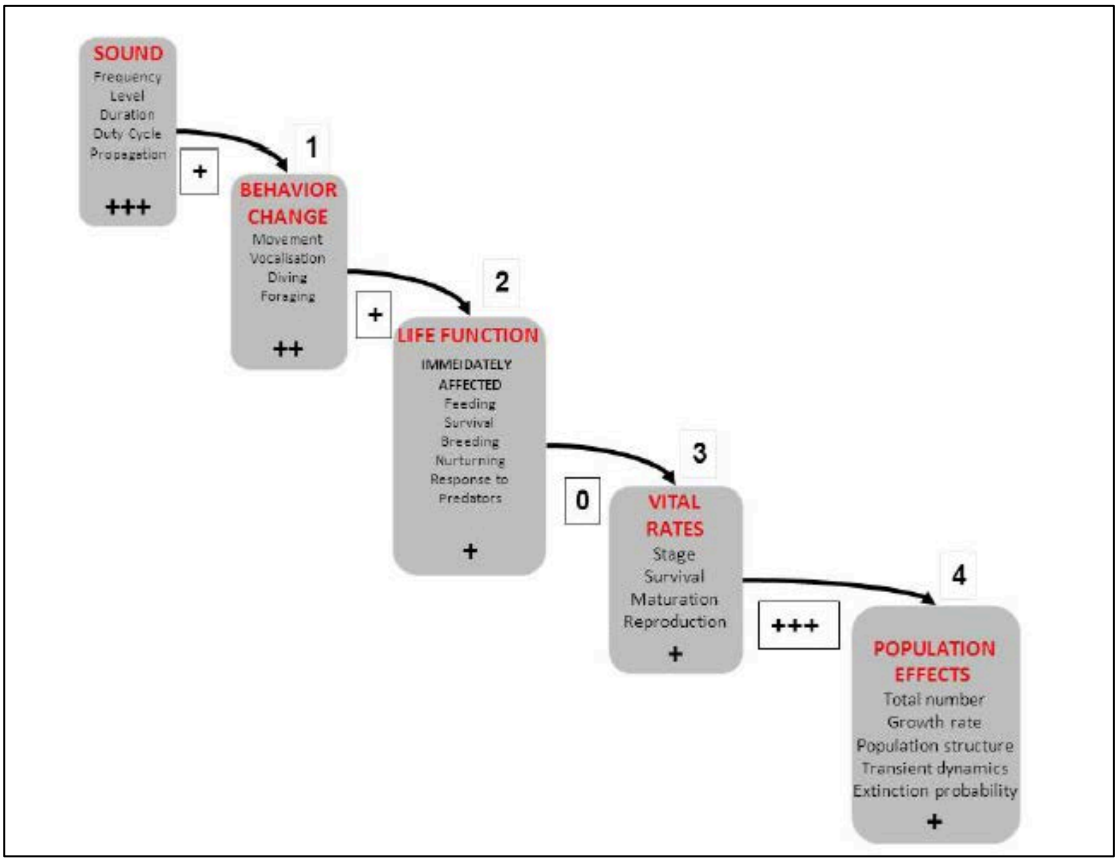

Figure 2. PCAD Model. Arrows define transfer functions leading from the presence of a sound source to effects that may be of biological significance. The number of plus signs within each box shows the level of knowledge about each of he processes, and the number of plus signs between boxes represents the current ability to infer an effect in this sequence (from NRC, 2005)

Negative impacts, particularly in terms of behavioural response, have been demonstrated on a wide range of marine mammals (as illustrated in the contributions and literature cited in this volume). However, population consequences are much more difficult to ascertain. The US National Research Council (NRC) developed a model, which they called the Population Consequences of Acoustic Disturbance (PCAD) (Figure 2). The diagram demonstrates why it is so difficult to infer significant effects of sound on marine life and also why, even if there are real effects of sound, to demonstrate a connection to sound as the cause, is also extremely difficult.

Figure 3 illustrates the information flow and decision pathway taken for a risk assessment. This shows a feedback process involving mitigation when the risk exceeds the trigger level for management action. It is an adaptive process to managing risk (Boyd *et al*., 2008).

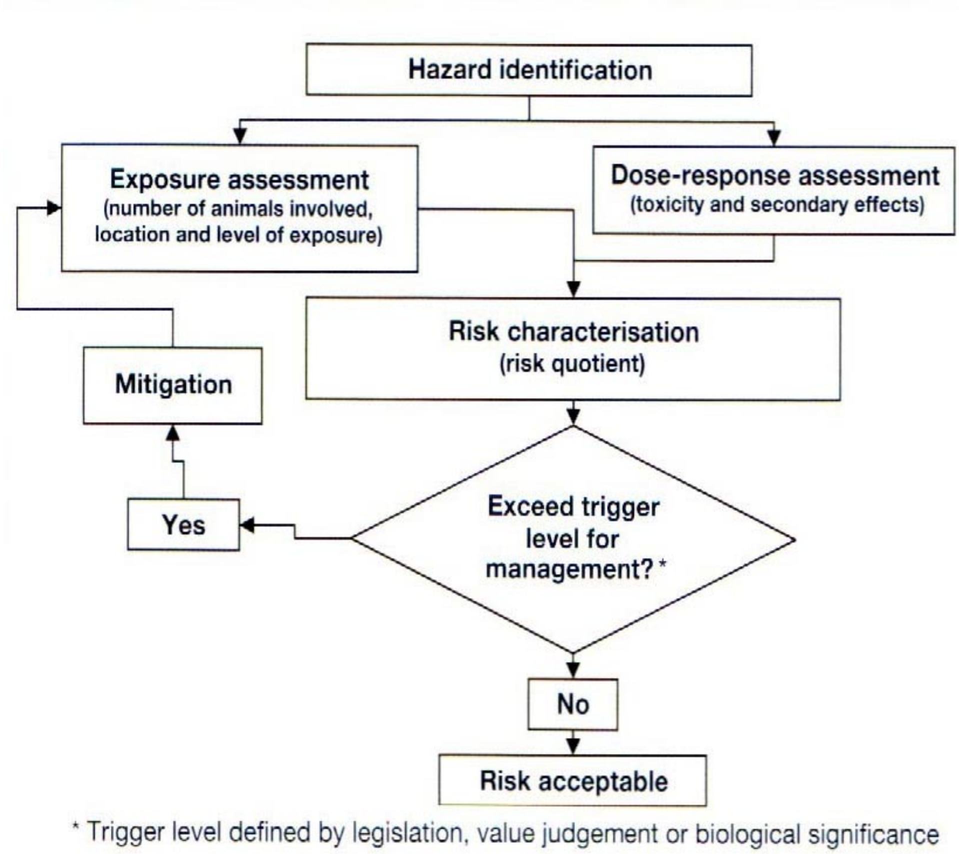

Figure 3. The Information Flow and Decision Pathway to be taken for a Risk Assessment Process (from Boyd *et al*., 2008)

A fundamental part of any human activity should be an environmental impact assessment (EIA), and in many situations these are a requirement under national or international law. And yet, the scope and content of such an assessment can vary greatly between and even within countries.

An Environmental Impact Assessment should first collect baseline biological and environmental information to describe the area being exposed to a human activity that might be detrimental to animals. The proposed operations then need to be fully characterised to identify the hazard. This involves describing the sound source in some detail, the local sound propagation features, and potential cumulative effects from other sound sources as well as other human activities that may not generate noise but can add to the pressures upon the local animal populations (*e.g.* fisheries bycatch, pollution, and resource depletion). Impact monitoring should be introduced before, during and after the operation so that there can be a proper evaluation of the effect in both the short-term and long-term. Using the above risk assessment process, appropriate mitigation measures can be put into place at various stages if the risk is deemed to exceed an "acceptable" level. Figure 4 outlines the key considerations for an environmental impact assessment process.

1) **Baseline Environmental & Biological Information**

- *Literature reviews*
- *Visual & acoustic surveys of animals*
- *Soundscape measurements*

2) **Characterisation of Proposed Operations**

- *Source characterization – pressure levels, energy levels, frequencies, rise times, kurtosis, presence of harmonics, pulse repetition rates, total duration* (need to standardise metrics)
- *Local sound propagation features – noise measurement & modelling*
- *Potential cumulative effects (multiple stressors)*

3) **Impact Monitoring**

- *Direct noise measurements in real time*
- *Visual detections of animals & their responses – MMOs, other observers*
- *Acoustic detections – towed PAM, fixed PAM systems*
- *Other methods – Infra-red, active acoustics, drones, gliders, telemetry*

4) **Post-Operation Evaluation**

- *Continued monitoring of animals – numbers, distribution, activities*
- *Environmental monitoring – soundscapes, other human activities*

Mitigation Measures

- *Quieting technologies – vibroseis, bubble curtains, insulation sleeves*
- *Spatial & seasonal avoidance*
- *Operational shutdowns*
- *Ramp up*
- *Alerting or harassment devices*
- [*Active noise control (stapedial reflex)*]

Figure 4. Considerations for an Environment Impact Assessment

The purpose of this workshop was to 1) review contents that are common to all EIAs, such as baseline surveys, overall impact evaluation, and general mitigation methods; 2) examine more detailed assessments relating to particular activities (seismic, shipping, sonar, pile driving, etc); and 3) provide case studies of monitoring approaches that can be applied to the EIA process.

Those issues formed the basis for presentations from key speakers followed by general discussion. The aim was to bring together marine mammal scientists, environmental bodies, regulators and industry to produce a series of recommendations that can form specific guidelines for application across Europe.

Around 120 persons from 25 countries participated in the workshop, examining requirements for assessing the impacts upon marine mammals of introducing noise into the marine environment. The all-day workshop was held on 6th April 2014 at the Aquarium-Museum in Liège, Belgium, immediately preceding the 28th Annual Conference of the European Cetacean Society. It was jointly organised by the European Cetacean Society and the two regional cetacean conservation agreements, ASCOBANS and ACCOBAMS through the Joint Noise Working Group, with an organising committee comprising Peter Evans, Sigrid Lüber, Yanis Souami, Heidrun Frisch, Maylis Salivas, and Florence Descroix-Comanducci.

This special publication follows the three main themes:

- Common Issues for Environmental Impact Assessments: baseline surveys, impact evaluation, general mitigation methods
- Impact Assessments for Specific Anthropogenic Activities
- Noise Studies contributing to EIA Assessment

Each themed session comprised a number of presentations followed by questions and then a general discussion addressing that theme. These were then drawn together into a final discussion session in which a number of specific recommendations were made. The thirteen contributions to the workshop are presented here.

This publication distils the information presented at the meeting, and draws some general conclusions with specific recommendations arising from the discussions. Sponsorship for the Proceedings comes from UNEP/ASCOBANS to whom we are very grateful, and I would also like to thank Heidrun Frisch, Maylis Salivas, Florence Descroix-Comanducci, Sigrid Lüber, and Yanis Souami for their invaluable support.

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Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene, C.R., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, J.W., Thomas, J.A., and Tyack, P.L. 2007. Marine mammal noise exposure guidelines: initial scientific recommendations. *Aquatic Mammals*, 33: 411-521.

Thomsen, F., Lüdemann, K., Kafemann, R., and Piper, W. (2006). *Effects of offshore wind farm noise on marine mammals and fish*. COWRIE Ltd, Newbury, UK.

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UPDATING THE NOISE EXPOSURE CRITERIA OF SOUTHALL *ET AL.*, 2007, *AQUATIC MAMMALS* 33(4): 411-521

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This paper provides a brief history of the establishment of noise exposure criteria in the USA to date. The key stages were as follows:

- In 1997, an expert panel was convened by a US government agency to streamline the process for permitting offshore seismic operations in California. In that meeting one expert made an offhand guess, without scientific backing, that the onset level for auditory injury may be 180 dB SPL. A regulator there captured it and incorporated it in NOAA (National Oceanic and Atmospheric Administration) regulations. It persisted for a decade - long after empirical research showed it to be invalid.
- In 1998, I reconvened the above expert panel to outline for NOAA the science available for setting proper noise exposure criteria for marine mammals.
- In 2003, I again convened the panel, expanded it, and tasked it with writing the noise exposure criteria, supported by NOAA funding. The intent was to give regulators a scientific and uniform basis for issuing permits instead of making one-off, arbitrary decisions as above.
- In 2005, the panel began writing, and simultaneously I convened a second panel to write noise exposure criteria for fish and marine turtles.

The mammal paper appeared in print as Southall *et al*. (2007), and the fish and turtle paper has recently been published as Popper *et al.* (2014). Table 3 from Southall *et al.* (2007) is displayed here to show the existing criteria for onset of injury in seals and cetaceans (see Table 1). Table 5 is also displayed to show the existing criteria for behavioural response, with focus upon single pulses (see Table 2). In 2014, the Noise Exposure Panel decided that sufficient new data had been published since 2007 to support updating some of the criteria just mentioned. The remainder of this contribution discusses which criteria definitely would be, and which criteria might be changed using these new data.

Brandon Southall sent a proposal to the International Association of Oil & Gas Producers' Joint Industry Program (JIP) to support the Noise Exposure Panel for two years to make the indicated updates. According to this proposal, the Panel would divide into three sub-groups to work simultaneously on three separate topics with papers to be published as they are completed. The topics to be considered, and the panelists to conduct the work were proposed as:

Table 1. Proposed injury criteria for individual marine mammals exposed to “discrete” noise events (either single or multiple exposures within a 24-h period (from Southall *et al.*, 2007: Table 3)

Marine mammal group	Sound type		
	Single pulses	Multiple pulses	Nonpulses
Low-frequency cetaceans	Cell 1	Cell 2	Cell 3
Sound pressure level	230 dB re: 1 μPa (peak) (flat)	230 dB re: 1 μPa (peak) (flat)	230 dB re: 1 μPa (peak) (flat)
Sound exposure level	198 dB re: 1 μPa^2-s (M_{lf})	198 dB re: 1 μPa^2-s (M_{lf})	215 dB re: 1 μPa^2-s (M_{lf})
Mid-frequency cetaceans	Cell 4	Cell 5	Cell 6
Sound pressure level	230 dB re: 1 μPa (peak) (flat)	230 dB re: 1 μPa (peak) (flat)	230 dB re: 1 μPa (peak) (flat)
Sound exposure level	198 dB re: 1 μPa^2-s (M_{mf})	198 dB re: 1 μPa^2-s (M_{mf})	215 dB re: 1 μPa^2-s (M_{mf})
High-frequency cetaceans	Cell 7	Cell 8	Cell 9
Sound pressure level	230 dB re: 1 μPa (peak) (flat)	230 dB re: 1 μPa (peak) (flat)	230 dB re: 1 μPa (peak) (flat)
Sound exposure level	198 dB re: 1 μPa^2-s (M_{hf})	198 dB re: 1 μPa^2-s (M_{hf})	215 dB re: 1 μPa^2-s (M_{hf})
Pinnipeds (in water)	Cell 10	Cell 11	Cell 12
Sound pressure level	218 dB re: 1 μPa (peak) (flat)	218 dB re: 1 μPa (peak) (flat)	218 dB re: 1 μPa (peak) (flat)
Sound exposure level	186 dB re: 1 μPa^2-s (M_{pw})	186 dB re: 1 μPa^2-s (M_{pw})	203 dB re: 1 μPa^2-s (M_{pw})
Pinnipeds (in air)	Cell 13	Cell 14	Cell 15
Sound pressure level	149 dB re: 20 μPa (peak) (flat)	149 dB re: 20 μPa (peak) (flat)	149 dB re: 20 μPa (peak) (flat)
Sound exposure level	144 dB re: $(20\ \mu Pa)^2$-s (M_{pa})	144 dB re: $(20\ \mu Pa)^2$-s (M_{pa})	144.5 dB re: $(20\ \mu Pa)^2$-s (M_{pa})

Note: All criteria in the “Sound pressure level” lines are based on the peak pressure known or assumed to elicit TTS-onset, plus 6 dB. Criteria in the “Sound exposure level” lines are based on the SEL eliciting TTS-onset plus (1) 15 dB for any type of marine mammal exposed to single or multiple pulses, (2) 20 dB for cetaceans or pinnipeds in water exposed to nonpulses, or (3) 13.5 dB for pinnipeds in air exposed to nonpulses. See text for details and derivation.

Table 2. Proposed behavioural response criteria for individual marine mammals exposed to various sound types, specific threshold levels are proposed for single pulses. See the referenced text sections and tables in Southall *et al*. (2007) for severity scale analyses of behavioural responses to multiple pulses and nonpulses (from Southall *et al.*, 2007: Table 5)

Marine mammal group	Sound type		
	Single pulses	Multiple pulses	Nonpulses
Low-frequency cetaceans	Cell 1	Cell 2[1]	Cell 3[6]
Sound pressure level	224 dB re: 1 μPa (peak) (flat)	Tables 6 & 7	Tables 14 & 15
Sound exposure level	183 dB re: 1 μPa^2-s (M_{lf})	Not applicable	Not applicable
Mid-frequency cetaceans	Cell 4	Cell 5[2]	Cell 6[7]
Sound pressure level	224 dB re: 1 μPa (peak) (flat)	Tables 8 & 9	Tables 16 & 17
Sound exposure level	183 dB re: 1 μPa^2-s (M_{mf})	Not applicable	Not applicable
High-frequency cetaceans	Cell 7	Cell 8[3]	Cell 9[8]
Sound pressure level	224 dB re: 1 μPa (peak) (flat)	[Tables 18 & 19]	Tables 18 & 19
Sound exposure level	183 dB re: 1 μPa^2-s (M_{hf})	Not applicable	Not applicable
Pinnipeds (in water)	Cell 10	Cell 11[4]	Cell 12[9]
Sound pressure level	212 dB re: 1 μPa (peak) (flat)	Tables 10 & 11	Tables 20 & 21
Sound exposure level	171 dB re: 1 μPa^2-s (M_{pw})	Not applicable	Not applicable
Pinnipeds (in air)	Cell 13	Cell 14[5]	Cell 15[10]
Sound pressure level	109 dB re: 20 μPa (peak) (flat)	Tables 12 & 13	Tables 22 & 23
Sound exposure level	100 dB re: $(20\ \mu Pa)^2$-s (M_{pa})	Not applicable	Not applicable

[1] “Low-Frequency Cetaceans/Multiple Pulses (Cell 2)” section
[2] “Mid-Frequency Cetaceans/Multiple Pulses (Cell 5)” section
[3] “High-Frequency Cetaceans/Multiple Pulses (Cell 8)” section
[4] “Pinnipeds in Water/Multiple Pulses (Cell 11)” section
[5] “Pinnipeds in Air/Multiple Pulses (Cell 14)” section
[6] “Low-Frequency Cetaceans/Nonpulses (Cell 3)” section
[7] “Mid-Frequency Cetaceans/Nonpulses (Cell 6)” section
[8] “High-Frequency Cetaceans/Nonpulses (Cell 9)” section
[9] “Pinnipeds in Water/Nonpulses (Cell 12)” section
[10] “Pinnipeds in Air/Nonpulses (Cell 15)” section

- Group 1: TTS/PTS and Frequency weighting functions. (Easiest to write and most critical for regulators)
    - Jim Finneran
    - Darlene Ketten
    - Paul Nachtigall
    - Bill Ellison
- Group 2. Behavioural Reaction Subgroup
    - John Richardson
    - Peter Tyack
    - Anne Bowles
    - Jeanette Thomas
- Group 3. Sound Source Characterization and Propagation as related to noise criteria
    - Jim Miller
    - Bill Ellison
    - Charles Greene

When each paper is finished, it will be reviewed by the whole panel and published with all panelists listed as authors. The plan is to later re-print all three papers together in a special issue of *Aquatic Mammals* for ease of access to the criteria.

The papers published since 2007 will be used in the following categories:

1. Separate criteria for phocids & otariids. The 2007 paper combined the two families due to lack of data. Much new data now allows us to separate them.
2. New criteria for TTS/PTS onset in mid- and high-frequency cetaceans. Most of the new papers apply to the mid-frequency cetaceans (dolphins, beluga, etc.)
3. New frequency weighting curves for mid- and high-frequency species. M weighting curves in Southall *et al.* (2007) were too conservative at low frequencies and not conservative enough at high frequencies. A new approach based on equal loudness contours or equal latency curves will be used.
4. New criteria on intermittent exposures. New research has shown that the dolphin ear undergoes some recovery in the interval between two loud sounds. The new criteria must take this factor into consideration.

The papers published since 2007 may or may not be sufficient to support new criteria in the following categories. The panel will decide which criteria are scientifically robust during its deliberations.

1. Possible criteria for behavioural disturbance. Three field studies on the behavioural response of marine mammals to sonar or airgun sounds are presently under way and are analysing the results using consistent statistical methods.

2. Possible criteria for a context-based approach to behavioural disturbance. A new paper has shown that at low exposure levels the context (feeding, migrating, with or without young, etc.) may determine the response whereas at high exposures, the level may determine the response.
3. Possible new criteria for sea otters. New data are available from the University of California, Santa Cruz marine mammal laboratory.
4. Possible criteria for propagation effects on the pulsatile nature of seismic pulses (change from pulse to non-pulse with distance).

The new data available on pinniped hearing appear in the following publications:

- Reichmuth, C., Holt, M.M., Mulsow, J., Sills, J.M., and Southall, B.L. 2013. Comparative assessment of amphibious hearing in pinnipeds. *Journal of Comparative Physiology* A, 199: 491-507.
- Mulsow, J. and Reichmuth, C. 2010. Psychophysical and electrophysiolgical aerial audiograms of a Steller sea lion. *Journal of the Acoustical Society of America*, 127: 2692-2701.
- Sills, J.M., Southall, B.L., and Reichmuth, C. 2014. Amphibious hearing in spotted seals. *Journal of Experimental Biology*, 217: 726-734. (JIP funded project).
- Reichmuth *et al.* Papers on ringed, spotted, and bearded seal TTS to airguns to be available for update of Southall *et al*. 2007. (JIP funded project).

The new data available on onset TTS/PTS in mid-frequency cetaceans are found in:

- Mooney, T.A., Nachtigall, P.E. and Vlachos, S. 2009a. Sonar-induced temporary hearing loss in dolphins. *Biology Letters*, 5: 565-567.
- Mooney, T.A., Nachtigall, P.E., Breese, M., Vlachos, S. and Au, W.W.L. 2009b. Predicting temporary threshold shifts in a bottlenose dolphin (*Tursiops truncatus*): The effects of noise level and duration. *Journal of the Acoustical Society of America*, 125: 1816-1826.
- Finneran, J.J., and Schlundt, C.E. 2010. Frequency-dependent and longitudinal changes in noise-induced hearing loss in a bottlenose dolphin (*Tursiops truncatus*). *Journal of the Acoustical Society of America*, 128: 567-570.
- Finneran, J.J., and Schlundt, C.E. 2011. Subjective loudness level measurements and equal loudness contours in a bottlenose dolphin (*Tursiops truncatus*). *Journal of the Acoustical Society of America*, 130: 3124-3136.
- Finneran, J.J. and Jenkins, A.K. 2012. *Criteria and thresholds for U.S. Navy acoustic and explosive effects analysis*. San Diego, California: SPAWAR Systems *Centre* Pacific.
- Finneran, J.J., and Schlundt, C.E. 2013. Effects of fatiguing tone frequency on temporary threshold shift in bottlenose dolphins (*Tursiops*

truncatus). *Journal of the Acoustical Society of America*, 133: 1819-1826.

- Finneran, J.J., C.E. Schlundt, B.K. Branstetter, J.S. Trickey, V. Bowman, and Jenkins, K. 2015. Effect of multiple impulses from a seismic air gun on bottlenose dolphin hearing and behavior. *Journal of the Acoustical Society of America*, 137(4):1634-1646.
- (JIP funded project)

The new papers available on hearing in high frequency cetaceans include:

- Lucke, K., Siebert, U., Lepper, P.A., and Blanchet, M.A. 2009. Temporary shift in masked hearing thresholds in a *harbour* porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. *Journal of the Acoustical Society of America*, 125: 4060-4070.

- Popov, V.V., Supin, A.Y., Wang, D., Wang, K., Dong, L., and Wang, S. 2011a. Noise-induced temporary threshold shift and recovery in Yangtze finless porpoises *Neophocaena phocaenoides asiaeorientalis*. *Journal of the Acoustical Society of America*, 130: 574-584.

- Kastelein, R.A., Gransier, R., Hoek, L. and Olthuis, J. 2012b. Temporary hearing threshold shifts and recovery in a *harbour* porpoise (*Phocoena phocoena*) after octave-band noise at 4 kHz. *Journal of the Acoustical Society of America*, 132: 3525-3537.

- Kastelein, R.A., Gransier, R., and Hoek, L. 2013. Comparative temporary threshold shifts in a *harbour* porpoise and *harbour* seal, and severe shift in a seal (L). *Journal of the Acoustical Society of America*, 134: 13-16.

The new papers available on frequency weighting functions are:

- Finneran, J.J., and Schlundt, C.E. 2011. Subjective loudness level measurements and equal loudness contours in a bottlenose dolphin (*Tursiops truncatus*). *Journal of the Acoustical Society of America*, 130: 3124-3136.

- Finneran, J.J. and Jenkins, A.K. 2012. *Criteria and thresholds for U.S. Navy acoustic and explosive effects analysis*. San Diego, California: SPAWAR Systems *Centre* Pacific.

The new paper on intermittent exposures is Finneran, J.J., Carder, D.A. Schlundt, C.E., and Dear, R.L. 2010. Temporary threshold shift in a bottlenose dolphin (*Tursiops truncatus*) exposed to intermittent tones. *Journal of the Acoustical Society of America*, 127(5): 3267-3272.

The papers available on behavioural response include:

- Ellison, W.E., Southall, B.L., Clark, C.W. and Frankel, A.F. 2012. A new context-based approach to assess marine mammal behavioural responses to anthropogenic sounds. *Conservation Biology*, 26: 21-28. DOI: 10.1111/j.1523-1739.2011.01803.x

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The paper discussing the importance of context in behavioural response is:

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Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene, C.R., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, J.W., Thomas, J.A., and Tyack, P.L. 2007. Marine mammal noise exposure guidelines: initial scientific recommendations. *Aquatic Mammals*, 33: 411-521.

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ENVIRONMENTAL ASSESSMENTS AND MARINE MAMMALS: AN ADVISOR'S (AND REGULATOR'S) PERSPECTIVE IN THE UK

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For this workshop, we were invited to give an introduction to Environmental Impact Assessments (EIA) in relation to marine mammals, and to present information from the perspective of a 'regulator'. The 'regulator' is the competent authority responsible for issuing the necessary licences and consents required for development to go ahead. While not representing regulators themselves, each of the authors are technical advisors within the UK Statutory Nature Conservation Bodies (SNCBs)[1], and provide independent and expert advice to the regulators to inform their decision making. As such, the advice we provide to the regulators allows them to make informed decisions about the likely impacts of marine developments and whether they can be licensed (given consent) without breaching environmental legislation.

In this contribution, we present the UK approach to environmental assessment processes (mainly EIA) with a focus on marine mammal issues.

The information presented largely outlines the process within England and Wales (there are some differences in Scottish legislation). Nevertheless, given that EIA is a process underpinned by EU legislation, the issues are common across EU member states. The focus of this article is on impacts from anthropogenic underwater sound from marine renewable developments, namely from pile driving for offshore wind developments, although principles are similar for alternative marine sectors that create underwater sound (*e.g.* seismic surveys, oil & gas construction and prospecting, and aggregate extraction).

The article is structured in two parts. First, we describe the main environmental assessment processes, concentrating on EIA. Secondly, we outline five key issues commonly encountered in EIA when assessing the effects of anthropogenic underwater noise on marine mammals.

A SUMMARY OF ENVIRONMENTAL ASSESSMENT PROCESSES IN EUROPE

There are three key environmental assessment processes in Europe, each underpinned by European directives:

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[1] Natural Resources Wales (SNCB) has a functionally separate regulatory arm within the organisation, which is responsible for issuing licences

1) Strategic Environmental Assessment (SEA): 'SEA Directive', European Directive 2001/42/EC[2] "on the assessment of effects of certain plans and programmes on the environment"; transposed into UK law through the SEA Regulations;
2) Habitats Regulations Appraisal or Assessment (HRA): 'Habitats Directive', Council Directive 92/43EEC[3] "on the conservation of natural habitats and wild fauna and flora"; transposed into UK law through the Habitats Regulations;
3) Environmental Impact Assessment (EIA): 'EIA Directive', Council Directive 85/337/EEC (as amended and consolidated)[4] "on the assessment of the effects of certain public and private projects on the environment"; transposed into UK law through the EIA Regulations.

The focus of this paper is on environmental assessments for specific developments or projects and, therefore, we will not cover SEA here because it is a process relating to the assessment of high-level strategic plans and programmes usually undertaken at a broad scale (*e.g.* regional seas) (see ODPM, 2005). We will briefly describe 'project level' HRA but will concentrate on the EIA process.

Habitats Regulations Appraisal/Assessment (HRA)

HRA is a legally required process applicable to any 'plan' (programme of developments) or 'project' (individual development) likely to have a significant effect on a European site (*e.g.* a Special Area of Conservation [SAC]). The purpose of an HRA is to firstly determine whether there is a likely significant effect (LSE) and, if so, to ascertain beyond reasonable scientific doubt that a plan or project, alone or in-combination with other plans or projects, will not have an adverse effect on the 'integrity' of any European site as evaluated against the site's 'conservation objectives'. Usual practice is that information collected, analysed and interpreted during the EIA will inform the HRA process, although the HRA must be documented separately.

The HRA should only focus on the effects of the proposal on the internationally important habitats and/or species (the site's qualifying interests or features) for which the site is (or will be) designated. For marine mammals, this represents only the species listed on Annex II of the Habitats Directive (grey seal, common seal, harbour porpoise and bottlenose dolphin). The developer is required to provide the competent authorities/statutory advisors with sufficient information to inform the HRA; developers do not carry out the HRA themselves. All competent authorities (regulators and/or their advisors), before giving consent to a plan or project, must check whether it would be likely to have a significant effect (LSE) on a 'European site'. LSE is not defined in the Habitats Directive or Regulations. However, in the European

[2] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32001L0042

[3] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31992L0043

[4] http://ec.europa.eu/environment/eia/eia-legalcontext.htm

Court of Justice 'Waddenzee' judgment[5] (the findings of which have been upheld in subsequent legal cases), the concept of the phrase 'cannot be excluded' sets the degree of caution to be used and has effectively embedded the precautionary principle in the LSE stage of the HRA process.

If it cannot be excluded that the plan or project, either alone or in combination with other plans or projects, will have a LSE on the site(s), then it must be subject to an 'Appropriate Assessment' of its potential impacts in view of the site's conservation objectives. This allows the competent authority to be able to conclude whether there will be no adverse effect on site integrity, or otherwise. At this stage of the HRA, the competent authority must consult the SNCB and have regard to their advice.

In cases where an adverse effect on the integrity of a European site cannot be ruled out, via an AA, and yet the competent authority still wishes to give consent to the proposal, there is a derogation under Article 6(4) of the Directive. Firstly, the competent authority should, in discussions with the developer, consider whether there are any 'alternative solutions'. If alternatives are available and applicable, the competent authority cannot grant development consent. If there are no alternative solutions, for the development to proceed there would need to be 'imperative reasons of overriding public interest' (IROPI), and compensatory measures (*e.g.* compensating for loss of critical habitat by restoring/creating critical habitat elsewhere) would need to be secured by Ministers to ensure the coherence of the network of European sites is maintained.

Environmental Impact Assessment (EIA)
There is an enormous body of literature on EIA and so the following section is only a brief summary of the key stages of the process. The reader is referred to a variety of planning guidance for further information:

- Guidance on specific aspects of EIA: http://ec.europa.eu/environment/eia/eia-support.htm
- Advice notes from the Planning Inspectorate: http://infrastructure.planninginspectorate.gov.uk/legislation-and-advice/advice-notes/
- Guidelines for Ecological Impact Assessment in Britain and Ireland (Marine and Coastal) Institute of Ecology and Environmental Management, 2010: http://www.cieem.net

EIA in Europe was developed to create a 'level playing field' for all developers to consider and provide information on the environmental implications of a development (project). EIA ensures robust assessments are made of developments or activities that have the potential to have significant impacts on the environment. The process is intended to inform the statutory bodies and the public about the potential environmental risks of proposed developments. Unlike in HRA, the precautionary principle is not embedded in

[5] Landelijke Vereniging tot Behoud van de Waddenzee and Nederlandse Vereniging tot Bescherming van Vogels v Staatssecretaris van Landbouw, Natuurbeheer en Visserij, C-172/02, [2005] Env LR 14.

the EIA process; rather, it is applied proportionally as a matter of policy and good practice.

The EIA Directive (85/337/EEC as amended and consolidated) has been in place since 1985 and applies to a wide range of public and private projects, which are defined in Annexes I and II of the Directive. All projects listed in Annex I are considered to have significant effects on the environment and an EIA is mandatory (*e.g.* large infrastructure/civil engineering projects such as crude oil refineries and nuclear power stations). For projects listed in Annex II (*e.g.* offshore windfarms, tidal turbines, fish-farming), the national authorities have discretion on whether an EIA is needed, but must adhere to the selection criteria laid down in Annex III, which requires consideration of key characteristics of the project, the environmental sensitivity of the project location and the kind of impacts likely to be of concern. This is carried out through a "screening procedure", undertaken by the authority, which determines the effects of projects against specified thresholds/criteria or on a case-by-case basis and so whether EIA is required.

Following screening, the EIA process can be summarised as follows (Figure 1):

1) Scoping - determining the detail in the ES that should be provided by the developer;
2) Environmental Statement (ES) – the description of the project and its anticipated environmental effects;
3) Consultation - the environmental authorities and the public (and affected Member States) must be informed and consulted;
4) Decision - the competent authority decides whether to give consent, taking into consideration the results of consultations;
5) Implementation – the subsequent process of the development, ultimately leading to construction. Baseline and impact monitoring and mitigation often required.

Scoping

'Scoping' is the process of determining the level of detail to be included in the ES, i.e. which receptors (species) and impact pathways that should be considered, to be included in the ES (NRW, 2015). The developer may request the competent authority to outline what should be covered in the ES, and what information should be provided by the developer (a 'scoping opinion'). The environmental impacts must be assessed for the entire life of the project, which includes construction, operation and decommissioning. For offshore windfarms, 25 years is a typical timeframe. For tidal range energy generation developments, the life of a project can be up to 120 years.

All environmental impact pathways must be assessed on the basis of realistic worst-case scenarios. The collection of worst-case scenarios that result in maximum environmental impact is called the "Rochdale envelope", named after a UK planning law case (PINS, 2012). This approach allows for flexibility in specifying the project design and covers potential variations within the project. Thus, if a worst-case scenario from a project design results in an acceptable environmental impact, any reduction to the design (*e.g.* fewer wind-turbines, smaller pile diameter) will likely reduce the environmental impact and will have been already adequately assessed within the ES. Changes to the project design that fall beyond that assessed (*e.g.* larger footprint, more wind turbines, larger pile diameters) are likely to result in environmental impacts that fall outside the limits of the worst-case predictions in the ES and would require re-assessment. However, the Rochdale envelope approach routinely results in impacts being over-inflated and assessments being over-precautious. Such assessments, although designed to assist the developer, unfortunately may hinder the project consenting process. Clearly, a pragmatic approach is required and early engagement is encouraged.

Environmental Statement
The developer must provide information on the environmental impact as outlined under Annex IV of the EIA Directive. This information is documented in the ES. The ES should address all likely significant environmental effects and exclude those that are considered unlikely. The ES describes the (biodiversity) value of area/receptors affected by the development, the baseline environmental information, and the characterisation of environmental change/effects likely to be caused by the project. Cumulative impacts (additive effects from multiple projects) must be included and measures to avoid/reduce/remedy impacts (mitigation) should be proposed.

Decision
Based on the results of consultations, the competent authority decides whether the project receives consent. The public is informed of the decision afterwards and can challenge the decision before the courts. For large-scale offshore renewable energy projects that exceed 100 MW of power generation (termed Nationally Significant Infrastructure Projects [NSIP] in England and Wales), the Planning Inspectorate (PINS) representing the Secretary of State in England and Wales is charged with examining the likely effects. If the NSIP were considered environmentally acceptable, PINS would issue a Development Consent Order (DCO). Devolved governments/regulators subsequently issue specific marine licences for the development in territorial waters. For smaller projects (<100 MW), the devolved country regulator(s), rather than PINS, issue Electricity Act and marine licences.

Implementation
After consent, there is a suite of processes (non EIA) progressing to construction, a description of which is beyond the scope of this article.

The project may require baseline and/or impact monitoring and usually will need some mitigation measures to reduce environmental harm. The concept of ‘proportionality’ was introduced in the 2014 EIA Directive amendments (Directive 2014/52/EU) to ensure that any environmental impact monitoring was carried out in proportion to risk. This is an important requirement to avoid the undesirable situation of engaging in detailed, lengthy and expensive monitoring when it may not be appropriate (i.e. when impact risk is very low). Post-construction monitoring, however, is important to determine if impacts predicted in the ES are correct.

Mitigation plans to reduce environmental effects are refined at this stage as the project envelope (project design) takes shape. Mitigation is discussed below.

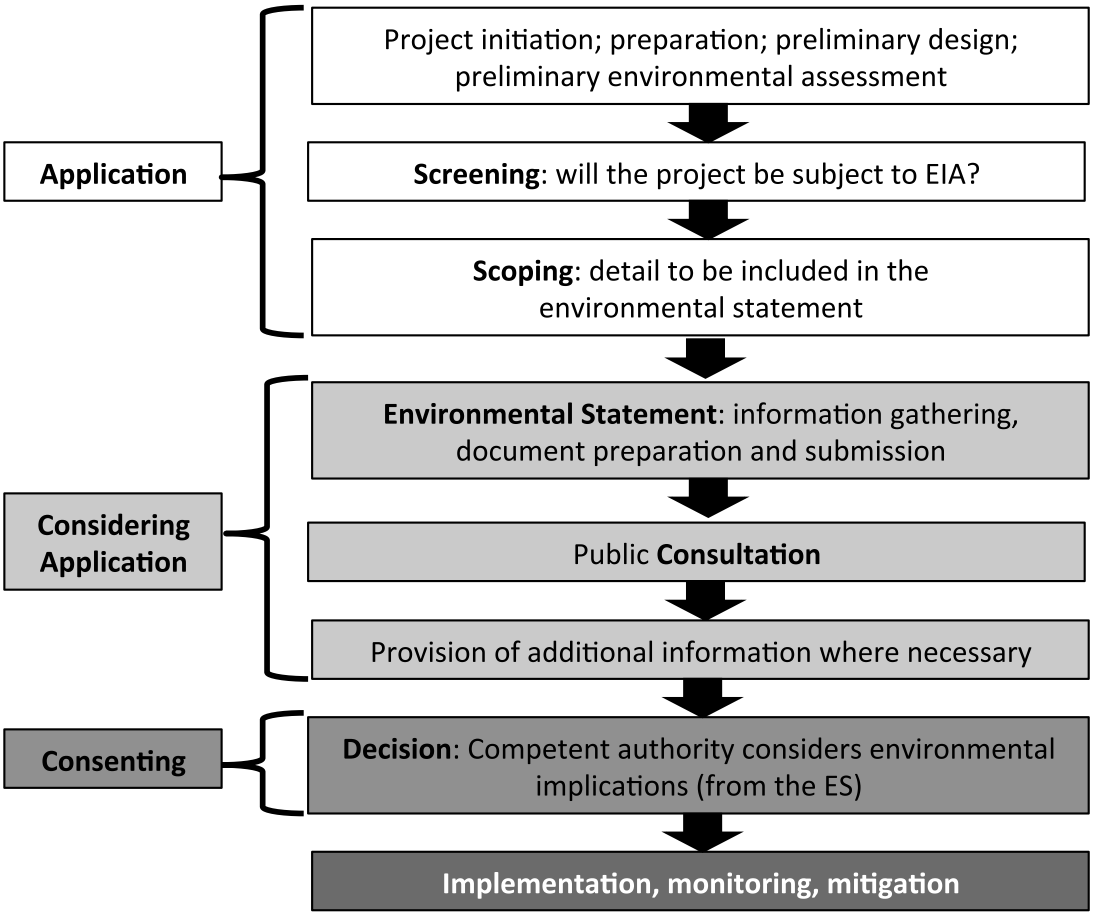

Figure 1. Summary of the EIA process (Adapted from Tyldesley, 2010)

Contrary to the simplicity represented in Figure 1, the EIA process is complex, highly iterative and dynamic. It is also very costly and can take many years. In recent years, EIAs have become larger and more complex, making any statutory assessment of their content (quality and predictions) progressively more difficult and time consuming. Thus, early (non-statutory) engagement among statutory advisors, experts and developers (and/or their consultants) is especially important to ensure the technical scope of the assessments are adequate, any environmental issues are discussed (ideally with resolution), and the process is agreed before the ES is delivered.

MARINE MAMMALS AND PILING NOISE: CHALLENGES AND KEY ISSUES IN EIA

Marine mammals are protected in UK through a variety of directives, conventions, legislation and policies. The main legislative driver in the UK and Europe for cetaceans is the European Habitats Directive and we focus on this legislation in this article. Under the Directive, Member States must establish SACs for species listed under Annex II of the Directive and take measures to establish a system of strict protection for Annex IV species (European Protected Species [EPS], including all cetaceans). Seals are not EPS but are protected under the Habitats Directive only where they are designated features of SACs (and are assessed by the HRA process). However, under EIA, impacts to seals are often given similar considerations to those of cetaceans. The UK Government has a legal obligation to adequately transpose the Habitats Directive and ensure strict protection is afforded to cetacean species as EPS, and Annex II species features of SACs. Failure to do so could expose the UK devolved administrations to legal action by the European Commission with a consequent risk, if the failure is not addressed, of incurring infraction fines.

Article 12 of the Directive makes it an offence to deliberately disturb, injure or kill EPS. Deliberate (i.e. that which is foreseeable) disturbance must be non-trivial or significant for the EIA to address impact reduction, for example, through mitigation measures. The SNCBs interpret significant disturbance as that which could contribute to a detrimental impact on the conservation status of the species (JNCC *et al*., 2010). If disturbance cannot be avoided through risk management (mitigation plans), then, and as a last resort, a licence to disturb (EPS) may be granted to certain activities, where appropriate. As a result of devolution in the UK, there are differences in the legislation; in Scotland the disturbance offence is wider ranging, covering situations where there is a risk that individual animals could be deliberately or recklessly disturbed. Therefore, many more marine EPS licences are therefore issued in Scotland. Developers, researchers and consultants need to ensure they refer to the correct regional legislation.

During construction of offshore windfarms, pile driving of turbine foundations is a key source of underwater sound that has the potential to deliberately disturb or injure cetaceans and seals. We now provide a brief overview of five key issues or challenges in relation to anthropogenic underwater sound, EIA and marine mammals.

Key Issue 1: *Different measurements, metrics and modelling used across EIAs*

EIA quality and approach is highly variable among projects. A variety of noise measurements are reported in ESs often without stating how, where, when and how frequently measurements were taken or with what equipment. In recognition of this fundamental issue, a number of recent guidelines have been issued in an attempt to provide some steer in standardising data collection and reporting (Robinson *et al*., 2014).

Sound levels thought to cause injury or behavioural disturbance in marine mammals are outlined by the criteria of Southall *et al.* (2007). These criteria are widely accepted as the best currently available indication of possible acoustic injury and disturbance levels. However, Permanent Threshold Shift (PTS) metrics are extrapolated from Temporary Threshold Shift (TTS) measurements on few captive animals and may not relate well to wild animals. Moreover, there is likely to be large individual variation in sensitivities and thus the criteria may not be representative of wild marine mammal populations. These criteria are, therefore, generally considered precautionary. However, some recent studies confirm that for some species the thresholds are reasonable estimates of sound levels likely to cause injury, and they are under review at present (see Gentry, this issue). Another set of metrics commonly used in British EIAs is the Nedwell *et al*. (2007) criteria. These are largely defined around a behavioural scale, which is adjusted to the hearing sensitivities of animals.

The most common way of determining the magnitude of impact of underwater noise from piling on marine mammals is through sound propagation modelling. Usually, sound is modelled to decay as it propagates away from the source (pile) through a homogenous water column; a variety of models are used across EIAs. At a certain distance from the source, the expected noise level is reduced to a level that is thought not to cause hearing injury to marine mammals. This is typically modelled spatially as a PTS contour (interpreted as injury) and/or significant behavioural disturbance contours. The model contours delineate a measurable area of ensonification that is multiplied by a species density (usually but not always from that area) to provide an estimate of the number of animals affected. This number is expressed as a percentage of the population to indicate the likely level of population effect. Noise propagation models, however, are unlikely to fully represent the natural conditions of the area where topographical features, water depth and environmental conditions profoundly affect how sound propagates through water and how it is perceived by animals in the water column. These assessments are likely to be over-precautionary (although untested), but provide a useful scenario of the worst-case level of impact.

With such variation in metrics, modelling frameworks and environmental conditions presented across EIAs, it becomes difficult to compare effects among them, especially when considering cumulative effects (see later).

Key issue 2: *How much injury or disturbance is acceptable?*

Even if we have carefully predicted the likely injury sound levels at which we believe there to be an effect, and we have calculated the number of animals affected, how do we determine an acceptable level of injury, or disturbance? It is relatively straightforward to predict if sound levels are likely to result in injury (PTS), but to determine whether disturbance from lower sound levels is detrimental in the long-term is difficult and is generally attempted through modelling scenarios that scale up effects on individuals to population level effects (see later).

A variety of thresholds have been used to indicate the magnitude of effect that is likely to be considered unacceptable. ASCOBANS (as applied to the harbour porpoise) suggests unacceptable interactions (anthropogenic mortality) should not be more than 1.7%, of which no more than 1% should be caused by bycatch (with the aim of reducing this to zero) (ASCOBANS, 2000). Habitats Directive guidelines suggest an indicative threshold for a large decline as being 1% per year (Evans and Arvela, 2012). Some consented offshore windfarm EIAs, however, have considered that an effect resulting in a change (disturbance) of greater than 10% or 20% is significant (moderate and high magnitude respectively), implying that a change less than these threshold values is acceptable. EIAs will typically qualitatively rank the level of some impact as minor, moderate and high, and generally incorporate magnitude and duration into the grading. The quantification of these levels, however, is only occasionally achieved. Thompson *et al*. (2014) developed a useful population assessment framework for seals and suggested that a change to the seal population of >20% is considered high (major significance) and >10% is considered medium (minor to medium significance, depending on duration of impact).

Crucially, however, these levels of change are often based on the ability to statistically detect/measure differences between impacted and baseline data, rather than on the biological importance of the effect. Clearly, the ability to detect/measure is dependent on survey effort and good monitoring data. For most marine mammal monitoring schemes consisting of short-term baselines (typically <2yrs for EIA), only very large changes (*e.g.* >30%) are likely to be detected (*e.g.* Taylor *et al*., 2007). If a change is not detected, however, does that mean a change has not happened? Conversely, if a change has been detected it is critical to be able to attribute that change to the development (*e.g.* windfarm) or other factors; thus, proper survey design with controls (*e.g.* Before-After-Control-Impact [BACI], gradient designs) is required, if the ability to detect change is important (i.e. a condition of the development's consent). When an argument is used that change/impact needs to be detectable or measurable for there to be action (*e.g.* mitigation) but the power to detect change is low (due to few data having been collected / few surveys), this creates a problematic situation that requires careful, legal consideration: absence of evidence is not the same as evidence of absence.

Key issue 3: *Scaling up to population effects*

There are challenges in scaling up from the effects of disturbance to individuals or aggregations (in local areas) to the effects on the wider population. Modelling is often employed in such scenarios and requires population demographics to inform the model. A common approach to simulating population change is through Population Viability Analysis (PVA) (*e.g.* Thompson *et al*., 2014). However, confidence intervals (CIs) are usually large owing to uncertainties in the parameters, and they increase with how far ahead in time the model is projected. When CIs become too wide, it is practically useless at informing likely impacts. For population modelling to be useful, specifying the spatial scale of the population is critical – local, regional, national, international, bioregional, global. Typically, in the UK (and Denmark, for example), marine mammal management units are used as the appropriate spatial scale (ICES, 2014; IAMMWG, 2015; J. Teilmann, this volume).

More sophisticated models using vital rates, demographics, expert elicitation, Bayesian statistics and a multitude of layered assumptions are now being employed to determine population effects. Following on from the US Population Consequences of Acoustic Disturbance approach (NRC, 2003), a Population Consequences of Disturbance (PCOD[6]) modelling framework was

[6] http://www.gov.scot/Topics/marine/science/MSInteractive/Themes/pcod

created in the UK from SNCBs' and Regulators' desire to scale up impacts from pile driving to the population level (King *et al*., 2015). An alternative approach using agent-based modelling was devised for the North Sea offshore wind industry: Disturbance Effects on the Harbour Porpoise Population in the North Sea (DEPONS[7]) (van Beest *et al*., 2015). PCOD and DEPONS also attempt to quantitatively assess cumulative effects (see below).

Key issue 4: *Cumulative (in combination: HRA) effects*

Although cumulative impact assessments (CIA), which attempt to establish the additive effects of multiple developments, are required under EIA and HRA (termed 'in-combination' rather than 'cumulative' for HRA), they are difficult to undertake. This is because, for example, other project information may not be in the public domain, is commercially sensitive, or it may not be possible to obtain relevant information. Cumulative effects operate at a wider spatial (and temporal) scale to that of the project under consideration, making them difficult to assess adequately. There are many uncertainties involved with assessing cumulative effects, the result being that the information tends to be speculative and qualitative. Moreover, CIAs are rarely able to consider other developments for the life of the project because it is difficult to predict the future – usually only projects that are consented or in application are considered.

Understanding cumulative impacts on marine mammal populations, however, is probably the most important consideration in assessing population level effects that inform relevant conservation and management. Thus, an adequate CIA mechanism is urgently required. Some of the recent modelling approaches (PCOD, DEPONS) attempt to quantify the cumulative effects of piling noise, where noise from known piling schedules can be modelled to determine population effects over specified time periods. It is important to note that noise zones need not overlap for there to be cumulative impacts. Additionally, marine mammal management units provide a spatial basis for the scale at which cumulative effects should be considered and the spatial limit of projects to include or exclude.

Variation in metrics/measurements and modelling across EIAs (see Key issue 1) creates difficulties in comparing and combining data for CIA. Also, as a result of these differences in techniques/measurements, each project CIA in a region is likely to have different results and interpretations of potential impacts, despite including and addressing a similar set of projects and impacts. CIA therefore would be ideally carried out by a central, independent organisation (*e.g.* the regulator), so that a consistent set of measurements is utilised and all relevant and known projects and activities are included to inform likely impact at a broad scale over a set period of time. Such centralisation would better inform potential management scenarios and marine planning. However, until this has become government policy, each project must carry out their own CIA.

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[7] http://depons.au.dk/

Key issue 5: *Mitigation to prevent hearing injury (not disturbance)*

Consent conditions and the environmental management measures must strike a careful balance: they must be appropriate and proportional to the risks posed by the development of the project, allow the delivery of offshore wind projects which are technically and economically viable, and have acceptable levels of environmental impact. Moreover, they must comply with the more stringent legal requirements to maintain populations of European Protected Species at a 'favourable conservation status' and ensure no adverse effect on European site integrity (through processes such as EPS licensing and HRA for Annex II species). There is therefore a high level of interest from all parties to have the right marine mammal mitigation protocol in place.

For mitigation of piling noise, close range (near field) mitigation is aimed at avoiding auditory injury (TTS, PTS) rather than disturbance, and is usually administered at the project level. The JNCC mitigation protocols to minimise injury during piling (JNCC, 2010) are widely accepted as best practice in the UK. Here, the suggested mitigation currently includes:

- a standard 500m radius marine mammal exclusion zone which should be clear of marine mammals before piling commences;
- marine mammal observers (MMOs) that visually inspect the mitigation zone for animal presence;
- passive acoustic monitoring (PAM) to acoustically monitor the mitigation zone;
- and piling soft starts where a slow ramp-up in piling energy is designed to provide sufficient warning to allow animals to vacate the local area (mitigation zone) before the noise reaches injurious levels.

UK is the only European member state to use MMOs during piling operations. Soft starts are the most widely applied mitigation measure (Table 1).

Table 1. Differences in marine mammal mitigation for offshore piling across the EU (Adapted from Xodus, 2013)

Country	Soft start	ADD	MMO & mitigation zone	Seasonal restrictions	Noise limits	Restriction on contempo-raneous piling	Develop-ment in SACs
Belgium	✓	✓	✗	✓	✗	✗	✓
Denmark	✓	✓	✗	✗	✗	✗	✓
Germany	✓	✓	✗	✗	✓[2]	✗	✗
Netherlands	✓	✓	✗	✓	✗	✓[3]	✓
UK	✓	✓[1]	✓	✗	✗	✗	✓

[1] Used occasionally
[2] Noise limit at 750 m from pile (160 dB SEL/190 dB SPL)
[3] Restricts piling to one development at a time

Piling at night is desirable for the offshore wind industry to maximise use of hired equipment and optimise costs, especially when weather conditions are good (*e.g.* in summer). But for piling at night or in poor visibility when MMOs are redundant, PAM is the only option for detecting vocalising cetaceans; however, PAM does not work for seals or non-vocalising cetaceans. If night-time piling is permitted (through consenting conditions) it would need to primarily rely on soft-starts. However, if piling at night was strictly prohibited, this would extend the time it takes to complete piling and this may be worse in terms of population effects than getting piling completed quickly. Mitigating piling is thus a balance of several pressures and is not easily resolvable.

Acoustic Deterrent Devices (ADDs) may be used to keep animals away from areas where injury might occur. While ADDs might be considered a potential mitigation method for piling (Xodus, 2013), they introduce further anthropogenic sound into the marine environment (albeit at lower levels than from piling) and may need to be appropriately managed and licensed. Additionally, unless mitigation monitoring is employed during initial ADD use, we cannot be sure that ADDs are being effective at mitigating.

The Netherlands and Belgium are the only countries to currently have seasonal restrictions on piling (Table 1). Spatial and temporal management of piling and construction programming, however, needs to be managed by the regulators. In the UK, the devolved nature of governance (inshore/offshore, devolved authorities) adds complexity to such regulation.

The mitigation discussed so far is designed to reduce injury. But how do we mitigate against disturbance? If disturbance is deemed to be significant, there is likely to be a requirement to reduce the sound emitted. Sound dampening technologies are possible, *e.g.* Big Bubble Curtains, sound jackets etc, but these are rarely (if ever) used in the UK, possibly due to oceanographic conditions (water depth, current speeds). Alternative foundations are a possibility: floating turbines, gravity bases, etc., although the latter conflict with other receptors, *e.g.* benthos and coastal processes. Optimising the duration of construction piling is a consideration for reducing disturbance. However, piling is generally temporary (although that is a relative term) and intermittent and, therefore, disturbance to marine mammals may also be temporary. Windfarm operation is longer term (25 years) but operation noise is benign by comparison to construction noise.

CONCLUSIONS

For an EIA, assessment (and mitigation) of the impacts from a project should be proportional to risk and the regulator must consider the risks to marine mammals alongside the risks to other receptors and processes, *e.g.* fish, birds, benthos, protected habitats and coastal processes, to ensure compliance with environmental legislation. Although generally high on the agenda due to their protection status, marine mammals may not necessarily be the priority among the suite of environmentally sensitive receptors and impact pathways. Their influence on the consenting process is determined by the magnitude of likely impacts and the requirements of the relevant legislation. For marine mammal features of SACs, however, the HRA process must demonstrate that there will not be an adverse effect on site integrity (as evaluated against the site's conservation objectives) - a requirement that is much more stringent than the EIA's 'risk-based and proportionate' approach. As such, some of the issues described above that might provide useful information for assessing impacts in an EIA framework, might not be suitable for assessing the lack of effects under HRA.

Challenges that are common across all or most of the five issues described above include dealing with uncertainty, finding pragmatic solutions to the issues (*e.g.* affordable technological solutions), assessing effects (including cumulative) at the population level, and better determining the effects of sound on marine mammals when we know relatively little about their biology and behaviour. There have also been many advances in understanding and managing the impact of piling noise on marine mammals: there is a general raised awareness of species sensitivities and legislative requirements, risk assessment standards follow good practice guidelines when industry and advisors/regulators work together to resolve issues, mitigation of potential injury at close ranges is largely reliable, and there is a drive for new technology in construction/ mitigation.

In this article, we briefly outlined the two main project level environmental assessment processes in the UK (HRA and EIA) and touched on five key issues in EIAs in relation to impacts on marine mammals from piling noise. These are some of the issues that the regulator, advisor, consultant and developer are tackling in the current offshore wind consenting framework; hopefully, they provide the reader with some inspiration for further applied research.

ACKNOWLEDGEMENTS & DISCLAIMER

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ENVIRONMENTAL IMPACT ASSESSMENTS FOR OCEAN NOISE: LESSONS FROM THE UNITED STATES

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Over the past two decades, the United States has frequently found itself at the vanguard of the environmental assessment of ocean noise. The National Marine Fisheries Service (NMFS), the U.S. federal agency with management responsibility for cetacean and most pinniped species, was among the first government agencies worldwide to establish thresholds for acoustic impacts on marine mammals, and the U.S. Department of the Navy and other agencies were among the first to produce environmental impact assessments and programmatic impact assessments for acoustic projects. The 2000s, in the United States, saw the advent of the Population Consequences of Disturbance project, an initiative led by the Office of Naval Research (National Research Council, 2005), as well as the CetSound program, a public-private effort at predictive density modeling and noise mapping across the U.S. territorial sea and exclusive economic zone (NOAA, 2012). The results of both projects are beginning to find their way into environmental impact assessments. These days, virtually every request for “take” authorisation, under the U.S. Marine Mammal Protection Act, has an acoustic component (Roman *et al.*, 2013), driving assessment of an ever-widening range of noise-producing activities in the ocean.

Over time, these U.S. efforts have influenced other countries in their development of environmental assessment and regulatory policy for underwater acoustics. Most notable, perhaps, has been the proliferation of NMFS’ thresholds for behavioural harassment, which, since their advent in the late 1990s, have spread to the UK, Canada, Germany, Australia, and several other jurisdictions (*e.g.*, Weir and Dolman, 2007). But numerous other conventions in acoustic impact assessment also have their origins in the United States: the “behavioural risk function,” the “severity index” for behavioural response, the categories of low-, mid-, and high-frequency cetaceans, and on and on. Since 2008, the Marine Strategy Framework Directive has spurred considerable development in Europe, producing, for example, cumulative impact analyses for North Sea wind farm construction (King *et al.*, 2015) that are more ambitious than anything yet produced in the United States. Nonetheless, U.S. efforts continue to attract enormous interest, as witnessed by the considerable international attention paid to the revision of NMFS’ auditory impact criteria (NOAA, 2013).

It should go without saying that no jurisdiction should adopt the work of another uncritically. In importing the standards of another country, regulators may cast a blind eye to the legal, political, cultural, or other factors extrinsic to biology that helped influence their development. The purpose of this presentation is to inform international readers of the specific legal context in which certain analytical methods for ocean noise assessment have arisen in the United States. In particular, it will explain the role of the Marine Mammal Protection Act (MMPA), the leading U.S. statute for ocean noise regulation, in impact assessment, and how tensions inherent in the MMPA have retarded U.S. standards.[8]

THRESHOLDS FOR "BEHAVIOURAL TAKE" UNDER THE MMPA

"Take" is the basis of most ocean noise regulation in the United States. Under the MMPA, all "takes" of marine mammals are prohibited without prior authorisation, which is available only to applicants that make formal application to NMFS (or, if certain species are affected, to the U.S. Fish and Wildlife Service) and that meet a number of standards set forth in the statute. For most activities, the MMPA defines the lower bound of "take" as the "potential" disturbance of a "marine mammal or marine mammal stock in the wild by causing disruption of behavioural patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering" (U.S. Code, 2015). This definition was adopted by the U.S. Congress more than twenty years ago, in the wake of a case, known as *United States v. Hiyashi* (1994) that highlighted the lack of an objective statutory definition sufficient to sustain the Act's criminal and civil penalties.

The MMPA's "take" definition interacts with other statutory standards in significant ways. Perhaps most importantly, it works with the Act's "incidental take" provisions to limit the impact that any proposed activity can cause. Most proposed activities that would take marine mammals are not permitted to produce a greater than "negligible impact" on any particular marine mammal species or population, or to take more than "small numbers" of any particular marine mammal species or population (U.S. Code, 2015). In applying these standards, NMFS routinely estimates the number of takes a particular activity will cause. Should the number of takes exceed the Act's "small number" ceiling, or result in a greater than "negligible impact," the authorisation cannot issue and the activity cannot legally take place. Thus a great deal of economic, political, and biological consequence follows from the agency's interpretation of "take." Noise-generating activities are particularly sensitive to agency interpretation given the large number of impacts they can cause.

Not surprisingly, NMFS has avoided any application of the law that would substantially limit its ability to authorise take in other instances. To that end, it has sedulously avoided defining the "small numbers" and "negligible impact" standards with greater specificity, despite the repeated urgings of the U.S. Marine Mammal Commission and the conservation community. Indeed, it has seldom, if ever, published the denial of an MMPA application, and never a denial on the grounds of "small numbers." When an applicant proposes to take a number of marine mammals that the agency deems excessive, it is asked to re-work its take analysis (as in the case of the National Science Foundation's application to conduct a seismic survey off central California) or, in some cases, its proposal. Courts have abetted this behaviour by according

[8] The original presentation made a number of additional observations concerning U.S. environmental impact assessment and mitigation analysis that, for the sake of space, are omitted here.

NMFS considerable discretion in interpreting the law; still, they have made it clear that the agency's discretion is not limitless. Thus, for any given application, the agency is bound to estimate the percentage of marine mammals, within each affected species or population, that would be taken, in determining if the "small numbers" standard is met (*Centre for Biological Diversity v. Kempthorne*, 2009); and it must provide meaningful, population-specific rationales to authorise high levels of take under the Act's "negligible impact" standards (*Natural Resources Defense Council v. National Marine Fisheries Service*, 2015). But NMFS persists in interpreting the MMPA's authorisation standards in a manner that preserves its discretion.

The same pressures affecting the agency's articulation of the "small numbers and "negligible impact" standards have strained its interpretation of the MMPA's "take" definition, especially its interpretation of the behavioural harassment definition, quoted above. NMFS first quantified the definition in the 1990s to meet its authorisation needs. At the time, the literature on acoustic impacts was sorely limited, and the agency relied on a pair of expert workshops, including one convened as part of a multi-stakeholder process on high-energy seismic surveys, to determine its thresholds: the now-familiar 120 dB (broadband SPL) threshold for behavioural take from "continuous" noise sources; the 160 dB (broadband SPL) threshold for behavioural take from "intermittent" or "impulsive" noise sources; and the 180 dB (broadband SPL) threshold for auditory impact from all noise sources. The weakness of these thresholds is well recognised despite their current use in multiple jurisdictions. Pointing to NMFS' 160 dB standard for impulsive noise, Nowacek *et al.* (in press) recently expressed strong concern about "the simplicity, artificial rigidity, and increasingly outdated nature of impact thresholds used in environmental assessments and rulemaking", and recommended a behavioural risk function that more closely reflects the best available science. Yet NMFS, while acknowledging their deficiencies and need for revision (NMFS, 2013), continues to apply the same thresholds in authorising take from seismic surveys and other activities.

The agency has a strong incentive to maintain its current thresholds, particularly its 160 dB threshold for impulsive noise. In most regions where the U.S. seismic industry operates, that threshold, corresponding to an impact radius under 10 km, is just sufficient to meet the agency's unstated "small numbers" standard, which falls in the neighbourhood of 30 percent for any single marine mammal species or population (see Fig. 1). Over the years, NMFS has repeatedly rejected calls, from its own experts (Burns *et al*., 2010; Brower *et al*., 2011) as well as from the wider community, to recategorise industrial seismic airguns as a hybrid "impulsive" and "continuous" noise source, given the spreading of sound across the interpulse interval through reverberation and multi-path propagation. But classification as a "continuous" noise source would lower the applicable take threshold from 160 dB to 120 dB (broadband SPL) and drive take estimates for at least some populations well above 30 percent. Similarly, the agency has refused to recategorise certain lower-energy sources, such as chirp profilers, as continuous for purposes of behavioural "take" estimation, despite their sounding multiple times per second. NMFS has acknowledged the need to revise its take threshold for impulsive noise, and made a concerted effort to do so in 2012 (NMFS, 2013); yet tellingly, after almost three years, it has failed to publish even proposed guidance for public comment.

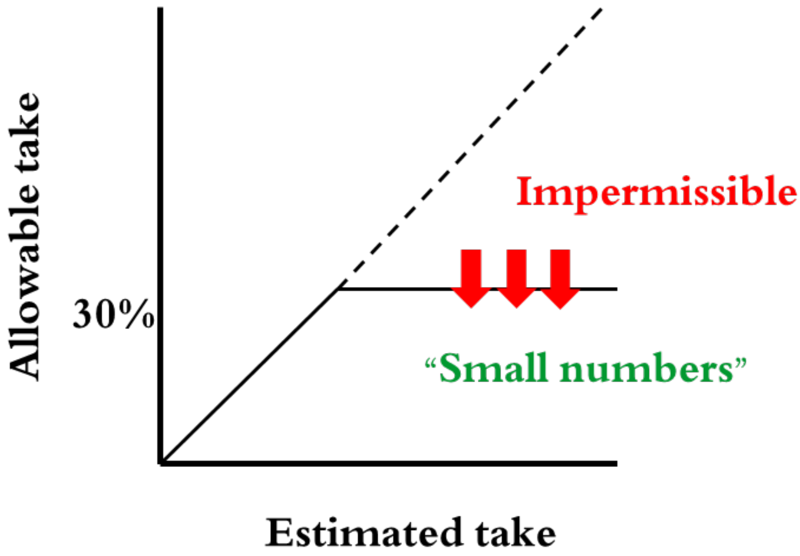

Figure 1. The tension generated by the interaction of the MMPA's "take" and "small numbers" thresholds. The agency has a strong incentive to keep estimated take levels below the threshold, even if doing so leads to scientifically dubious outcomes

In short, "take" is as much a legal concept as a scientific one. Its application in the United States has been motivated, in part, by concerns unrelated to biology, and particularly by the agency's interest in preserving its discretion within a hard-ceilinged statutory system. Those interests have kept the U.S. federal government from progressing beyond a set of dangerously simplistic thresholds that fail to capture the full extent of impact from seismic airguns and other noise sources. Other jurisdictions should not tie themselves to the same limitations, and those that have adopted the U.S. standards, especially those for impulsive noise, should not wait for NMFS to establish new ones before revising theirs. Finally, states should look critically at any revised standards NMFS does issue, with the understanding that they are produced, in part, to sustain a limited regulatory regime and, although different in substance, are likely to reflect similar tensions in the MMPA.

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HOW CAN WE REDUCE CONFLICTS BETWEEN MARINE INDUSTRIES AND MARINE MAMMALS?

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BACKGROUND AND INTRODUCTION

I work for a research organisation that provides solutions for a variety of clients, both public bodies and industry, and we do that independently. So although I am very familiar with the industry perspective (and that of regulators as well), I cannot speak for these bodies. In this brief paper I will sketch out some of the issues that are from my point of view relevant in the context of the environmental management of noisy marine industry activities. I will start with the (main) marine industries that generate sound and outline potential conflicts between these and marine mammals. Then, I will sketch out the tools that are in place to assess effects and impacts and discuss potential environmental barriers to project implementation. I will finish with some thoughts on how to minimise conflicts between marine industries and marine mammals.

POTENTIAL CONFLICTS BETWEEN MARINE INDUSTRIES AND MARINE MAMMALS

There are a number of human activities that generate underwater sound, namely marine construction and industrial activities (*e.g.* pile driving, drilling, dredging), shipping, those involving military and non-military sonar, seismic surveys and other more localised activities such as fish farming (use of acoustic deterrents), and research activities. The harvesting of marine renewable energy using offshore windfarms and wave and tidal energy converters is so far fairly localised but at least in Europe, there are ambitious plans to install devices on a larger scale in the coming years. We also know that marine mammals use sound as their primary mode of communication and for other functions as well such as, for example, navigation and foraging. Human generated sound can have a wide variety of effects from subtle behavioural reactions to injury and – in extreme case – death. Noisy activities, the generated noise levels and impacts on marine mammals, have been extensively covered in a number of excellent reviews (*e.g.* Richardson *et al.*, 1995; Southall *et al.,* 2007; OSPAR, 2009; WODA, 2013).

THE PLANNING PROCESS AND EIAs

In general marine industries are regulated as part of the planning process for new developments or activities. In Europe, most regulation derives from the national implementation of EU-wide directives such as the Environmental Impact Assessment (EIA) Directive (EC 1985, updated 2011) and the Habitats Directive (EC 1992). Important also is the Strategic Environmental Impact Assessment Directive (EC 2001) that is devised to look at larger areas and in site-selection for industrial activities. In the USA, one has to mention the

Marine Mammal Protection Act (MMPA). EIAs are also undertaken in many other parts of the world (for further information, see http://www.iaia.org). An exemplary planning process is shown in Figure 1. It can be seen that a proposed project has to go through a number of phases with some of them involving an environmental assessment and / or monitoring from pre-planning (SEA; usually funded by authorities), consenting (EIA, in most cases funded by the developers) to operational monitoring (post EIA monitoring, funded by the developer).

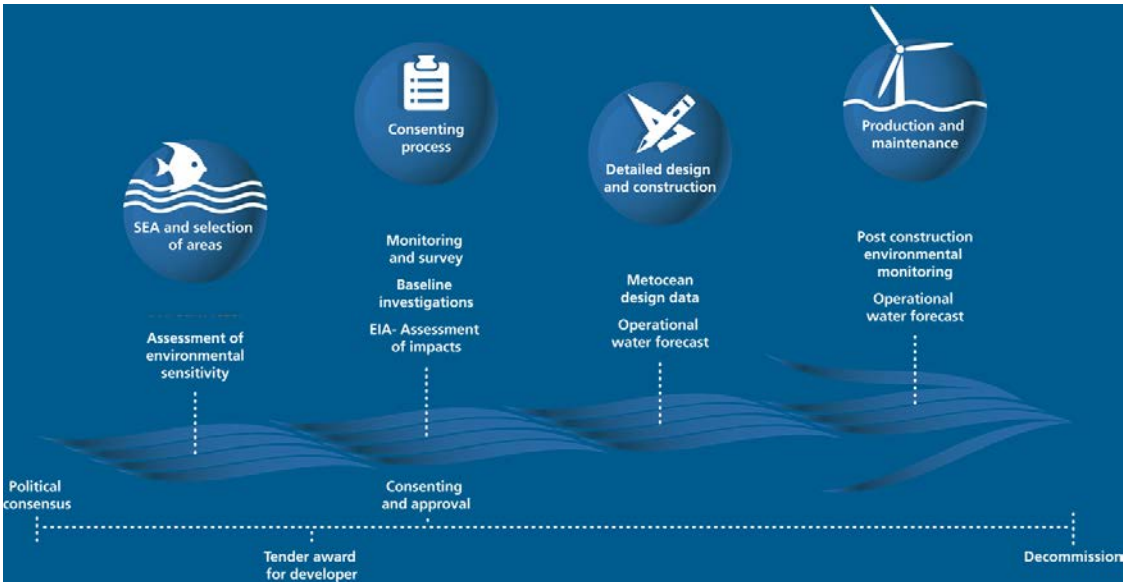

Figure 1. Overview of the planning process (example wind farms, regulation applies to European situation)

At the heart of the planning process lies the EIA that also involves a number of steps (Figure 2). The EIA is in principle paid by the developer, although there are cases – for example in Denmark - where government entities commission them (i.e. Energinet.dk; see also www.energinet.dk/EN). The EIA is a consultation process at the heart of which is the Environmental Impact Statement (EIS). The EIS generally involves description of the local environment often including an inventory of species and other components that could be affected (= baseline), a description of the (maximum extent of the) development, a detailed assessment of the possible effects of the development on the local environment, along with what mitigation is proposed to reduce those effects. Regulators then examine the EIS and decide whether or not the residual effects should have a permit. If a permit is granted, it may come with conditions to ensure mitigation, and often includes a post-construction monitoring programme. When it is considered that there is insufficient information to adequately describe the local environment, there is need for surveys or research prior to the writing of the EIS. The process is in general transparent, with public consultation of the scoping documents and the EIS. Comments are sought from stakeholders, and may be discussed by planners, their consultants, and the regulators. In an ideal situation, the process uses best available science and includes expert review by (or on behalf of) the regulators.

The EIA process can be accompanied by guidelines on how environmental impacts should be undertaken. One positive example are the standards for offshore wind farm EIAs as published by the German regulator (BSH, 2013). They comprise detailed requirements for the baseline, construction and post-construction assessment covering benthos, fish, seabirds, marine mammals and underwater sound. The standards have been compiled by the BSH with the help of an advisory group of experts. The advantage of this process is that developers have clear knowledge of what is expected in the EIA process and can thus estimate costs much more precisely. Another advantage is that the regulator is better able to compare the results from different investigations.

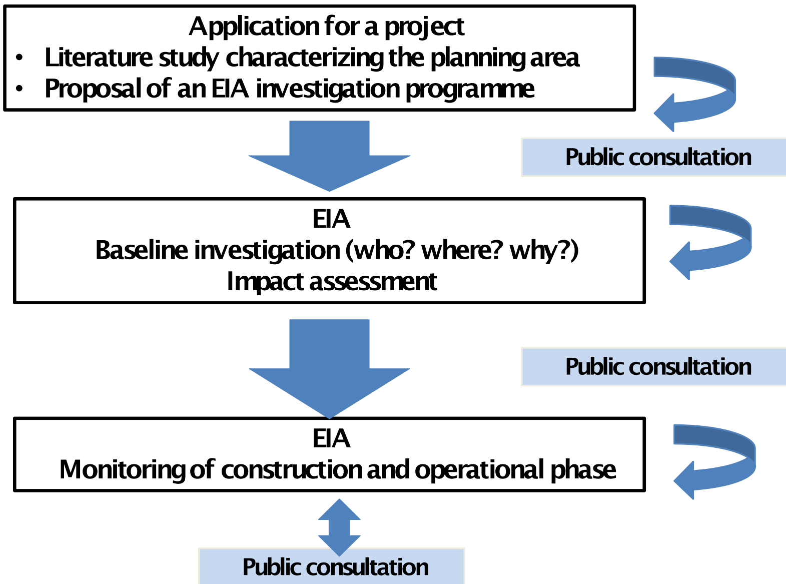

Figure 2. Overview of the EIA process (example: wind farms in Europe)

ENVIRONMENTAL BARRIERS

With regards to environmental issues, there appear to be the following risks for implementation of projects:

Insufficient baseline data. Assessing the environmental situation before planning of individual projects goes ahead, is challenging. For example, monitoring large areas at sea requires high effort and costs, and thus, in many cases, insufficient data on the distribution and abundance of marine mammals are available (for a review and case studies, see for example Thomsen *et al.*, 2011). Little is known (or in many cases can be known) about the long-term variation in occurrence of animals. Yet, without this information, it may be impossible to separate environmental and human generated effects in the impact assessment.

Low levels of information on effects of noise on marine mammals. The issue of marine mammals and noise has received increased attention in the past decade, and much progress has been made in understanding how human generated sound affects cetaceans and pinnipeds. However, there are still knowledge gaps. To remain with the wind farm example, we know that harbour porpoises (*Phocoena phocoena*) show a relatively short term avoidance response to pile driving at several km distance from the source (*e.g.* Brandt *et al.*, 2011). From exposure studies using airguns, we also know that one individual experienced TTS at relatively low level of exposure (Lucke *et al.*, 2009). However, if the degree to which temporal displacement of porpoises from the pile driving site has negative consequences is unknown, it can nevertheless be modelled (see King *et al.*, 2015). Very recently, the MaRVEN project (**Ma**rine **R**enewables, **V**ibrations, **E**lectromagnetics and **N**oise; European Commission, Directorate of Research and Innovation, 2013-2015, see www.dhigroup.marven.com) reviewed the knowledge on sound impacts from renewables, and concluded that information on sound sources (i.e. sound levels and how far these spread out from the source) is now relatively good. Risk mitigation in the form of engineering and other solutions to reduce noise impacts, is also much advanced (reviewed by Verfuß, 2014). Most behavioural change (*e.g.* displacement) is case specific and depends upon the behavioural context (for a review, see Nowacek *et al.,* 2007). It is therefore difficult to predict behavioural effects. This uncertainty may lead regulators to apply over-precautionary management measures in order to be on 'the safe side'. The consequences then could be unnecessarily increased costs for developers – in many cases funded directly by public subsidies.

CONFLICT REDUCTION

Conflicts between industry and marine mammals can be reduced by **focusing upon comprehensive planning tools applied early in the process.** The SEA stage and marine spatial planning (EC, 2014) are very important. The use of tools such as habitat modelling where data from sightings can be extrapolated using ecological relationships to map ecological suitable habitats and to map potential areas of interaction are important (*e.g.* Skov and Thomsen, 2008; Skov *et al.,* 2014). A better understanding of the factors affecting behavioural response will help in assessing population level consequences of sound impacts. For example, there are ambitious plans to install offshore wind farms off the East coast of the US. In those areas, many whale species are present that use rather low frequency sound for communication and it can be hypothesised that pile driving will affect them at least as much as porpoises if not more so, due to the low frequency characteristics of the piling sound (see wind farm related sound review, in Thomsen *et al.*, 2006). Yet, no study has investigated the effects of pile driving on larger whales. Studies of that nature are ambitious and can be costly. Industry has for many years funded research on sound effects on marine mammals, as the Joint Industry Programme on E&P Sound and Marine Life continues to demonstrate (see www.soundandmarinelife.org). Another example from Europe is COWRIE (Collaborative Offshore Wind Research into the Environment, 2001-2010). COWRIE funds were based on the interest from the refundable deposits paid by wind farm developers. Set up by Crown Estate, funds were used to carry out research into the impact of offshore wind farm developments on the environment. A summary of the knowledge gained can be found in Huddleston (2010).

CONCLUSIONS

From the above, I conclude that we have to make a much better use of already existing processes (Marine Planning, SEA, and EIA) in order to reduce the adverse effects of industry on marine life. We need to turn our science – for example habitat modelling - into tools for marine spatial planning. Industry should continue to play a crucial part in funding research on the effects of sound.

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AIRGUN OUTPUT AND EFFECTS: NEW RESEARCH FUNDED BY THE JOINT INDUSTRY PROGRAM

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INTRODUCTION

The Joint Industry Program (JIP) is an association of 12 oil and gas companies that have pooled resources to fund research on the acoustic output of industry sources, and the effects of that output on marine animals. This presentation follows that division; output will be described first.

The acoustic output of airguns

The JIP has funded two studies on this topic; 1) measurement of the output of a full commercial array in deep water, and 2) measurement of the output of single airguns and typical gun clusters used to create these arrays.

Study 1: The output of a 21 element commercial array (3590 in³ volume) was measured in 990 m deep water in the Gulf of Mexico using two vertical line arrays (EARS buoys) on which some hydrophones had been desensitised (to prevent clipping). Recordings were made over a grid and the data were binned for every 10th degree of azimuth, and at every 3º of takeoff angle along each line of azimuth. Frequencies were measured to 25 kHz. The resultant large data set characterises output in a sphere around and beneath the array. A final report is expected in the first half of 2014.

Although the specific output cannot be described here, a note about the source level of commercial arrays is appropriate. The media often reports airgun array source levels as about 260 dB, approximately the level of a lightning strike. This figure is derived by making a measurement far from the source and back calculating to what the level must have been at a point source to create it. This is a flawed process because seismic arrays are not a point source. They are a “distributed source” in which the guns are spread over an area of 20 m by 20 m or more. The greatest level a marine mammal could experience close to a commercial array, is around 235 to 238 dB.

Study 2: Seventy-four combinations of airgun models that the oil and gas industry uses, and all the volumes that are available for each model, were measured in a fjord in Norway. Some typical gun clusters (2-3 guns per cluster) were also measured. A barge equipped with a crane arm suspended the guns or clusters into the water that was surrounded by a walkway from which 20 hydrophones were suspended, varying from 1 m to 100 m (vertically) from the guns. Frequencies were measured to 50 kHz to test whether earlier claims of gun output to 150 kHz were accurate. Twenty-five measurements of particle motion were also made as the basis for estimating the effect of airguns on fish.

A draft final report was written, but there is no plan to publish the full data set. Instead, the data have been given to the three parties that write propagation models for airgun arrays, namely, Gundalf, Nucleus, and JASCO. The authors of these models are now changing the codes in their models to use the actual measured values instead of the estimated values used previously. The result will be future models that more accurately predict airgun propagation in various marine environments than are presently possible.

As an example of the results, a graph was shown depicting the modeled output of a 30 in^3 gun, and of a 3039 in^3 array. The average ambient noise level in the open sea outside the fjord was about 120 dB re 1 μPa. Inside the fjord the level was about 90 dB re 1 μPa, meaning that high frequency output would be most discernable at the measurement site. Even at that site the highest frequencies recorded were 2-3 kHz. If any higher frequencies were produced they were below the extremely low ambient noise level at this site.

The Effects of Airguns on Marine Mammals

The JIP has funded three studies on the effects of airguns on: 1) hearing in the bottlenose dolphin, representing the animal group that is most frequently exposed to airgun sound; 2) hearing in ringed, spotted, and (planned) bearded seals because industry is moving into the Arctic where these seals have not previously heard human sound; and 3) behaviour of humpback whales.

Bottlenose dolphins. Three captive dolphins at the SPAWAR laboratory in San Diego, California, had their audiograms measured before and immediately after exposure sessions in which they received 10 consecutive pulses (at 10 s intervals) from a 20 in^3 airgun. The gun was initially placed at a distance and was operated at low pressures to keep the received levels low. Then the gun was move successively closer, and the operating pressures were increased until a maximum possible output of 195 dB SEL was reached at about 3.9 m distance from the animals. No onset TTS (defined as 6 dB of shift, the smallest amount of shift that can be reliably measured from trial to trial) occurred in any of the three subjects. The paper being published about this study concludes: *"The potential for airguns to cause hearing loss in dolphins is lower than previously predicted."* This statement refers to the level previously used in U.S. regulations to define TTS onset in this animal group. The implication of this finding is that the criterion set by Southall *et al*. (2007) to define the onset of PTS (injury), namely 198 dB SEL, was extremely conservative. Using these data to set more realistic criteria for the onset of PTS is one of the major goals of the JIP-funded study to update the Noise Exposure Criteria described in my previous presentation.

Arctic phocids. Receding ice in the Arctic has allowed oil companies to begin offshore exploration for oil and gas deposits. Marine mammals in the area have never before been exposed to industry sounds, and the effects of airguns on seal hearing ability cannot be predicted. Therefore, the JIP funded a study at the University of California Santa Cruz to measure these and other effects. Two ringed seals (*Phoca hispida*) and two spotted seals (*Phoca largha*) were obtained, have been trained to participate in hearing tests, have undergone basic audiometry tests, and are now trained for hearing tests in the presence of an airgun. One bearded seal (*Erignathus barbatus*) pup was captured in 2014 and is presently being trained at the Alaska Sea Life Center to participate in hearing tests. Arrangements are being made to capture a second bearded seal pup in late 2015.

To date, underwater and aerial audiograms and critical ratio results, reaction times, and masking have been obtained for the ringed and spotted seals. The spotted seal results, a species whose hearing had never before been measured, were recently published (Sills *et al*., 2014). This species has extremely acute hearing in both air and water. Most pinnipeds are better in one medium than the other, but spotted seals are sensitive in both, possibly due to the presence of predators in both media. Below 10 kHz, spotted seals have much greater sensitivity than either bottlenose dolphins or harbour porpoises, implying that they are potentially more susceptible to anthropogenic sound. Actual susceptibility will be determined in the upcoming trials and with an airgun.

The spotted seal critical ratios were in the range of 14-18 dB, among the lowest measured for any mammal. Because of these results, a pilot study was done on the seals' ability to detect a low frequency tone pip in the presence of a recorded airgun pulse that been smeared in the time domain after propagating about 30 km from the source. Sills *et al.* (2014) conclude from this pilot study that the species is "quite efficient at extracting signals from noise." Trials with an airgun will begin shortly. A special 5 in^3 gun has been made specifically for use in an experimental pool. The experimental design will mimic the one used in the above study on bottlenose dolphins.

Humpback whales. Australia has two populations of humpback whales: an east coast population that rarely if ever hears airguns, and a west coast population that hears them annually. This study compared the naïve and experienced populations in terms of their responses to airguns. This is a five-year study of behavioural responses to a passing array, ramp up, and hard start. The focus is on mother-calf pairs and their consorts; calves are believed to be the most susceptible component of the population. The animals are observed by onshore observers using theodolites, focal follow from boats, D-tags on whales, and bottom-mounted acoustic recorders, affording full observation in air and under water. To date the sound sources used in testing were a 20 in^3 gun, a 140 in^3 array, and a 440 in^3 array. In 2014, a 3,000 to 4,000 in^3 commercial array will be used as the sound source.

The behavioural responses observed to date showed no strong avoidance of a passing sound source. The whales were migrating north to south, and the sources were towed from west to east at right angles to their migratory paths. Animals slowed their swim speeds and breathing rates, but made no other consistent response, suggesting that they waited for the source to pass and then proceeded on their migratory path with little deviation. There was no obvious relationship between the level of sound and the type of behavioural response given, although data analysis is not yet complete.

Animals showed no response to ramp-up at 175 dB received level, and only minor response to hard start at the same received level. All these conclusions are tentative, and may change when the animals are exposed to the full commercial array later in 2014.

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HARBOUR PORPOISES REACT TO LOW LEVELS OF HIGH FREQUENCY VESSEL NOISE

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INTRODUCTION

The dramatic increase in human activities and encroachment at sea in the last century has led to a substantial increase in ambient noise levels (McDonald *et al*., 2006; Hildebrand, 2009) that may have the potential to negatively affect the auditory scene analysis, behaviour, and physiology of cetaceans with broad scale implications for the fitness of individuals and populations (Richardson *et al*., 1995; Nowacek *et al*., 2007). Shipping is by far the dominant anthropogenic source of underwater noise at low frequencies, and is responsible for the vast majority of anthropogenic noise inputs to the marine environment (Ross, 1976; Tyack, 2008). Baleen whales exploit similar frequency bands to the frequencies of peak power outputs from large vessels in deep water (Clark and Ellison, 2003) and are therefore considered to be at the highest risk of adverse effects from ship noise (Payne and Webb, 1971; Southall *et al*., 2007). Conversely, the possible effects of vessel noise on small toothed whales have been largely ignored due to their poor low-frequency hearing (Au, 1993; Au and Hastings, 2008). Perhaps surprisingly, given their hearing abilities, several studies have demonstrated that harbour porpoises do show what appears to be avoidance behaviour in response to vessels at long ranges (Barlow, 1988; Evans *et al*., 1994; Palka and Hammond, 2001), where the radiated noise, rather than the physical presence of the vessel, is more likely to deliver the negative stimulus. Many small toothed whale species inhabit shallow waters, which are high productivity areas (Culik, 2004) that have some of the heaviest vessel traffic densities of any marine habitats (Tyack, 2008). However, the shallow water environment acts as a steep high-pass filter where the low-frequency sounds do not propagate well (Katsnelson *et al*., 2012). Therefore this, in combination with the poor low-frequency hearing of porpoises, suggests that porpoises may respond to noise energy at mid- or high-frequencies that are present in vessel noise (Aguilar de Soto *et al*., 2006; Hermannsen *et al*., 2014), but these are currently not considered when estimating noise impact on cetaceans (European Commission, 2008; Van der Graaf *et al*., 2012).

Here, we test this hypothesis by studying the behaviour of captive harbour porpoises in a net pen being exposed to noise of passing vessels. We show that a strong, stereotyped, behavioural response in the form of porpoising is triggered by low levels of the high-frequency component of vessel noise that can occur at more than 1000 metres from the source. The implication is that thousands of porpoises in shallow water habitats with dense vessel traffic may potentially face daily, repeated noise-induced behavioural disruptions, which is a potentially large, but so far, overlooked conservation issue.

METHODS

The study took place between September 2011 and August 2012 at the Fjord&Belt Centre, Kerteminde, Denmark, where four harbour porpoises are kept in a semi-natural net-pen complex. The enclosure (30 x 20 m^2, average depth of 4 m) is situated in the canal connecting the Great Belt with Kerteminde Fjord, and is fenced off by a steel sheet piled wall along shore, and nets on the two shorter ends.

Two broadband recording stations (calibrated Reson TC 4014 hydrophone, low noise amplifier, 16-bit A/D National Instruments converter, laptop computer with LabVIEW software) of vessels passing the enclosure were placed at the opposite, open ends of the porpoise pen, sides mostly affected by the underwater noise coming from the surrounding harbour. The self-noise of the recording system was measured in an anechoic chamber at the Danish Technical University with the same configurations as used during the experiments.

Sound recording was started as soon as a boat came into view. Background ambient noise was recorded opportunistically when no boats were observed. Observations of porpoise behaviour were made simultaneously with vessel noise recordings. Response of the animals to boat presence was classified into two categories: “reaction” or “no reaction.” “Reaction” to noise was defined to occur when one or more animals suddenly and dramatically increased their swimming speed and sprayed the water upon surfacing in a stereotyped manner in a behaviour coined “porpoising” (see Supplementary Video S1 in Dyndo *et al*., 2015). This type of behavioural response is commonly used in studies of noise influence on captive porpoises (*e.g.* Teilmann *et al*., 2006; Kastelein *et al*., 2012). “No reaction” response was defined as a lack of porpoising while the porpoises may have responded in other ways, inconsistent with the definition of porpoising.

A number of selection criteria were applied to the dataset in order to analyse the most representative levels of noise affecting the porpoises (see details in Dyndo *et al*., 2015). The selected segments of unfiltered noise were low-pass filtered at 100 kHz (4th order, Butterworth) to avoid the inclusion of omnipresent porpoise clicks in the level calculations. Several measurements were performed to characterise the vessel noise: cumulative sound exposure levels (cSELs) were used as a proxy for accumulating received levels (Madsen *et al*., 2006) from all the echo sounder pulses in a 30-second-long periods of high-pass filtered noise. The broadband noise level was quantified as root-mean-square (rms) sound pressure level over four intervals (i.e., 3 seconds and 30 seconds with maximum energy vessel noise, and 3 seconds before and 30 seconds around the time of porpoise reaction). The rms sound pressure levels were also computed in 36 third-octave bands (centre frequencies from 25 to 80000 Hz) that were later combined into 12 octave bands (OL; centre frequencies from 31.5 to 63000 Hz). Furthermore, following Southall *et al*. (2007), a marine mammal frequency weighted (M-weighted) rms sound pressure level was computed over the low-pass filtered (4th order, Butterworth, 100 kHz) vessel noise data. The direct relationship between the probability of porpoise reaction and the effect of the presence and level of echosounder pulses, the broadband rms level, and rms sound pressure level in different frequency bands (63- and 125-Hz third-octave bands, and 31.5 - 63000 Hz octave bands) were assessed using a multivariate generalised linear mixed-effects model (GLMM). The methods are described in more detail in the original publication (Dyndo *et al*., 2015).

RESULTS AND DISCUSSION

Vessel noise from 133 boats of various size and design was recorded at two stations across the net pen. A total number of 80 good quality recordings (14 registered at the left station and 66 at the right station) was selected. In 22 cases (27.5%), a very robust and stereotyped reaction, in the form of porpoising (see Supplementary Video S1 in Dyndo *et al*., 2015), was observed when different boats were passing the net-pen complex.

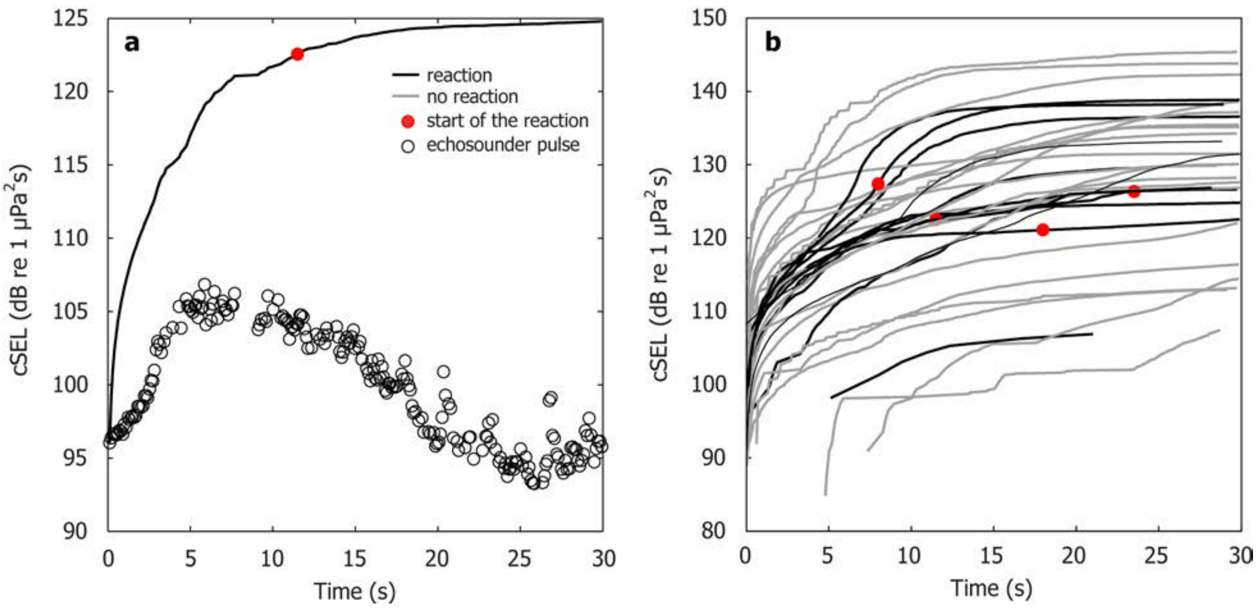

Figure 1. Sound exposure levels (SELs) of 200-kHz echosounder pulses recorded at the porpoise enclosure during the passage of vessels that did (N=11) and did not (N=20) trigger a reaction. (a) An example showing the accumulation of energy (expressed as SEL) of the individual echosounder pings (black circles) over a 30-second time window with the highest energy in the echosounder frequency range (the highest energy segment was selected for 180-220 kHz pass-band recordings; the SEL were calculated for 160 kHz high-pass filtered recordings). This vessel did trigger a porpoising response and the time of reaction is indicated with a red circle marker. (b) Cumulative sound exposure levels (cSELs) of echosounder pulses from vessel that did (black lines) and did not (grey lines) elicit a distinct reaction of porpoises. The red dots mark time when porpoising was noticed. Please note that sometimes the reaction did not occur during the 30-second time window with the highest energy in the echosounder frequency range.

Most studies on the effects of noise on odontocetes have been focused on transients, with much emphasis on mid-frequency sonars (i.e. Kastelein *et al.*, 2008, 2011, 2012). Here we verified the potential effects of echo sounders operating at 200 kHz on harbour porpoise behaviour. Among 80 recorded vessels, 31 (39%) had a high-frequency (200 kHz) echosounder turned on (no other echosounders were recorded). A distinct reaction of the porpoises was observed in the presence of 11 of them (35%), but no statistically significant relationship between the presence of echosounder pulses and reaction was shown (p-value$_{BHY}$ = 0.9464). Moreover, the commencement of porpoising did not coincide with the largest changes in the cSEL, nor a particular cSEL value (Figure 1) and there was no significant difference between the cSELs of echosounder pulses from vessels that did, and did not, elicit the response (p-value$_{BHY}$ = 0.8170; Figure 1). The high-frequency echosounders were therefore unlikely to have caused the observed porpoising reactions, which suggest that the vessel noise itself triggered the responses.

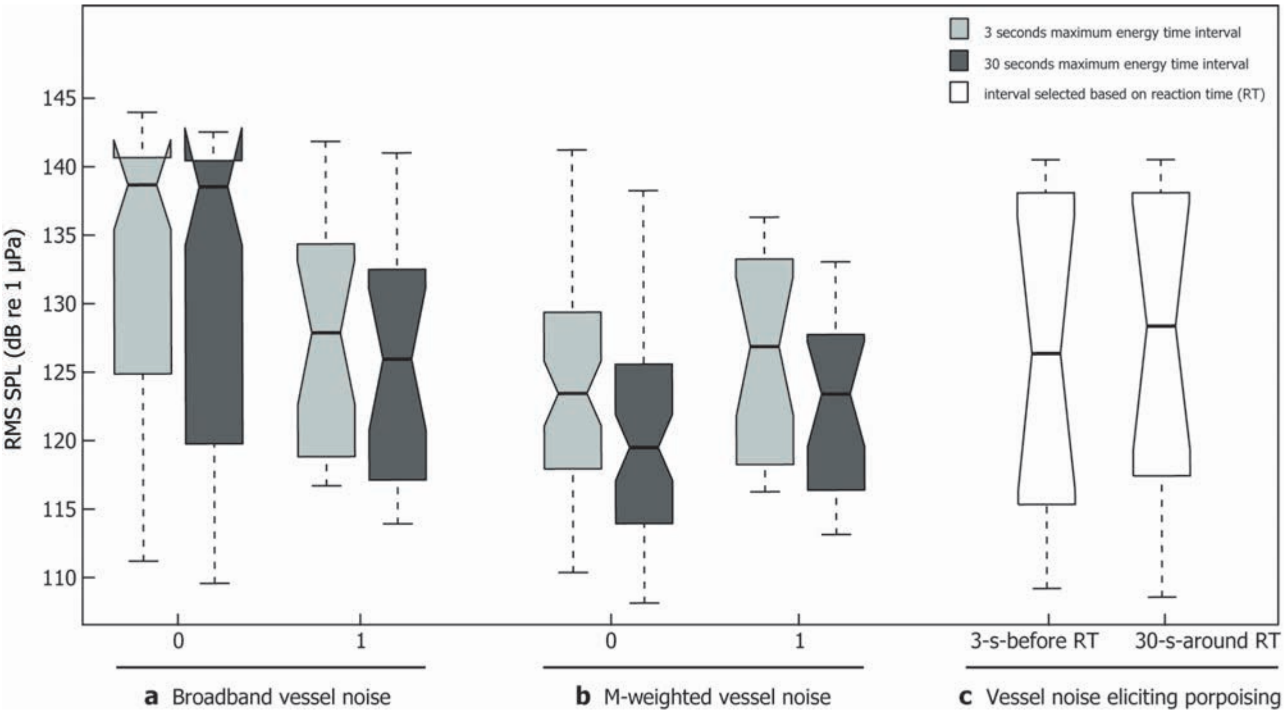

Figure 2. The distribution of rms sound pressure level calculated over different time intervals. (a) 3 seconds and 30 seconds of broadband vessel noise with maximum energy, (b) 3 seconds and 30 seconds of M-weighted vessel noise with maximum energy, (c) 3 seconds before and 30 seconds around reaction time (RT) - only for vessel noise eliciting porpoising behaviour. The thick line inside the box shows the median; the lower and upper edges of the box indicate the 1st and 3rd quartile, respectively; whiskers bound the minimum and maximum of the distributions. 0 - no reaction, 1 - reaction (porpoising) was observed. rms = root-mean-square.

Current recommendations of continuous underwater noise exposure criteria often stipulate a certain broadband rms level that cannot be exceeded (Southall *et al.*, 2007). Our data imply (Figure 2a) that broadband rms levels cannot be used to predict behavioural responses to vessel noise of harbour porpoises, a high frequency species (Kastelein *et al.*, 2002). The broadband rms level was higher when porpoises showed no reaction to vessel noise (Figure 2a). Results of a GLMM corroborated this finding by demonstrating that the association between the broadband rms sound pressure level and probability of reaction was not statistically significant (p-value$_{BHY}$ = 0.8414). This suggests that exposure levels in certain spectral bands may be responsible for the observed responses.

To identify the frequency components of the vessel noise that were most likely to cause the behavioural response of the porpoises, a GLMM was performed for each of the 12 octave bands with centre frequencies between 31.5 Hz and 63 kHz, and two third-octave bands with centre frequencies at 63 and 125 Hz proposed by the Marine Strategy Framework Directive (MSFD) as indicators of general noise levels from continuous sources such as boats (European Commission, 2008).

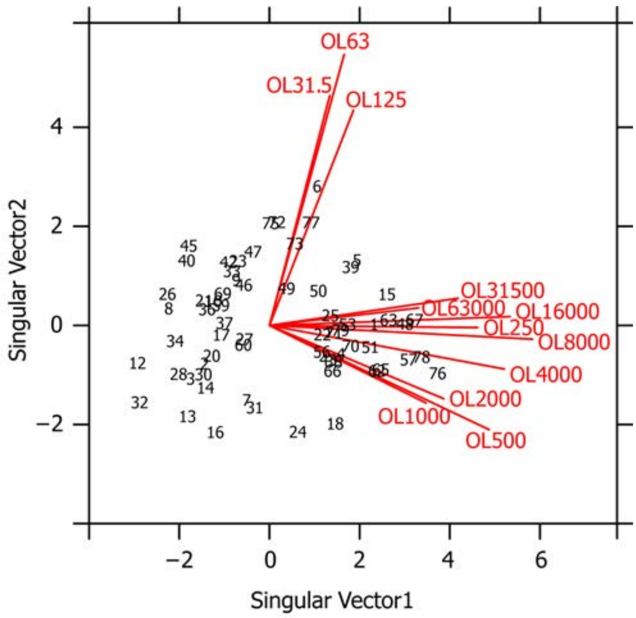

Figure 3. Biplot representing the correlation structure of the dataset in a two-dimensional space (Gabriel, 1971). In the biplot, black numbers represent the observations and the red vectors represent the variables. Axes refer to the first two singular vectors of the singular value decomposition. Observation scores are in deviation from their average for each of these singular vectors (the values were centred by variable). Note the homogeneous distribution of observations with no groups or extreme values and the clear aggregation of vectors into two different groups: low-frequency bands (OL31.5, OL63 and OL125 Hz), and high-frequency bands (OL250 - OL63000 Hz). OL = octave level.

The results showed a statistically non-significant relationship between the porpoise reaction in both the 63- and 125-Hz third-octave bands (p-value$_{BHY}$ = 0.8414 and 1.0000, respectively). In contrast, results of the GLMMs for the octave bands indicated a statistically significant, positive association between the probability of porpoising and rms levels in bands with centre frequencies at 500, 2000, 16000 and 31500 Hz (p-value$_{BHY}$ = 0.0276, 0.0348, 0.0331, 0.0331, respectively). Moreover, a two-dimensional biplot (Gabriel, 1971) indicated two clear groups of vectors representing the octave bands with centre frequencies between 31.5 and 125 Hz and, separately, from 0.25 to 63 kHz (Figure 3). Based on these findings, the correlated bands were merged into broader bandwidths, low (31.5 - 125 Hz) and high frequency (0.25 - 63 kHz), and their effects on porpoise reaction were tested. Yet again, the results of the GLMMs showed a statistically non-significant relationship between porpoise probability of reaction and sound pressure level at low frequencies (p-value$_{BHY}$ = 0.8414). The proposed 63- and 125-Hz bands of the MSFD are therefore unsuited for establishing exposure limits for behavioural effects of vessel noise on porpoises and likely also for other small toothed whales, and they are, in general, poor proxies for noise loads at higher frequencies in shallow water environments (Hermannsen *et al*., 2014).

Conversely, we show that higher levels of medium to high frequency components (0.25 - 63 kHz octave bands) of vessel noise significantly increase the probability of porpoising (p-value$_{BHY}$ = 0.0273). This prompted us to test if the M-weighting proposed by Southall *et al*. (2007) could be used as a simple response variable for practical implementation. The idea appears logical in view of the fact that the rms sound pressure level computed over a high-pass-filtered version of the vessel noise to some degree matches the high frequency hearing of porpoises (Kastelein *et al*., 2002). A box plot was created to examine the distributions of the rms pressure levels of high-frequency M-weighted [cut-off frequencies: 200 Hz - 100 kHz; (Southall *et al*., 2007)] noise that did and did not elicit a behavioural response (Figure 2b). Compared to the non-weighted data (Figure 2a), a clear change in the level distributions was observed, with a higher level of M-weighted noise coinciding with a higher probability of porpoise response. This observation was supported by the GLMM results (p-value$_{BHY}$ = 0.0273). The porpoises responded to increases in the part of the noise spectrum where their hearing is good (Kastelein *et al*., 2002, 2010), implying that the onset of a behavioural response is triggered by the perceived loudness of the sound (Finneran, 2008; Wensveen *et al*., 2014). This finding lends weight to the recent proposal by Tougaard *et al.* (2015) that behavioural responses of porpoises can be predicted from a certain level above their threshold at any given frequency.

Our results suggest that behavioural and environmental covariates do affect the response threshold level of harbour porpoises, as the mean onset level of 123 dB re 1 µPa (rms, M-weighted; ranging from 113 to 133 dB re 1 µPa) for the porpoising behaviour is only slightly above the levels of noise that did not trigger the reaction (120 dB re 1 µPa, rms, M-weighted; ranging from 108 to 138 dB re 1 µPa). Nevertheless, such low levels are routinely encountered by porpoises in the wild from passing vessels at ranges of more than 1 km (McKenna *et al*., 2012; Hermannsen *et al*., 2014), which can then explain the reported vessel avoidance of porpoises at considerable ranges (Barlow, 1988; Evans *et al*., 1994; Palka and Hammond, 2001). Consequently, if wild porpoises respond to the same levels as documented here (Olesiuk *et al.*, 2002), vessel noise may in heavily trafficked areas have a large, but so far undetected, effect on porpoises and potentially also on other small toothed whales (Buckstaff, 2004; Pirotta *et al*., 2012).

Porpoising and other behavioural responses to ship noise may be short-term, but they come at the cost of the energetic investment in moving, lost opportunities in foraging and social behaviour, as well as potential abandonment of calves. Thus, repeated vessel-noise-induced short-term behavioural disruptions, as documented here, may have fitness consequences for porpoises in densely trafficked areas. This hypothesis can be tested with onboard acoustic and multi-sensor tags where behavioural states, locomotion effort, feeding success, and ventilation rates can be logged in concert with noise exposure levels (*e.g.* Aguilar de Soto *et al.*, 2006).

CONCLUSIONS

We conclude that porpoises respond to low levels of medium to high frequency vessel noise. This finding is consistent with observations of ship avoidance at sea (Olesiuk *et al.*, 2002), and points to a potentially large, but so far largely overlooked, conservation problem in areas of dense shipping and high porpoise numbers. The 63- and 125-Hz bands proposed in the European MSFD are not suited as measures of behavioural disturbance of porpoises whereas filtering using M-weighting (Southall *et al.*, 2007), loudness (Wensveen *et al.*, 2014) or the audiogram (Tougaard *et al.*, 2015) seem to provide a meaningful proxy for estimating behavioural disturbance with a tentative 50% onset at 123 dB re 1µPa (rms, M-weighted) averaged over 30 s. Before implementation in mitigation measures and conservation efforts, we recommend that such a threshold should be tested thoroughly on a larger number of animals in the wild.

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IMPACT ASSESSMENTS FOR PILE DRIVING - WHAT ARE THE REQUIREMENTS FOR A PROPER EIA FOR MARINE MAMMALS?

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BACKGROUND

Since the first offshore wind farm was erected in Denmark in 1991, the global development of offshore wind energy has grown exponentially. In recent years, energy from wind is doubling every three years (Mann and Teilmann, 2013, and www.4coffshore.com/windfarms). As wind turbines on land become increasingly unpopular, offshore wind farms are expanding rapidly while also benefiting from higher wind speeds at sea. Shallow areas and pile driving are often preferred for economic reasons. However, suitable shallow areas (<50m depth) for wind farms are globally limited and often in conflict with other interests like shipping, fishing, and nature conservation. These conditions make environmental concerns in relation to offshore wind increasingly relevant. Environmental impact assessments (EIA) are required in the EU before large construction activities can be started. The quality of offshore EIAs mostly rely on available information, which is often lacking details and data from the relevant area, making EIAs unreliable or useless in many cases. In this paper I will propose some necessary steps and recommendations when performing EIAs in relation to pile driving and marine mammals.

INFORMATION REQUIREMENTS

At the initial planning of an EIA, the following basic requirements should be found in the literature, or new data should be collected to be able to assess impacts at the individual and population level from pile driving:

1) *Detailed information on construction activities*

- Size of piles (currently varying between 3-10 MW, and will likely increase in the future)
- Source level (depending on size of pile and hammer force)
- Number of strikes (depending on size of pile and seabed)
- Duration of piling (depending on number and size of pile, seabed, hammer force)
- Other construction activities (*e.g.* number and type of vessels, dredging, scour protection around foundations, other wind farms in the area)

2) *Local knowledge of the impacted area*

- Seabed (bathymetry and bottom substrate make a big difference in noise from piling and sound propagation)
- Acoustic properties of the water (depth variations, salinity, temperature, haloclines, themoclines, etc.) to be able to model sound propagation and source levels at any point in the area, until levels are below relevant thresholds.

3) *Spatial and temporal density of animals*

- Knowledge on population structure is essential to know if one or several populations are affected.
- If data on spatial and temporal density for each population in area of impact is not available year round, it should be collected.
- Abundance of the population(s) in question is needed to be able to assess the proportion of the population affected and the impact on population level.

4) *PTS, TTS thresholds and behavioural response of the species present*

- Thresholds from each relevant species should be established if not known.
- Clear international guidelines for acceptable impacts are not available; therefore, acceptable impacts should be agreed on either nationally or for the specific project. This has to be done for each species and population in relation to individual impact, population impact, and the current conservation status.

EXAMPLE OF APPROACH IN IMPACT ASSESSMENT ON HARBOUR PORPOISES

The technical basis for the EIA for Kriegers Flak in the Danish part of the western Baltic Sea is used as an example of how the points given above could be addressed (Dietz *et al.*, 2015). The EIA was paid for by the Danish energy authorities and was used as the basis for political approval and as background material during the call for contractors. Addressing each of the four information requirements listed above:

1) If all details of the construction work are available, this should be the basis for an impact assessment; however, in most cases the details listed above are not available and a worst-case approach based on available information from the authorities or the contractor must be used instead. *E.g.* if the EIA is made years before the actual windfarm is constructed, the size of each turbine (currently available or planned turbine size vary between 3-10 MW) may not be known as the contractor likes to use the largest turbines to increase economic outcome.

For Kriegers Flak, scenarios using monopiles up to 10 MW (10 diameter foundation piles) were provided. Therefore, pile driving of 10 MW monopiles was used as the worst-case scenario, as the sound intensity is higher, the larger the pile is when rammed into the sea floor. However, the larger the monopiles are, the fewer are needed and the larger the distance between turbines will be, so it is also necessary to consider not only single pile driving events, but also the duration of the entire construction and the long term impacts for a full impact assessment (see Dietz *et al*., 2015 for more details).

2) An acoustic model was constructed based on the local oceanography (NIRAS, 2015).

3) Knowledge on population structure in the relevant area is essential to estimate the impact on each potential population. It is often very difficult to determine exact borders between overlapping populations, but for Kriegers Flak, data from telemetry, genetics, morphometric and acoustics were collected by the EIA or previous projects over many years and made it possible to separate neighboring populations (Sveegaard *et al*., 2015, Dietz *et al*., 2015). The results show that both the Baltic Sea and the Belt Sea populations of harbour porpoises were affected as well as a local stock of harbour seals and the Baltic Sea grey seal population. However, as the harbour porpoise populations apparently overlap, it was not possible to separate them and assess seasonal densities for each population.

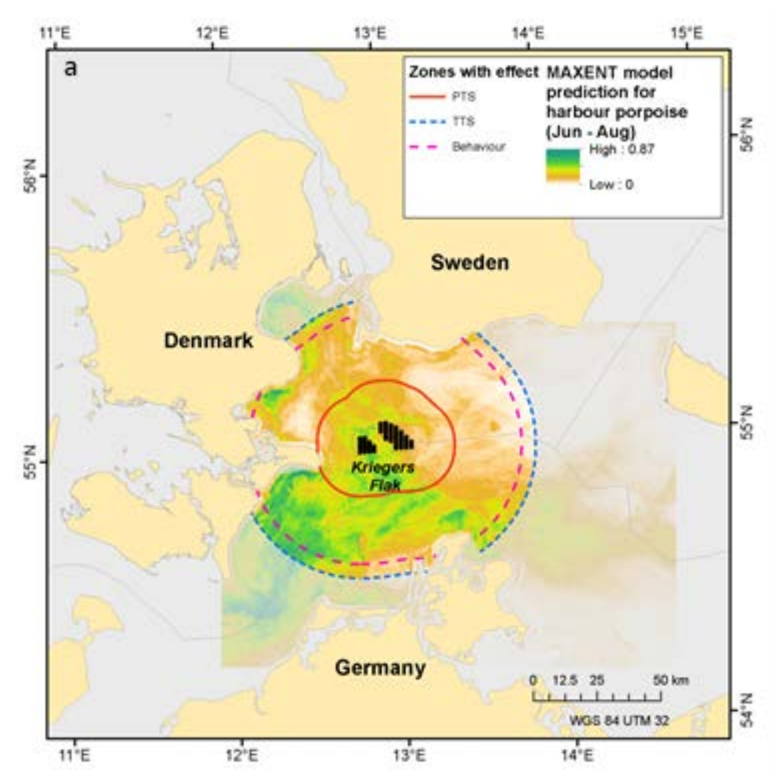

Figure 1. Predicted probability of presence of harbour porpoise based on satellite tracked *harbour* porpoises and a MaxEnt model. Prediction is for summer months (Jun-Aug). Zones of impact are indicated based on thresholds in table 1, a fleeing speed of 1.5 m/s and the acoustic propagation model in NIRAS (2015)

Maxent modelling was used to create local densities of harbour porpoises in the Western Baltic Sea based on satellite tracking and environmental parameters in 400 m grid cells. Acoustic loggers (CPODs) were used to successfully validate the model (Mikkelsen *et al.*, in prep.).

4) In 2014, the Danish authorities formed a working group with the task of investigating how underwater noise from pile driving during offshore wind farm construction could be regulated in order to take due consideration of protected marine species. It was the wish that the work of the group could be used as a basis for future regulation of underwater noise from pile driving in Denmark. The group provided the following table of threshold values for PTS, TTS and behavioural response for harbour porpoises, harbour and grey seals based on a literature review.

Table 1. Threshold values for PTS, TTS and behavioural effects (MMWG, 2015). In some cases M-weighting according to Southall *et al*. (2007) was used. For porpoises, high frequency cetacean M-weighting (M_{HFC}) was used and for seals, pinniped water M-weighting (M_{PW}) was used when indicated in the table

Species	Threshold origin	PTS (dB re 1μPa^{2}s SEL cum)	TTS (dB re 1μPa^{2}s SEL cum)	Behavioural response (dB re 1μPa^{2}s SEL single strike)
Harbour porpoise	From Working Group 2014. Memorandum prepared for Energinet.dk. 2015	183	164	140
	From Dietz *et al.* 2015	198 (M_{hfc})	164	140
Harbour seal/grey seal	From Working Group 2014. Memorandum prepared for Energinet.dk. 2015	200	176	-
	From Dietz *et al.* 2015	186 (M_{pw})	171(M_{pw})	171(M_{pw})

CONCLUSIONS

The MMWG proposed to set the maximum acceptable limit of impact to a sound level where no animals would experience PTS. In the case of Kriegers Flak, no mitigation would result in that about 1500 harbour porpoises, 300 grey seals and about 10 harbour seal would experience PTS. When introducing pingers and seal scarers to deter animals before pile driving, reducing the sound level from piling by 16 dB would reduce the risk of PTS to almost zero. However, even after reducing the noise level, there are still a considerable number of animals experiencing TTS and noise levels high enough to cause significant behavioural reactions, which should also be taken into consideration.

The approach described above is now introduced in Danish wind farm EIAs and provides much clearer and more comparable estimates of impacts between projects than before. Nevertheless, cumulative effects of many offshore activities throughout the range of a population are still not addressed. An approach to address cumulative effects is being developed under the DEPONS project where an individual based model (IBM or ABM) includes harbour porpoises of the entire North Sea. The model includes all known pressures and life history parameters of harbour porpoises (for more information see http://depons.au.dk/). In this way, the effect of additional future projects can be evaluated at a population level. However, this model is built upon the limited available information on how animals are affected by various human activities. Further research is needed for many species to assess the true influence of cumulative effects.

Finally, it is recommended that nations across the EU develop universal criteria for assessing impact on marine mammals and other marine life to agree on what impacts may be unacceptable.

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IMPACT ASSESSMENT FOR SONAR

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Naval sonars are high intensity sound sources that operate within the frequency ranges that marine mammals can hear. The high intensity of sonar led many early impact assessments to focus on what levels of sound might damage or injure an animal. They assumed that the most sensitive organ for sound was the auditory system, so they focused efforts on finding a way to estimate what sound levels might damage hearing. During the 1990s, the US Office of Naval Research supported a research program to determine what levels of sound would temporarily reduce the sensitivity of hearing in marine mammals, assuming that this was a harmless signpost for injury at higher levels (*e.g.* Schlundt *et al.*, 2000; Finneran *et al.*, 2002; Nachtigall *et al.*, 2004). The red symbols in Figure 1 mark the onset of noise-induced hearing loss. The blue line in the Figure shows how the sound pressure level must vary to maintain the same energy as in the one-second (1s) signal in the centre of the Figure. This line comes close to the other red symbols that indicate onset of hearing loss for signals with different durations. This research showed that to a first approximation, the threshold for injury is a certain amount of sound energy delivered to the ear. The usual measure for sound pressure is the sound pressure level (SPL) expressed in dB re 1 µPa and the usual measure for sound energy is the sound exposure level (SEL) expressed in dB re 1 μPa^2-s. The SEL is the same as the SPL for a sound with a duration of 1s, but shorter sounds have less energy and so a lower SEL than SPL, and longer sounds a greater SEL than SPL.

This research led Southall *et al.* (2007) to propose an acoustic injury threshold to cetaceans for sounds such as sonar with multiple pulses, of 198 dB re 1 μPa^2-s in terms of SEL. Most military sonars have source levels in the 220-240 dB re 1 µPa at 1 m range. This means that for one 1s pulse of a sonar to pose a risk to a cetacean, it would have to be within 10-100 m of the sonar. Naval ships move rapidly enough that it would be unlikely for multiple pulses to add enough energy to increase SEL over the threshold at greater ranges. There is one important caveat to the use of SEL to predict TTS. If you look carefully at Figure 1, you can see that the longer duration a sound, the lower level is required to induce TTS (the red TTS symbol for the sound shorter than 1s is above the blue line, while that for longer exposure is below). This means that the SEL criterion may not accurately predict TTS, and this may particularly be a problem for long exposure. Finneran *et al.* (2010) estimate the probability of TTS as a function of both SPL and duration, providing a better fit to the data than does SEL.

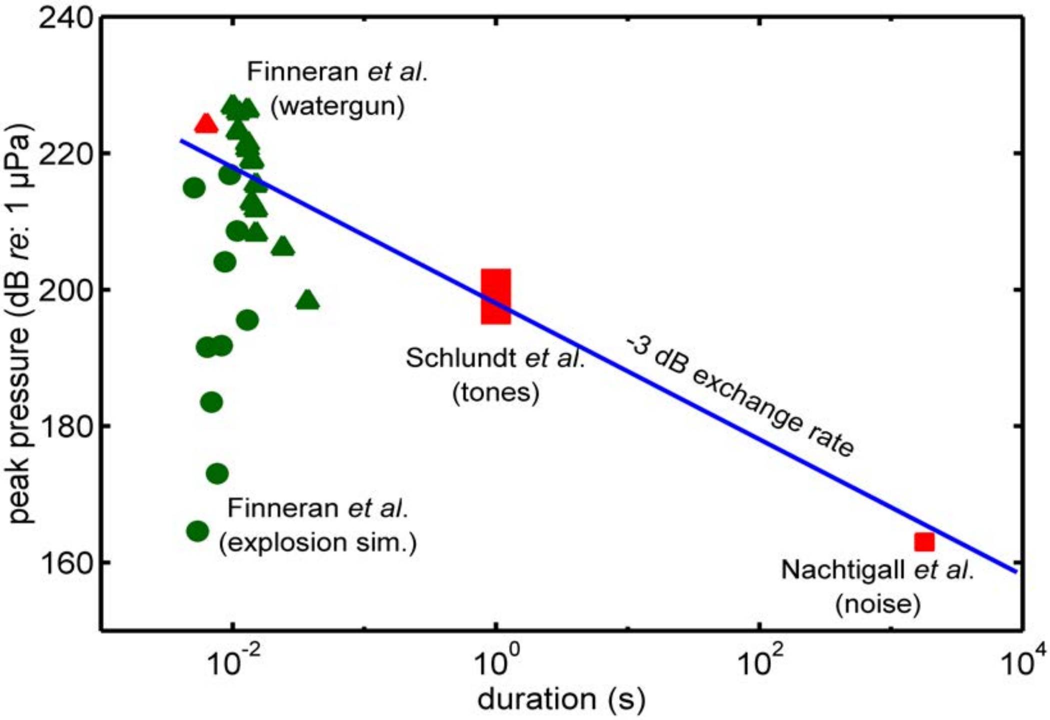

Figure 1. Levels of sound that cause temporary threshold shift (TTS) in the hearing of bottlenose dolphins (*Tursiops truncatus*) as a function of duration (data from Finneran *et al.* 2002, Schlundt *et al.* 2000, Nachtigall *et al.* 2004). The red symbols mark exposures that caused TTS; the green symbols, those that did not.

Near the time when this TTS research had been published and was being incorporated into policy, evidence started to emerge of a surprising new risk of injury or death to a poorly known group of cetaceans, the beaked whales. Beaked whales are a family of toothed whales. They are larger than dolphins and smaller than sperm whales, live in deep water, and surface cryptically. They are so hard to sight at sea that some species are known only from stranded specimens. In 1998, Frantzis (1998) published a paper in *Nature* suggesting that sonar testing might have caused an atypical mass stranding in which a dozen beaked whales stranded alive across 38 km of coast over about a day. Unlike most mass strandings, in which whales strand in one or several groups, the average separation between these whales was 3.5 km. Frantzis (1998) searched for potential causes, but the only one that seemed capable of causing strandings of so many animals over tens of km within hours was a sonar exercise that was reported to have coincided closely in time with the strandings. Once the pattern of these atypical strandings was identified, it allowed more comprehensive analyses, which have identified from 12 to several dozen cases with varying strength of evidence linking atypical mass strandings of beaked whales to naval sonar exercises (D'Amico *et al.*, 2009). Veterinary pathologists analysing whales from several of these strandings also identified decompression symptoms, suggesting that whales do not just die from stranding but may be injured or die at sea, harm that may be difficult to detect (Fernández *et al.*, 2005).

These sonar-related strandings posed a problem for policy makers concerned about protection of whales. The expected ranges of minor auditory effects was 10-100 m from ships operating sonar, but the odds seemed vanishingly small that these ships got so close to so many beaked whales during sonar operations. The consensus of the research community was that the sonar might elicit a behavioural reaction that in turn interfered with the whales' physiological capacity to manage gases under pressure from diving, or that led the whales to strand (Cox *et al.*, 2006). But there was no way to estimate the level of sound exposure that might pose a risk of triggering this chain of events.

This policy problem led to the development of a series of studies designed to measure how beaked whales responded to experimental exposure to sonar and other sounds. The first requirement was to develop a means to measure behaviour and received sound level on a whale diving a kilometre or more beneath the sea surface. Johnson and Tyack (2003) describe an electronic tag that can be attached to a whale non-invasively with suction cups, and which measures acoustic dosage and behavioural responses. With this tag, it was possible to tag a beaked whale, to measure pre-exposure behaviour, to expose it to an escalating dosage of sonar or other sound stimuli, and to measure how it responded and what acoustic dosage was associated with the onset of the response. It is very difficult to tag beaked whales, so the sample size of these experiments is relatively low, but they have defined behavioural responses with great precision and have measured the acoustic dosage required to elicit each response.

Figure 2 shows data from the full 14 h deployment of a tag on a Cuvier's beaked whale, *Ziphius cavirostris*, the species most involved in sonar related strandings (DeRuiter *et al.*, 2013). Beaked whales make long deep dives, such as those shown at 12:00, 15:00 and 23:00 hours, using echolocation to forage in the dark. As can be seen in the middle row of the Figure, the whales change heading a lot as they find and capture their prey. In between deep foraging dives, beaked whales make shorter "shallow" dives, although note that to a beaked whale a dive of several hundred metres may count as shallow. After recording data for a first pre-exposure deep dive, this tagged whale was exposed to a controlled exposure of sonar sounds. The period of sound exposure is indicated in red colour on Figure 2.

Controlled exposure experiments that are designed to determine the sound exposure level at which a whale starts to respond to the stimulus have a protocol calling for the sound level at the whale to slowly escalate to a maximum level. In the case of this exposure, the red symbols on the top cell of Figure 3 show how the sound pressure level at the whale increased from below 80 dB re 1 μPa to ~ 130 dB re 1 μPa over the course of the CEE. When the received level of sonar reached 98 dB re 1 μPa, the whale responded to the sonar with a premature cessation of echolocation for foraging. It then responded with a prolonged avoidance response that included energetic fluking (indicated by dynamic acceleration), and low variation in heading for 1.6 h after the exposure ended (DeRuiter *et al.*, 2013).

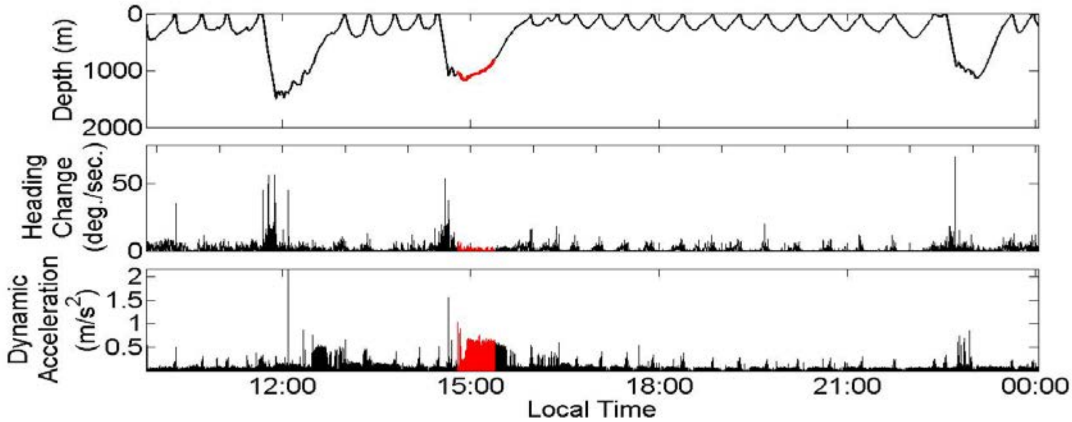

Figure 2. Data from a Cuvier's beaked whale, *Ziphius cavirostris*, tagged in 2010 in waters off southern California, and exposed to sonar sounds. The time when sonar was broadcast is indicated in red. Note the decreased variation in heading and increased dynamic acceleration, which correlates with energy spent on movement, during sonar exposure (From DeRuiter *et al.*, 2013)

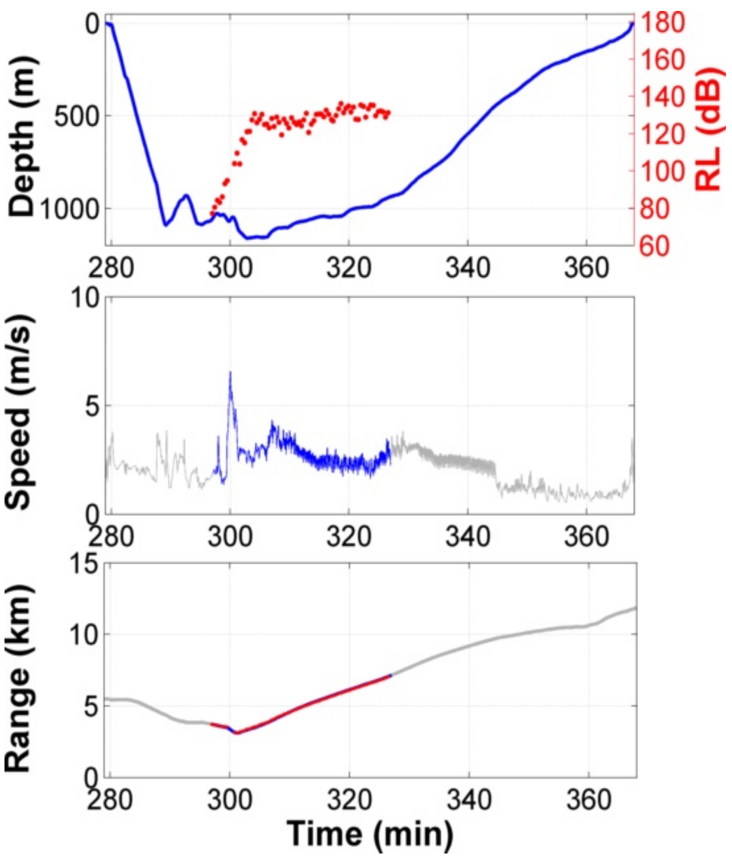

Figure 3. Blow up of the second deep dive shown in Figure 2, when the *Ziphius* was exposed to sonar. The top cell shows the received level of each sonar ping in red, overlaid on the dive profile. The middle cell shows that the whale responded to the sonar with a burst of speed up to 6.5 m/s as it dove downwards from >1000 m to >1100m depth. This was followed by a sustained period of elevated speed associated with the increased energy expenditure shown in Figure 2. The bottom row shows that the whale was about 4 km from the sonar sound when it started responding to the sonar. Its long directed ascent allowed it to swim from 4 km to a distance of 12 km from the source before it surfaced.

The duration of this deep dive was longer than usual with an unusually slow ascent and an unusually long (6.6 h) post-exposure inter-deep-dive interval (Figure 2). Modelling of diving physiology (Kvadsheim *et al.*, 2012) and analysis of the behaviour provide no evidence that this kind of strong sustained avoidance response harmed this whale, but this kind of response has been accepted as a safe indicator of threshold for risk for more intense or prolonged reactions.

New data collected from studies such as those just illustrated allow us to estimate the sound levels and distances at which different species might start to be disturbed by sounds of sonar or other sound sources. The most sensitive species appear to be beaked whales, which have been shown to respond to killer whale playback at exposures as low as 98 dB re 1 µPa (Tyack *et al.*, 2011), to mid-frequency active sonar (MFA) playback at levels of 98, 127 (DeRuiter *et al.*, 2013), and 138 dB re 1 µPa (Tyack *et al.*, 2011), to a pseudo random noise (PRN) with the same bandwidth and duration as MFA used as a control for sonar at a level of 142 dB re 1 µPa (Tyack *et al.*, 2011), and to ship noise at a level of 136 dB re 1 µPa (Aguilar Soto *et al.*, 2006).

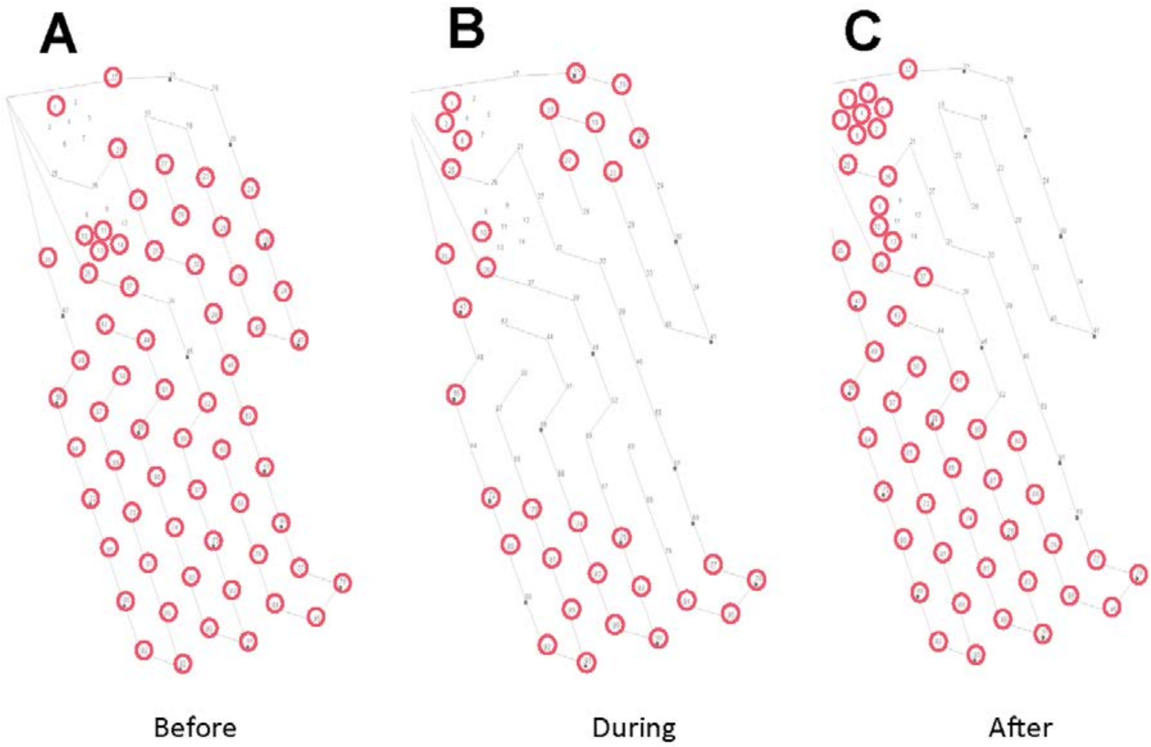

Figure 4. Detection of echolocation clicks from Blainville's beaked whale (*Mesoplodon densirostris*) on the AUTEC naval range in the Bahamas, before, during, and after a sonar exercise *centre*ed in the middle right portion of the range. Cell **A** highlights in red circles the hydrophones that detected clicks during the 20 h before a sonar exercise. Cell **B** highlights in red circles the hydrophones that detected clicks during the 23 h during a sonar exercise. Cell **C** highlights in red circles the hydrophones that detected clicks during the 22 h after the sonar exercise stopped. Note the large gap in detections in the *centre* of the range during the sonar exercise. The typical spacing between hydrophones is ~4 km, so the area over which whales silenced and/or avoided the exercise had a radius of 10 km or more (From Tyack *et al.*, 2011)

Thus, whereas TTS experiments suggested that risk of injury to toothed whales from sonar might be limited to ranges within about 100 m of the warship, the relatively low response thresholds found in controlled exposure experiments (CEEs) suggest that the behaviour of beaked whales may be disrupted at much larger ranges from sonar exercises. We can use the sonar equation for a back-of-the-envelope estimate of the range at which a warship operating a sonar at a source level of 230 dB re 1 μPa @ 1 m might reach the 140 dB received level at which many beaked whales respond to sonar CEEs. Assuming a sound transmission loss of 20 $\log_{10}$(range) and a sound absorption of 0.185 dB/km for the 3 kHz sonar sound, a received level of 140 dB, sufficient to elicit a response, would be obtained by whales at a range of about 20 km[9]. However most of the CEEs carried out to date use actual sonar stimuli but often from a sound source that is stationary and less powerful than an operational naval sonar. It is reasonable to ask whether actual sonar exercises evoke responses at such great ranges.

Once controlled exposure experiments demonstrate exactly how a whale species responds to sonar, other methods can be developed to monitor responses on a broader basis. For example, one of the earliest indicators of a beaked whale response to sonar during deep foraging dives is cessation of echolocation clicks. If a whale is still clicking during a sonar exercise, the implied continuation of foraging indicates that its foraging behaviour is not being disrupted. It turns out that these beaked whale clicks can be monitored by an extensive array of hydrophones on one of the testing ranges, the AUTEC range in the Tongue of the Ocean, Bahamas, where the US Navy conducts sonar exercises. Tyack *et al.*, (2011) show which hydrophones on the range detected beaked whales before, during, and after a sonar exercise. Figure 4 shows a large area where no beaked whales were recorded clicking during the exercise compared to before, indicating a response range of >10 km during the exercise, which is close to that predicted by the response criteria observed during controlled exposure experiments. Responses on these scales can be monitored on instrumented training ranges such as the one illustrated in Figure 4. However, most monitoring and mitigation measures for ship-based sound depend upon observers on the ship. The scale of response documented for beaked whales here is much too large for ship-based monitoring to be effective.

[9] SL = 230 dB. RL = 140 dB. SL-TL=RL. TL = 20 log10(range) + 0.185dB/(range*1000). If range = 20 km, 20 log10(20,000) = 86 dB and absorption loss = 3.7 dB. TL = 86 + 3.7 = 90 dB. 230 – 90 = 140.

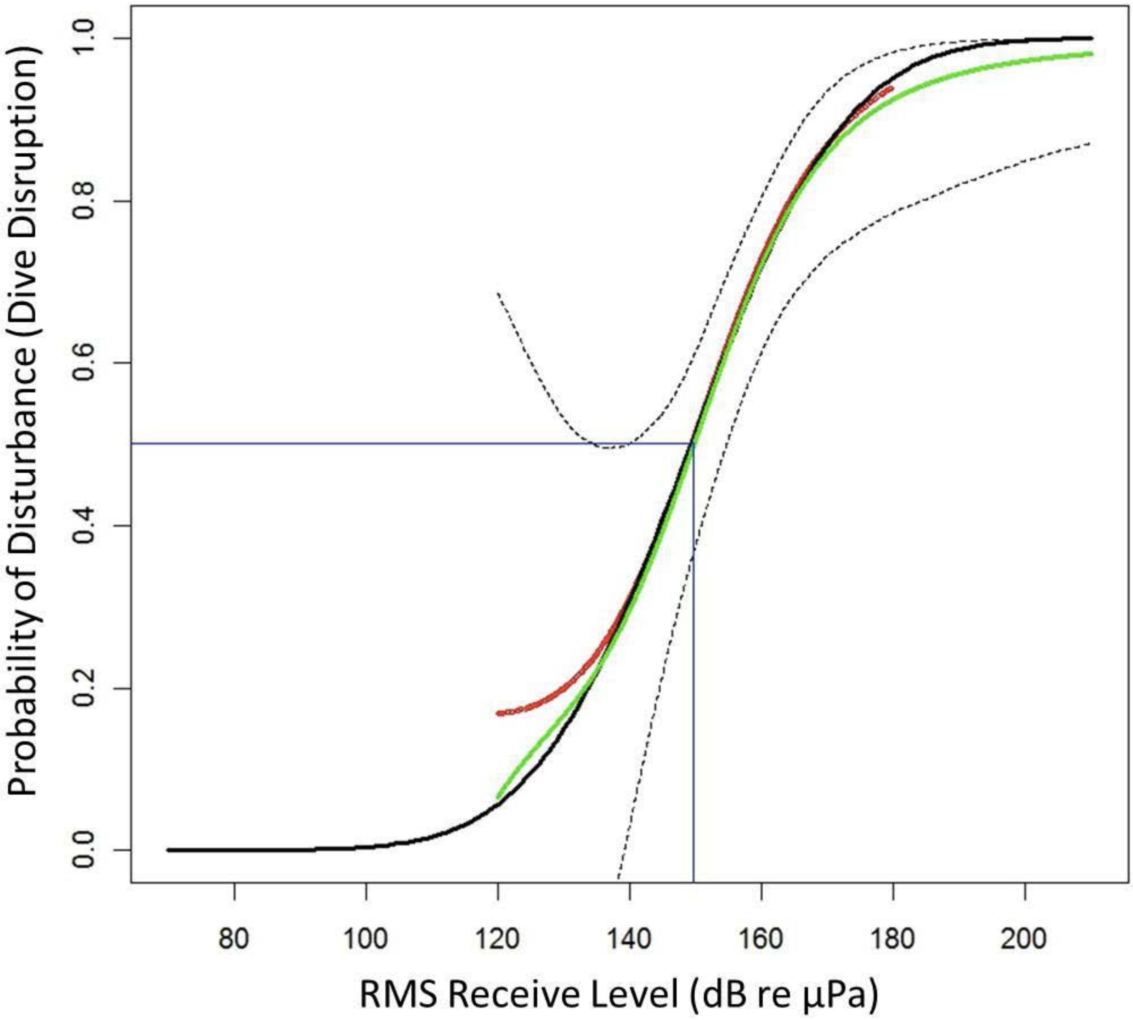

Figure 5. Probability that Blainville's beaked whales on the AUTEC naval range will not forage as a function of the received level of sonar pings. Two statistical fits to the actual data are indicated in red and green; an approximation that extends beyond the data is indicated in black. The dashed line indicates 95% confidence limits (From Moretti *et al.*, 2014)

Moretti *et al.*, (2014) used propagation modeling and measurements on the AUTEC naval range hydrophones to estimate the level of sonar sound exposure at each location where a group of beaked whales started clicking during synchronised deep foraging dives that started during sonar exercises. They also measured the normal rate at which beaked whales started foraging dives near each hydrophone on the range under baseline conditions of no sonar exposure. They then used statistical modeling to calculate the probability of disturbance (reduction in the rate of foraging dives) as a function of received level of the sonar pings. Figure 5 shows the resulting risk function. This function samples whales that remain near the sonar exercise. Tyack *et al.*, (2011) provide data suggesting that beaked whales move away from sounds such as sonar. If there is avoidance based upon variation in sensitivity, then the Moretti *et al.*, (2014) results will be biased towards sampling the least sensitive portion of the population. The sonar exposure at which a whale will start to forage during exposure may also differ from those at which a whale ceases foraging as exposure starts. Given these differences, the Moretti *et al.*, (2014) estimate that the finding of 50% of the whales avoiding an exposure of about 150 dB re 1 μPa is quite close to the observation from CEEs that about half of the whales show onset of disruption at about 140 dB re 1 µPa. The dose : response functions do not just provide one estimate of disruption, but estimate the actual variability in responsiveness of the population tested. With appropriate statistical methods, confidence intervals can also be estimated.

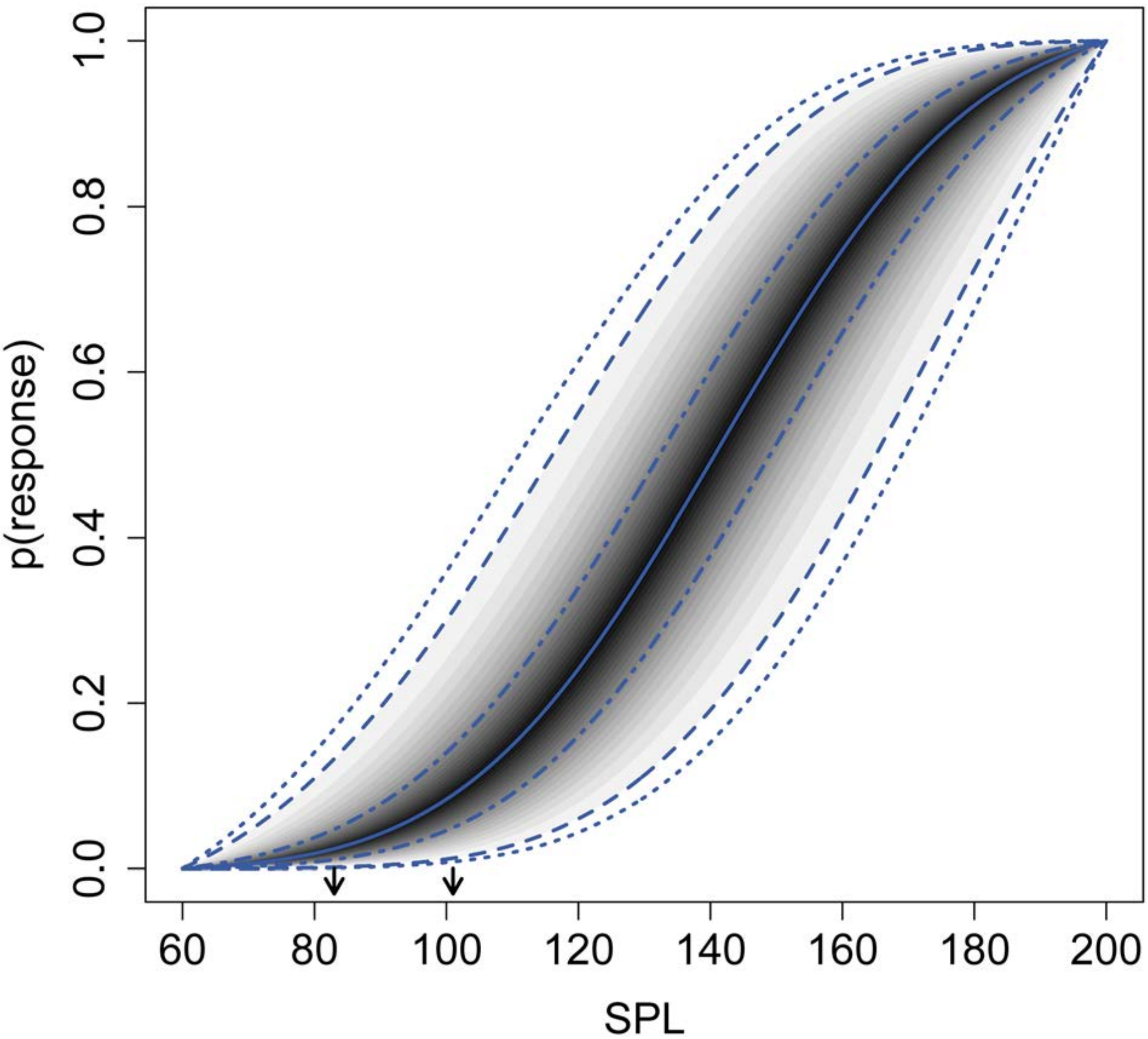

Figure 6. Acoustic dosage:behavioural response function for killer whales exposed to sonar sounds in controlled experiments. The solid blue line indicates the best estimate of the model, and the successive broken lines show the 50%, 90%, and 99% credible intervals. (From Miller *et al.*, 2014)

Similar dose:response functions can be derived directly from controlled exposure experiments. The recent dose:response curves derived from these studies have measured sound exposure levels at which behaviour was disrupted. Antunes *et al.* (2014) studied avoidance responses of pilot whales, one of the few delphinid species tested, and estimated 50% of the population would not respond to sound exposure levels below 170 dB re 1 µPa. Out of 13 playbacks, one whale responded at about 120 dB re 1 µPa, four around 160 dB re 1 µPa, and no response was observed in the others, even though some were exposed above 180 dB re 1 µPa. Miller *et al.* (2014) performed a similar study of killer whales. This species was more sensitive than pilot whales, with a mean response threshold of 142 +/- 15 dB re 1 µPa.

Most initial criteria for what level of sound caused disruption of behaviour, used single numerical values such as 120 or 160 dB re 1 μPa. However, the responsiveness of animals varies considerably depending upon their behavioural context, age, sex, hearing abilities etc. The risk functions illustrated in Figures 5 and 6 demonstrate how empirical studies can incorporate this natural variability to make a more precise estimate of how responsiveness varies with acoustic exposure. These methods also provide powerful means to estimate which species or sound stimuli have similar or different patterns of responsiveness, which will be important for deciding how to pool species/stimuli in regulatory policies. Managers tasked with protecting populations may also want to test whether important sub-populations, such as mothers with young calves, may be more sensitive than the entire population. Another very important point about these risk functions is that much of the attention has focused on high probabilities of response, which usually are associated with sound levels consistent with close proximity to the sound source. At normal cetacean densities, few animals will be expected in such close proximity. However, lower probabilities of response are associated with such low sound levels (*e.g.* 10% response at 100 dB re 1 μPa for killer whales avoiding sonar in Miller *et al.,* 2014). These low levels are associated with large ranges of many tens of kilometres, which encompass such large areas that the number of animals predicted to respond may be quite large even at the low probability of response.

The key message of this work for management of environmental risks is that effects of intense sound sources such as sonar, pile driving, and seismic survey, may occur over such large areas that new approaches for monitoring and managing the conservation risk are required.

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DETECTION OF MARINE MAMMALS IN EUROPEAN WATERS USING SHIP-BASED THERMOGRAPHY: PROSPECTS AND LIMITATIONS

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Abstract Mitigating the contingent effects of anthropogenic noise frequently relies on the continuous surveillance of the acoustic source's environs. Recent advances in ship-based perimeter surveillance, using a state-of-the-art 360° IR-scanner to generate a thermographic video stream, now allow automatic real-time detection of whales, facilitating effective observations both night and day. So far, tests proved the system's reliable performance at ranges up to ca. 5 km in polar, sub-polar and temperate environments (waters cooler than 16°C), under low visibility (particularly night-time), and at high sea states (corresponding to Beaufort 7). Additional recent studies in subtropical waters confirm for waters up to 22°C the discriminability of whale blows at somewhat reduced, yet still sufficient, ranges. The system's current implementation provides automatic detection, localisation, documentation and real-time verification, serving as assistant to the marine mammal observers who are thereby relieved from the bulk of their protocolling duties. Noteworthy features are the system's unwavering alertness 24/7, its quasi-360° coverage, and its highest possible thermal sensitivity (and hence long detection ranges) due to a cryogenically cooled sensor head.

INTRODUCTION

Acoustic emissions from loud hydroacoustic sound sources, *e.g.* naval sonars and seismic air guns, are of growing concern for being potentially harmful to marine mammals. Consequently, competent authorities frequently require the implementation of mitigation measures when permitting such activities to be conducted within their jurisdiction. The most common mitigation practice is to implement a marine mammal watch, i.e. a team of observers who visually monitor the ship's environs and request a shut-down of the acoustic source whenever marine mammals are sighted within a predefined detection zone (see Figure 1), with the aim of preventing animals getting into the exclusion zone while hydroacoustic equipment is active. While this work is tiresome and limited to daylight hours, most hydroacoustic activities operate 24/7 for weeks to months, requiring large teams to uphold reliable observations while nevertheless, providing only rather limited monitoring capabilities at night.

A system that supports such sighting efforts, preferably automatically and unrestricted by light conditions, hence appears to be of great value to both cetaceans (by providing better protection) and hydroacoustic users (by extending their operational periods due to improved night-time surveillance capabilities). Automatic detection thereby offers 1) covering the MMOs' back when focusing the attention to a (potential) sighting; 2) maintaining constant vigilance, regardless of deployment duration; 3) repeatedly retriggering the observers' alertness by demanding his/her decision on (even false) events; 4) providing robust distance estimates of events, regardless of sea state or fleetingness of blows; 5) providing instant validation capabilities by replaying video footage of events; 6) providing evidence regarding operational decisions; and 7) providing objective proof of conformity with regulations.

To this end, we developed a ship-based thermal imaging system for automated marine mammal detection based on an actively stabilised, 360°, naval infrared scanner and an artificial intelligence powered algorithm that detects whale blows on the basis of their thermal signature. So far, the technology has been tailored to and tested extensively under polar and subpolar (sea surface temperature (SST) <6°C) water conditions, as this is where the technology was expected to perform best (Zitterbart *et al.*, 2013).

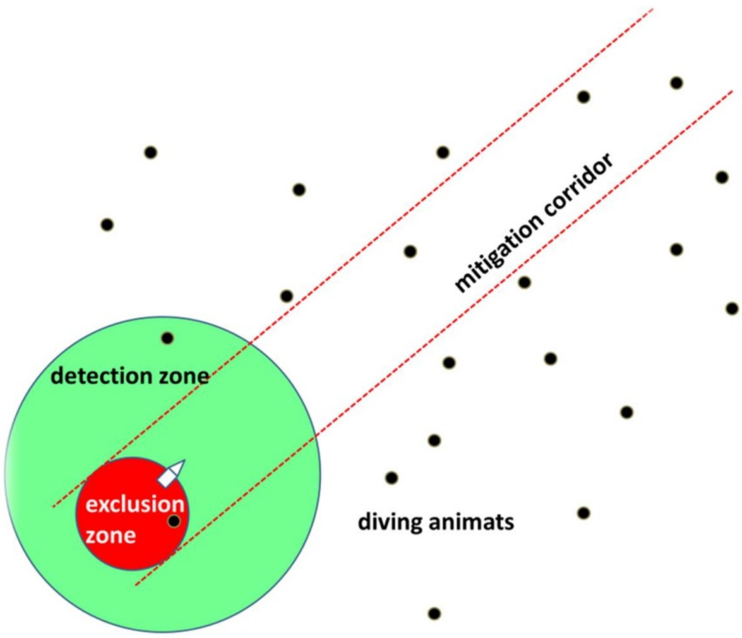

Figure 1. Schematic of mitigation approach, showing the pre-defined exclusion zone (based on acoustic threshold considerations), and an ensuing minimum detection radius as necessary to prevent whales from getting into the exclusion zone undetected (See Zitterbart *et al.*, 2013) for further details)

The system's performance is independent of daylight and exhibits under the above-mentioned conditions an almost uniform, omnidirectional detection capability within a radius of 5 km. It outperforms alerted observers in terms of number of detected blows and ship-whale encounters (Zitterbart *et al.*, 2013). Our results demonstrate that thermal imaging can be used without restrictions in these realms for reliable and continuous marine mammal protection. Hereinafter we describe the system in its most recent implementation and discuss its potential for use in the ACCOBAMS[10] and ASCOBANS[11] areas.

[10] Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic Area (www.accobams.org).
[11] Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (www.ascobans.org).

The automatic marine mammal mitigation system (AIMMMS)

AIMMMS is commercially available from Rheinmetall Defense Electronics, RDE, Germany[12]. The system comprises the hardware components (produced by RDE) and a licence of the AWI software, currently optimised for polar and subpolar oceanic conditions. The hardware is subject to export control, which, however, usually does not constrain its use in and by European nations.

On RV *Polarstern*, our development and test platform, the system is mounted on the crow's nest 28.5 m above sea surface (Figure 2). The thermal imaging device proper (left panel, dark sensor head) is mounted on an actively stabilised gimbal (left panel, white object), scanning 360° horizontal × 18° vertical at 5 revolutions per second, providing a 5-Hz video stream of the thermal field of the ship's environs at horizontal and vertical resolutions of 0.05°/pixel and 0.03°/pixel, respectively. The cryogenic sensor is cooled to 84K by a Sterling cooler. On RV *Polarstern*, the rear 60° are shielded by the crow's nest and therefore not visible in the thermal video stream.

The video stream is piped to a custom data acquisition and processing software, providing data management, graphical user interface, and a detection algorithm. The latter is based on thermographic data collected during nine expeditions to the Arctic and the Southern Ocean, each lasting from 4 to 11 weeks in the period between 2009 and 2013. These resulted in 300 days total system uptime with 1000 TByte data produced and 2240 hours of video material archived.

Figure 2. Installation of the AIMMMS Infrared System on RV *Polarstern*

To detect blowing whales in the video stream, the software applies a learning, multistage detection/classification algorithm (Figure 3), which subsequently reduces the amount of data while increasing the complexity of analysis with the aim to concurrently minimise the number of missed events and false alerts. The software algorithms utilise concepts of machine learning by employing a support vector machine, which allows optimising of the software to the environmental conditions it operates under. A schematic of the data flow is given in Figure 3, along with typical data rates as determined empirically during an expedition to the Southern Ocean.

[12] http://www.rheinmetall-defence.com/de/rheinmetall_defence/systems_and_products/c4i_systems/reconnaissance_and_sensor_systems/automatic_marine_mammal_mitigation/index.php

The thermographic imager provides data at a rate of 40 Mb per second. These are split into 31600 overlapping segments per second of range dependent size (decreasing with distance from the ship), which are fed to the algorithm's first stage, the detector. The detector checks each snippet for contrast changes within a specific time interval, producing, on average, about 5000 candidate snippets, which feature thermal anomalies of all kinds (passing birds, blowing whales, whipping antennas, splashing waves, etc.). These candidate snippets are fed into a classifier (i.e. the second stage), which had undergone prior training, to extract only those anomalies that resemble blowing whales (5 to 6 per hour). These are presented (as endless video loops) via the graphical user interface to the human operator, who, as the last (third) stage, verifies the nature of the thermal anomaly. During RV *Polarstern* expedition ANT 28.2, an average about one whale was thus encountered every other hour. (However, it is important to note that whales occurred quite irregularly, i.e. sometimes none for days, sometimes many within an hour).

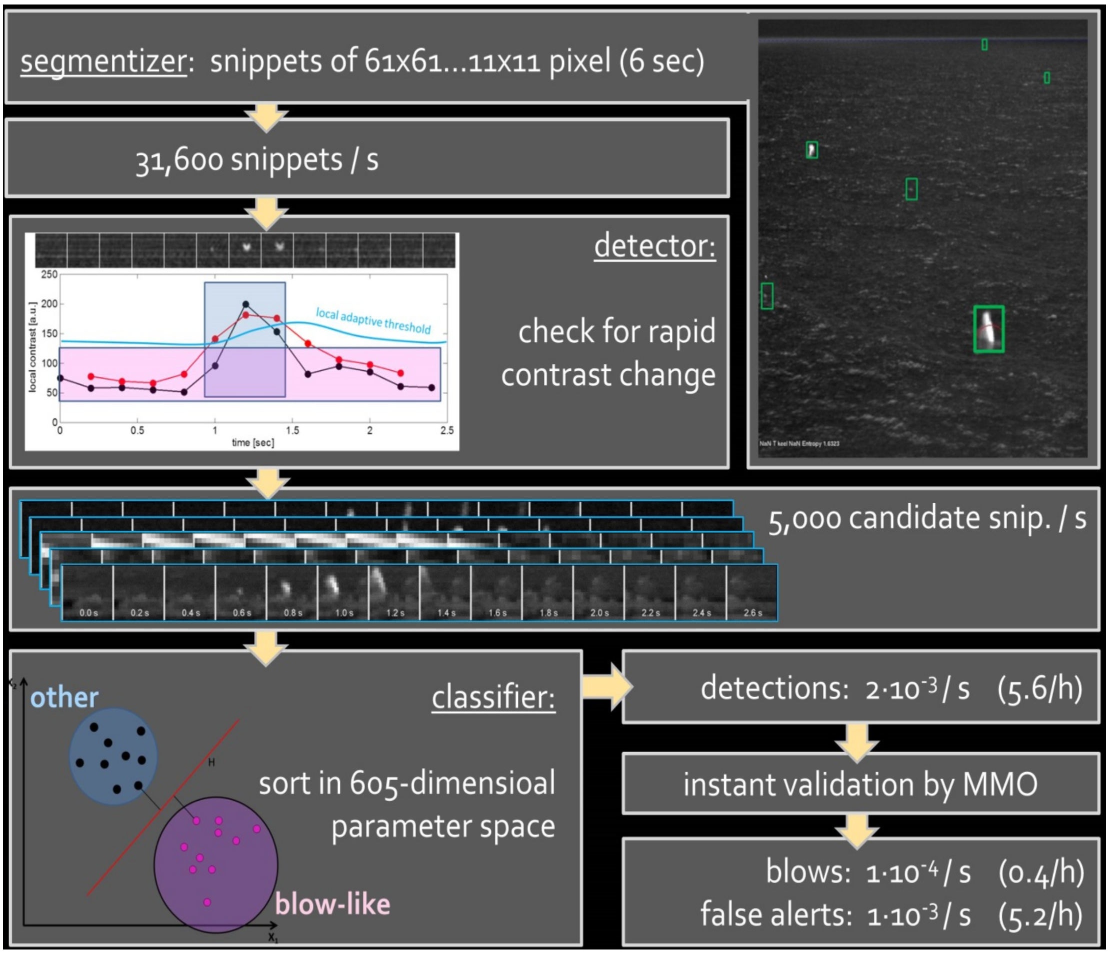

Figure 3. Schematic of data flow and rates of automatic detection algorithm

Environmental conditions

Day/ Night

The thermal signal emitted by a whale blow comprises both a) the black-body radiation emitted by the droplets contained within the blow and b) ambient thermal radiation from other sources (primarily the sun) scattered on these very droplets. Whether process (a) or (b) dominates the received signal was unresolved at the outset of our project. However, meanwhile, numerous night-time recordings of blowing whales have been acquired (see, for example, Figure 4), proving that process (a) is sufficient to render a blow discriminable in the thermal image. In fact, observers monitoring the thermographic videos considered the discriminability of blows to generally be better at night than during the day. This is probably due to a lessening of global contrasts as caused by reflections of daylight on the sea surface (breaking waves in particular) and holds true for all our studies in polar, subpolar, temperate and subtropical regions. With regard to the automatic detection algorithm proper, the factor most critically governing its performance is the local signal to noise ratio. This is at night – due to the lack of reflections from breaking waves – significantly less than during the day, providing advantageous detection conditions for the thermal imaging based automatic detection algorithm.

While a quantitative night-time comparison of automatic thermographic detection with visual observers is all but impossible due to observers then being blind, so to speak, the lack of theoretical arguments for a reduced discriminability of thermographic blow signatures and the improved signal to noise ratio at night-time, together with hundreds of automatic night-time detections, gives us confidence that this system provides reliable night-time surveillance equally well as during day-time - most likely even better.

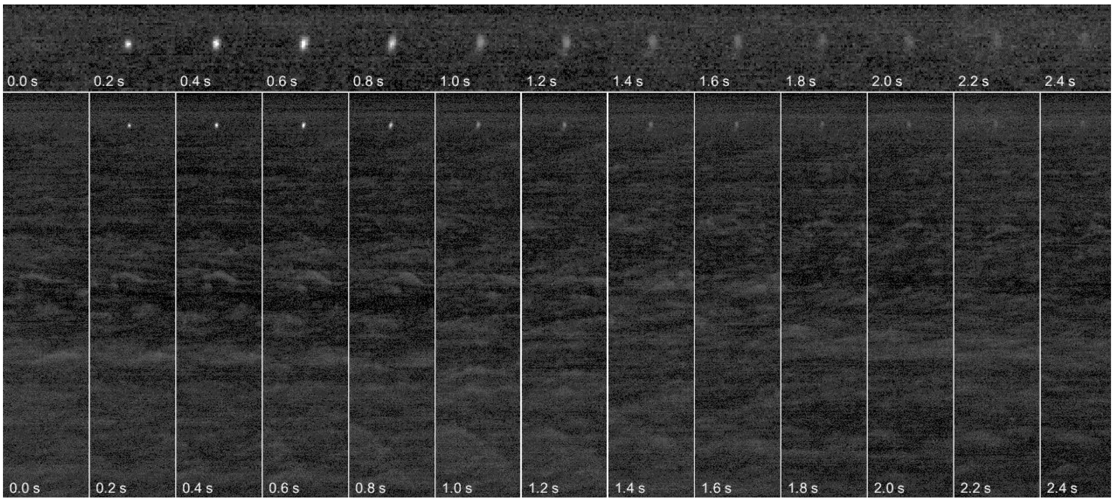

Figure 4. A night-time 2.8 seconds long sequence of video snippets starting on 28.12.2011 at 22:17:37 (0.2s spacing), showing an automatically detected whale blow (white dot at upper limit) at 1.7 km distance at night-time. (Evening Astronomical Twilight: 20:24; Morning Astronomical Twilight 03:12). Latitude 57.108°S Longitude 0.0165°W. Bottom row: 5° horizontal sector of IR image (full vertical height). Top row: cut-out of blow area, 1.05° by 1.05°

Temperature realms

The ASCOBANS[13] area primarily comprises temperate waters (6° – 16°C) year-round while ACCOBAMS[14] features temperate waters in winter and subtropical waters (16° - 22°C) in summer. While the current implementation of AIMMMS was trained primarily on data from polar and subpolar regions (❶ in Figure 5), it nevertheless detected whale blows under temperate conditions between Cape Town and the Antarctic (green hues between Cape Town and ❶ in Figure 5). Most recently, during system trials off Australia, more than 90% of the visually observed groups within 2 km of the sensor could also be detected by visual screening of the IR footage on computer displays for sea surface temperatures of typically 22°C. Earlier findings by Baldacci *et al.* (2005) from the Mediterranean Sea are in line with our results.

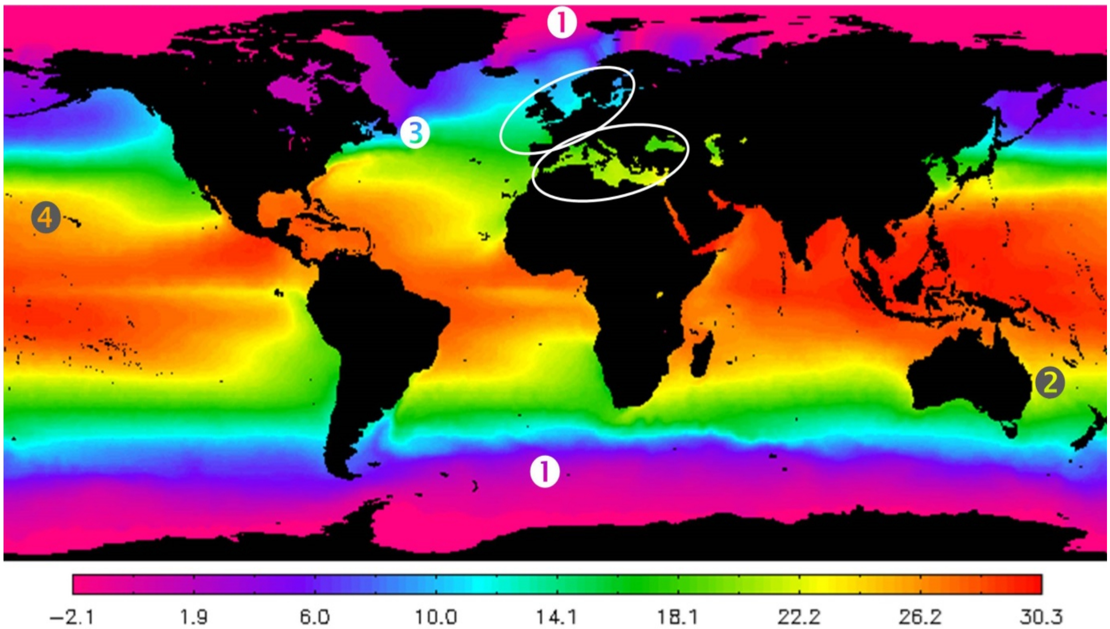

Figure 5. Climatologic ocean surface temperatures with locations of AIMMMS test sites indicated by numbers. ❶ The Southern Ocean and Fram Strait, (polar and subpolar realm); ❷ East Australia (subtropical realm; ❸ Nova Scotia (temperate realm); ❹ Hawaii (tropical realm). Lower ellipse: schematic outline of the ACCOBAMS area; Upper ellipse: schematic outline of the ASCOBANS area. SST image from http://www.ospo.noaa.gov/data/sst/fields/FS_km5001.gif, accessed 2 July 2015.

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[13] The ASCOBANS area comprises the "marine environment of the Baltic and North Seas and contiguous area of the North East Atlantic, as delimited by the shores of the Gulfs of Bothnia and Finland; to the south-east by latitude 36°N, where this line of latitude meets the line joining the lighthouses of Cape St. Vincent (Portugal) and Casablanca (Morocco); to the south-west by latitude 36°N and longitude 15°W; to the north-west by longitude 15°W and a line drawn through the following points: latitude 59°N/longitude 15°W, latitude 60°N/longitude 05°W, latitude 61°N/longitude 4°W, latitude 62°N/longitude 3°W; to the north by latitude 62°N; and including the Kattegat and the Sound and Belt passages".

[14] The ACCOBAMS area comprises the "maritime waters of the Mediterranean and Black Sea and the Atlantic Area contiguous to the Mediterranean Sea west of the Strait of Gibraltar".

While our findings do not yet quantify the performance of the automatic detector under subtropical conditions, they clearly show that whale blows are thermographically discriminable from the background under such conditions, and that the ongoing development of an automatic detector with optimised performance for subtropical conditions is promising, rendering plausible an extension of the system's operational range to even Mediterranean summer conditions. Meanwhile, surveys there could be scheduled to the winter/spring period, to ensure highest detection probabilities and hence animal protection.

Sea State / Wind Speed

The system performs surprisingly well even at wind speeds (i.e. sea state once in equilibrium) up to Beaufort 6 to 7, conditions under which most hydroacoustic surveys would be paused. Figure 6 depicts the occurrence of detections as a function of wind speed and detection distance for data recorded during an expedition into the rather windy Southern Ocean. Detections occurred robustly within the 3 km range across all wind speeds (note that the plot is uncorrected for the frequency of wind speeds: less sighting opportunities exist at low wind speeds due to their rareness in this region). Between Beaufort 5 and 7, frequent sightings occurred even at ranges out to 5 km and beyond. Sea state conditions in European waters are likely to be similar, if not better.

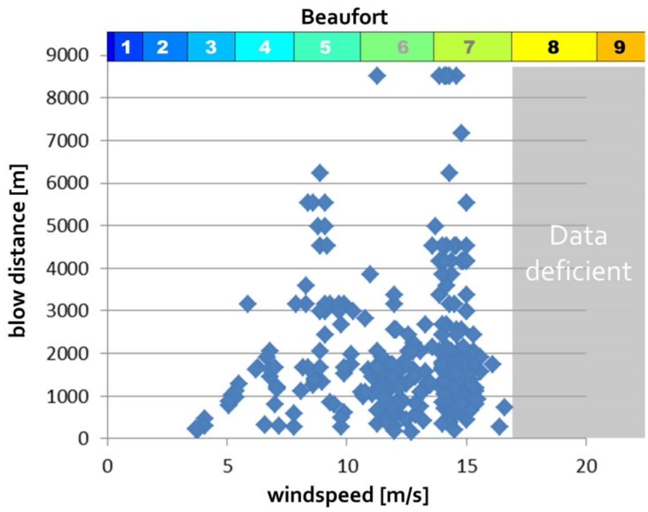

Figure 6. Scatter plot of detected blow's distance versus respective wind speed. Note that plot is not corrected for the frequency of wind speeds, explaining the small number of events at low wind speeds, which rarely occur in the Southern Ocean

Glare

Glare – the reflection of sunlight on the sea surface – is a major problem for MMO activities. The probability to detect a surfacing marine mammal in sectors subject to glare is reduced to almost zero. The sector of sea surface, which is not observable by an MMO, is dependent on the sun's position. IR imaging is also impeded by glare but to a significantly lesser extent. We measured which sector of the sea was not observable in the IR and visual contexts and found that while the visual observations are not possible within a sector of 15° – 25°, IR is impeded much less by glare with 5° – 7° degrees of non-observable sector (Figure 7).

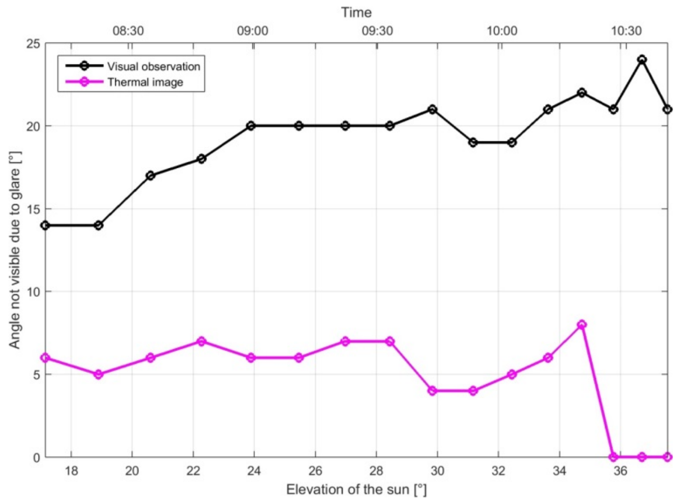

Figure 7. Angular sector of the sea, which is not observable due to glare in respect to time of day

DISCUSSION

Using this or technically equivalent (cryogenically cooled, 360°, 5 Hz, 0.05° optical resolution, high-precision gyre stabilised) systems to mitigate noise generating activities in the ACCOBAMS and ASCOBANS areas of course requires its ability to capture the species occurring in these areas. While larger cetaceans (mysticetes and sperm whale) do occur in both regions, they are predominantly populated with small to mid-sized odontocetes. These, in turn, occur less frequently in areas where we tested our system, so far resulting in only few sightings of similarly sized species, which are discussed hereinafter for applicability to the ACCOBAMS and ASCOBANS areas. It should be noted that in our evaluation – as in the text above - we distinguish between ***discriminability*** of the cue (blow, splash etc.) from the background clutter by a person screening the thermographic videos, and ***detectability*** of the cue by our (current) automatic detection algorithm.

Large cetaceans: So far, most large baleen whale species have been detected under temperate, subpolar and polar conditions. A sperm whale was detected at long range (6 km) in cold waters. Humpback whale cues are discriminable in subtropical waters. Whales of this group will be detectable in the ASCOBANS area year-round and in the ACCOBAMS area during winter and spring.

Medium sized cetaceans (3 m to 10 m): This group comprises beaked whales, orcas and minke whales. So far, minke whales (including dwarf minke whales) have been detected under temperate, subpolar, and polar conditions and orcas in polar waters, while beaked whales have not yet been captured. However, we ascribe this to a lack of opportunity rather than to their blow being too faint as they are known for their rather cryptic behaviour and preference for regions rarely visited by RV *Polarstern*.

Small cetaceans (<3 m): These have not yet been detected, primarily due to a lack of opportunity but also because the detector has so far been trained exclusively on signatures from large whales. Common bottlenose dolphins are discriminable in thermographic footage of subtropical waters at a range of up to 1 km and Dall's porpoises in (sub)polar waters up to several hundred metres (Weissenberger and Zitterbart, 2012). Discriminability and detectability might increase when animals form schools, which generate a unique thermal signature that might be exploited for automatic detection by a customised detector algorithm.

Contrary to passive acoustic monitoring, which requires the individual to vocalise to render its acoustic detection possible, thermographic monitoring only requires the whale to surface or (preferably) to blow. As the latter occurs regularly, reliable surveillance is available for whales exhibiting dives not longer than 30 min, as long as the detector is sensitive enough (i.e. cryogenically cooled) to detect whales within the entire detection zone (Zitterbart *et al.*, 2013). For the ASCOBANS and ACCOBAMS species, this generally holds true for all species except sperm whales (unless logging) and beaked whales. In turn, these latter species click regularly during their dives, rendering PAM a suitable complementary detection method.

Application to research questions

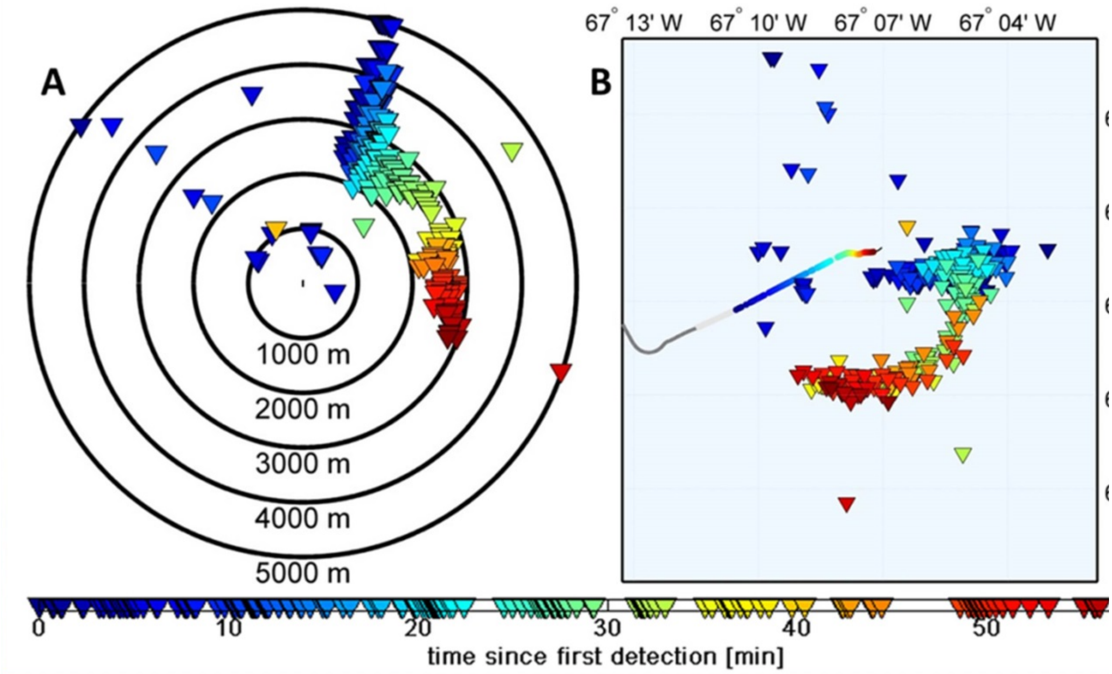

Figure 8. Plots of locations of detected blows during a ship-whale encounter. Coloured triangles represent position (left relative to ship, right geo-referenced) with their temporal sequence given in the time bar at the bottom (relative to first blow detected).

Apart from operational applications for mitigation purposes, this system allows localising whales at sea even for agitated sea states with the smallest possible errors (c.f. (Zitterbart *et al.,* 2013; Figure 8). Potential information that may be retrieved from such encounter analyses might be, for example, species and context specific quantifications of occurrences of flight responses or stand-off radii. Given the fact that all encounters are documented this way, robust and traceable evaluations of marine mammal responses near acoustic sources are within reach once the system becomes a standard tool to be employed during seismic surveys.

CONCLUSIONS

By now, AIMMMS has proved its reliability and versatility during numerous expeditions and under a wide range of environmental conditions. Data already confirm the algorithm's unrestricted night-time aptitude and robust performance under all sea states at which hydroacoustic surveys are being operated. Ongoing projects aim to test and optimize the algorithms performance for different (smaller) cetacean species and warmer waters. Applicability of the system to the ACCOBAMS and ASCOBANS regions appears possible with regard to the environmental conditions and with respect to species composition in the respective areas, although limitations in detection range are anticipated for the smaller sized cetaceans. Therefore, the systems practicality relating to mitigation will be a matter of the applicable detection/exclusion zones.

ACKNOWLEDGEMENTS

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BALTIC SEA INFORMATION ABOUT THE ACOUSTIC SOUNDSCAPE (BIAS): STANDARDS FOR MEASUREMENTS AND SIGNAL PROCESSING

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INTRODUCTION

BIAS is a project running from 2012 to 2016 and funded by EU-LIFE (LIFE11 ENV/SE/841) together with national sources in the Baltic Sea countries, Sweden (lead), Finland, Estonia, Poland, Germany, and Denmark. The aim of the project is to develop methods to implement the European Commission's Marine Strategy Framework Directive (MSFD) (European Commission, 2008) on a regional sea basis (the Baltic Sea) with respect to descriptor 11 of the Directive (emission of energy, including underwater noise). This includes, among other tasks, establishment of baseline levels for underwater noise in the Baltic by means of measurements and as part of that, to develop measurement protocols and analysis tools. The key requirements given beforehand was specified by the ruling of the European Council (European Commission, 2008), later interpreted by the TSGNoise group (Dekeling *et al.*, 2014). This includes a requirement of the EU member states to report trends in annual average noise levels in the third-octave bands centred at 63 Hz and 125 Hz. This report deals with the standards developed within BIAS in order to obtain recordings of noise and perform the fundamental signal processing required to extract noise levels in the two third-octave bands in question. These noise levels will subsequently be used as input to modelling of noise levels in the entire Baltic.

A large range of decisions must be made during design of an extensive monitoring program such as BIAS, relating to selection of number of recording stations and their locations, choice of recorders, recording settings and subsequent signal processing. The basis for these decisions is not only the requirements of the Directive, but also the wish for recordings to be usable for other purposes than strictly specified within MSFD.

Selection of data loggers

Minimum requirements decided for recorders are shown in Table 1. An extensive market survey for available data logger systems in early 2013 resulted in identification of two commercially available systems, which fulfilled all criteria and at the same time were within the economic limits of the BIAS budget. These were:

1) Loggerhead DSG-OCEAN recorder, Loggerhead Instruments, Sarasota, Florida, USA
2) SM2M, Wildlife Acoustics, Boston, Massachusetts, USA

Both systems are 16 bit single channel systems based on HTI96min hydrophones. The main difference at the time was a larger memory capacity of the SM2M (4x128 Gbyte vs. 1x128 Gbyte). It was decided to allow each country to use either of the two recorders or even a combination of both. This was done to accommodate the fact that some countries already had recorders available and as standards for any monitoring program ideally should not rely on specific measuring instruments, it was seen as a strength of the standards that they were able to accommodate two different instruments.

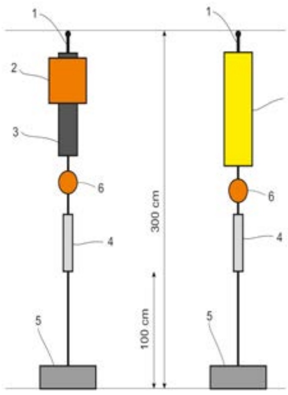
Table 1. Key requirements of sound recorders used in BIAS

Parameter	Target	Justification
Bandwidth	10 Hz-12 kHz	Noise recorded above 10 kHz is to a high degree from more local sources, rather than propagated from distant sources and thus not representative for regional noise levels. Upper limit of 12 kHz selected to allow inclusion of third-octave band centred at 10 kHz.
Sampling rate	Saved at min. 24 ksamples/s. Min. 4 times oversampling, digital filtering and decimation	Follows from bandwidth requirements. Oversampling required for appropriate anti-aliasing filters.
Dynamic range	16 bit	Judged to be sufficient most of the time, with only occasional clipping and/or limitation by self noise.
Sensitivity	Clip level ~165 dB re. 1 µPa	Clipping by close passage of very loud sources considered to be a rare event with little influence on end results.
Channels	Minimum 1	
Recording format	Raw (pcm) or non-lossy compression format	
Battery endurance	AT least 3 months	Would require four service visits per year, a reasonable trade-off between high cost of servicing and risk of loss of data.
Memory capacity	At least 3 months of recording at min. 33% duty cycle	Twenty minutes of recordings every hour was considered sufficient to characterise the mean and to provide input to noise modelling.

Rig design

A key element in acoustic monitoring is the design of the recording rig, which must be sufficiently robust to withstand the harsh ocean conditions, yet be light enough to allow reasonably easy deployment and recovery (Dudzinski *et* *al.*, 2011), and finally not generate noise that can interfere with the recordings. A rig workshop was conducted in 2013 and resulted in two different recommended designs for the SM2M and the DSG-Ocean, respectively (Figure 1, left). A central design requirement was a fixed hydrophone height of 3 m above the sea floor. To avoid noise from surface floats and strumming in long cables, it was decided to make a design entirely without surface markers. Instead, the retrieval was by means of a disposable anchor (gravel bag, concrete tile or similar) of at least 20 kg weight and an acoustic release mechanism. The SM2M is positively buoyant in itself, whereas the DSG-Ocean had to be fitted with extra buoyancy in the form of hard urethane foam cut to shape and mounted on the top of the recorder (Figure 1). As a safety measure, secondary flotation (hard plastic trawl balls) was added between the recorder and the acoustic releaser.

A third trawl resistant rig design (not shown) was developed for the Polish waters, to reduce the risk of losing equipment to the abundant fishery with otter trawls.



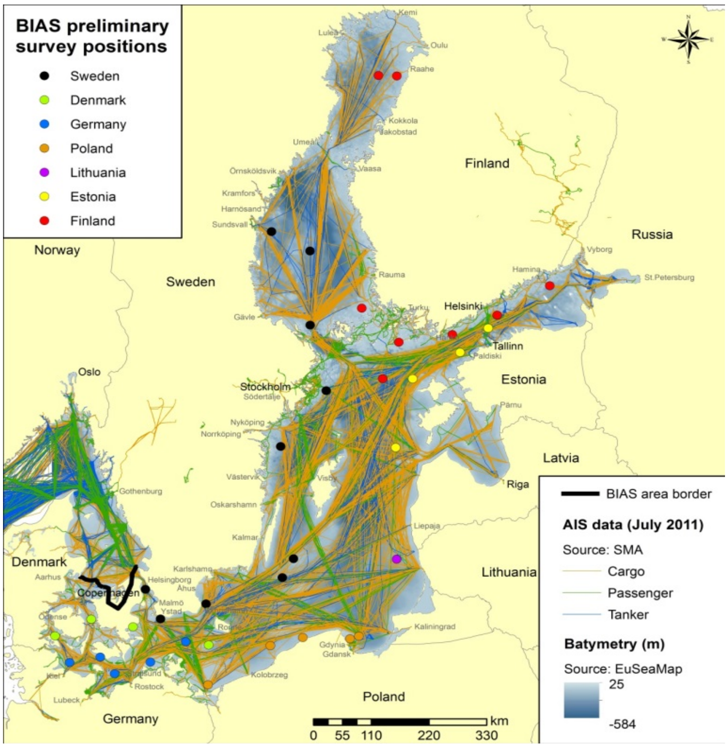


Figure 1. Left: Rig design for the two different recorders used. Legend: 1) hydrophone, 2) flotation (urethane foam), 3) DSG-Ocean, 4) Acoustic releaser, 5) disposable anchor, 6) secondary flotation and 7) SM2M. Right: Positions of recording stations within the BIAS project plotted on top of a map showing shipping density from AIS data

Positions

Thirty-six positions were selected across the Baltic (Figure 1, right), south and east of a line running across the southern Kattegat. Positions were selected according to a number of criteria, seeking a balanced and representative design with respect to bathymetry, wave exposure, and bottom sediment. In accordance with recommendations from the TSGNoise (Dekeling *et al.*, 2014), positions were selected to belong to either of two types: either close to shipping lanes, to allow good recordings of sources, or distant from shipping lanes (to the degree possible in the heavily trafficked Baltic), to allow for estimation of transmission properties. Attention was also put on safety to ships and recording stations, i.e. positions were outside shipping lanes and areas with heavy otter trawl fishery activity.

Analysis

Third-octave band levels were extracted by custom written algorithms in MatLab. Each recorded file, lasting at least 20 minutes (lowest duty cycle accepted within BIAS was 20 min. every hour), was broken up into periods 20 s long (Figure 2). The power density spectrum for each period was estimated by a Welch average of 1 s non-overlapping and Hann-weighted segments, providing a 1 Hz spectral resolution. The appropriate third-octave band levels (63 Hz, 125 Hz, and an additional band at 2 kHz, not specified by the MSFD) were then extracted by summing the energy of the relevant 1 Hz bands of the power density spectrum estimate, thus providing mean third-octave levels every 20 s for the three bands. These means were available for at least 20 minutes every hour on some stations up to continuously for those stations with sufficient battery and memory capacity to record on a 100% duty cycle.

From the running estimates of the power density spectrum, other parameters can be derived, such as statistical measures (rms-bandwidth, median frequency, skewness, kurtosis, etc.), which can be used to characterise the noise in ways usable outside the strict requirements of the monitoring pursuant to the MSFD. Raw signals are saved for future analyses, including search for signals of biological origin (such as fish sounds and underwater calls from seals).

The output of the third-octave analysis is eventually transferred to the acoustic soundscape modelling, performed by Quiet Oceans, which will generate area-covering maps of modelled average noise levels in the three third-octave bands. These maps will in the end form the baseline data for the MSFD-monitoring and reporting and form the basis for the first assessment of good environmental status (GES) with respect to descriptor 11 (underwater noise) of the MSFD.

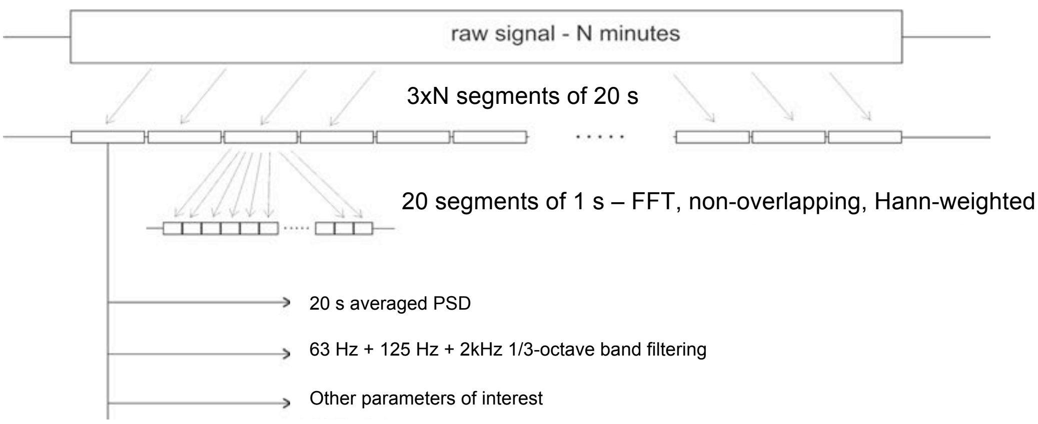


Figure 2. Schematic illustration of signal processing

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THE NOISE ISSUE: CASE STUDIES IN ITALIAN SEAS

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INTRODUCTION

In the Mediterranean Sea, marine life is threatened by habitat degradation due to human causes such as intense fishing, ship traffic, chemical pollution, coastal industrialisation, and seismic surveys for the exploitation of oil and gas resources. Other than being affected by chemical pollution, which contaminates the entire marine food web, cetaceans are also affected by noise pollution.

The concern that man-made noise can affect marine mammals has increased over the past few years, mainly within the context of naval sonars and seismic surveys. A huge literature is available (*e.g.* Richardson *et al.*, 1995; Merril, 2004; Simmonds *et al.*, 2004; Aguilar Soto *et al.*, 2006; Pavan, 2007; Tyack, 2009); however, we still lack the understanding of the long-term and cumulative effects of noise exposure and of the synergistic effects of the other stressors generated by human activities. In other words, the biology of "disturbance" and the effect of noise on the health of marine mammals and their prey species are not well understood yet.

SHIP NOISE

Ship traffic has been increasing in the oceans, especially in the Northern Hemisphere, in the last decades. The propulsion noise of ships accounts for most of the acoustic energy that humans put into the sea. Commercial shipping is estimated to have elevated the average ambient noise levels in the 20-200 Hz band by about 10 dB in the past century (Green *et al.*, 1994; Andrew *et al.*, 2002). Payne and Webb (1971) point out that this is the dominant frequency band used by baleen whales for communication, and increased noise may significantly reduce the range over which they can communicate (Clark *et al.*, 2009). Also, other sources may emit loud sounds underwater and noise and vibration can propagate from the coasts too.

In some cases, sound sources radiate low-frequency sound over very large areas thereby exposing populations to low sound levels (<120 dB re 1 µPa) over relatively long periods of time (chronic exposure) (Nieukirk *et al.*, 2004). In other cases, sound sources radiate mid- to high-frequency high-power sound over relatively small spatial scales and individual animals are exposed to higher levels of sound (>160 dB re 1 µPa) over relatively short periods of time (acute exposure).

Ship traffic (Figure 1) is an example of a diffuse and almost continuous chronic source of noise pollution that may radiate over very wide areas because of the efficient sound transmission of low frequencies. With the noise produced by ship traffic, we may have two scenarios, one in close proximity of individual ships and one over large distances where the noise irradiated by a number of moving sources merges into a relatively constant and diffuse background noise, more or less dominated by cumulated ship noise.

The marine environment has its own acoustic peculiarities (Wenz, 1962) and cetaceans are extraordinarily well adapted to them. In these mammals, acoustic communication and perception have acquired a privileged role compared with other sensory modalities. Marine mammals are acoustic specialists; they depend on sound for their life (*e.g.* communicating, navigating, finding food and mates, detecting predators and threats), and the anthropogenic noise may have an impact on several of their behaviours, including feeding and environment sensing (Clark and Ellison, 2004; Aguilar de Soto *et al.*, 2006). Although the long-term impacts on marine mammals from increased noise are not yet known with certainty, increased noise besides producing disturbance and stress, limits an animal's ability to hear, communicate and echolocate, and therefore may have serious implications for reproduction and survival.

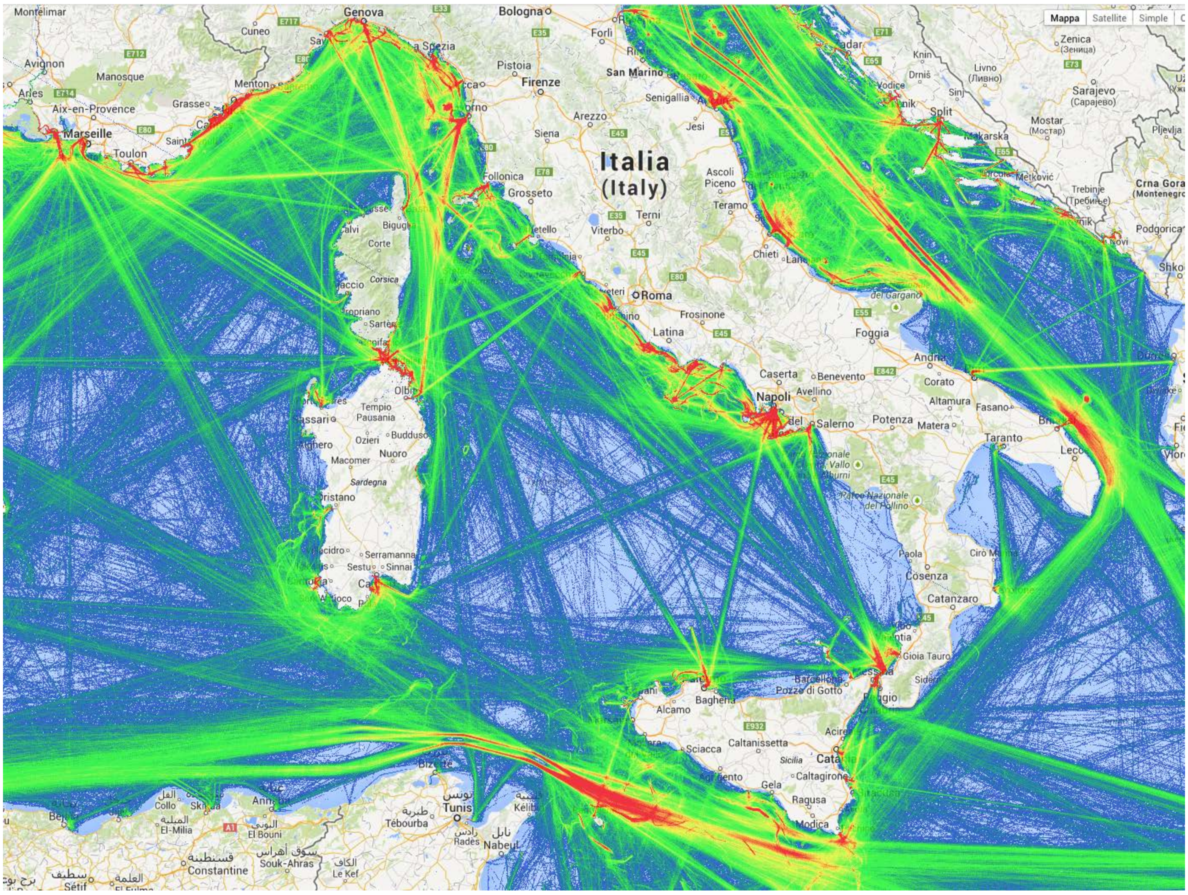

Figure 1. Map of ship traffic density around Italy (www.marinetraffic.com)

The large scale monitoring of ships' emitted noise is required to model noise diffusion, to assess the impact on the underwater environment, and to develop suitable strategies for the spatio-temporal management of underwater noise (McCarthy, 2004; Agardy *et al.*, 2007; Weilgart, 2007; Pavan, 2007, 2008). Ship noise impacts can then be reduced by lowering the noise emitted by engines and propellers, and eventually by modifying ship routes to avoid sensitive areas such as breeding grounds, feeding grounds, and migratory corridors (Pavan, 2008).

NOISE MONITORING PROJECTS IN ITALIAN SEAS

Within the framework of the Marine Strategy Framework Directive (MSFD 2008/56/EC), which identifies noise as one of the elements (Descriptor 11) to evaluate the state of the marine environment, several research projects on underwater acoustics are being developed in Italy. Among them, the collaboration between INFN, INGV, University Roma 1 and Roma 3, and the CIBRA University of Pavia, within projects KM3NeT, ESMO and SMO (Riccobene *et al.*, 2012; Favali *et al.*, 2013), has a number of perspectives: to study the population of cetaceans in the area, monitor underwater noise, initiate studies on the possible acoustic detection of neutrinos, and study possible connections between geophysical signals and acoustic signals in tsunamigenic events.

The acoustic sensors available on the underwater infrastructures allow the real-time monitoring of a wide range of frequencies, up to over 70 kHz, useful for the detection of communication and echolocation signals of marine mammals. In the station of Catania, EMSO-SN1, a specific sensor for low frequencies located at 2000 m depth, 25 km off Catania, allows monitoring in the band 1-1000 Hz for the study of seismic signals, the detection of infrasonic signals of whales, and the measure of shipping noise with tracking of the sources by AIS (Automatic Identification System) to assess source levels (Riccobene *et al.*, 2012; Pulvirenti *et al.*, 2014; Sciacca *et al.*, 2014).

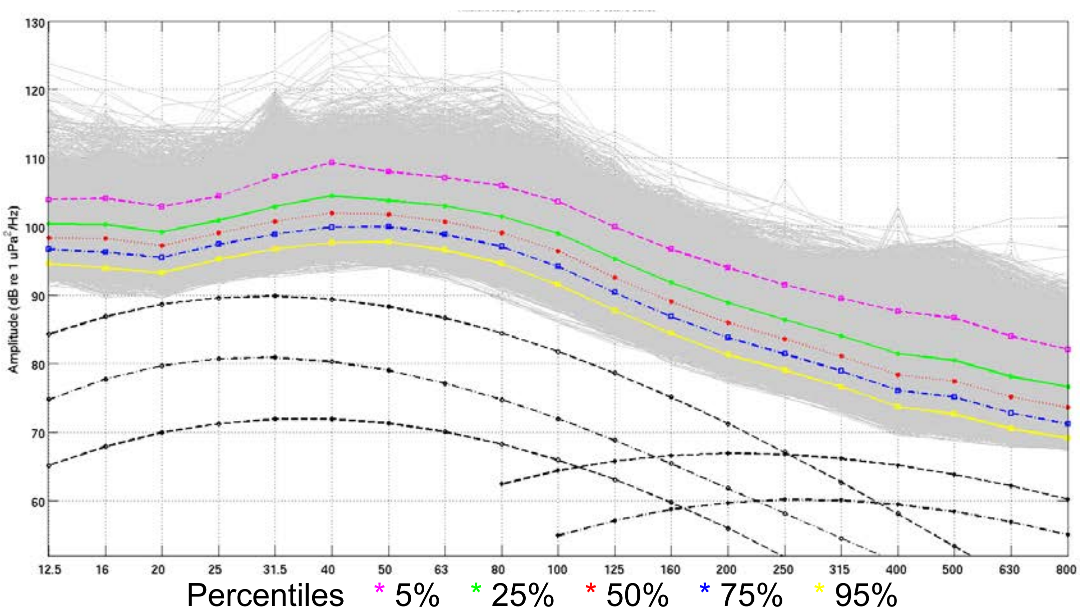

Figure 2 – The grey traces show all the spectra recorded by the SN1 station (Adapted from Pulvirenti *et al.*, 2014); the black lines show the Wenz curve for ship noise (left) and for wind noise (right)

Studies made with the EMSO-SN1 revealed the presence of fin whales in the Gulf of Catania and also an unexpected high level of ship noise, with average levels exceeding 100 dB and with peak levels, measured at 2000m depth, largely exceeding 120 dB (Figure 2) during the passage of the noisiest ships (Pulvirenti *et al.*, 2014). Such amount of noise completely masks communication sounds emitted by fin whales (Figures 3 & 4), with an impact on their communication system but also a strong impact on our ability to detect them and thus with a severe limitation for the study of their presence, distribution, and density (Sciacca *et al.*, 2014; Sciacca *et al.*, in press).

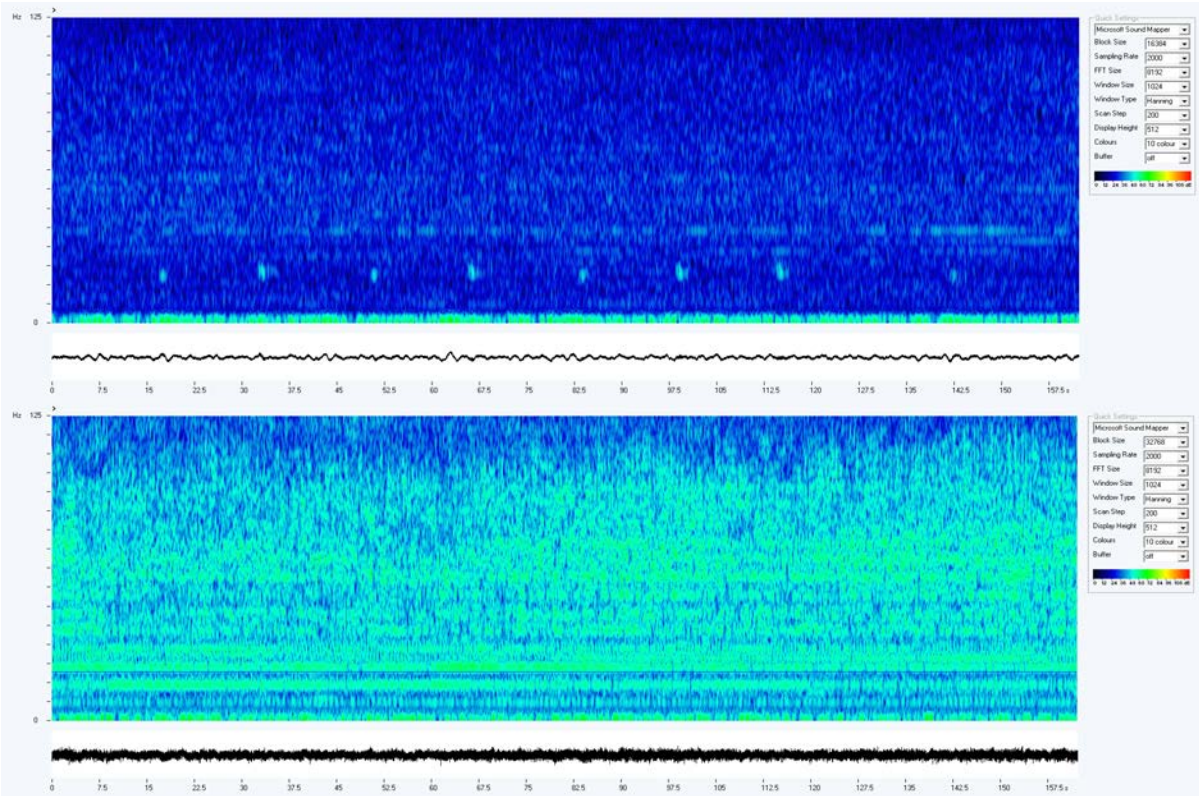

Figure 3. Spectrogram of fin whale vocalisations in quiet period (top); the bottom spectrogram shows the noise of a passing ship that completely masks any whale vocalisation (x-axis 160 s, y-axis 0-125 Hz)

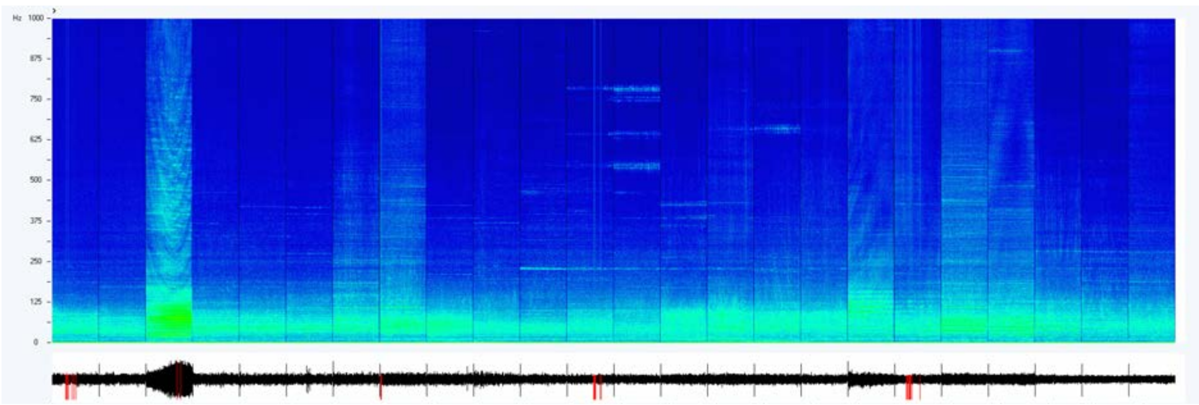

Figure 4. Spectrogram of ten frames, 10 min each, of recording made by EMSO-SN1 25 km off the port of Catania (y-axis 0-1kHz)

Monitoring ship noise helps to provide long-term statistics on levels and spectral structures, while the concurrent recording of AIS (Automatic

Identification System) allows the identification and tracking of ships in transit, responsible for the noise recorded by the sensor, to assess source levels, and estimate the contribution to background noise in the frequency bands used by baleen whales to communicate.

This part of the project allows an evaluation of low frequency noise due to vessel traffic and will produce the noise statistics required for the assessment of the environmental status of our seas in agreement with the Marine Strategy Framework Directive, as well as a model of the masking of fin whale sounds.

In order to correctly assess the impact of ship noise on large areas, it is required to model the long-range propagation of noise from single sources as well as the long-range interaction of multiple sound fields.

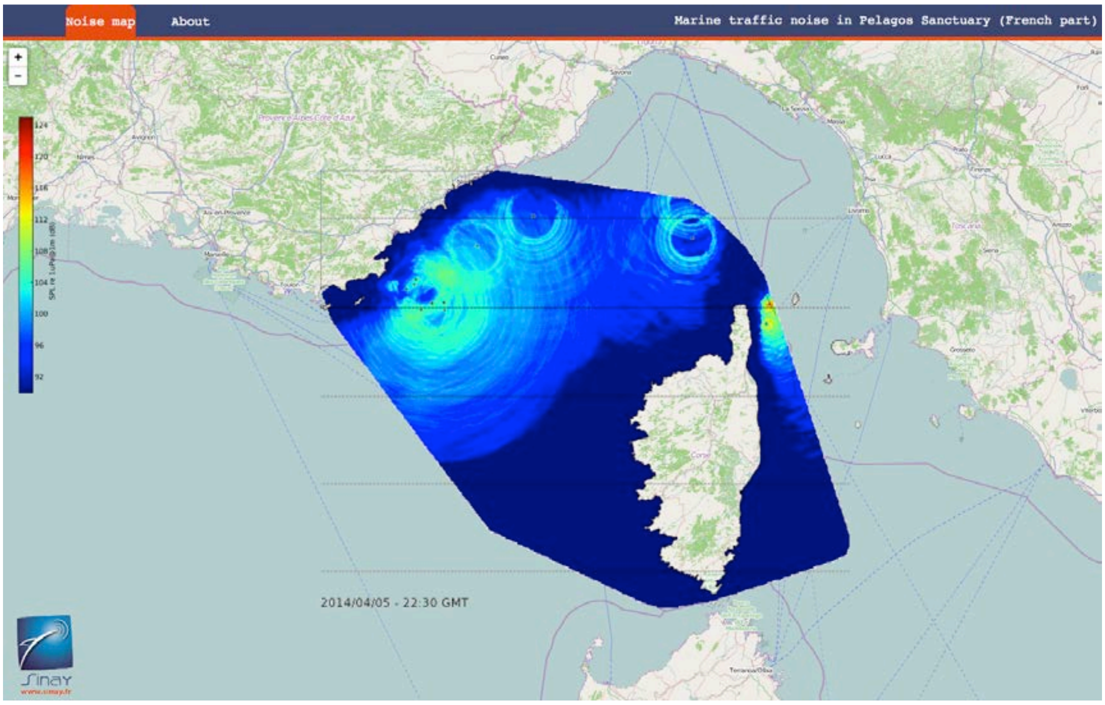

Figure 5. Online map of noise according to a model fed in real-time by ships tracked with AIS (Automatic Identification System) (www.oceannoisemap.com)

In the Pelagos Sanctuary (Ligurian Sea), and in the English Channel, a pilot model shows in real-time, on a public web page (www.oceannoisemap.com), the noise fields generated by ships tracked by AIS (Maglio *et al.*, 2014); every ten minutes, ships transiting the area are detected and, on the basis of their speed and category models, the noise spreading around is mapped according to the local propagation models. The model uses the sound pressure and spectral distribution of the sources obtained from measurements made on ships representative of different categories; however, the model can be gradually improved thanks to the measures obtained from the platform EMSO-SN1 that identifies each transiting ship to estimate its source parameters. Through the model, it is also possible to simulate different scenarios, such as redistributing the ship routes, as well as the noise abatement resulting from the possible application of ship quieting technologies, as suggested by the IMO (International Maritime Organisation).

Last but not least, organisations related to the Italian stranding network are developing protocols for the study of the hearing organs of stranded animals to possibly assess their integrity or reveal damage related to noise exposures. This type of information, along usual strandings data, are then collected and made available on the online Italian strandings data bank (mammiferimarini.unipv.it) created by the University of Pavia and the Natural History Museum of Milan on behalf of the Italian Ministry of the Environment.

WAY AHEAD

Whereas most interest in anthropogenic sounds has focused on marine mammals and a few other vertebrates (sea turtles), there is an increasing concern regarding the impact of such sounds on fishes and marine invertebrates (McCauley *et al.*, 2003; Popper *et al.*, 2004). Until now, this issue has only been addressed on a limited scale; moreover, ecological and ethical concerns are rarely expressed and no mitigation procedures are required so far. The effects of various types of sound (*e.g.*, impulsive vs. continuous) and long-term impacts of how anthropogenic sounds affect the behaviour and ecology of fishes need exploration in the immediate future. This issue will need further research, which should also take into consideration the ecological direct and indirect effects on the entire food web and on fisheries.

Acoustic impacts on the marine environment need to be addressed through a comprehensive and transparent research, management and regulatory system that includes all sources of noise, whether continuous and ubiquitous (such as shipping) or localised in space and time (sonars, seismic surveys, offshore and coastal construction works, scientific experiments, etc). This system should address chronic and acute anthropogenic noise, long-term and short-term effects, cumulative and synergistic effects, and impacts on individuals and populations.

THE « ACOUSTIC HABITAT»

Within the framework of the noise issue, the biology of “disturbance” and the effects of noise on the life history of marine mammals and their prey need to be improved and expanded.

Independent of species, what emerges from recent advances is that individuals and therefore populations rely on an “acoustic habitat” for establishing and maintaining normal communication and an efficient sensing of the environment; when their acoustic habitat is degraded, acoustic communication and acoustic sensing are degraded. This then leads to the concept of an “acoustic ecology” and of an “acoustic landscape” within which the acoustic communication functions properly and without which the social system can become dysfunctional.

In other words, each species has its specific “acoustic niche” within a larger “acoustic habitat”; by analogy with the terrestrial environment, each species needs its own level of “acoustic comfort” to behave according to its own evolution path.

Acoustic ecology research leads to the conclusion that there are costs associated with the loss of acoustic habitat (*e.g.*, in the reduction of feeding efficiency, mating success, predator avoidance), and these costs can affect primarily individuals and then populations.

It is likely that for a broad range of marine mammals, acoustic masking is having an increasingly prevalent impact on acoustic information transfer including both communication and other key activities such as navigation and prey/predator detection. In an evolutionary time frame relevant to species adaptations, the impacts generated by human activities are both quite recent and relatively rapid.

CONCLUSIONS

The growing focus on the noise issue, at the institutional level, which in Europe is essentially related to the Marine Strategy Framework Directive, is leading to the development of specific strategies for the monitoring of underwater noise and for the monitoring and reduction of noise sources.

In this last area, the awareness that shipping noise is a continuous and ubiquitous phenomenon has led the IMO (International Maritime Organisation) to produce recommendations and guidelines for reducing ship noise by recommending manufacturers to adopt appropriate implementation of quieting solutions and shipping companies to adopt specific maintenance plans (MEPC66/17, 2013).

The implementation of long-term monitoring and research plans based on a stable European infrastructure allows for a multidisciplinary approach that is functional to the understanding of complex phenomena, such as noise pollution and the impact on marine life, that is conditioned by multiple direct and indirect anthropogenic pressures.

Support for research and for long-term monitoring plans, including the study of strandings, is therefore fully functional to the implementation of the Marine Strategy Framework Directive, the monitoring of the ecological effects of climate changes, and the monitoring and tuning of the strategies to preserve the marine environment.

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FROM FOOTPRINT PREDICTION TO RISK ASSESSMENT AND FOCUSED MITIGATION

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Modelling of construction or operational noise is often done without consideration of the existing ambient noise in the area of the project. Yet, a measure of ambient noise is particularly essential to quantify the noise footprint generated by the project, and especially for the assessment of both detectability and behavioural risks.

Statistical noise mapping can be used as a relevant tool to assess risks by providing an acoustic footprint. The noise footprint describes and quantifies an area for which an impact sound of interest is above the ambient noise. In other words, the acoustic footprint is the geographical area for which the sound of interest is above the baseline ambient noise level made of natural noise and anthropogenic noise arising from other activities.

This quantification can be done by means of acoustic modeling (Jensen *et al*., 2000) which allows mapping of the noise at basin scales. The benefits of noise mapping are that it describes actual received levels, taking account of the sound propagation properties of the local environment (Folegot, 2012). The footprints are obtained by comparing the noise of the project with the baseline ambient noise across the auditory bandwidth of the species (Southall *et al*., 2007). In order to take into account the uncertainties, a statistical approach to the modelling is relevant for an environmental impact assessment (EIA) study.

An illustration is given in Figure 1 where the emergence of the noise from a fictional piling activity above the baseline median noise is illustrated for the summer season, and for a specific auditory band. To achieve this quantification, two steps have been implemented:

1. The baseline statistical noise estimation;
2. The footprint noise estimation.

Baseline statistical noise mapping

The first step consists of mapping the baseline ambient noise from information about shipping taken from the Automated Information System network (AIS), and oceanographic data such as temperature, salinity, sea-state and bottom properties (Boyer *et al.*, 2004). To account for the variability, stochasticity and uncertainties of key physical and environmental parameters, a statistical approach based on Monte Carlo simulation (Robert and Casella, 2004) is proposed. In simple terms, this approach is based upon the concept of building up confidence in the result based on convergence over a suitable number of runs. The underlying procedure adopted in this study is to add randomly generated values, which are taken from within a certain level of variability from the mean values. This procedure is then iterated, giving rise to a number of sound fields equal to the number of runs/iterations. The probability of having a certain noise level for each location (longitude, latitude) on the map is then calculated based on all noise values obtained at that position, as a probability density function.

This approach has the advantage of capturing and estimating the sensitivity of the noise maps to both the variability and uncertainty inherent in input variables and gaps in knowledge. A number of snapshots of shipping activity and environmental situation can therefore be modelled and used to calculate the median values of noise at every given location. It corresponds to the level of sound that occurs 50% of the time, also called the 50^{th} percentile (Figure 1, left). A similar approach for each of the other percentiles gives a comprehensive characterisation of statistical noise. Although large variabilities from area to area are likely to be observed, the ambient noise from distant anthropogenic noise is usually described by the highest percentiles (say 25^{th} to 75^{th} percentiles – noise levels occurring 25 to 75% of the time), while local noise events are described in the smallest percentiles (say 1^{st} to 25^{th} percentile – noise levels occurring 1 to 25% of the time). The very large percentiles such as the 95^{th} and above percentiles usually describe natural noise.

The left-hand side of Figure 1 shows that the shipping route oriented North-East South-West, and the access to a main harbour located at 38°N and 13°30’E induce both noises that can be perceived at least half of the time.

Footprint noise mapping

The second step consists of mapping the footprints for frequency bands of interest. Indeed, the physical acoustic characterisation of the footprint represents the emergence of the broadband sound from the project above the broadband baseline noise. The perceived footprint for a given species represents the emergence of the perceived signal above the perceived ambient noise across the same band of hearing (Figure 1, right). The zone of audibility is therefore smaller than the acoustic broadband footprint. The generated footprint maps are obtained after integration on the frequencies of interest and integration of different oceanographic conditions (waves and surface roughness). The area is considered part of the noise footprint if, at this point, the median (or 50 percentile) seasonal project noise is greater than the median seasonal ambient noise.

On the right-hand side of Figure 1, the effects of bathymetry (shallow versus deep waters), the presence of islands, and the levels of the existing shipping noise determine the shape of the footprint.

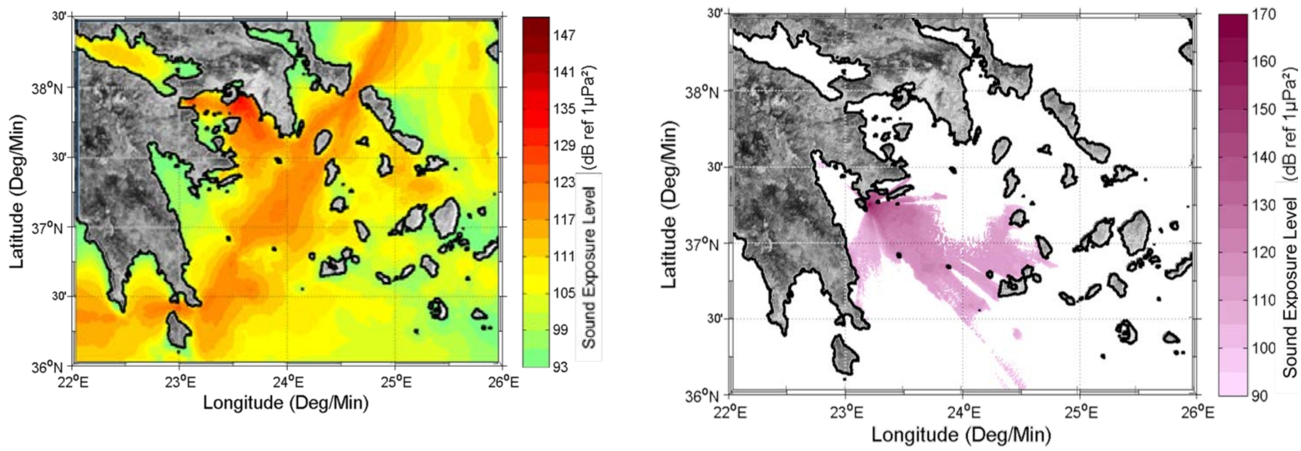

Figure 11: Concept of footprint: on the left-hand, the baseline median noise levels (50th percentile) induced by shipping are mapped for the summer season. On the right-hand, the map shows the emergence of the noise from a fictive piling activity above the baseline median noise. Both maps are done in a common auditory band.

Deriving risk assessment from footprint

The risks for physical injury can be inferred from the footprint by applying thresholds (Southall *et al*., 2007). However, the major benefit of the footprint assessment is that the areas of audibility and possible behavioural response are quantified.

The cumulative impacts for repetitive sounds (*e.g.* multiple strikes of a piling activity) are also quantified from the single sound footprint assessment, since the same area defines the geographical limits for cumulative effects from multiple strikes; if one strike does not add to the existing soundscape then multiple strikes will also not.

The benefits of deriving risks from the noise footprints are:

- ✓ They take into consideration the influence of existing noise generated by maritime activities not related to the project;
- ✓ They take into consideration the effect of the environment, in particular the effects of oceanography and bottom type;
- ✓ They assess the maximum area of cumulative impacts for multiple sounds, which is restricted within the limits of the footprint;
- ✓ They assess the area for cumulative sounds.

Strategic spatial planning for mitigation and monitoring strategies can also be derived from the mapping of the footprint which helps identify the noise and risk hot spots from the sound propagation properties of the local environment.

CONCLUSIONS

This paper presents a methodology for quantifying the auditory footprints of anthropogenic sounds arising from maritime projects, which gives a quantification of detectability. This quantification is done by the means of modelling, which allows a description of the noise at basin scales. The footprints are obtained by comparing the noise of the project with the baseline ambient noise across the auditory bandwidth of the species. By taking into consideration the influence of existing noise generated by maritime activities not related to the maritime project, and the effect of the environment, in particular the effects of oceanography and bottom type, the noise footprint is a decision aid to assess the maximum area of potential behavioural changes, and the maximum area of cumulative impacts.

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OCEAN NOISE: COMPOSING SOUNDSCAPES FROM REAL-TIME ACOUSTIC DATA STREAMS

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INTRODUCTION

For many reasons, evaluating the acoustic impact of artificial sound sources in the marine environment is a complex and expensive proposition. First, we face the relative lack of information on the sound-processing and analysis mechanisms in marine organisms. Although we are capable of cataloguing and recording the majority of these signals, we still do not know enough about the important role they play in the balance and development of populations. Second, the possible impact of sound emissions may not only concern auditory reception systems but might also interfere with other sensory and systemic levels, possibly challenging the life of the affected animal. Complicating the situation even more is the fact that a prolonged or punctual exposure to a determined noise can have negative short-, medium-, and long-term consequences not immediately detected by observers. The lack of provision and research resources contributes to the greatest difficulty in obtaining objective data that would allow the efficient control of anthropogenic noise in the ocean.

In addition, we find ourselves with a most pressing problem that relates to the standardisation of measurements. Until recently, there was no well-defined protocol for measuring marine acoustic pollution or any agreement on the enunciation of these measurements. Although the effects of noise on the marine environment are increasing, the variability of the available parameters to measure these effects leads to heterogeneous or fragmented results that appear of little use in orientating preventative and precise management actions.

The European Marine Strategy Framework Directive

Most studies lack information on the long-term effects of noise sources on specific populations. There are very few data on current ambient noise levels in most regions and even fewer historical data. Information on trends is not available either in European or International waters. According to the Marine Mammal Commission (2007), underwater ambient sound levels will increase over time with more human activity (shipping, offshore industrial construction and exploitation) in the marine environment.

Organisms that are exposed to sound can be adversely affected both on a short timescale (acute effect) and on a long timescale (permanent or chronic effects). These adverse effects can be widespread and the European Commission decided in September 2010, under the Marine Strategy

Framework Directive (MSFD) that two indicators for underwater noise be used in describing ocean Good Environmental Status (Van der Graaf *et al.*, 2012).

The first indicator refers to impulsive sound sources and the impact that it addresses is "considerable displacement", meaning a displacement of a significant proportion of individuals for a relevant time period and spatial scale. The indicator is addressing the cumulative impact of sound generating activities and possible associated displacement, rather than that of individual projects. This indicator is clearly a pressure indicator, and a possible future target would thus be in the form of a threshold of, or a trend in, the proportion of days when impulsive sounds occur and in their spatial distribution.

The second indicator concerns ambient noise, or continuous low frequency sounds, mostly referring to shipping noise, that should be measured at representative locations backed up by noise models that would strengthen the analysis by overcoming bias introduced by changes in human activities or by the natural variability of the environment and will extend the monitoring to poorly or uncovered areas.

These two indicators will enable European Member States to get an overview of the overall pressure from these sources, which has not been achieved previously. A necessary follow-up in future years would be to evaluate effects on biota and set targets and potentially take measures to reduce levels.

Marine invertebrates and sounds

Interestingly, most of the literature arising from noise effects on marine organisms concerns endangered species that use sound for daily activities. Less attention has been paid to commercial species, in particular invertebrates like cephalopods. Indeed, reliable data in this field is extremely limited and, in light of the scope and importance of ocean systems, urgently required. Furthermore, of the three main forms of life in the seas (mammals, fish and invertebrates), cephalopods represent the group about which the very least is understood. Situated as they are in the food chain between fish and marine mammals, they are also key bio-indicators for balance in the vast and complex marine ecosystem.

In fact, little is known about sound perception in invertebrates, but evidence points to the notion that cephalopods may be sensitive to low frequency sounds. All cephalopod species present statocysts in the cephalic cartilage region. Highly sophisticated structures, the statocysts are responsible for determining the position and balance of the animal, and are analogous to the vestibular system of vertebrates. These balloon-shaped structures present sensory hair cells, which line the inside wall of the inner sac and include two receptor systems: the macula-statolith system, which indicates changes in position according to gravity and linear acceleration, and the crista-cupula system which determines angular acceleration.

Although to date there is no definitive scientific evidence for it, statocysts may play an important additional role in low frequency sound reception. While there is uncertainty regarding the biological significance of particle motion sensitivity versus acoustic pressure, electrophysiological methods confirmed the species' sensitivity to frequencies under 400 Hz.

A recent series of experiments included the controlled exposure of four cephalopod species to a low-frequency sweep and revealed consequent noise-induced lesions (André *et al.*, 2011, Solé *et al.*, 2012, 2013). These were new to cephalopod pathology (Figure 1). Their presence in all the noise-exposed individuals (vs. their absence in controls) and their definite progression over time were consistent with the massive acoustic trauma observed in other species that were exposed to much higher intensities of sound, *e.g.* birds and terrestrial mammals.

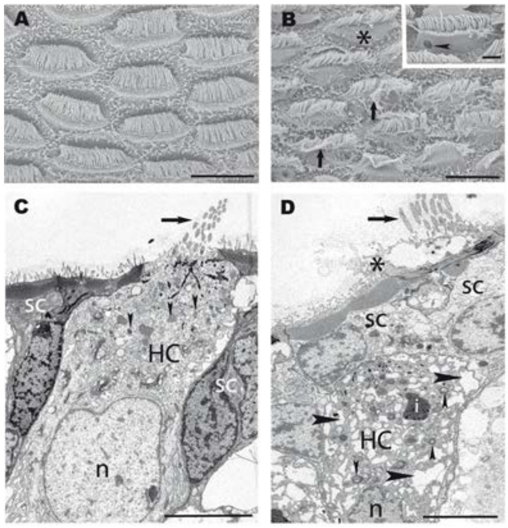

Figure 1. (A, B) Scanning electron microscope and (C, D) transmission electron microscope images of Sepia officinalis macula statica princeps. (A and C) Control specimens, not exposed to sound; (B and D) sound-exposed individuals (From André *et al*., 2011)

Why the relatively low levels of low frequency sound had caused such lesions in cephalopods demands further investigation. In particular, it will be critical to determine the mechanism onset of the acoustic trauma to definitively understand if these animals are more sensitive to particle motion or acoustic pressure, or to a combination of both. Future electrophysiological experiments coupled with postmortem imaging techniques are also underway to determine the tolerance-to-noise threshold of these species. However, the presence of lesions in the statocysts clearly points to the involvement of these structures in sound reception and perception. Given that low frequency noise levels in the oceans are on the increase (*e.g.* shipping, offshore industry, navy manoeuvres), that the role of cephalopods in marine ecosystems is only beginning to be understood, and that reliable bioacoustic data on invertebrates are scarce, such future studies have an important contribution to make to the sustainability of the marine environment. However, these results already indicate that the problem may run well beyond whales' and dolphins' sensitivity to noise. Some activities - airgun surveys, pile driving, sonar exercises, are the most prominent, clearly have the power and have shown to potentially harm a wide variety of species; but these laboratory findings introduce an additional question about whether other activities (*e.g.* shipping, fisheries and offshore operations) that are largely represented in the oceans and produce continuous low frequency sounds, are affecting the marine fauna. If relatively low received levels and short time exposure can induce acoustic trauma during CEE, the effects of similar noise sources on these species in natural conditions may already be considerable. Given that invertebrates are showing sensitivity to noise associated with such activities, we must ask whether noise, like other forms of pollution, is capable of affecting the entire web of ocean life.

Automated real-time noise measurement and monitoring of marine mammals

Long-term solutions to address noise issues will not come easily, but immediate mitigation actions exist and can be taken to control noise effects in areas where future noisy operations are scheduled, *e.g.* seismic surveys, construction, operation of windmills and navy manoeuvres. Often, the scarce governing law is tough in theory but weak in practice. Making the necessary improvements requires more scientific knowledge and political resolve than have yet been advanced. Furthermore, since the noise proliferation problem is global, it must ultimately be addressed on an international scale. We cannot pretend that an issue as complex as undersea noise pollution is resolved tomorrow. Yet now, significant progress is at least possible, before the problem of increasing noise pollution becomes intractable and its impacts irreversible.

Many cetacean species can be identified by their specific calls. The recording of these signature acoustic signals can reveal their presence in monitored areas. Since sound propagates efficiently in water, the detection range of these signals can be quite large, exceeding 100 km in favourable conditions for low-frequency calls (*e.g.* Stafford *et al.*, 1998, Sirovic *et al.*, 2007, Simard *et al.*, 2008), far above visual detection methods. This acoustic potential to non-intrusively detect and monitor cetacean species in their environment gave rise to passive acoustic monitoring (PAM) techniques, for which research is very active as revealed by the series of international workshops and conferences increasingly dedicated to this rapidly evolving field since 2003 (*e.g.* http://www.oceanoise2015.com). Advances in electronics, computers, and numerical analysis now make this PAM technology more accessible and affordable to small research budgets. Various systems have been used, including radio-linked systems, drifting buoys, and arrays of autonomous recorders for versatile and long-term deployments. The goal of such PAM systems is the continuous mapping of the presence and distribution of whales over ocean basins and assessing their densities, sometimes in quasi real-time. Their performance in effectively accomplishing these tasks depends on the characteristics of the targeted cetacean acoustic signals, the environment, the type of equipment used, its deployment and configuration. This performance may significantly vary from case to case. However, in any case, PAM's success first depends on the capacity to isolate the target signals from the rest of the sounds in which they are embedded, especially for distant sources and low signal to noise ratios (SNR). The acoustic signal source level, propagation loss, and local background noise levels determine detection ranges. Moreover, cetacean sounds vary considerably in time–frequency, from infrasonic calls of baleen whales to ultrasonic clicks of toothed whales, and in amplitudes among species and within a species' vocal repertoire. Ocean noise level also exhibits considerable variability in space and time, caused by fluctuating natural sources, such as wind, ice, rain, sounds produced by various organisms, and anthropogenic sources such as shipping. Sound speed structures over the water column can focus sounds from distant sources into sound channels. The 3D spatial arrangements of the sources and the hydrophones, their depth relative to the sound channel, are therefore relevant to the PAM configuration.

In addition to the development and broad use of PAM techniques, another challenge is to obtain long-term access to data for the assessment of the large-scale influence of artificial noise on marine organisms and ecosystems. Understanding the link between natural and anthropogenic acoustic processes is indeed essential to predict the magnitude and impact of future changes of the natural balance of the oceans. Deep-sea observatories have the potential to play a key role in the assessment and monitoring of these acoustic changes.

The Laboratory of Applied Bioacoustics (LAB) of the Technical University of Catalonia, BarcelonaTech (UPC) is currently leading an international programme entitled ''Listen to the Deep Ocean Environment (LIDO)'' to apply and extend developed techniques for passive acoustic monitoring to cabled deep sea platforms and moored stations. The software framework, called SONS-DCL, is currently active at the ANTARES (http://antares.in2p3.fr/) neutrino observatory, the OBSEA (http://www.obsea.es) shallow water test site, the NEPTUNE Canada (http://www.neptunecanada.ca/) observatory, the JAMSTEC (http://www.jamstec.go.jp/e/) network of underwater observatories, and at the NEMO (http://nemoweb.lns.infn.it/) site, as well as through a zero-cost contract with the CTBTO (Comprehensive Nuclear Test Ban Treaty) hydroacoustic stations. Part of the system was also tested for suitability on autonomous gliders in collaboration with the CMRE (NATO Undersea Research Centre) and on wavegliders (Jupiter Research Foundation) to track humpback whales. Applied solutions have also been deployed: in the Arctic in collaboration with STATOIL to measure and mitigate noise sources associated with Oil & Gas operations; in the Caribbean Sea to monitor cetacean populations (French Agency of Marine Protected Areas) through a partnership with Quiet-Oceans; as well as in the Amazon for the conservation of the boto (*Inia geoffrensis*) and tucuxi (*Sotalia fluviatalis*) with the Brazilian National Institute of Amazon Research (INPA, Manaus) and the Mamirauá Institute for Sustainable Development (Tefé). Recognising the technical advances of the software package has led to the creation of SONSETC (http://sonsetc.com), a spin off from the UPC, aimed at providing advanced sound solutions to the offshore industry, government bodies, port authorities, and engineering firms. The vision is to deliver solutions that far exceed current acoustic monitoring technology, increase and highlight the benefit of acoustic measurements, and accompany industries' concern for the marine environment.

The development and implementation of the real-time component of SONS-DCL in existing observatories has offered a unique opportunity to monitor noise at a spatial and temporal scale never before realised. Access to the continuous flow of data has allowed the development of an exclusive database of sound sources that are permanently updated and used to calibrate the algorithms. These are applicable to almost any scenario, sea state, geographic location and noise level.

The system can be implemented on cabled observatories, autonomous radio-linked buoys, moored antennas, autonomous vehicles (including gliders), towed arrays and, existing data sets.

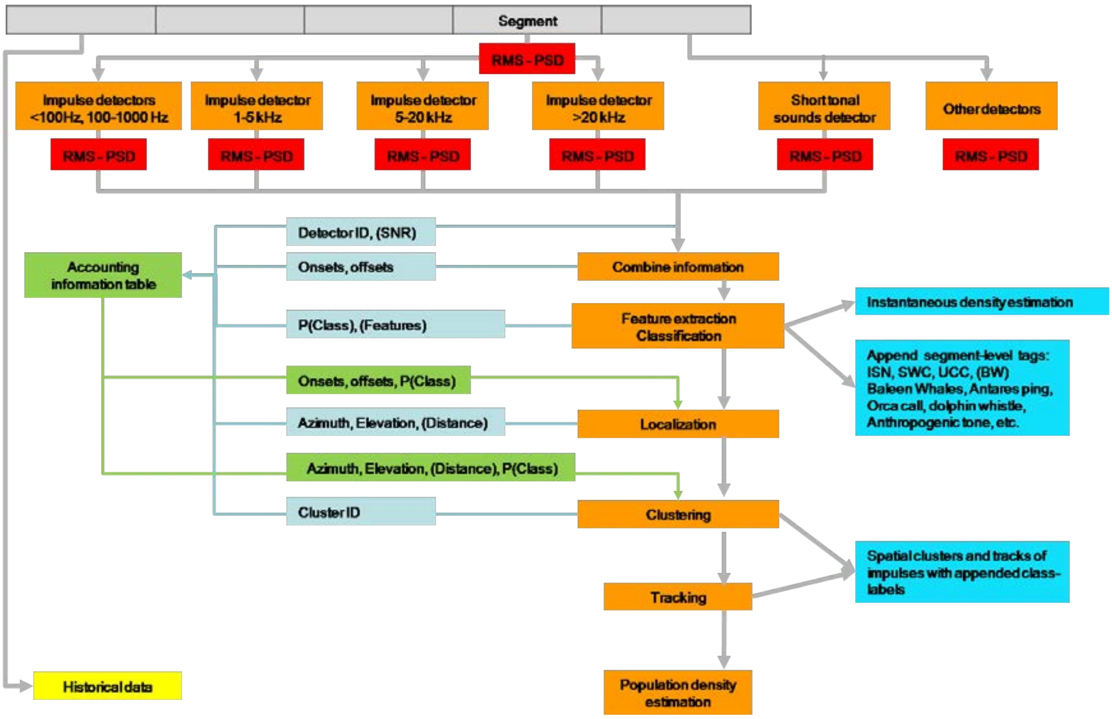

Figure 2. Overview of the SONS-DCL software package architecture

The software package contains several independent modules to process real-time data streams (Houégnigan *et al.*, 2010; André *et al.*, 2011; Zaugg *et al.*, 2010, 2011, 2012;). Among these, there are dedicated modules for noise assessment, detection, classification and localisation of acoustic events, including marine mammal and fish vocalisations (Figure 2). To summarise the LIDO system, it takes as input an acoustic data stream and produces as output the characterisation of the acoustic events that were detected in the data (written to an XML file), spectrograms for quick visualisation and compressed audio. These outputs are then made available on the Internet where they can be viewed with a specific application. A custom alert service is also available, warning the user of the presence of acoustically sensitive species in the area of activity. SONS-DCL is designed to be modular and dynamic (allowing the choice of detectors/classifiers), depending on the objectives and geographical areas. SONS-DCL is conceived for ease of operation (non-expert) and provides a monitoring system that automatically operates 24/7, without the need of post processing.

The public interface can be found at http://www.listentothedeep.com. It should be noted that the compressed audio is provided to allow users to listen to a sound stream with minimal bandwidth usage; but it is specifically not intended for scientific analysis. The raw data are optionally stored locally if there is an interest in subsequent research (Figure 3).

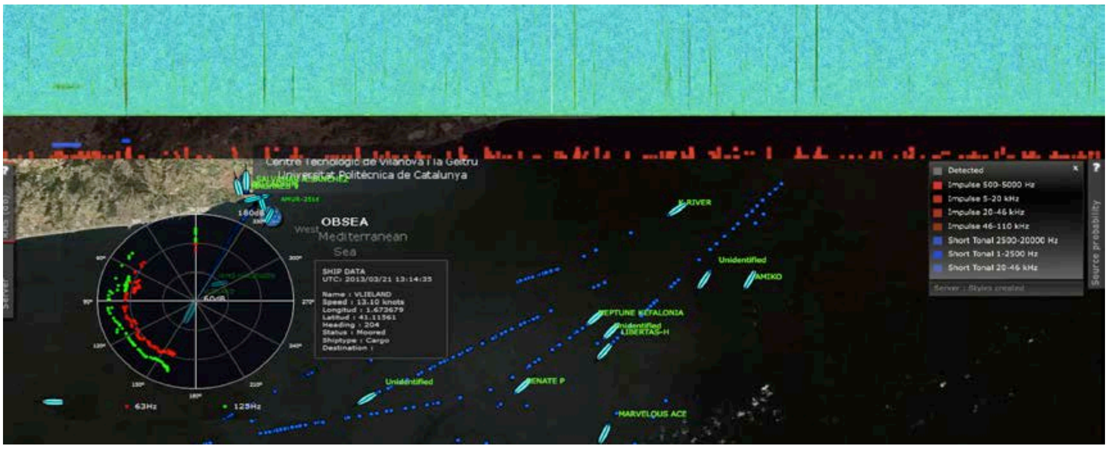

Figure 3. Screenshots of the SONS-DCL interface

The LIDO system provides a unique opportunity to improve understanding of marine noise, and by allowing open access to large series of data it helps reduce the cost of further research, as well as aids the design of protocols and optimises the analysis of results. By providing internet-based real-time feedback, LIDO is also capable of offering data on the steps taken to mitigate man-made noise. The technology has been adapted to offer internet-based tools to ocean users, such as oil and gas companies and windmill parks that are taking steps to reduce their noise output.

A recent partnership with Quiet-Oceans, the developer and owner of the software package QUONOPS (see Folegot and Clorennec, this volume) is now allowing access to acoustic maps that are built through the combination of environmental and anthropogenic parameters and the real-time feed from LIDO observatories that serve to calibrate the noise models and provide online soundscape maps (Figure 4). These maps can immediately be accessed through a specific application on mobile devices or desktops from anywhere in the world (Figure 5), thus allowing the online management of areas of interest, *e.g.* MPAs.

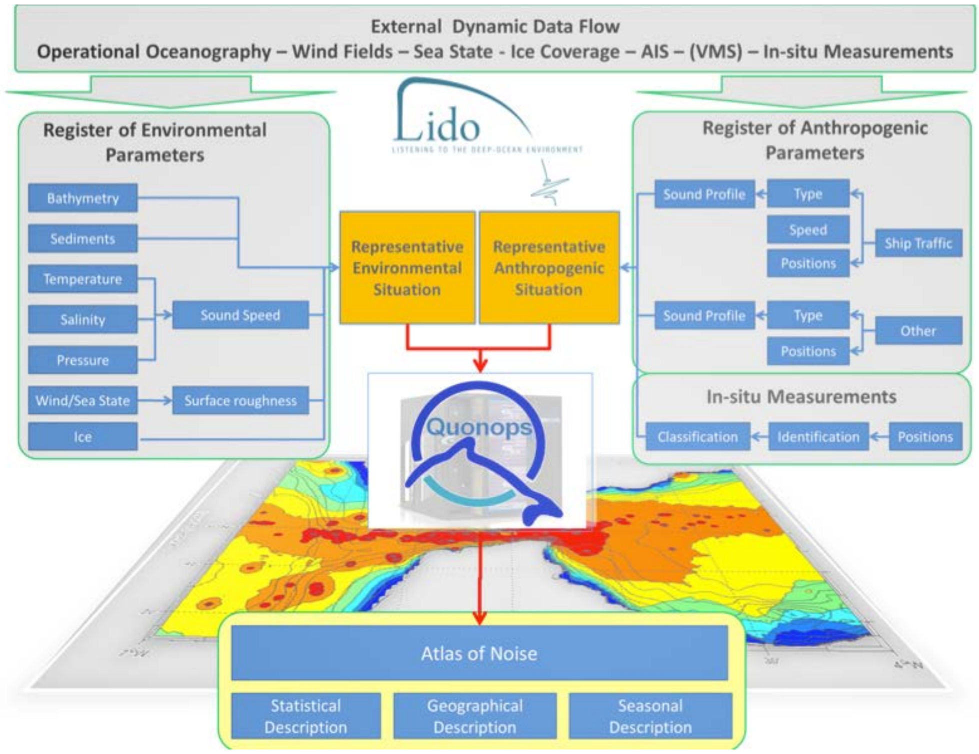

Figure 4. Architecture of the noise modelling provided by Quonops that is calibrated through the real-time feed from LIDO observatories

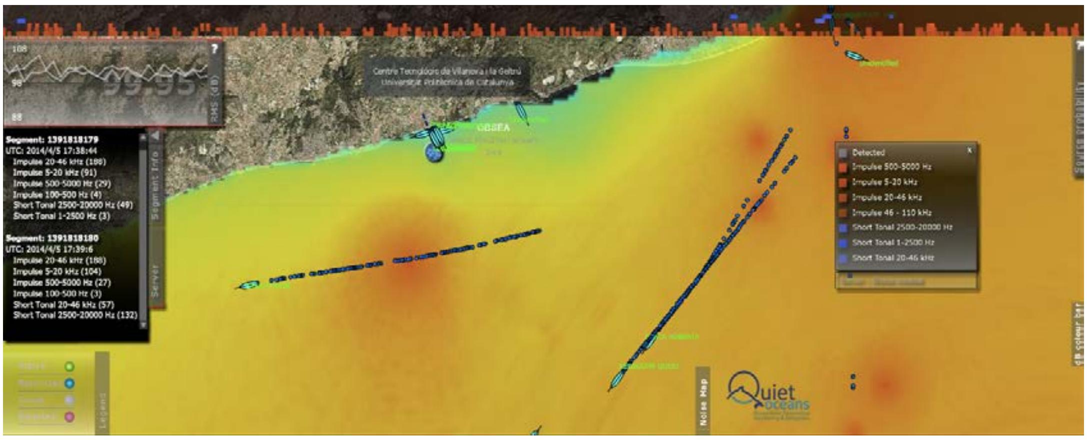

Figure 5. A noise map off Barcelona coast produced by SONS-DCL and Quonops

Because of this internet-based service and the considerable efforts made by LIDO to produce a user-friendly website (www.listentothedeep.com) that a non-expert can operate and understand, LIDO is now internationally recognised as a unique scientific resource. Its concept helps changing the way in which research on noise effects on the marine environment is conducted, not only by making such a large resource accessible to the scientific community at large, but also by providing all ocean users with a robust tool to mitigate noise effects.

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WORKSHOP SUMMARY, CONCLUSIONS & RECOMMENDATIONS

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Introductory remarks by Peter Evans highlighted the overlap in acoustic production spaces between different cetacean taxa and anthropogenic activities producing noise such as shipping, seismic surveys, and mid-frequency active (MFA) sonar, and introduced the context of theoretical zones of noise influence at increasing distances from the sound source (hearing loss, discomfort & injury, behavioural response, acoustic masking, and detection). He briefly described the information flow and decision pathways typically used in the risk assessment process, and then outlined the knowledge gaps in assessing population consequences of acoustic disturbance (PCAD model). Finally, he outlined the steps to be taken for a robust EIA under the headings baseline environmental and biological information, characterisation of proposed operations, impact monitoring, post-operation evaluation, and appropriate mitigation measures.

In the first themed session, Roger Gentry introduced the Noise Exposure Criteria that were developed by a United States NOAA expert panel and published in the journal, Aquatic Mammals, in 2007. He then outlined work being conducted since then to refine and update those noise exposure criteria, with subgroups established to address TTS/PTS onset and frequency weighting functions (for mid- and high-frequency species), behavioural reactions, and improved sound source characterisation and propagation, and several publications arising on each of these topics.

Tom Stringell then described the EIA process adopted in the UK from an advisory & regulatory perspective. This can be divided into the application stage (project initiation, screening, scoping, and submission of an environmental statement), consideration of the application (consultation, further information gathering, and review by the competent authority), and the consenting process involving implementation and monitoring of mitigation measures. A number of challenges for the process were considered, applied to the entire life of the project: 1) the problem of not having standardisation of metrics across projects; 2) how to assess impacts (e.g. displacement, injury, barrier effects) at the appropriate scale; 3) deciding thresholds of significance to populations and how to assess population level effects; 4) determining cumulative effects; and 5) developing appropriate mitigation measures.

Michael Jasny, representing advocacy, illustrated some of the deficiencies in the EIA process with examples from the United States experience. He emphasised the need to include all potential impacts (including sub-lethal ones like masking), and to be conservative when accounting for uncertainty and sensitivity in impact models. Programmatic EIAs were to be encouraged, as was the use of proxies in cumulative impact analyses, whilst the necessity for monitoring and mitigation beyond the safety zone (time/area management, noise quieting technologies) was emphasised.

Frank Thomsen concluded the session with a review of the EIA process from an industry perspective. He summarised the operational, social/political, environmental and regulatory risks, emphasising the lack of comprehensive planning tools, the uncertainty about sound effects, and determining what is effective mitigation. In order to reduce conflicts between industries and marine life, he recommended better use of already existing EIA processes, an urgent need for a better earlier planning process facilitated by authorities (SEA or Strategic Environmental Assessment), better use of science as a tool for marine spatial planning, acknowledgement of the role that industry can play to fund research on sound effects, and better use of agreed guidelines for EIAs to further reduce risks.

The second session examined specific anthropogenic activities and summarised our current knowledge of their impacts on marine mammals. Roger Gentry started by presenting some of the results of the Joint Industry Program on Sound & Marine Life funded largely by companies that are members of the Oil & Gas Producers Association. These included measurements of airgun output at different frequencies, experimental determination of TTS in dolphins and arctic seals, and a five-year behavioural response study of humpbacks to a moving airgun array, ramp-up and hard-start.

Monika Dyndo reviewed the effects of shipping noise, highlighting the fact that it was the dominant source of low frequency underwater noise globally, and that there had been an estimated 15 dB increase between 1964 and 2004. Recently, however, it has also been demonstrated that there is a high frequency (up to 160 kHz) component to ship noise. Results were presented of an experimental study of harbour porpoises demonstrating a reaction to low levels (123 dB re 1 μPa, M-weighted) of high frequency vessel continuous noise.

Jonas Teilmann & Jakob Tougaard outlined the development in global offshore wind energy, and listed the requirements to assess impacts on individuals and populations from pile driving as: 1) information on construction activities (size of piles, source levels, number of strikes and their duration, other sources of noise); 2) complete knowledge of the impacted area (nature of the seabed and acoustic properties of the water); 3) spatial and temporal density of animals (including consideration of population structure); and 4) PTS/TTS thresholds and behavioural responses of all of the marine mammal species present. They then presented an individual based population model for porpoises in Inner Danish waters to evaluate the influence of various disturbance scenarios and thus better assess cumulative effects. A recommendation was made for universal criteria for assessing impacts, and in the decision process for what can be regarded as unacceptable.

Peter Tyack introduced current knowledge of the potential impacts of mid-frequency (2-10 kHz) active sonar as used during naval exercises nine of which in the last 15 years have been associated with mass strandings involving mainly beaked whale species. Experimental behavioural studies have demonstrated unusually long surfacing intervals, unusually straight courses, increased speed, reduced clicking and direct avoidance by Cuvier's beaked whales in response to both simulated and real sonar exposure. Premature cessation of foraging clicks were recorded in both Cuvier's and Blainville's beaked whales at received levels varying as low as 97-102 dB re 1μPa (rms broadband). Studies of this nature on a range of odontocete species were used to develop multi-species exposure-response functions.

The third session included presentations from a number of research projects contributing to noise monitoring and mitigation methods. Elke Burkhardt gave a brief demonstration of a ship-based infrared method used to more effectively detect whale blows so that appropriate mitigation measures could be implemented. The method performed well at ranges up to c. 5 km in cold environments (up to 20 degrees C), in low visibility (particularly night-time), and high sea states (at least up to Beaufort 7).

Jakob Tougaard introduced the BIAS programme – Baltic Sea Information about the Acoustic Soundscape. The aim of this project was to establish a baseline for underwater noise in the Baltic for a uniform implementation of descriptor 11 (i.e. average noise levels at 63 and 125 Hz centre frequencies) of MSFD in the region, developing a data platform for the Baltic and appropriate analysis tools. Two acoustic loggers fulfilled the criteria: DSG-OCEAN by Loggerhead Instruments and SM2M by Wildlife Acoustics. Around forty stations were deployed, some close to shipping lanes to obtain source information, and others far from shipping lanes so as to estimate propagation loss.

Gianni Pavan reviewed noise studies in the Mediterranean, highlighting the significance of shipping as the dominant source of continuous ambient noise in the region. Measurements have been taken using cabled seafloor observatories (NEMO-KMS/SMO/EMSO). He demonstrated the impact of ship noise by showing how the noise of a passing ship completely masked any fin whale communicative sound, reducing its ability to communicate to just a few miles. Using a modelling approach, a real-time map of ship noise was presented based on AIS tracking of vessels (see www.oceannoisemap.com). The model, developed by SINAY (France) and MarSensing (Portugal) also allows one to simulate the benefits of quieting technologies and other noise reduction strategies.

Thomas Folegot showed how statistical noise mapping can be used as a relevant tool to assess risks by providing an acoustic footprint, illustrating this with seasonal maps to determine to what extent shipping noise exceeds other background noise. The benefits of noise mapping are that it describes actual received levels, taking account of the sound propagation properties of the local environment. It can be used to evaluate the probability to exceed noise exposure thresholds for PTS, TTS and behavioural responses by different species at a particular instant as well as cumulatively. From these, risks, mitigation & monitoring strategies can be developed.

Finally, Michel André demonstrated how soundscapes can be composed from real-time acoustic data streams and utilised as a risk management technique for implementing EIAs. He emphasised the uncertainties that exist within the noise issue: the species affected, behaviours concerned, sound characteristics, cumulative effects, and available tools for monitoring, mitigation, modelling, stranding response, and environmental impact assessment. Introducing the LIDO (Listening to the Deep-Ocean Environment) project, he showed the management benefits of real-time passive acoustic monitoring, measuring both local and global noise, mapping marine mammal distributions, and describing foraging behaviour (e.g. sperm whales in the Ligurian Sea). It was noted that the software package SONS-DCL behind LIDO is readily available to interested parties and can be operated by a non-expert.

Each themed session was followed by a discussion involving all the workshop participants. From these, a number of key points were tabled, and this was followed by a more general discussion at the end. A number of important recommendations were made under the following headings:

1) *Baseline Environmental & Biological Information*

- Need to make better use of Strategic Environmental Assessments, with regular updates on the basis of new information; SEA's can help attract information and funding from a variety of sources besides government
- There is much scope for using predictive modelling to fill in gaps in our knowledge of species distributions, habitat usage, and potential impacts of anthropogenic activities
- There is a role for more real-time and predictive measurements of soundscapes
- The quality of existing EIAs is very variable both within countries and between; there is a need for improved standardisation and for continued revisions of the EU EIA Directive (Note: a revision of this Directive came into force on 15 May 2014)

2) *Characterisation of Proposed Operations*

- Source characterisation – pressure levels, energy levels, rise times, kurtosis, presence of harmonics, pulse repetition rates, total duration: all these need to be measured and those metrics need to be standardised
- A library of calibrated wave forms should therefore be established along with a library of ships and their noise characteristics
- Local sound propagation features need to be determined through noise measurement and modelling
- Potential cumulative effects (multiple stressors) need particular consideration

3) *Impact Monitoring*

- Direct noise measurements should be made in real time – with emphasis on received levels

- Visual detections of animals and their responses – need to assess how effective are MMOs, and consider possible use of observers on independent platforms
- Acoustic detections – role of towed PAM, fixed PAM systems, and D-tags should be considered; there is a need for hydrophones to be placed into the airgun streamer
- Other detection methods should be considered – infra-red, active acoustics, drones, gliders, telemetry
- During seismic surveys, there is a need for additional monitoring of cetacean behaviour when airguns are off
- Tags should provide more response data than simply visual observations alone
- Careful interpretation is needed of the results of behavioural response experiments including consideration of low sample sizes, the environmental & behavioural context, captive *vs* wild situation, actual *vs* simulated noise signals

4) *Post-Operation Evaluation*

- Continued monitoring of animals should take place through the lifetime of the project – measuring numbers, distribution and activities
- Environmental monitoring should also occur – soundscapes, other human activities, preferably with access to an online system to retrieve information in a timely fashion after the noise event
- Generally, a better feedback mechanism for impact evaluation should be established
- Post-operation evaluation needs to be taken into account by the regulators

5) *Mitigation measures*

A number of mitigation measures were identified that should be applied depending upon appropriate local circumstances:

- Quieting technologies – vibroseis, bubble curtains, insulation sleeves, and alternative foundations *e.g.* gravity bases
- Spatial and temporal displacement to minimise overlap of the conflicting activity and animals
- Operational shutdowns
- Ramp up
- Alerting or harassment devices
- Possible role of active noise control (*e.g.* stapedial reflex) in some species
- Some progress has been made on the first of the above proposed mitigation measures: IMO guidelines were issued earlier in 2014, encouraging technologies to reduce shipping noise, but there will be a need to optimise power output following cavitation reduction (so far, only cruise ship lines and Navies are prepared to do this); online real-time feedback to the bridge/ship's captain on noise levels has shown potential, as may labelling of 'quiet' ships; three marine vibrator prototypes are being built and will be tested in about one year's time;

costs for bubble curtains are currently very high but could be used in priority areas; potential use of gravity based devices for noise reduction
- Technological modifications to vessels need to take account of possible reductions in fuel efficiency, and whether reduction in vessel speed may actually generate greater rather than less noise (this could be tested remotely by using AIS to identify individual vessels alongside application of real-time received noise level measurements, but need to carefully consider local differences in the environment)
- If animals can be detected at a reasonable range from the noise source (for example, by infra-red, active acoustics, or PAM systems), one has the ability to temporarily shut down the operation; however, these methods can be expensive, for example an infra-red unit may cost 380,000 euros; nevertheless, it has proved very useful to alert human observers as a support detection mechanism, and its effectiveness can be increased with experience since the infra-red computer system is based upon learning
- It is important to use measures that mitigate noise and not solely injury.

In some countries (e.g. the UK), it is the developer who does the contracting for baseline surveys, impact monitoring, and preparing environment impact statements. A more independent system would be for developers to contribute to a central fund administered by the competent management authority, which then does the contracting.

PROGRAMME

[09:00-10:00 Closed Meeting of Joint ASCOBANS-ACCOBAMS Noise Working Group]

10:00-10:30 Registration

10:30-10:40 Introductory Remarks: Peter Evans

Common Issues for Environmental Impact Assessments:
baseline surveys, impact evaluation, general mitigation methods
(15-min talks, 5 mins for questions)

10:40-11:00 Updating Noise Exposure Criteria for Marine Mammals: Roger Gentry
11:00-11:20 Introduction to EIAs from regulatory perspective: Tom Stringell
11:20-11:40 Introduction to EIAs from advocacy perspective: Michael Jasny
11:40-12:00 Introduction to EIAs from industry perspective: Frank Thomsen

12:00-12:30 Discussion

12:30-13:30 *Lunch*

Impact Assessments for Specific Anthropogenic Activities
(15-min talks, 5 mins for questions)

13:30-13:50 Seismic: Roger Gentry
13:50-14:10 Shipping: Monika Dyndo
14:10-14:30 Pile driving: Jonas Teilmann
14:30-14:50 Sonar: Peter Tyack

14:50-15:30 Discussion

15:30-16:00 *Tea/Coffee Break*

Noise Studies contributing to EIA assessment
(15-min talks, 5 mins for questions)

16:00-15:10 Elke Burkhardt
16:10-16:30 Jakob Tougaard
16:30-16:50 Gianni Pavan
16:50-17:10 Thomas Folegot
17:10-17:30 Michel Andre

17:30-18:00 Discussion

18:00-18:30 General Discussion

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