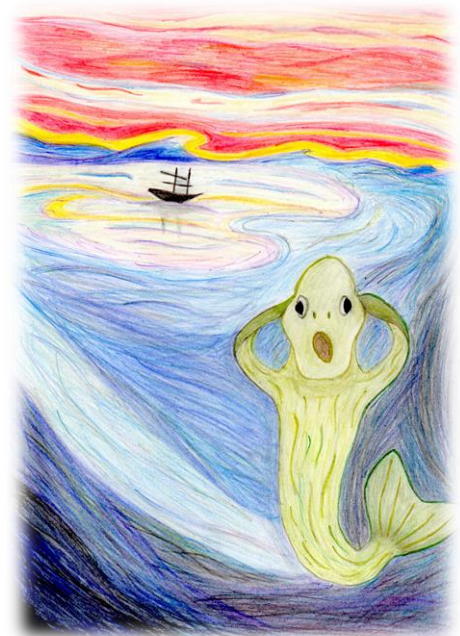


# RACKET IN THE OCEANS

## WHY UNDERWATER NOISE MATTERS, HOW TO MEASURE IT, AND HOW TO MANAGE IT

A position paper by the Observatory for responsible innovation  
(Institut Interdisciplinaire de l'Innovation – i3 UMR 9217)



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Observatoire de l'Innovation Responsable (Mines ParisTech)

**2017**

# Acknowledgements

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The Observatory for Responsible Innovation acknowledges the many contributors to this position paper<sup>1</sup>:

The working group (coordinated by Héloïse Berkowitz and Hervé Dumez), composed of Christian Audoly (DCNS), Eric Baudin (Bureau Veritas), Fabian Muniesa (Mines ParisTech, chairman of the Observatory), Aldo Napoli (Mines ParisTech), Céline Rousset (DCNS);

The participants to the Marine Sound series of workshops organized by the Observatory for Responsible Innovation, with special thanks to Michel André;

Michèle Breton (i3-CRG, École polytechnique, CNRS, Université Paris Saclay).

We also thank Bureau Veritas and Paris Sciences & Lettres (PSL) University for their contribution to the organization of the conference.

---

1 How to quote this position paper:  
Berkowitz Héloïse & Dumez Hervé [eds] (2017) *Racket in the oceans: why underwater noise matters, how to measure and how to manage it*. Paris: Observatory for Responsible Innovation / Palaiseau (France): i3-CRG (CNRS – École polytechnique).



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## FOREWORD: ADDRESSING OCEAN NOISE

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The range of visibility in the aquatic world is limited as a result of the attenuation of light in water. As a consequence, early aquatic animals have learned to use sounds to gather information on their environment. The evolution of an auditory system that can discriminate among sounds, determine the direction of a particular sound source, and detect it even when the environment is somewhat noisy, greatly increased the survival potential of those animals. Whether the most important function of hearing is communication or learning about surrounding environments, for example in order to detect preys or predators, sound is critical for most marine organisms. Anthropogenic sound sources have the potential to affect this channel of natural knowledge by masking the vital extraction of general information from the environment. Injuries, which could be defined as a temporary or permanent hearing impairment, have also been described in different marine taxa after exposure to noise. An important question is therefore whether the impact of anthropogenic sounds on marine animals is sufficiently serious to raise the concern of the scientific community and the public.

The data currently available suggest that such concern would indeed be justified.

Concerns about ocean noise were initially focused on the effects of artificial noises on marine mammals and later on fish. However, given marine invertebrates' capacity to use sounds to carry out most of their activities, recent findings on their sensitivity to noise has increased scientific alarm to the point of turning the issue of ocean noise into a problem to be dealt with at the scale of ecosystems. As a matter of fact, although a lot of effort has been made in the last two decades to reveal acoustic

trauma in mass stranded cetaceans, there is still no clear evidence of it, even when the stranding event was related to exposure to loud artificial sources. As we learn more about the effects of noise on other species, we may find that marine mammals do not primarily suffer from a direct exposure to sound on the short-term, but may be indirectly affected at population levels because of the impact of noise on their preys.

We may also witness changes in the behavior of major predators, such as sperm whales, which may choose to expose themselves to the intense acoustic energy derived from offshore operations after learning that squids potentially become debilitated by the noise those operations generate.

Despite the attention now widely paid to ocean noise issues, knowledge is still limited. Time, however, is running out for providing regulators with consensual data that would prompt limiting the impact of man-made sounds on marine ecosystems. Ocean noise actors, including industry, environmental agencies and NGOs, have the responsibility to learn from each other, put behind past obvious incompatibilities, and work together towards a responsible use of ocean resources.

Initiatives like "Racket in the Oceans" show the appropriate way of facilitating the necessary interchanges among ocean noise parties, with fundamental and applied science as the basis for seeking a balance between industrial and societal interests and wildlife conservation.



## EXECUTIVE SUMMARY

This position paper is devoted to the problem of anthropogenic noise in the oceans, and is addressed to public and private decision makers. Underwater noise is recognized as a major problem for life in the oceans, which represent 70% of the surface of the earth. We shall develop four key points:

1. Although there is no synthetic and general knowledge regarding the impact of noise on all marine species, there is by now a reliable and consistent body of evidence that the problem is far more serious than had been suspected, and that it deteriorates from year to year. When discussing the effects of underwater noise, we think immediately of marine mammals, like whales and dolphins, which strongly rely on sound to communicate, forage and orientate. Noise can disrupt behaviors such as feeding or breeding. We now also know that intense anthropogenic sources have the potential to cause cetacean strandings. But some fishes also communicate through sound and, can be therefore deeply disturbed by noise. Besides, studies have shown that animals that do not possess hearing organs, such as invertebrates, can also be permanently affected by exposure to noise, and eventually die as a consequence.
2. An indicator of noise disturbance is required to manage the problem. Though recognizing that there is no perfect measurement system, we must quickly establish a standardized, simple and reliable procedure. But while the European MSFD has provided Member States with guidelines on how to measure and report noise levels under Descriptor 11, there is so far no agreement on the noise disturbance indicators to be adopted. Uncertainties remain as to which species are affected in what circumstances and habitats, as well as concerning the role of specific sound source components in triggering damage to receptors.

3. Solutions to mitigate underwater noise from human activities are becoming available. Although all human activities at sea produce noise, it is generally agreed that shipping, Oil and Gas E&P, and renewable energy operations are primarily concerned.
4. The central question for public and private decision-makers is how to change quickly and adapt the behavior of industrial stakeholders so as to reduce underwater noise. Regulations are needed at the state level, at the level of port authorities, and of authorities managing marine protected areas. Incentives and subsidies are probably necessary to help industries evolve and adopt available techniques. Underwater noise is a complex management problem because of its scale and the multiplicity of concerned actors. We must share knowledge and information, and map areas in terms of noise. We must also create institutions that bring different stakeholders together and are capable of devising both long-term and real-time solutions.

The first part of this position paper develops these four points. The second part outlines the scientific knowledge we have about the effects of underwater noise, the problem of noise measurement, readily available techniques to reduce noise or its effects, and cases of regulation. It aims at sketching the problem as it is understood today, and at supporting the efforts to be done by managing properly the stakes.

This position paper is a collective work. We thank the members of the working group, Christian Audoly, Eric Baudin, Aldo Napoli, Céline Rousset, the co-organizers of the three workshops and the panelists of the conference held in Paris (20 September 2016), with a special mention to Michel André.



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# Introduction and synthesis

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# RACKET IN THE OCEANS

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Seen from space, the Earth offers the beautiful appearance that earned it the nickname “Blue Marble”. The oceans cover more than 70 percent of the Earth’s surface. For a long time, human beings deemed them too big and too deep to be impacted by their activities. We now know too well how untrue this is: from overfishing to acidification, plastic waste and harmful algal blooms, sustainable ocean management raises major issues related to climate change and pollution. Some of these topics, such as plastics or overfishing, have been given considerable media coverage. Others less so: that is the case of marine sound. And yet marine transportation, oil and gas exploration, and the exploitation of renewable marine energies generate a real racket in the oceans.

Scientists are beginning to better understand the extremely worrying impacts of marine sound on marine fauna. Animals that use sound to communicate underwater count among the first victims of noise pollution. Anthropogenic emissions directly affect them. Whale beach stranding constitutes only the most visible case. Indeed, as recently discovered (André *et al.*, 2011), even animals such as squids, which do not hear sounds as mammals do, can also be gravely touched. Effects are far-reaching on all marine life, from cetaceans to invertebrates and fish. Exposure of marine fauna to sound pollution results in a range of behavioral responses, physiological effects and physical injuries. It can also have ecological, population and cumulative effects, with dire consequences on the overall worldwide ecosystem. Too many simultaneous pressures, for instance overfishing and marine sound together, risk bringing about a tipping point where species disappear and whole ecosystems collapse.

Various attempts at reducing or at least taking into account underwater noise pollution have been already made. For instance, impact surveys are now obliged to address acoustic pollutions and their negative effects on species. Seasonal restrictions of economic activities aim to prevent sound from disturbing nesting periods. Exclusion zones have been defined, where no sound-intensive activity can occur at all. Existing legislation often requires Marine Mammal Observations (MMO), intended in particular to avoid vessel-whale collisions or ship strikes. Another required procedure, called soft-start, consists in slowly increasing the sound levels at the source. However, what happens if animals habituate to the noise and remain in the zone? Acoustic emissions will end up hurting them. Other regulations propose to establish noise level restriction, but that raises the problem of defining the restrictions. What is a good threshold? What about the case of multiple sound sources present in a given area?

To protect marine fauna from underwater noise pollution and preserve biodiversity, managers and decision makers need a certain number of capabilities to address such sound issues as behavioral response comprehension, noise measurement and prediction, or bio-sound detection. This situation contributes to the development of many new activities around sound, including measurement, modeling, signal processing, and impact assessment. These constitute both challenges and opportunities for marine industries, ocean conservation actors, and public decision makers.

This position paper aims at providing a synthetic view of the problem of underwater acoustic pollution and of ways to address it. It begins with a state-of-the-art of existing scientific knowledge about the

impact of noise on marine fauna. It then examines the complex technical question of noise measurement. Finally, it deals with potential solutions: from the technical to the managerial, some already exist, but putting them into practice remains difficult. Changing behavior or encouraging implementation can occur through financial incentives, regulation or nudge strategies.

With this position paper, we hope to raise awareness of the issue of underwater noise among public and private decision makers, and offer them information that can help them collectively design and implement solutions.

### **What do we know about the impact of noise on animals?**

Animals produce sounds or use sound features to communicate, recognize each other, hunt, locate themselves and their congeners, navigate, and reproduce. (Wartzok & Ketten, 1999). Introducing in the ocean anthropic-originated sound, that is, *underwater acoustic pollution*, might therefore affect animals.

There is a worldwide reliable and consistent body of evidence about sound's effects on different species of marine fauna. Taken separately, these pieces of evidence may not seem worrisome; considered together, they show that acoustic pollution has to be taken seriously.

Scientists acknowledge the effect of underwater acoustic pollution on animals. We first think of marine mammal, but it has been demonstrated that other species are also affected, including fish like cod, which communicate while mating. Effects are even broader than one could imagine, since they can touch species such as invertebrates, which do not use sounds to communicate.

Scientists are also increasingly aware of the difficulties involved in understanding and evaluating the impact of marine sound on fauna, difficulties that are partly due to the very complexity of marine ecosystems themselves.

### ***A reliable and consistent body of evidence***

*"If you look at all the recent strandings incidents, about half a dozen, you see a good correspondence between a ship track and the timing of the strandings. And it is consistently beaked whales that is the species most affected", (Geotimes, 2003)*

Sound is a variation of pressure and thus it can potentially affect any living organism. Effects of underwater acoustic pollution range from behavioral perturbations to physical injuries or even the animal's death. Direct perturbations of the auditory system likely constitute the worst type of effect. However, exposure to underwater noise pollution can influence stress levels, as it was shown with beluga whales (Romano *et al.*, 2004).

There are four zones with different levels of impact on species:

- ✓ The zone of audibility, where animals can pick up anthropic underwater noise.
- ✓ The masking zone where noise actually interferes with an animal's use of sounds (to detect other animals, to interpret, to hunt, and so forth). Things happen here as when two human beings try to communicate while passing by a construction site: since their voices are masked by the construction's racket, it is difficult to hear one another.
- ✓ The responsiveness zone where sound directly affects the animal's behavior.
- ✓ The mortality or injury zone.

Impact studies have to take into account different parameters, such as animals moving and having different reactions depending on the context (they could be feeding, breeding, or socializing), on the characteristics of the water, and other factors. It is therefore difficult to isolate and identify effects and causality links, and that is why so many controlled experiments are needed, and controls of controls.

Underwater acoustics has two components: pressure and particle-motion. Marine mammals are sensitive to sound pressure due to their hearing apparatus, but most fishes and invertebrates are more sensitive to sound particle motion (Nedelec, Campbell, Radford, Simpson, & Merchant, 2016). Different species with varied

complex physiologies are affected very differently, and research has to be tailored accordingly.

What do we concretely know today about the relevant species?

- Mammals

The frequencies of sonar systems vary from very low (infrasonic) to extremely high (ultrasonic). Military uses of active sonar systems usually operate in a mid or low-frequency range of acoustic emission. These systems' potential danger became evident in 2000, after beach strandings of whales of four different species occurred in the Bahamas. Mid-frequency sonar was highly suspected of causing the strandings. The US Navy initially denied any responsibility, but it was clear the danger increased with growing source levels of active sonar and the use of lower frequencies.

After this incident, beaked whales nearly disappeared from the area. Researchers concluded that whales had either abandoned their habitat or died after the sonar event. Since then, similar mass strandings have been witnessed in the Canary Islands, Greece, Madeira, the U.S. Virgin Islands, Hawaii and other sites around the globe, each time concomitantly to major sonar uses. Direct causality has so far not been demonstrated, but the recurrence of simultaneous sonar use and strandings has raised suspicion.

One of the main obstacles to prove a causal link between sonar pulses and whale beach strandings is that the animal's ear, once outside of water, degrades very quickly. Thus, when scientists or experts arrive at the stranding site, it is generally too late to perform a necropsy, i.e. to examine the animal and determine the cause of death.

Nevertheless, in July 2016, the Ninth U.S. Circuit Court of Appeals ordered the US Navy to reduce the use of low-frequency

sonar in the Atlantic, Pacific and Indian Oceans and the Mediterranean Sea to protect mammals. This decision was made at a time when evidence increasingly shows that whales do respond to underwater noise.

Numerous at-sea experiments have shown how different range frequencies impact on different types of mammals, from cetaceans to pinnipeds (Curé *et al.*, 2012; Miller *et al.*, 2014). Whales strandings are only the most spectacular instance of a wide array of harmful effects. Underwater noise has been shown to disrupt feeding and other vital behavior, and to cause marine mammals to panic and flee, or, still worse, to remain and be physiologically affected.

More questions remain concerning the cumulative effects of different sources of noise on mammals.

- Invertebrates

About ten years ago for the first time, people witnessed giant squid strandings off the Spanish coast. At the time, scientists suspected that sonar pulses had injured the animals. As with mammals, however, hard evidence was lacking.

Laboratory experiments have now shown that low-frequency underwater emissions from human activities can indeed affect squid and other cephalopods (André *et al.*, 2011). Thus, the problem does not concern only whales and other marine mammals, which have been long considered vulnerable to acoustic emissions. It touches also invertebrates, a whole group of different marine species that, paradoxically, are not known to use sound for living.

Experimental research has examined the effects of low-frequency emissions exposure on 87 animals from four different invertebrate species: two of squid, one of octopus, and one of cuttlefish. The findings suggest that underwater noise pollution has much broader effects on marine life than

How do you study impacts of sound on mammals?

"You need a baseline which gives you the normal pattern behavior, within a particular functional context. Then you quantify the behavioral responses to anthropogenic noise. And finally you compare responses to a reference model of disturbed behavior". (Charlotte Curé, Workshop on Impacts, 10<sup>th</sup> of March, 2016)

anticipated, as it showed that individuals suffered massive acoustic trauma on their statocysts, which help them move, sometimes even followed by peripheral damage that made things worse over time.

This could certainly explain the death of the giant squids stranded in Spain: they could have been directly killed by sonar pulses; or perhaps their statocysts had been destroyed, could no longer orient themselves, and wandered to the surface, where the change of temperature killed them. There is little doubt now that marine invertebrates are sensitive to low frequency sounds, which may be linked to a combination of sound pressure and particle motion. At-sea experiments must be multiplied to determine thresholds of exposure duration, frequency, amplitude, and so forth. Given the experimental results already obtained, we must also inquire into the long-term impact of noise on invertebrates that cannot move away from sound and are therefore also likely to suffer directly from noise pollution.

- Fish

What do we know in this regard about fish? Does noise pollution affect them, or are they protected from its effects? There is less scientific knowledge about fish than about mammals, but the experiments that have been conducted reached disquieting conclusions. There have been studies on behavior response in the open ocean, but more lab work is needed. A recent survey demonstrated that marine renewable energy construction sound affects migratory fish routes (Gill, Bartlett, & Thomsen, 2012). It also suggests that when fish are close to construction sites, they display behavior responses to noise a few kilometers away and may be physiologically affected.

Research also shows that sound pressure variations affect swim bladder fish such as the Atlantic cod (Andersson, 2011). Interestingly, it also suggests that fish developed in a very different soundscape and have not adapted to a noisier ocean.

More knowledge is needed on topics such as the effects on migratory fish species of electromagnetic fields and sound emissions generated by marine renewable energy. It is necessary to link reactions, such as migratory fish changing route, to real long-term impact, on which data is still unfortunately lacking.

### *Cumulative dose effects and risks for ecosystems*

There are in the ocean multiple sources of sound, both from human activities, and from the natural and animal worlds. We should be concerned about the potential cumulative impact of noises. How do different sources interact and affect species? To answer this question, we need to understand how often a given habitat is exposed to each sound, to identify the effect of each separate sound, and to analyze the interactions of effects. Cumulative effects on one given species are difficult to quantify. Evaluating the effects on populations and then on ecosystems is a challenge for future

research. We already know about different risks for ecosystems, from sequential megafaunal<sup>1</sup> collapses to trophic cascade effects and tipping points.

#### *Sequential megafaunal collapse*

First of all, the pressure on whales constitutes a major concern. The decline of big whales due to industrial whale fishing has been shown to provoke a sequential megafaunal collapse, as killer whales move from feeding on whales, to seals, sea lions and sea otters (Springer *et al.*, 2003). Each population sequentially collapsed due to past industrial whaling. Effects of marine sound on large mammals can therefore have more far reaching consequences than now imagined.

“At the end of the day, we want to really find out what is going on and have sensible threshold. We have to discuss long-term consequences of the behavior changes”. (Frank Thomsen, Workshop on Impact, 10<sup>th</sup> of March, 2016)

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1 Relative to the megafauna, i.e. large animals of a given region or habitat.

### *Trophic cascade effects*

In addition, there can be trophic cascade effects on ecosystems (Estes, 2016). As was shown in the case of sea otters and kelp forests, the disappearance or decline of a keystone predator past a certain point can result in the collapse of a whole ecosystem (Estes, Tinker, Williams, & Doak, 1998). The combination of sound with the consequences of climate change and other anthropic impacts could heighten the probability of an ecosystem's collapse.

### *Tipping points and marine sound*

Finally, another type of risk threatens ecosystems. Increasing human activities can lead ecosystems to undergo a major shift in their composition (fauna, flora, etc.), known as "tipping point" (Hicks, Crowder, Graham, Kittinger, & Cornu, 2016). In that perspective, understanding the whole scope of the impact of human activities on ecosystems appears essential for ocean management. That includes the effects of marine sound.

It is essential to anticipate tipping points before they occur, especially by identifying factors that may aggravate human pressures (Hicks *et al.*, 2016). New oil and gas marine exploration technologies, which generate considerable noise pollution, could constitute such a factor. For instance, the seismic air gun was a huge improvement over what was used before. It constituted a technological advance, and was widely adopted; it is nonetheless far from innocuous, and can play a role in driving the ecosystem to a tipping point. Establishing such tipping points with regard to noise pollution requires in the first place measuring sound and its impacts on fauna.

"Cetaceans can adapt more easily. But the adaptation to noise may not be a solution. If they change their reproduction sound, is that enough? They try to change their sounds, but underwater noise pollution can still be physiologically impacting them. The plasticity of mammals' behaviors is not a satisfying answer. You cannot say that it solves the problem". (Patrick Miller, Workshop on Impact, 10<sup>th</sup> of March, 2016)

## **What is sound and how to measure it in ocean?**

### *Definition of underwater noise pollution*

Sound is characterized by:

- ✓ A source: type of acoustic emission, its nature and characteristics
- ✓ Propagation: how sound propagates in a given zone, and how it cumulates with other sources
- ✓ A receptor: the affected organism

Sound travels underwater approximately four times faster than in the air, and with less attenuation. In the oceans, multiple parameters can affect the emissions received by marine fauna. The source itself will variably impact receptors based on factors such as its frequency (high or low), duration, and intensity. The distance between source and receptor also plays a role, and the environment's characteristics with respect to salinity, temperature, depth, sea

bed and surface properties will affect sound propagation. What makes sound phenomena particularly complicated is that sound does not propagate uniformly in water. High frequency emissions seem to decline faster than low frequency ones. For instance a 100Hz acoustic emission can be detectable hundreds of kilometers away whereas a 100kHz will stop after a few kilometers (Marine Mammal Commission, 2007). Finally, in the ocean, sound can affect animals along the three dimensions, including depth, which results in a complex three-dimensional soundscape.

In the Descriptor 11 of the Marine Strategy Framework Directive, sound is characterized as:

1. Impulsive sound: loud, low and mid frequency sounds used for seismic surveys, piling, sonars, explosions
2. Continuous low frequency sound: ambient noise like commercial shipping



Natural oceanic sound sources include earthquakes, waves, rainfall, animal noises, and so forth. Anthropogenic activities such as shipping, seismic surveys, research activities, sonar, or exploitation of resources in the sea floor constitute sources of more or less strong noise. Even though measuring underwater noise pollution is difficult, the evidence shows that it has greatly increased in the past sixty years.

Indeed, developments such as the growing number of offshore extraction sites, the steady growth of worldwide maritime traffic and cruising ships, and the emergence of Renewable Marine Energies (RME), have drastically increased the anthropic pressures linked to noise.

Effective monitoring and modeling are needed to gather and analyze underwater noise data. The challenge is to collect accurate information from extreme locations, as well as to obtain information at low cost, and finally to identify temporal and spatial variability.

#### *Measuring sound to better evaluate, monitor and manage impacts*

A hydrophone placed underwater in the ocean measures an intricate chorus of sounds that mix geophony (natural noises) and biophony (sound emitted by living organisms), with the anthropogenic noise we are interested in. Measurements include everything. In the first place, therefore, specific signal processing is required in order to differentiate the sources of noise. The second step consists of mapping the noise in the maritime area of interest, taking into account the fact there may be strong variations from one location to another within the same zone. Since the long-term deployment of a large quantity of underwater sensors to establish these noise maps is not feasible, one must use techniques based on numerical methods, calibrated on the basis of in-situ experimental data. Post-processing includes performing time-domain statistics. This procedure, with which the environmental status for underwater noise in a specific maritime area can be assessed, has been demonstrated recently in the BIAS

European project. The last stage consists in analyzing the statistical noise maps through bioacoustics criteria for the marine species to be protected in the area of interest, as was done in the AQUO Project.

The above general considerations on measurement procedures should apply in particular for the three main industries or activities causing underwater noise, i.e. shipping, oil and gas, and marine renewables. For that purpose, it is indispensable to develop standardized methods, describe methods for measuring the level of various anthropogenic noise sources (e.g. ships, underwater air guns and pile driving), and characterize underwater sound in a given maritime area. The harmonization of the measurement methods used by different stakeholders is a primary condition for comparing data across locations and assessing its evolution over time. It is therefore essential to encourage the recently begun standardization effort in underwater acoustics at the international level.

Marine renewables that use pile driving during the construction phase constitute another major source of high noise pollution. The diversity of sources highlights the importance of measuring underwater noise and of standardizing noise measurement across industries.

- **Shipping**

Shipping is a major noise-generating industry. Two European research consortia have investigated this topic: AQUO (Achieve Quieter Ocean) and SONIC (Suppression Of underwater Noise Induced by Cavitation).

For a given vessel, two main categories are generally acknowledged as the main sources of underwater noise: propeller/thruster and machinery. Propeller or thruster noise comes mainly from cavitation. Within defined conditions, when the propeller rotates, localized pressure changes on the propeller blades create bubbles that may not only damage propeller blade surfaces, but also induce underwater noise. Studies on efficiency improvement often lead to design and operate close to cavitating conditions. Both approaches (gain on

efficiency and reduction of underwater noise) are to be addressed simultaneously.

Machinery noise and vibrations are also significant contributors to underwater pollution. The efforts that have already been made to cut them down so as to increase long-term machine reliability and comfort on board tend also to reduce the noise footprint of ships significantly.

Since weather and sea conditions can affect signals of hydrophones, measuring underwater noise footprint constitutes a challenge. It is therefore necessary to take that into account and to combine measurement and modeling. Such approach raises methodological issues concerning, for instance, decisions about how to quantify the noise contribution of a propeller. Determining shipping noise footprint in an area requires various kinds of information about a ship's location and characteristics (e.g. vessel type, size, speed, as well as propulsor type and actual loading). Presently, AIS gives a ship's location, but otherwise limited information; and some classification societies provide data on individual vessels.

On the whole, detailed underwater noise measurements on individual vessels remain insufficient. A larger database of reliable measurements of radiated noise from a variety of vessels of different types and sizes operating at different speeds would be needed to improve the models representing ships as underwater noise sources.

- Industrial activity, including Oil and gas

Along with naval sonar systems, the oil and gas industry is one of the main sources of underwater noise pollution. At the international level, much of the data on oil and gas noise measurement results from the Exploration and Production Marine Sound and Life Joint Industry Programme<sup>2</sup>. Reviews of existing papers and literature produced a first classification of sounds in

the oil and gas industry, from airgun uses to airborne sound pollution. For instance, an overflying aircraft generates underwater noise pollution by transmission through the interface between air and water. A major source of noise pollution, common to other industries such as marine renewables (offshore wind farms for instance) is construction (pile driving, vibration, general impact). Underwater noise from impact pile driving is impulsive in nature. It is believed that most of the noise created by an oil and gas platform does not come only from the operations (drilling or production), but also from sources located on the platform above water, such as power generation (Spence *et al.*, 2007, p. 26).

The use of explosives also has potential harmful impacts on animals within its range. Explosives are employed for several purposes in the oil and gas industry, for instance to decommission offshore structures, remove obstacles, or seismic exploration. In contrast to low explosives, high explosives have fast rates of detonation and thus create a sharp pressure impulse, a shock wave that travels in all directions; the oscillations of the gaseous bubble left behind by a detonation in turn generates a series of pulses (Wyatt, 2008).

In this industry, when the energy produced is exactly known, it is relatively easy to characterize noise sources. The task is more difficult in complex environments, where many sources of noise coexist and there is uncertainty about energy production.

- Diversity of methods and the need for standardization

Measurement involves different steps, including deploying sensors, pre-processing data sets, processing signals, aggregating data, specifying format for data integration into models, and more. These steps have to be standardized for measurements to be actually commensurable.

Establishing the same sound pressure level (SPL) at a given reference distance of the source (typically 1m) is a key step toward developing standardized measurement methods.

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2 The Joint Industry Programme, or JIP, was formed in 2005 by the Oil and Gas E&P industry to support research on the effect of sound on marine life generated the industry's activities.

The international standardization process has already started. A working group at ISO has been elaborating normative documents, one of which was published recently and others are pending. Covering the entire topic will nevertheless take long, beyond 2020. Member states need to work together and support development or implementation of standards for:

- ✓ Terminology
- ✓ Modeling
- ✓ Measurement
- ✓ Long-term monitoring

Future programs should help Member States and Regional Sea Conventions implement operational monitoring programs. Assessment and regulation must also be considered at a sea regional basis.

- **Noise footprint and mapping**

Based on these different criteria it is possible to define the noise footprint of human activities, especially by combining local measurements and statistical modeling.

There are many different sources of sound: from nature, from animals, from ships, from extraction activities, renewables infrastructures, etc. These have been analyzed, but one of the main conclusions today is that much more information is still needed. There are multiple characteristics to take into account, but we cannot possibly have models for every single type of ship, or even for all types of activities. Yet everyone wants more information, whether it is from the AIS, from the naval industry, or from self-measuring ships.

Mapping soundscapes is essential to evaluate impact on whole habitats and ecosystems, taking into account that there is never only one sound source, and that multiple sources combine, interact and evolve differently over time and space depending on water characteristics such as salinity and temperature, as well as on human activities (level of traffic).

## **A comprehensive approach to solutions**

What is already known about underwater noise pollution depicts a dreadful situation. However, solutions exist – though they obviously have a cost. To reduce acoustic pollution in the ocean, two options are possible and could be combined: deploying existing innovations, and changing actors' behaviors. One of the main obstacles is cost: we have to find a way to deal with the issue of noise without creating too heavy a burden on such essential economic activities as fishing, shipping, mining and oil exploration, or the exploitation of renewable marine energies.

There exist many diverse and innovative solutions to reduce, mitigate, manage and monitor marine sound. They range from technical mitigation innovations in pile driving or cavitation, to managerial tools based on sound mapping monitoring combined with suitable indicators and real time monitoring tools. The overall costs of implementing solutions based on new design requirements or special noise mitigation devices remain a real issue with regard to both financial and competitive advantages costs. Deployment also raises the problem of regulations and incentive.

### **Technical solutions**

Technical solutions exist in many sectors, from shipping to oil and gas or marine renewable. Some seek to reduce the sound generated by ships or pile driving. Such innovations include air bubble curtains to mitigate the propagation of underwater sounds, which are used mostly for pile driving, one of the main source of noise in marine renewable industry. In shipping, reducing cavitation drastically reduces sounds. The cost impact can be moderate if taken into account in when designing the boat.

It can also be envisaged to replace a vessel's propeller by a better one. Solutions dedicated to machinery are also likely to dim underwater-radiated noise and improve comfort on board.



Interesting alternative techniques are those that can reduce sound while improving effectiveness or performance. For instance, certain shipping paints reduce drag by enhancing hydrodynamics, and thereby better fuel efficiency or have antifouling effects; as a consequence, they may also reduce ships' sound radiation.

The IOGP E&P Marine Sound and Life JIP report proposes diverse methods as potential seismic source treatment, from air gun silencers to LACS systems (piston-type source excited via internal combustion) (Spence *et al.*, 2007). Marine Vibroseis methods may also work as a sound-reduction system. Marine Vibroseis consists in the suppression of unwanted higher-frequency components, which is expected to have less environmental impact than surveys using airgun arrays (LGL and MAI, 2011). However, there are no direct studies of the biological effects of Marine Vibroseis operations. Overall, alternative techniques in the oil and gas industry still have to be commercially tested and need to move beyond the "proof-of-concept" stage.

Passive Acoustic Monitoring Systems (PAMS) seem to be attracting consensus, except perhaps in some areas where specific species cannot be detected (a silent whale cannot be detected through passive acoustics). PAMS refer to using hydrophones, i.e. underwater microphones, to detect and monitor animals, usually vocalizing mammals. In contrast to animal scarer systems, sonars or pingers, such systems introduce no energy in the environment, but they are limited by the

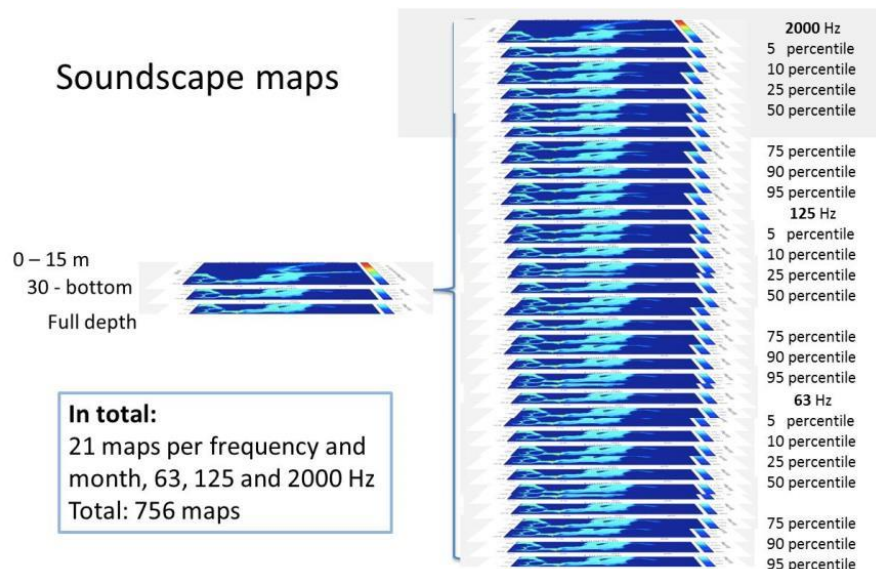
fact that they concern only marine mammals and not fishes or invertebrates.

There is therefore no one-size-fits-all solution. It is necessary to develop and deploy innovations, and to combine them in order to reduce sound at the source or mitigate its impacts on marine fauna.

### *Managing anthropic sound effects on animals*

So far most noise management devices have targeted marine mammals. For instance, Marine Mammal Observers (MMO) are one of the main managerial tools used during noise-producing activities, such as the construction of a platform. Protocols using MMO are generally deemed useful only in specific contexts; the tool has many limitations regarding distance of visibility, night-work, submersed passing animals, and other situations and phenomena. More precise decision-making tools are therefore required, especially to take into account effects on a broader range of marine life forms.

Raw sound data can be used to build soundscape mapping of the marine environment. Such maps can become a useful decision making tool in a context of high uncertainty. However, while visualization is helpful, it is not by itself a basis for making decisions, and must be combined with a quantification of noise levels and thresholds. For instance, showing the evolution of soundscapes in relation to ship speed reduction in a given area would help find the right thresholds for transportation.

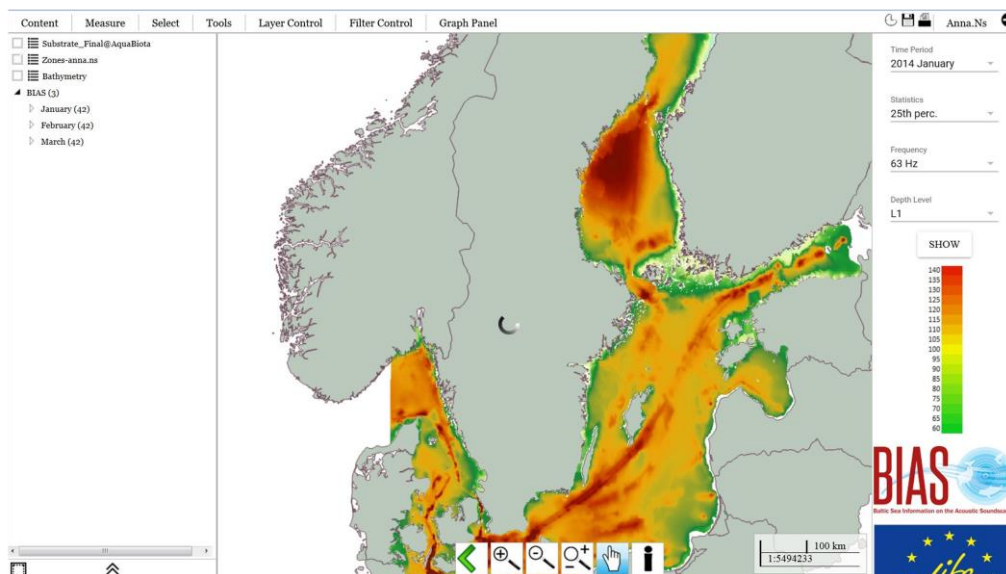


**Figure 1:** Constitution of soundscape maps (source: Peter Sigray, BIAS Team, "Baltic Information on the Acoustic Soundscape", Workshop 2, 02/09/16)

Thus, the BIAS project measured shipping noise for one year in 38 locations on the Baltic Sea. A large amount of data was produced, allowing soundscapes to be mapped (see Figure 1). The project resulted in the development of a GIS-based planning tool using in-situ observations and modeling, and resulting in soundscape mappings combined with maps of marine life. It thus became possible to focus on zones where cod is mating and to see how the cod area is affected by continuous zones.

Such tools allow managers to see the effects of increased or lower shipping noise pollution instantly.

Enhancing, developing and generalizing mapping tools to other regions and all forms of underwater noise pollution and species would certainly facilitate decision-making processes. This has been the goal-based approach of research consortia AQUO and SONIC, whose common guidelines are available online.



**Figure 2:** Soundscape in the Baltic Sea (source: Peter Sigray, BIAS Team, "Baltic Information on the Acoustic Soundscape", Workshop 2, 02/09/16)

### *Changing behaviors: regulation, financial incentives and nudge*

Most industries have already developed or employ technologies to reduce sound emissions or mitigate their effects. Shipping appears as a very innovative sector, but measures are still limited, largely due to implementation costs; these could be reduced if design were improved at an early stage of ship design. In renewable marine energies, innovations are already being implemented; feedback may give rise to further innovations. Regulation, especially in Germany and the Netherlands, seems to have been a strong driver in this process.

It appears that regulation does not follow innovation close enough, and that it therefore does not encourage enough the enforcement of underwater noise limitations. This might be linked to a lack of quantitative indicators and clear targets for environmental impact and surveillance, and probably reflects the difficulty, mentioned above, of obtaining reliable measurement.

The European Commission and the United States have already started to address the problem of marine sound. In the EU, the Marine Directive provides a legal framework for protecting the seas. Its overarching goal is to achieve by 2020 a “good environmental status” for EU’s Marine Waters. This label describes “the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive” (Marine Strategy Framework Directive, 2008 Art. 3(5)).

The pursuit of such goal has four main implications. First, it requires protecting marine ecosystems, that is to say, developing clean, healthy, productive seas that are fully functioning and resilient to human-induced environmental impacts. Second, it implies preventing the decline of biodiversity and guaranteeing that human-related substances and energy do not pollute the oceans. Third, it necessitates ensuring sustainable uses of EU marine resources and thus their continuity for future generations. And finally, it calls for

building common approaches and fostering cooperation at the EU and regional level.

While EU and US regulations have tackled some areas of marine sound, financial incentives could prove useful with regard to commercial fleets, as it is sometimes done in the car industry when bonuses are used to encourage buying new cars. Nudge strategies are also to be explored as ways to change behaviors, for instance by encouraging the use of antifouling paints that also reduce noise.

One could imagine a scenario with two different kinds of zones:

Protected zones, such as marine protected areas or opportunity sites, that is to say key marine habitats that are still free from noise pollution. As research already shows, it would be relatively easy to keep these zones quiet (Williams, Erbe, Ashe, & Clark, 2015).

Zones with high maritime traffic and industrial activities: making these noisy habitats quiet will be more complicated. For these zones, and for other areas where such activities are carried out, risk assessment will have to be based on population or habitat. Moreover, the development of adequate mitigation or monitoring systems and instruments will require differentiating among species and taking into account their particular behavioral responses.

One should reach out to both regulators and end-users (ship owners, oil and gas companies) to get them to collect data and generalize best practices, including technical innovations when they are cost-efficient. Collaborations between industry and public research will in this regard prove crucial for developing appropriate innovations, and for creating a framework for monitoring and enforcing, i.e. an adequate system of governance.

### **Governance Framework**

During the series of workshops on marine sound organized by the Observatory for Responsible Innovation, the governance mechanisms that will help articulate regional regulations into a more global

framework for marine sound emerged as a challenge of global scope.

Addressing underwater noise pollution raises three coordination issues. First, coordinating and connecting data at the global scale, i.e. integrating and taking advantage of big data. Second, coordinating knowledge about existing solutions across sectors. And finally, coordinating dialogues among regulators, economic actors and experts. In this section, we propose a governance framework to help integrate research efforts, industrial activity, and decision making.

### *Underwater Noise Data platform*

We identified the need for a collective data platform that would process and standardize sound data and provide it to end-users. Two paths seem viable:

creating a new data platform dedicated to sound related data drawn both from human activities and from animal and environment observations;

using the existing data platform of the Copernicus Marine Environment Monitoring Service (CMEMS), which is a system for monitoring the Earth. CMEMS consists in a complex set of systems that collect data from multiple sources (in-situ observations, satellites, earth observations, etc.) and then processes and standardizes it so as to provide it to end-users (Berkowitz & Herlem, 2015).

The goal of such a platform is to provide an inter-organizational space where different sectors and organizations (scientific or economic for instance) can bring data together to build a large-scale information system on marine sound. The platform would also offer a networking space where research projects and grant applications could be developed.

The workshops made clear that facing underwater noise requires more interdisciplinary collaboration; the above-mentioned platform would provide opportunities for it. In an initial stage, the platform could retrieve existing open data on underwater noise from industries such

as oil and gas (via the Exploration & Production Sound and Marine Life Joint Industry Programme), from research consortia (AQUO, SONIC), research centers, and other relevant institutions. It could also centralize new data-collection initiatives. The World Ocean Council seeks to launch a cross-industry initiative of that sort (Smart Ocean/Smart Industries), and the platform proposed here could provide end-users with such data.

The objective would be to centralize data produced by currently unrelated human activities (from earth observations to shipping) in order to address the questions of cumulative effects and tipping points.

### *Global governance device*

We also argue that more coordination is needed among actors. Conservation organizations and the business community should work together to design practices of environmental management that take both resource limitation and economic interests into account. The governance of heterogeneous organizations, with different agendas and interests, could take the form of a multi-stakeholder meta-organization (Berkowitz, Bucheli, & Dumez, 2016). Meta-organizations have been shown to facilitate dialogue among different actors, such as regulators, marine industries and research labs, and to facilitate the transfer of knowledge and innovation across sectors.

Due to large regional differences, managing underwater noise challenges requires a regional approach. For that reason we suggest the development of a global multi-stakeholder cross-sectoral meta-organization, with regional branches relying on UNEP regional sea program.

However, if the governance device is to be efficient and attractive for every stakeholder, it would also have to be cost-efficient and flexible, two characteristic features of meta-organizations. Such a governance device would foster self-regulation, enabling actors to collectively elaborate the rules best suited to each context, and to benefit from the strength of consensus-decision making processes.



## Conclusion

Even in the absence of a complete scientific picture of the range of its harmful effects, underwater noise pollution has emerged as a major environmental issue. Combined with other pressures, such as plastic discharge, acidification and overfishing, underwater noise pollution may contribute to serious regime shifts and ecosystems collapses.

What are the main challenges? Although progress has been made, more understanding is required in three main domains. First of all, we need more data on hazard identification and characterization (types of anthropogenic sound introduced into the marine environment and their key features). Second, we need more knowledge on the type of exposure (what are the patterns of habitat and sound distribution? what are the key areas of overlap between marine fauna and sound energy?). And finally, we need to better evaluate the response to sound of marine mammals and other animals. Difficulties nonetheless arise. The development and deployment of sensors is expensive, and their reliability can be questioned. They also raise energy efficiency issues. Innovative methodologies such as the use of passive acoustics could be an alternative for certain monitoring activities where sensors may replace radars. Combining measurement and modeling, in predictive models such as those developed in shipping is a fruitful alternative that should be developed and generalized across industries.

There are also management challenges to be faced, from developing and deploying decision-making tools to encouraging technical and technological innovations diffusion across industries. Current regulation requirements for sound producers are inconsistent, and current laws do not address specifically the noise produced by different industries such as oil & gas, commercial fisheries and aquaculture industries. The monitoring of effects and the control over compliance with mitigation measures are inadequate or even non-existing. There is no accounting for individually insignificant effects that may be

cumulatively significant. For all these reasons, there is a strong demand for an international cooperation that could take the form of a noise-dedicated multi-stakeholder meta-organization bringing together regulators, industries, experts and scientists.

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# Scientific, technical and managerial contributions

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# CONTRASTING WHALE BEHAVIORAL RESPONSES TO ANTHROPOGENIC NOISE AND PREDATOR PRESENTATIONS TO ASSESS BIOLOGICAL SIGNIFICANCE

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## Introduction

Underwater man-made noise has been recognized worldwide as a form of acoustic pollution for marine organisms, impacting both their physiology (e.g. hearing impairment, stress) and behavior (e.g. reduction of foraging effort, avoidance) (Southall *et al.* 2007). Marine mammals are considered a sentinel species to study effects of anthropogenic noise because i) they rely primary upon the acoustic channel to communicate, to search for food, to reproduce and to get information from their environment, and ii) they can vocalize and hear within the frequency range generated by anthropogenic sound sources (Nowacek *et al.* 2007).

Behavioral changes can have impacts on fitness of individuals that might further lead to consequences at the population level (New *et al.* 2014). For instance, a repeated and/or long-term alteration of whale foraging behavior in response to a given disturbance stimulus might lead the unhealthy animal to be more likely to die, or to not breed in a year it might otherwise have produced offspring. The development of new technologies such as multi-sensor tags that record different behavioral metrics (e.g. depth, acoustic recordings, heading) has provided the possibility to measure the behavior of free-ranging individual animals even the ones living under the sea surface like cetaceans (Johnson and Tyack 2003). Since then, it became possible to investigate the behavioral effects of anthropogenic noise on cetaceans by conducting controlled sound exposures, and quantifying the behavioral changes of the exposed tagged animals.

The basic recipe to experimentally investigate potential disturbance effects of a

given anthropogenic noise on the behavior of free-ranging animals has been based on the following: first, to characterize the normal behavioral pattern of animals (i.e. before any sound exposure) called “pre-exposure baseline behavior”; second, to expose the subject whale to a controlled dose of an acoustic stimulus and assess the behavioral changes in response to the stimulus. To do so, it is needed to choose and measure specific behavioral metrics that are relevant to the studied behavioral/functional context (e.g. a proxy for energy intake in a context of feeding). If comparing the behavior between baseline and sound exposure periods provides insights into the behavioral changes induced by the anthropogenic noise, the interpretation and biological significance of those responses can still be difficult to explain. A third ingredient can improve the recipe: comparing behavioral responses to the anthropogenic stimulus to a reference model indicating how animals react when they face a natural biological high-level disturbance stimulus (Curé *et al.* 2013, 2015). Reactions to an immediate predation risk can be such a good model (Frid & Dill 2002). Indeed, predator presence is a natural acute threat and is probably the highest level of disturbance animals can meet in natural conditions since it can lead for the animal prey to die. We expect that animal prey have evolved adaptive anti-predator response strategies that are biologically costly (altering fitness enhancing activities such as foraging), but that these responses had been selected through evolution because leading to the corresponding benefit of increased probability of survival (Lima & Dill 1990). Therefore, we expect anti-predator behaviors to be strong, clear, with a great potential to impact fitness of animals, and so

that they could be used as a 'yardstick' to assess the relative level of disturbance induced by anthropogenic stimuli.

The aim of this review paper was to illustrate such approach by investigating potential disturbance effects of naval sonar (3S project, Miller *et al.* 2012; Sivle *et al.* 2015) on the foraging behavior of two cetacean species in their feeding ground off the North Atlantic: the sperm whale (*Physeter macrocephalus*) and the humpback whale (*Megaptera novaeangliae*). Both species can be predated upon by the Killer whale (*Orcinus orca*) from which they can eavesdrop on calls allowing them to detect predator presence and to adopt an optimal strategy to get a chance to avoid predation (Curé *et al.* 2013, 2015). Therefore, sonar exposure and predator presentation were conducted and the measured behavioral responses of tagged whales were relatively compared to each other in order to index response to sonar to the expected high level of disturbance (template) in response to the predator.

## Methods

### General protocol

Experiments were conducted at summer time on sperm whales in 2008, 2009 and 2010 and in humpback whales in 2011 and 2012. Field work was conducted aboard a research vessel in the Norwegian waters. Briefly, the protocol comprised the following phases: 1) a tagging phase where a small motor boat was launched from the research vessel to attach a tag (DTAG, Johnson and Tyack 2003) on the animal by the mean of suction cups, 2) Baseline behavior data collection that started after at least 1h of recovery post-tagging period, 3) Sound and control exposures, 4) Detachment and recovery of the DTAG (programmed release). Full protocols are described in Miller *et al.* 2012, Sivle *et al.* 2015, and in Curé *et al.* 2012, 2013, 2015.

### Sonar exposures

Both species were tested with a hyperbolic upsweep sonar between 1 and 2 kHz (maximum source level of 214 dB re 1μPa m), and generated at a rate of 1s every 20 s

for at least 10min by a source towed by the research vessel and approaching the tagged animal. A no-sonar control exposure was also conducted to separate effects of sonar from effects of the approaching vessel and consisted of a silent approach of the source vessel in a similar way as for the sonar exposure but with no sonar transmission.

### Killer whale playbacks

Natural sound playbacks were performed from a dedicated motor boat launched from the research vessel. Sounds were played back at roughly 800m from the tagged whale using a player and amplifier connected to a Lubell speaker deployed in the water. In order to induce anti-predator responses, we aimed at simulating predator presence as much naturally as possible. Since killer whales are highly vocal species, we decided to simulate their presence by playing natural sequences of previously recorded mammal-feeding killer whale sounds (KW stimulus). We played also a broadband noise (CTRL stimulus) as a negative control to ensure animals specifically respond to the killer whale sounds and not to any sound generated by the playback system. Both playback stimuli had a frequency band of 0.5–20 kHz, an average rms source level of 150 dB re 1μPa m and lasted 15 min duration.

### Measure of the behavioral response

Since both species were in a context of foraging, we focused on investigating a potential alteration of whale feeding behavior in response to the sound exposures. Sperm whales perform long deep foraging dives while producing loud echolocation clicks to localize their prey and emit buzzes once the prey is about to be captured. Humpbacks' lunge-feeding is characterized by a strong increase of speed before engulfing a large volume of prey-laden water followed by a decrease of speed, which can be identified by a specific acoustic signature of the flow noise recorded on the DTAG (Sivle *et al.* 2015). To contrast the changes of foraging behavior to naval sonar to the anti-predator template, we focused on the production of regular clicks and buzzes (foraging sounds) while

conducting deep foraging dives (depth >100 m) for the sperm whale, and on the occurrence of lunge events during the feeding dives (depth >10 m) for the humpback whale. Foraging cues (regular clicks and buzzes for sperm whales, lunge events for humpbacks) were identified on the spectrogram of the acoustic recording made by the hydrophones of the DTAG. We used the depth sensor of the tags to investigate potential changes in max depth and dive duration of the foraging dives.

## Results

### *Responses to sonar*

Three out of 4 sperm whales that were exposed to the 1-2 kHz sonar signal interrupted feeding activity which was indicated by a decrease in the production of clicking and buzzing as well as a switch to shallower and shorter dives compared to baseline (Sivle *et al.* 2012; Isojunno *et al.* 2016).

In 10 out of 11 sonar trials conducted on the six humpback whales that were feeding prior to the exposure, all but one induced a cessation of feeding which was indicated by a significant reduction in lunge rate and a decrease of max depth and dive duration (Figure 1; Sivle *et al.* 2015; Sivle *et al.* in revision).

### *Responses to killer whale playback*

Three out of 4 sperm whales that were feeding prior to the KW playback stopped their foraging dive and returned prematurely to the surface. Five out of 5 humpbacks stopped lunging during the KW playback. This result was shown in sperm whale by a strong reduction of production of regular click and buzz together with significantly shorter and shallower dives (Curé *et al.* 2013), and in humpbacks by a cessation of lunging along with shorter and shallower dives compared to the period preceding the exposure (Figure 1; Curé *et al.* 2015).

### *Responses to the controls*

For both species, no alteration of foraging (no change in the dive profile or in the

production of acoustic foraging cues) was observed in response to the no-sonar control and to the CTRL playback.

## Discussion

Whales ceased feeding in response to the predator presentation. As expected, the responses were strong, clear and highly consistent among individuals within species and could be used as a behavioral template of high level behavioral disturbance in order to relatively compare other potential disturbance stimuli such as naval sonar exposure. Similar cessation of feeding was also elicited in response to the 1-2 kHz naval sonar.

Other behavioral metrics such as social behavior and horizontal avoidance could be investigated to build a broader picture of the response and to index level of disturbance for each category of behavioral parameter (Curé *et al.* in press). Moreover, we know that animal behavioral responses in general may vary according to other factors such as body condition, gender, age, behavioral state (breeding/foraging/migrating), group composition and environmental factors such as availability of refuge, etc (Wartzok *et al.* 2003; Curé *et al.* 2015). Therefore, the anti-predator template and responses to anthropogenic stimuli must be compared as much as possible within a similar context.

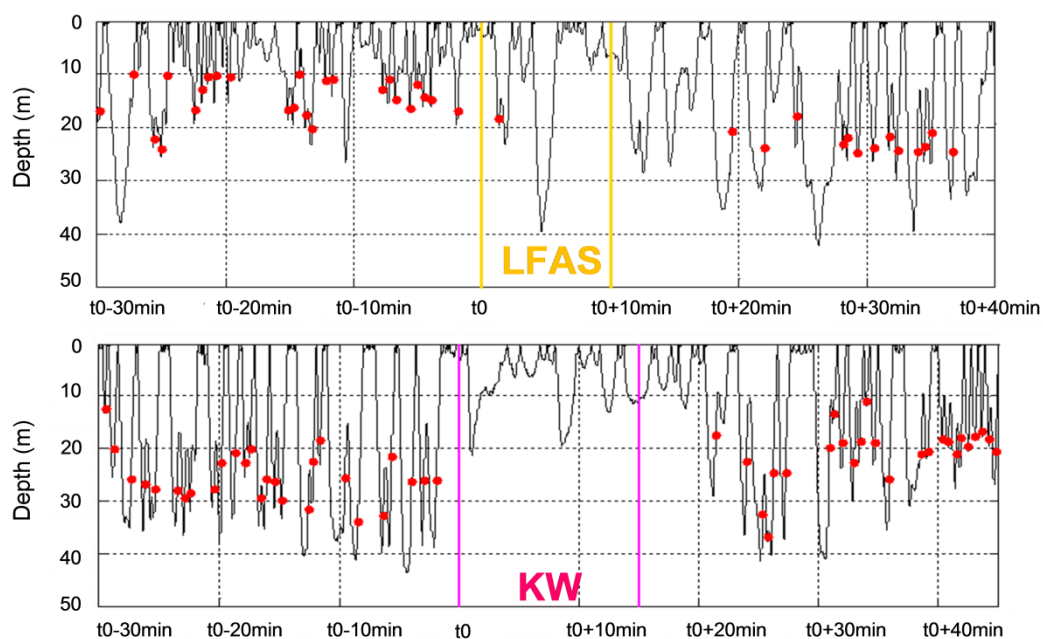
The current study has shown that behavioral responses to playback of predator sounds can be an effective high-level disturbance template to assess the biological significance of responses to anthropogenic disturbances. Specifically, we have shown that in the sperm whale and the humpback whale, the disturbance of foraging behavior induced by naval sonar may be as severe as the one induced by an acute predation risk and are therefore expected to be costly responses. Ultimately, the degree to which such responses lead to declines in health of an individual depend crucially upon how often the animals are exposed to the disturbance, and their ability to compensate for declines in health from the disturbance (i.e by feeding more).

## Conclusion

Facing the urgent need to quantify and interpret the effects of anthropogenic noise on cetaceans, this study provide an interesting approach for guiding predictions of highly sensitive species and for helping in interpreting behavioral responses to potential disturbance stimuli in order to further establish well balanced mitigation and management decisions (Frid & Dill 2002, Sih 2013).

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**Figure 1:** example of cessation of feeding in the tagged humpback whale mn12\_171ab in response to 1-2 kHz sonar (LFAS, delimited with yellow vertical bars) and to killer whale sounds playback (KW, magenta bars). The dive profile is represented along with indication of feeding (lunge) events (red dots). *t0: start of exposure*





# HIGH PERFORMANCE MODELING OF THE PROPAGATION OF BIOLOGICAL SOUNDS IN THE OCEAN: NEW NUMERICAL TOOLS IN THE STUDY OF CETACEANS

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## Introduction

The conservation of cetaceans has been a major environmental concern for the last 50 years. Indeed, the population of most large whales probably went down to the verge of extinction during the XX<sup>th</sup> century (*Handbook of the mammals of the world*, vol. 4), due to non-sustainable whaling. Since then, new dangers are arising for large and small cetaceans, such as the general level of man-made noise in the oceans (see *Boyd et al. 2011*, for an international quiet ocean experiment).

One of the first and the most difficult task for cetaceans preservation is to estimate their actual number (see for instance *Branch et al., 2004* for the difficulty of estimating whales population). To be able to decide on conservation measures, it is most important to be able to evaluate their effects, and thus the potential recovery of the species.

Passive acoustic monitoring has been increasingly used to estimate cetaceans populations (*Mc Donald and Fox, 1999*). However, distance evaluation is necessary to make population estimation (see distance sampling methods, *Marques et al. 2013*). This is easily done with an array of hydrophones, by time delay of arrival computation (*Giraudet et al., 2008*) or matched-field processing (*Kuperman et al., 2004*). However, installing an array of hydrophones means complicated field work that is not always possible. Although it is rather common for measures with towed hydrophones, for small cetaceans for instance, it remains difficult for fixed instruments and large wavelength measurements.

In this study, we propose to build a tool for the localization of a sound-emitting whale with only one hydrophone, which will be a very new and useful system for the community. Our method has been tested only on artificial simulation as far, but a run of in-situ observations in January will allow us to test it on real data, and to have a ground truth validation of our work.

## General idea of the method

A fixed hydrophone is a common tool for oceanographers and biologists studying whales: it is not expensive, and it allows long term survey of acoustical signals. However, it has not been possible until now to recover the emitters' position with only one hydrophone. We propose a new idea to reach this goal: to use the information we have concerning the bathymetry, the sound velocity variation, the ground's properties, etc. The assumption is that the whale's signal will be modified while propagating in the complex oceanic medium: by reflexions, transmissions and refractions. Thus, information about the whale's environnement is "hidden" in the signal that we receive. If we have a good knowledge of the velocity changes in the water layer and of the ground (bathymetry, composition), we can use this information to locate an unseen whale. However, we need a very accurate model of sound propagation to be able to take advantage of this information in the signal, and this is why we decided to work with highly sophisticated modern models, available for the whole community.

## Modeling softwares

Because the sound is the first way of communication in the ocean, the physics of

sound propagation have been intensively studied this last 50 years, involving large scale simulation with different kind of methods (*Jensen et al., 2011*). Most of the efforts however have been focused on modelling active acoustics, which implies sending an artificial signal and analyse its propagation through water and (or) ground (oil industry prospection, fisheries or military sonars). The most frequently used methods include ray propagation and parabolic methods (*Eter, 2012*). Also, most methods assume the source of the sound to be known and then predict the propagation of the acoustic wave. In this case, we are interested in finding the location of the source, given the geometry and the recorded sound. For this to be feasible, we first need to develop fast and accurate computational methods for wave propagation problems based on state-of-the-art techniques such as finite elements methods (FEM) and boundary elements methods (BEM). Both of these methods present a high degree of accuracy but require large computing resources.

The first method that we use for this study is SPEC-FEM open-source software (*Komatitsch, 1999*). SPEC-FEM was first developed for the simulation of seismic wave propagation at large scales in full waveforms. The method combines finite element methods and spectral elements, using a weak formulation of the equation of propagation, which is solved on a mesh of hexahedral elements. We are adapting this very accurate method to bioacoustical signals. FEM methods are rather CPU-time consuming, so we are limiting our present study to large baleen whales (balaenopteridae) such as blue whales (*balaenoptera musculus*) and fin whales (*b. physalus*) that emit low frequency moans (around 20 Hz) very well adapted to our methods. However, depending on the size of the simulation box and with the help of high performance computational resources, in France (Université de Toulon, TGCC France) and in Chile (PUC, Santiago), we hope to be able to extend the method to other species such as humpback whales (*megalopterae novaeangliae*).

The boundary-element method is potentially faster for computing wave propagation, because only the interfaces and boundaries of homogeneous regions are being discretized. To this end, we are investigating the use of the open-source BEM++ library (*Smigaj, 2015*), which provides frequency-domain acoustic models.

## First tests of the method

Our simulation with its first results is presented on figure 1. We constructed an artificial 2D box representing a plausible underwater environment two kilometers long (figure 1.a, top).

We simulated the propagation of a real signal of a blue whale (taken from S. Buchan recording in Corcovado) at low frequency (around 20 Hz). This signal does not require too large a computational time.

The signal propagation is simulated from a point *E* (position of the supposed whale) to a point *R* (position of the fixed hydrophone). A simulation is launched to model the propagation of the signal from a grid of 36 virtual whale positions towards the hydrophone. These positions are sampling the water domain, each 200 meters in horizontal plane and each 20 meters in the vertical plane (assuming the whale normally emits sounds while it's not more than 100 meters deep, see for instance *Stimpert et al. 2015*). We then perform a correlation analysis to find the position which is best correlated with the signal emitted from point A position.

We obtain a robust estimation of the emitter's position if the grid point is sufficiently close to the emitter's position, around 50 meters or less (depending on the bathymetry). Since adding virtual grid positions to the model is little time consuming, we find that putting an array of 50m-spaced virtual emitters in our model (a box corresponding to the local bathymetry) should allow us to find the position of the emitter.

However, this is a first test and it should be completed by ground validation.



## Field measures and validation

To validate our method and extend it to acoustical surveys in pristine areas of South America, we are constructing a net of acoustical observatories in the coastal areas of Chile (see fig. 2 and *Malige et al. 2016*).

Blue whale sounds are already being recorded in Corcovado gulf to evaluate blue whales communication (see for instance *Buchan et al., 2015*). We are using these sounds for our first test and adjustments of the method.

In addition, we are planning the installation of two buoys, one in Magallanes strait in southern Patagonia, in collaboration with Juan Capella and Jorge Gibbon (Universidad de Magallanes), and the other close to Chañaral Island, in the northern part of Chile, in collaboration with Maritza Sepulveda (Universidad de Valparaíso). We will thus have signals from other baleen whales, such as fin whales (common in Chañaral) and humpback whales (common in the Magallanes strait).

These two buoys will be equipped with a Cetacean research hydrophone and a simple recording device, designed by DYNi team in Toulon University and CNRS (LSIS laboratory). This low-cost recording device is designed to stay underwater for long periods, while recording with programable sampling frequency ranging from a few kHz to very high frequencies (2MHz maximum sampling frequency).

In Chañaral, a team of trained biologists from Valparaíso University will measure the whales' positions while the buoy will be recording their songs during the austral summer. Thus, we will be able to have ground truth for our position estimation method, as well as an estimation of ship noise impacts on general acoustical behaviour of the whale (study by M. Sepulveda).

## Ship noises

Ship noise interference is also being investigated thanks to our models. In figure 1.b, we show that source localization can be dramatically affected by the presence of a

passing ship's noise. In this test, we ran our simulation adding a ship passing by, at a distance of about 300 m of the hydrophone. The noise level of the ship was taken to be 180 dB ref. 1  $\mu$ Pa, in accordance with *Richardson et al., 1995* review book, and the signal was taken from our own recording of a boat and truncated to 30 Hz (numerical limit of our model). A virtual whale emitting a moan with the same order of magnitude, at 20 Hz, was placed in the model box, at 500m from the hydrophone, not in a line with the boat. We found that the noise produced by the boat prevented our algorithm from recovering the source's position: in figure 1.b, the correlation maxima no longer shows a peak at the corresponding position.

With low frequency sound such as blue and fin whale's moans, the sound wavelength in the water is about 75 meters. For these long wavelengths, the ears separation is not sufficient to help the whale in finding the range of the source of a sound, but reverberation on the ground could help it locating its mates, especially in shallow coastal waters. If this is the case, it is very possible that a ship passing will cut off this position estimation from the whale. Thus, noise caused by ship, even when it's not sufficient to mask the whole signal from a co-species, will make it more difficult for the whale to know where the other whale is, even at a relatively close range (500 meters).

## Conclusion

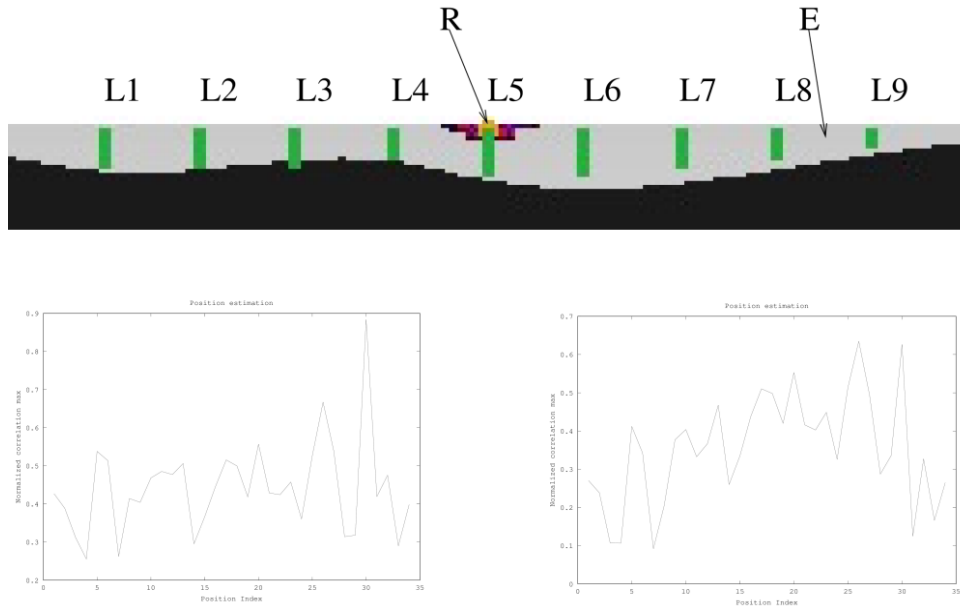
We are developing a new tool in a all-inclusive way, from the mathematical modeling to the ground data acquisition, with the aim of providing a new tool for the study and preservation of aquatic mammals (see *Patris, 2016* for the detailed exposition of the goal of this work). The method is quite new, but has only been tested with artificial boxes so far. A ground-truth validation will be acquired during austral summer.

Along with the final tests of our method, our team also work on extending the use of high performance modelling in other contexts of cetacean conservation: we worked on river

dolphins (*inia geofrensis*) in Amazonia (Iquitos, Peru), and we are considering adapting our model to higher frequency but smaller volumes to study boat noise and dolphin acoustics in rivers.

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**Fig. 1:** Model. a. (top) Geometrical representation of the modeled box. R is the position of the receiver (hydrophone on a buoy) E is the position of the virtual whale, and green lines are a virtual grid of possible positions for the whale. b. (left) correlation maxima versus position index. The peak of the correlation maxima points to the position 30, which is indeed the closest point to the virtual whale. c. (right) The same plot but with a ship passing by: the correlation peak is lost in a large bulk corresponding to the noise correlation with itself. In this case, it's not possible to infer the whale's position anymore (see text).

Iquitos (Peru)

Chañaral (Chile)

Corcovado (Chile)

Carlos III (Chile)



**Fig. 2 :** map of the acoustic observatories.



# SURFACE SHIP PASS-BY NOISE FOR SOUND SOURCE IDENTIFICATION

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With the advent of environmental criteria for sound pressure levels radiated by commercial ships in the coming years, the naval community needs to define standards to measure noise radiated by such craft [1][2]. To achieve certification, passing ship noise mapping should be a useful tool to help the naval industries acoustically design their ships. Indeed, noise mapping makes it possible to localize the different vehicle acoustic sources and provides information about their contributions to the global acoustic pressure level. Compared to global levels, the noise mapping results are of interest to focus the noise reduction on the main acoustic contributors. They also give input data quantifying the source power for simulation tools and permit the validation of simulations.

In aerial environments where standards have been applied for several decades, vehicle pass-by noise mapping technologies have been developed and adapted to the aeronautic [3], railway [4], and automotive industries [5]. The publications are numerous in the literature of these domains but are almost non-existent in the underwater domain. Results prove the interest of such procedures whereas they are of high cost. They are carried out in parallel to certification when the pass-by cost itself is expensive. In this context, the feasibility of an underwater pass-by procedure was interesting to investigate. Thanks to French DGA support through a PhD thesis and to RAPID tool, the ARMADA project lead by the French company MicrodB (subsidiary of VibraTec), in partnership with the GIPSA Lab in Grenoble, was carried out between 2012 and 2016. It ended with experimental measurements using a scale model of a surface ship towed in a mountain lake. Results are encouraging

and prove the interest of underwater pass-by noise mapping [6].

The first interest of the project was the description of the sources composing the acoustic signature of a surface ship. Indeed, array dimensioning and processing is influenced by the acoustic sources of interest: frequency content, location, speed. The 3 components identified in the acoustic signature are noises coming from the propeller, from its cavitation, and from internal machines. The same classification was proposed in the European AQUO project [7]. The components have different physical origins: hydro-acoustic or vibro-acoustic, meaning that the surface ship emits close sources with large frequency bands and tones. Depending on the speed, each component's contribution to global noise varies. Pass-by analysis with acoustic mapping for different speeds can help to determine their contribution to global noise and their evolution with the speed. Following this classification, a simulation tool was developed to synthesize far-field noise emission with a few typical surface ship sources [8]. The tool was used to validate the array processing.

In aerial environments, the pass-by noise mapping task is classically addressed using far-field microphone array measurements with beamforming processing. Due to vehicle movement, some adaptations are needed compared to fixed noise sources to compensate the Doppler Effect and to focus on the moving vehicle. The literature is less extensive for the underwater environment than the aerial one, with only a few studies conducted on towed-ship models for denoising [9][10]. In the underwater environment, the signal-to-noise ratio is poor and hydrophone arrays only contain a few sensors due to their high cost and

difficult installation and maintenance. This explains the difficulty of underwater pass-by noise applications. Indeed, beamforming array processing has a poor spatial resolution with small arrays and it is not possible to separate two close sources at low frequencies. A second issue is the dynamic range, which can be only of few decibels in noisy environments. This can be solved by higher microphone density but also leads to expensive solutions underwater.

For the purpose of surface ship noise mapping, linear antennas can give source positions along the ship in one dimension. They form larger arrays with better space sampling than 2D antennas, but suffer from their relatively small size and few hydrophones: usual pass-by aerial arrays have over 50 microphones! The adaption of aerial methodologies with advanced processing improves resolution and dynamic range.

The innovation in processing lies in the passive synthetic aperture array technique to improve low-frequency resolution, the use of beamforming results to improve trajectory accuracy and deconvolution methods in noisy environments.

Since beamforming suffers from poor resolution at low frequencies, a passive synthetic aperture array technique was proposed to improve the localization resolution for monochromatic sources at low frequencies, e.g. vehicle mechanical noise sources [11]. Many passive synthetic aperture array studies have been reported over the last two decades. These studies have mostly considered the case of towed arrays [12]. In the case of pass-by noise mapping, the idea developed in the project was to replace towed arrays by vehicle displacement to synthesize a larger array.

Another specificity of the underwater application is the small distance between the surface ship and the array compared to the ship size, leading to beamforming level amplification on the map border. The issue has been solved with specific weighting, which smooths the distance working from the distance to the array center [6].

Whereas beamforming has been improved and gives the acoustic hot spots, some of the sources are not separated at low frequency and large frequency range, or wrong alarms and bad interpretation could be due to low dynamic range. These artefacts are due to the convolution of the source distribution by the array pattern and additive measurement noise not included in the source model which disturbs the beamforming processing. It is usual to apply deconvolution methods on beamforming map to solve those issues. A spatial blind beamforming deconvolution was developed during the project using the assumption of sparse sources and the presence of Gaussian noise in the model [13]. It has proved its robustness against noise and does not require an accurate localization initialization.

Another main issue in moving-source mapping is the knowledge of the trajectory of the moving object containing the sources. Indeed, trajectory errors induce localization artefacts in beamforming results, which can degrade performances and bias physical source interpretations. A novel method has been proposed [14] to correct trajectory mismatches. This method requires first localization maps along the trajectory to estimate the trajectory mismatches by spatial intercorrelations between source localizations. A reference map is then defined to estimate a corrected trajectory.

The developed methodology was initially validated from simulation and aerial experiments before water experiments. The good results encouraged a unique pass-by experiment of a 1:5 scale model of a surface ship in a mountain lake in order to assess the efficacy of the array processing proposed in the ARMADA project. The pass-by configuration was separated between artificial sources and own model ship sources. The former proved the performances of the methodology and the latter permitted first analysis in accordance with state-of-the-art results for true hydroacoustic sources. The application of the new weighting strategy on a configuration of two sources shows a dramatic reduction in the number of non-physical sources. The localization and contribution results are thus more accurate,

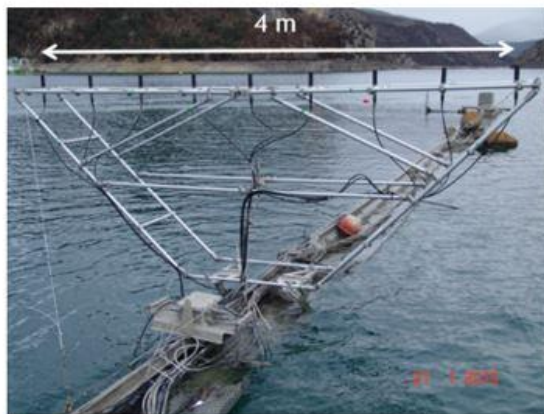
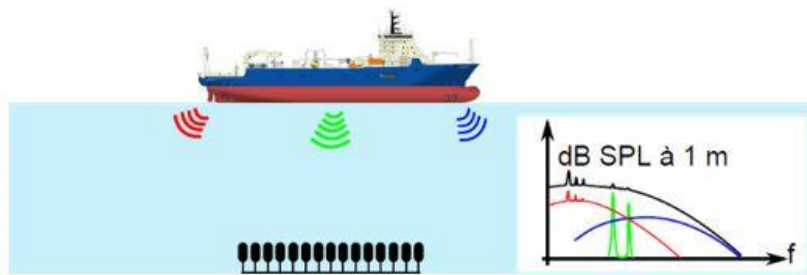
improving the physical interpretation of the results. Moreover, an experiment with two low-frequency sinusoidal sources was considered. The use of the synthetic aperture array method made it possible to localize both sources with the synthetic antenna, which is not possible with the real antenna. It is therefore possible to obtain more accurate results from blind deconvolution as the number of sources is small enough and they do not spread spatially.

Thanks to the ARMADA project, the feasibility of surface ship pass-by noise with accurate sound source identification was established. The methodology works from a linear hydrophone array of a few sensors deployed in the ship direction, which is a realistic set-up for industrial processing. Advanced processing makes it possible to compensate the measurement difficulties (small arrays, trajectory uncertainties, noisy environment). Future perspectives will be to apply the methodology to a real ship at sea. The bottlenecks are now on experimentations rather than processing: trajectory measurement, deploying an array, accurately positioning the array.

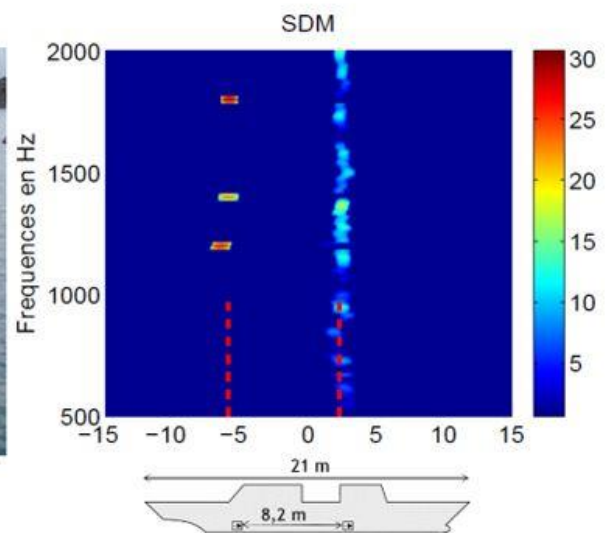
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Hydrophones antenna in Castillon lake



Measurement and localization of ship noisy sources



# **REVIEW ON EXISTING DATA ON UNDERWATER SOUNDS PRODUCED BY THE OIL AND GAS INDUSTRY (FOR THE JOINT INDUSTRY PROGRAMME)**

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During the exploration, development, production and decommissioning phases of offshore oil and gas reserves, the industries contribute to the noise levels in the oceans, estuaries and rivers of the world. The purpose of the latest JIP review report [1] is to provide an updated catalogue and assess the available data that characterise the underwater sounds made by the oil and gas industries in all phases of their activities, till date. The latest JIP report builds upon the works of a similar report [2] compiled by Roy Wyatt in 2008. However; due to the scarcity of data in some areas - either due to the classified nature of the reports or otherwise - other noise sources such as shipping, hovercraft and other production noises are also included in relevant sections for comparative purposes.

Measurements of underwater noise generated by the Oil and Gas industry are scarce. Given the volume of traffic and industrial activity around the shores of the oceans, it is surprising that so little is known of the likely impact the man-made noise may have within the oceans and to the marine life that resides within. Measurements of acoustic noise made over the last 40 years, at a site off the southern Californian coast, reported a general increase in low frequency noise (< 150 Hz) with time [3]. The increase in this noise level has been widely attributed to increases in shipping and other anthropogenic (human made) noise (often termed anthropogenic noise). In some areas, the noise background levels have been reportedly doubled every decade for the last six decades, primarily due to the increased shipping [3].

Few measurements have been made on underwater noise sources, and those that have been made are often limited in the

scope of the measurements due to the vessel availability time, operational, recording and weather constraints. Comparison between measurements by different observers can be difficult due to the vast range of ever changing conditions encountered in the ocean and the range of metrics that can be used to describe the acoustic properties of a sound source. It is well known that, local conditions (geographic, geological, oceanographic and meteorological) all have a very substantial impact on the way in which sound propagates from a source, through the water, and to a measurement receiver. As the receiver is often located at a considerable distance from the source, it is usually necessary to measure/quantify many other parameters (related both to the transducers and the ocean) in order to attempt to determine the true nature of the source itself.

The noise levels summarized in the JIP ambient noise review report [1] are stated either as values measured by the corresponding researcher(s) or in an extrapolated form (to a distance of 1 m from the source) following a consistent set of units. To do this extrapolation, a number of assumptions have been made, particularly relating to the local conditions under which the measurements were determined, the nature of the source signal and propagation characteristics. The readers of the report were however forewarned that the extrapolated values be used as guideline only [1], as the variability of the transmission of sound and the nature of the sound source itself is difficult to quantify and an accurate translation between the remotely measured values and the extrapolated (back projected) values is sometimes difficult.

The JIP report [1] also contains a summary anthropogenic noise values published in various research articles, commercial and technical reports and other surveys for: seismic exploration sources; engineering sources such as: profilers, deterrent devices, sonars, communication devices, explosives, pingers/boomers; vessel noise generated from various type of commercial shipping or other related sources; underwater construction, drilling and dredging noise; production and other related noise sources. The data presented in the JIP report covers the literature published/reviewed till date.

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# STANDARDIZATION IN UNDERWATER ACOUSTICS – NEEDS AND STATUS

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## Introduction

A standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose.

International Standards bring technological, economic and societal benefits. They help to harmonize technical specifications of products and services making industry more efficient and breaking down barriers to international trade. Conformity to International Standards helps reassure consumers that products are safe, efficient and good for the environment.

Standardization should not be confused with regulation. For example, in the domain of aerial acoustics, the requirement that such maximum noise level or indicator is to be fulfilled in a given environment (e.g. workspaces) for a given human activity is a regulation, and the procedure and set-up for the measurement is a standard. A standard may also impose a design requirement on a product. Policy makers will use standards as far as possible to enforce a regulation.

Contrarily to airborne acoustics where many documents have been made available for different purposes for a long time, no standard was available for underwater acoustics until now. One of the main reasons is that most of the topic was in relationship with military purposes, each Navy using its own procedures while keeping confidentiality. The increasing development of anthropogenic activity at sea combined with the awareness of bio-acousticians regarding environmental impact and protection of marine life changes the context. There is currently a consensus among stakeholders (scientists, industry, government representatives and policy makers) to have at one's disposal some

internationally approved standards for underwater acoustics.

## Needs for standardization in underwater acoustics

Electromagnetic waves propagate poorly underwater, contrarily to acoustic waves which can be observed at long distance from the emitter, depending on source level and frequency.

The development of the first sonar systems together with submarines about one century ago has initiated an extensive use of underwater sound by navies mainly in relation to underwater warfare. Underwater acoustic detection and stealth, as well as mine warfare, are the main issues for military naval applications, and for that purpose the different terms of the sonar equation must be determined properly. Despite the fact that Navies use their own procedures which can vary depending on the countries, there is an interest for a common terminology, and for accurate methods for the measurement of radiated noise from vessels and of the acoustical characteristics of sonar systems.

There are also similar needs for civilian applications where underwater acoustic detection has been used for a long time and is still expanding. Apart from the industrial exploitation of the seas which will be addressed below, applications include:

- ✓ Echo sounding, determination of sea floor properties,
- ✓ Detection of objects on the sea floor, such as wrecks or objects of historical interest,
- ✓ Fish detection, in order to locate and optimize catches,
- ✓ Sea life monitoring and bioacoustics,
- ✓ Acoustic ocean tomography and remote detection of seismic events.

Note also that since 1995 most of research vessels are designed with a limit value of

underwater radiated noise, defined by an ICES working group.

More recently the increasing worldwide demand of energy and natural resources and the globalization of economy have led to a steady increase of maritime traffic and industrial anthropogenic activity at sea. The increasing concern of the scientific community regarding the impact of underwater sound on marine life incites policy makers and stakeholders of the maritime domain to mitigate their impact through appropriate measures. An important milestone was the adoption of the MSFD (Marine Strategy Framework Directive) requiring European Member States to monitor the environmental status of maritime areas and to take appropriate measures to achieve a good environmental status (MSFD, 2008).

The main topics in relation with anthropogenic activity at sea are:

- ✓ Maritime traffic: Noise and vibrations on board ships has been a priority topic for a long time at IMO (International Maritime Organization), because of crew safety or passenger comfort issues. Recently, the IMO issued non-mandatory guidelines for the design of commercial vessels with the objective the protection of marine life (IMO, 2014). Besides, the European Union supported two collaborative with the objective to mitigate underwater noise related to shipping in European maritime areas, including also research on propeller cavitation noise, which is a major noise source on commercial vessels. Synthesis documents of these projects are (AQUO & SONIC, 2015), and (AQUO, 2015) with a summary in (Audoly, 2016) for the latter.
- ✓ Oil and gas survey and exploitation: The search of offshore oil and gas fields in the sediment layers beneath sea bottom is done through seismic surveys requiring the emission of low frequency high intensity impulsive sounds produced by “underwater air guns”. Another aspect is related to the preparatory phases for exploitation and the operational phases. There, some noisy underwater activity can occur (drilling, pumping, conveying fluids and/or sediments in pipes)
- ✓ Marine renewable energy: There is currently a move to develop renewable

energy production, and the seas offer a great potential, using different types of systems: wind turbines mounted on piles or on floating structures, underwater tidal turbines, ocean thermal converters. The main matter of concern is the pile driving operation during the installation phase of offshore wind turbines, which produces high intensity impulsive sound (note that at least two countries, Germany and Netherland, have already enforced a regulation on that aspect with limit levels). On the other hand, the noise emitted during the operational phases should not be neglected, in particular when several devices are installed close one to the others.

In that context the priority needs for standardization are the determination of source levels emitted by ships and possibly other sound sources, the sound emitted by pile driving operations and the measurement of ambient noise in relation with anthropogenic activity.

### **Status of actions for standardization at international level**

A few years ago, a new subcommittee ISO/TC 43/SC 3 “Underwater acoustics” was created with the following scope: “Standardization in the field of underwater acoustics (including natural, biological, and anthropogenic sound), including methods of measurement and assessment of the generation, propagation and reception of underwater sound and its reflection and scattering in the underwater environment including the seabed, sea surface and biological organisms, and also including all aspects of the effects of underwater sound on the underwater environment, humans and aquatic life”.

Four working group are currently active:

- ✓ Measurement of underwater sound from ships: A first standard, the ISO 17208-1, was published in the beginning of year 2016, dealing with “Measurement of underwater sound from ships — Part 1: Requirements for precision measurements in deep water used for comparison purposes. A second part of this standard is under study with the purpose to determine the ship source level, instead of the radiated noise level

affected by the reflection of waves on the sea surface, by applying a correction term.

- ✓ Underwater Acoustics – Terminology: the objective is here the adoption a common language, as presented in (Ainslie, 2016). The corresponding standard, the ISO 18405, is nearly completed.
- ✓ Measurement of radiated noise from marine pile driving: The ISO 18406 is completed and could be published shortly.
- ✓ Standard-target method of calibrating active sonars: The work in progress, project ISO 20073, is dealing with a method based on the use of reference calibrated targets for calibration of active sonars for imaging and measuring scattering, which is of interest for both civilian and military applications.

Other topics considered for the future in the work plan are:

- ✓ Underwater acoustics – Measurement of ambient sound
- ✓ Underwater acoustics – Measurement of sound pressure
- ✓ Underwater acoustics – Measurement of sound from offshore petroleum operations
- ✓ Underwater acoustics – Calibration of autonomous acoustic receiver/recorder systems

Apart from the actions at the level of the ISO, the IEC is also contributing to the standardization issues in underwater acoustics with a working group on “Acoustic Characterization of Marine Energy Converters”, in particular tidal turbines.

## Summary and way ahead

Despite the existence of specific procedures within Navies and some national standards or regulating documents, no international standard was available until now in underwater acoustics. As it is of general interest for stakeholders and scientists to adopt common language and procedures, in particular in order to compare measurements one to the others and to be able to carry out good quality

environmental impact assessment studies, the standards organizations, in particular the ISO/TC 43/SC 3 are working actively to fill the gaps. A first standard for the measurement of radiated noise from ships was published recently, and two others on terminology and sound arising from marine pile driving are expected soon. A work plan has been established for future actions.

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# HOW EFFICIENT ARE POTENTIAL REGULATIONS ON UNDERWATER NOISE?

## A FRAMEWORK PROPOSED BY THE AQUO PROJECT

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The 7<sup>th</sup> Framework Program, within the scope of « Sustainable Surface Transport » and « Oceans of Tomorrow » has funded the three-year research project “AQUO”, covering the impact of underwater noise radiated (URN) from shipping and its adverse impact on the fauna.

AQUO’s goal based approach aimed at building a methodology and the corresponding tools to help the policy makers establishing the most appropriate mitigation plans for the concerned waters.

The main issues of the underwater noise topic (governance, measurements on site and in basin, source and propagation models, species, technical solutions and mitigation scenarios) have been addressed throughout the different work packages. They constitute the skeleton of the AQUO final guidelines and support the overall methodology that is described in this paper.

### Introduction and context

The scientific community’s concern on the underwater noise on anthropogenic maritime activity and its adverse impact on marine life increased together with ship traffic status and trends.

Until 2008, none of the Oceans and biodiversity related international conventions and National regulations have explicitly addressed underwater noise issues. Since then, throughout the Marine Strategy Framework Directive (MSFD) [1], the European Union clearly identified underwater noise as one of the descriptor of the Good Environmental Status of its waters. Two indicators have been set-up to address the two main types of noise linked to anthropogenic activities: impulsive noise (to

be linked mainly with oil and gas exploration or pile driving) and low frequency continuous noise from shipping. The research efforts of AQUO have focused on listing and assessing practical solutions with regards to the latter. It has to be mentioned here that the EU funded as well another project “SONIC” on the same topic committing both consortia to deliver consistent and commonly structured outcomes and guidelines [6]. It has highlighted meanwhile the importance of the topic.

Moreover, to emphasize the position of the topic, it is of prime importance to mention the milestones of the IMO guidelines adopted 2014 [2].and the issuing of ISO 17208-1 in March 2016 [3].

### Methodology overview

The aim of AQUO’s approach is to enable a practical assessment of the various solutions and mitigation measures. Let’s list down the key stones to understand how it has been built.

At both ends of the noise radiated from shipping, there are:

- ✓ each ship considered as a single noise source,
- ✓ ship traffic, to be considered as an accumulation of noise sources,
- ✓ the resulting noise is thus pending to be managed as accurately as possible,
- ✓ predictive values of noise sources from numerical (URN patterns, [11]) and scaled (basin mock-up) models,
- ✓ on-site measurements, including the mandatory insight on the related uncertainties,



- ✓ ship traffic data from available Automatic Identification System,
- ✓ sound propagation phenomena from multiple single sources to a whole basin scale,
- ✓ appropriate and representative noise indicators within time and space using percentiles.

Furthermore, the core of the topic is not only the noise level on its own but its potential impact on the receivers (i.e. marine fauna). It is thus necessary to identify:

- ✓ the species of interest,
- ✓ their corresponding noise sensitivity criteria.

This embedded three-axis approach including single ship noise sources, ship traffic and species provided by the LIDO software package ([listentothedeep.com](http://listentothedeep.com))<sup>1</sup> constitutes the skeleton of the methodology and the key inputs of the corresponding Quonops® patented tool [12] that enables a quantitative assessment through the production of noise maps. Considering real time actual data, a picture of the current situation can be obtained, but one of the highest added-value of the methodology is also to assess the consequences of:

- ✓ noise mitigation direct scenarios at a ship traffic level, linking ship operation strategies and underwater noise,
- ✓ technical solutions and their expected noise reduction at a single ship level, generally through improved design or alternatively by retrofit, further extrapolated to ship traffic.

These simulations express the benefits not only for noise levels at a basin scale but for a given species providing a given sensitivity criteria.

Figure 1 illustrates these different key stones and how the AQUO methodology leads to assess the noise footprint from shipping: Four main processing chains related to the selection to the relevant species to be considered, the physical characteristics and the shipping characteristic of the area, and the individual properties of the vessels converge toward the Quonops® tool which will assemble all this information to deliver the related statistical noise maps. The application of noise reduction scenario will modify the statistical noise maps and allows for a quantitative assessment of the efficiency of the mitigation measures envisioned.

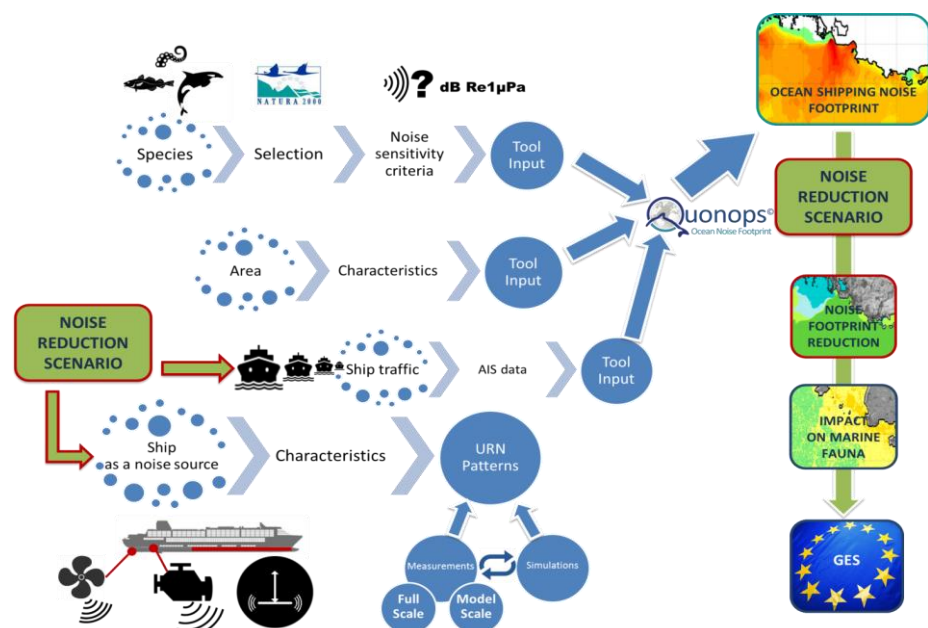


Figure 1: Overall AQUO's methodology

<sup>1</sup> <http://www.listentothedeep.com/>



## Applicability

The results of this methodology depend on the specificities of the area where it is applied, but the method itself is wide-ranging and can be applied in any maritime area. To demonstrate this feature, the method has been applied during the AQUO project timeline in three different locations: offshore Brittany and South-East coast of France and offshore Barcelona, Spain. This practical implementation went through all the mandatory steps of baseline measurements and model calibration processes [7], [10].

Figure 2 summarizes the scenarios which were developed [8], [9] and tested within the framework of AQUO. It demonstrates the maturity of Quonops®, able to quantify the benefits in terms of noise and in terms of impact on the fauna.

It has also to be noted that the commitment of AQUO's consortium to achieve practical guidelines [4] has been ensured by working also on the solutions considering:

- ✓ The influence on fuel efficiency,
- ✓ The implementation difficulties with regards to direct design, refit and maintenance costs.

AQUO has shown that imposing a regulatory limit of to the noisiest ships seems to be the most effective solution, which is consistent with the recent Bureau Veritas (BV) URN class notation NR614 [5]. Fulfilling BV requirement could be achieved by an improvement in design of future vessels, and for existing vessels by proper maintenance and by adapting operational settings. However, it is not realistic to impose noise limits for all vessels in all maritime areas. Therefore it is the role of Member States to define the priority areas and related marine species to be protected.

The final message is not to highlight one or another solution but to make available a solution package that should be used by policy makers, protected area managers, port authorities or ship owners to decide through appropriate criteria, what solutions should be preferred with regards to their benefits.

The best way ahead would be to deploy the methodology and tools in some pilot areas involving all the stakeholders (owners and operators, biologists, policy makers and evaluators).

Scenario type	Mitigation measure	Maritime area	Global Noise Reduction in the 125Hz third-octave	Reduction of the Size of the Area of Risk from Baseline Situation			
				Masking Predator Call for Harbour Porpoise	Behavioural Reaction of Harbour Porpoise	Masking Cod Spawning Communication	Behavioural Reaction of Cod
Individual Noise Reduction	Reduction of ship URN noise (technical solutions)	Atlantic	Significant reduction in all area	Not evaluated		-15%	-24%
	BV-controlled vessels limit	Atlantic	Significant reduction in all area	-1%	-21%	-13%	-30%
	BV-advanced vessels limit	Atlantic	Large reduction in all area	Not evaluated		-22%	-43%
Traffic regulation	Grouping by 3 vessel-packets while transiting	Atlantic	Significant reduction in all area			-3%	-8%
	Insuring minimal distance of 10km between individual vessels while transiting	Atlantic	Significant reduction in all area			-2%	-8%
Speed limitation	Speed limited to 13 knots for all vessels in the MPA only	Atlantic	No significant gain			-2%	-13%
	Speed limited to 13 knots for all vessels in the full area	Atlantic	Significant reduction in all area	Not applicable			
Spatial planning	Fostering deep waters	Med	Reductions and increases across the area	Not applicable			
	Fostering shallow waters	Med	Reductions and increases across the area	Not applicable			
	Traffic Separation Scheme translated 10km offshore	Atlantic	Reductions and increases across the area	Not evaluated		-2%	-1%

**Figure 2:** Overview of the scenario tested using AQUO's methodology and Quonops® and corresponding results

## Acknowledgements

This work was developed in the frame of the collaborative project AQUO (Achieve Quieter Oceans by shipping noise footprint reduction), funded by the European Commission within the Call FP7 SST.2012.1.1-1: Assessment and mitigation of noise impacts of the maritime transport on the marine environment, Grant agreement no 314227, coordinated topic “The Ocean of Tomorrow”. The content of this paper does not reflect the official opinion of the European Union. Responsibility for the information and views expressed in the paper lie entirely with the authors.

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- 4 Synthesis of recommendations. “Underwater Noise Footprint of Shipping: The Practical Guide”. AQUO Project, report D5.8 (2015).
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- 6 Guidelines for Regulation on UW noise from commercial shipping, prepared by AQUO and SONIC Projects, 30 November 2015
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# HOW DOES THE MARINE STRATEGY FRAMEWORK DIRECTIVE PROTECT EUROPEAN SEAS & OCEANS FROM THE IMPACTS OF UNDERWATER NOISE?

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This presentation informs the assembly of the international conference on underwater noise: Racket in the oceans on the frame of the Marine Strategy Framework Directive (MSFD) and underwater noise issues and to develop further advices on the implementation of the second cycle of the Marine Strategy Framework Directive.

Firstly, the main Union environmental regulation linked to underwater noise issues, including the Environmental impacts assessment Directive, the Strategic environmental assessment Directives and finally the Marine strategy framework directive, associated to its good environmental status commission decision will be described.

Secondly, the decision on the good environmental status of Union marine waters will be presented, including information on its ongoing revision process. Thirdly, an overview of the progress and the existing references developed under MSFD, in particular through the technical group on underwater noises (TG noise) will be given.

Fourthly, the presentation will highlight the future actions of the draft work programme for 2016-2019 on the common implementation strategy of MSFD.

## **EU laws protecting the marine environment from adverse underwater noise effect**

This part of the presentation provides an overview of the EU legislation contributing to the prevention of anthropogenic noise in European Union seas.

## ***Environmental impact assessments & Strategic Environmental Assessments***

In direct relation to all permitting activities such as seismic survey from oil and gas exploration, dredging activities, the package of environmental impact assessment from strategies to the projects will apply. It includes:

- ✓ the strategic environmental assessment, falling under the scope of Directive 2001/42/EC<sup>1</sup> on the assessment of the effects of certain plans and programmes on the environment and on public consultation in early decision-making process;
- ✓ the environmental impact assessment of projects falling under the scope of Directive 2011/92/EU<sup>2</sup> (codified) on the assessment of the effects of certain public and private projects on the environment.

Principles laid down in the strategic environmental assessments are:

- ✓ to provide for a high level of protection of the environment;
- ✓ to contribute to the integration of environmental considerations into the preparation of plans and programmes with a view to promoting sustainable development.

For the environmental impact assessment principles are:

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- 1 Directive 2011/92/EU of the European Parliament and of the Council of 13.12.2011 on the assessment of the effects of certain public and private projects on the environment Text with EEA relevance OJ L 26, 28.1.2012, p. 1-21.
  - 2 Directive 2008/56/EC of the European Parliament and of the Council of 17.6.2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) (Text with EEA relevance) OJ L 164, 25.6.2008, p. 19-40.

- ✓ to protect the environment and quality of life;
- ✓ to ensure approximation of national laws with regard to the assessment of the environmental effects of public and private projects.

Certain public plans and programmes that are likely to have significant effects on the environment should be subject to a strategic environmental assessment, as required under the Directive bearing the same name. Public and private projects that are likely to have significant effects on the environment are subject to an environmental impact assessment, as required by the Environmental impact assessment directive.

Other directives may apply, given that they have an indirect link with permitting and recreational human activities. Together, all these laws contribute to the overall goal of preserving our common and shared environment on ecosystem entities. These include the Water Framework Directive, Habitats Directive, Birds Directive, Marine Strategy Framework Directive, Invasive alien species Directive, Air quality Directive and others.

#### ***The Water Framework Directive (WFD):***

This Directive, establishing a Union in the field of water policy applies to each river basin district lying within the territory of the Member States. The amended directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy Its purpose, as stated in article 1, is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater... and thereby contributes to :

- ✓ the protection of territorial and parts of marine waters; and
- ✓ achieving the objectives of relevant international agreements, including those which aim to prevent and eliminate pollution of the marine environment, by Union action under its Article 16(3) to cease or phase out discharges, emissions and losses of priority hazardous substances, with the ultimate aim of achieving concentrations in the marine environment near background values for naturally occurring substances and close

to zero for man-made synthetic substances.

Also, depending on the nature of the projects, their emissions and products, other directives may apply such as the [landfill directive](#)<sup>3</sup> and the [industrial emission directive](#)<sup>4</sup>.

#### ***The Marine Strategy Framework Directive***

The Marine Directive, *establishing a framework for community action in the field of marine environmental policy (MSFD, Directive 2008/56/EC)*, aims to achieve the “good environmental status” of the EU’s marine waters by 2020. Seas in good environmental status are clean, healthy and productive and are characterised by 11 topics called descriptors. The directive also emphasises the need to maintain a sustainable use of marine resources and it implies managing the pressure exercised by human activities on the marine environment, including land-based activities. The ecosystem-based approach is an underlying principle of the directive. Each Member State is required to develop and implement a marine strategy in its marine waters, in cooperation with other Member States sharing the same marine region. This strategy is reviewed every 6 years.

Those strategies include 5 steps:

1. an initial assessment of their marine waters,	reported in 2012 & to be revised in 2018
2. the determination of the good environmental status of their marine waters,	reported in 2012 & to be revised in 2018
3. the setting of environmental targets	reported in 2012 & to be revised in 2018
4. the establishment and implementation of coordinated monitoring programmes, and	reported in 2014 & to be revised in 2020
5. the identification of measures or actions that need to be taken in order to achieve or maintain good environmental status	reported in 2015 & to be revised in 2021

3 Council Directive 99/31/EC of 26 April 1999 on the landfill of waste.

4 Directive 2010/75/EU of the European Parliament and the Council on industrial emissions.



In 2012, for the first time Member States reported on the state of their marine waters, on what they consider as being their “good environmental status” to reach in 2020 and on their objectives and targets. The European Commission assessed these first elements of the strategy against the Directive’s requirements in 2014 and highlighted that Member States had to put more effort to be able to reach the 2020 goal. For example there was need to focus more on joint action and planning and more ambitious regional cooperation so as to improve coherence in the implementation of the Directive across the EU’s waters.

A second Commission report<sup>5</sup> assessing Member States’ monitoring programmes, adopted in January 2017 highlights that monitoring programmes are either incomplete, or will be put in place too late.

### **The ‘Good environmental status’ Decision: more focus on state & pressure notions**

The MSFD defines “good environmental status” as “the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive”. GES implies that marine resources are used sustainably, ensuring their continuity for future generations. The MSFD sets out eleven qualitative descriptors

upon which GES should be based. As such, GES is achieved when,

- ✓ [Descriptor 1](#). Biodiversity is maintained
- ✓ [Descriptor 2](#). Non-indigenous species do not adversely alter the ecosystem
- ✓ [Descriptor 3](#). The population of commercial fish species is healthy
- ✓ [Descriptor 4](#). Elements of food webs ensure long-term abundance and reproduction
- ✓ [Descriptor 5](#). Eutrophication is reduced
- ✓ [Descriptor 6](#). The sea floor integrity ensures functioning of the ecosystem
- ✓ [Descriptor 7](#). Permanent alteration of hydrographical conditions does not adversely affect the ecosystem
- ✓ [Descriptor 8](#). Concentrations of contaminants give no effects
- ✓ [Descriptor 9](#). Contaminants in seafood are below safe levels
- ✓ [Descriptor 10](#). Marine litter does not cause harm
- ✓ [Descriptor 11](#). Introduction of energy (including underwater noise) does not adversely affect the ecosystem.

A 2010 Commission legislation<sup>6</sup> further detailed a set of parameters to help Member States in characterising and defining “good environmental status” of their marine waters. For underwater noise, it looks at anthropogenic sounds that may be of short duration (e.g. impulsive such as from seismic surveys and piling for wind farms and platforms, as well as explosions or long lasting (e.g. continuous such as dredging, shipping and energy installations). Member States would have to measure the Distribution in time and place of loud, low and mid frequency impulsive sounds as well as look at trends in emissions of continuous low frequency sound.

This piece of legislation is currently under review since 2014, and a revised proposal was voted favourably by the MSFD regulatory committee last November. The revised version develops the notions of state, pressure and impact on marine waters, while elaborating on the criteria and

<sup>5</sup> Report from the Commission to the European Parliament and the Council assessing Member States' monitoring programmes under the Marine Strategy Framework Directive, COM/2017/03 final

<sup>6</sup> Commission Decision of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters, 2010/477/EU.



methodological standards to be applied by Member States in their determination of good environmental status, and the assessments and monitoring of their seas.

### **Achievements of the MSFD technical group on underwater noise**

The MSFD's "Common implementation Strategy", which brings EU Member States' experts and stakeholders together to discuss MSFD issues, has a technical group on underwater noise referred to as TG Noise. It is tasked to share experiences and develop guidelines for assessment and monitoring. In 2012 it drafted a report clarifying<sup>7</sup> the purpose, use and limitation of the indicators and described methodology that would be "unambiguous, effective and practicable".

The TG Noise had subsequently identified potential priority work items for support to the operational implementation of Descriptor 11. In 2013, the main focus of TG Noise was on developing operational guidance for monitoring and noise registration for member states. This document provided EU Member States with the information needed to set up monitoring in their marine waters, as required by the MSFD. In 2014, TG Noise provided further advice on the actual progress of monitoring and including advises for the review of the Commission Decision. Since 2015 TG Noise has been working on the upcoming updates of the Art.8 MSFD assessment, while still watching progress on monitoring, in particular for the Mediterranean and Black Sea regions. TG noise has also followed and discussed the development of a register for impulsive noise, supported by the Regional sea conventions in the Baltic and North Atlantic regions, OSPAR and HELCOM. This register is now available and collected by International Council for the Exploration of the Seas (ICES). TG Noise also serves as a platform for discussions to initiate and

promote joint monitoring programmes for ambient noise in Europe. TG noise advice could thereby enable Member States to make a proper assessment of their progress towards achieving good environmental status for this particular descriptor.

A list of reference documents on underwater noise and MSFD at European level are suggested at the end of the article.

### **Future objectives, tasks for the MSFD technical group on underwater noise**

During 2016-2019, TG Noise will pursue a number of tasks. It will continue to assist Member States and Regional Sea Conventions on the implementation of operational monitoring on a number of issues, notably:

- ✓ Establishing the monitoring of ambient noise in a (sub)region;
- ✓ Establishing and interpreting of the noise registers;
- ✓ Applying agreed criteria to provide advice on additional indicators for noise and other forms of energy;
- ✓ Provide input to and follow-up on the review of the GES decision with regard to descriptor 11;
- ✓ Assessment of good environmental status ;
- ✓ Review outcomes of relevant projects.

Other tasks include providing advice on future assessments; developing work on impacts of noise and noise pressure indicators; and ensuring regional coherence notably in developing coordinated monitoring and Regional Action Plans. The work in the TG Noise is related to activities undertaken in Regional Seas Conventions with regard to setting up a register of loud impulsive noise and the development of a joint monitoring programme for ambient noise, though not exclusively. TG Noise provides the link between existing regional initiatives (OSPAR ICG Noise), BIAS (HELCOM) and other Member States in regions where initiative are now under development, e.g. ACCOBAMS (Barcelona Convention).

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7 Van der Graaf AJ, Ainslie MA, André M, Brensing K, Dalen J, Dekeling RPA, Robinson S, Tasker ML, Thomsen F, Werner S (2012). European Marine Strategy Framework Directive - Good Environmental Status (MSFD GES): Report of the Technical Subgroup on Underwater noise and other forms of energy.

## Mains issues and conclusions

Member States have to implement their monitoring programme on underwater noise issues, as well as their programme of measures. They should get prepared for the updates of the assessment and target setting set for 2018. So it remains essential to gather and analyse monitoring data sets. In addition, for impulsive noise, Member States could use the ICES impulsive noise source register, developed under OSPAR and HELCOM conventions. Other Regional Sea Conventions could also consider this impulsive noise register as a good example to develop. Also, for ambient noise, Member States are encouraged to set up joined/coordinated monitoring programmes developed at a regional levels, as is for example the case for the one developed by HELCOM.

Furthermore the use of biodiversity descriptors to strengthen the analysis on the impacts of underwater noise remains crucial. Data, knowledge such as abundance, reproduction and behaviour of relevant key species (e.g. marine mammals and fish) would be necessary to progress towards the analysis of underwater noise impacts on this relevant key-species.

In conclusion, Member States should prepare the second cycle of MSFD, in revising by 2018 their targets, assessment and GES of their marine waters, in regard to MSFD and to the future revised good environmental status decision. They should move towards the development of good environmental status by determining pressure thresholds. Through the abovementioned MSFD Common Implementation Strategy and through funding opportunities such as LIFE+, European Maritime and Fisheries Funds, Horizon 2020 and European Regional Development Fund, the European Commission is providing support to this effect, whereby. Underwater noise issues and impacts are being considered. The MSFD ensures that the EU's seas are used sustainably. In this sense further progress on underwater noise will provide more clarity to how economic activity can develop while respecting the marine environment.

## Main reference documents on underwater noise and MSFD at European level

- ✓ 2012, Van des Graaf AJ and al., European Marine Strategy Framework Directive - Good environmental status (MSFD GES): Report of the technical subgroup on underwater noise and other forms of energy, [http://ec.europa.eu/environment/marine/pdf/MSFD\\_reportTSG\\_Noise.pdf](http://ec.europa.eu/environment/marine/pdf/MSFD_reportTSG_Noise.pdf)
- ✓ 2014, JRC Scientific and policy reports, Technical guidance on monitoring for Marine Strategy Workshop elements, <http://publications.jrc.ec.europa.eu/repository/bitstream/JRC88073/lb-na-26499-en-n.pdf.pdf>
- ✓ 2014, JRC Scientific and policy reports, Monitoring guidance for underwater noise in European Seas. Part I Part II, <https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/monitoring-guidance-underwater-noise-european-seas-part-ii-monitoring-guidance>
- ✓ 2015 CEFAS, Impacts of noise & use of propagation models to predict the recipient side of noise.
- ✓ Outcomes of MSFD TG noise 2016 Workshop on impacts (still to be published)
- ✓ IMO MEPC.1/Circ.833: Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life
- ✓ Accobams, 2013, methodological guide: "Guidance on underwater noise mitigation measures".
- ✓ Member States guidance documents, such as UK guide - 2014 -Good Practice Guide No.133 Underwater noise measurement, <https://www.gov.uk/government/news/cefass-leads-development-of-underwater-noise-monitoring-network>.

EU funded projects related to underwater noise issues such as AQUO SONIC, BIAS, MARVEN and others are also representing good progress in the field.

Relevant MSFD documents may also be found on CIRCABC (Environment/marine strategy), <https://circabc.europa.eu/faces/jsp-/extension/wai/navigation/container.jsp> and the MSFD Competence Centre <http://mcc.jrc.ec.europa.eu>.





## FROM PAPER TO PRACTICE: APPROPRIATELY ASSESSING ANTHROPOGENIC NOISE IN OUR OCEANS

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The ocean environment is filled with natural sound from animals and physical processes. Species living in this environment are adapted to these sounds. Over the past century anthropogenic marine activities have increased levels of noise, and in turn are causing physical, physiological and behavioural impacts on marine fauna, including cetaceans, pinnipeds, polar bears, sirenians, marine and sea otters, marine turtles, fin-fish, elasmobranchs and marine invertebrates including both molluscs and crustaceans. (Southall et al 2007, Hildebrand 2009, André et al 2010, Prideaux et al, in press).

Levels of threat are now well defined. Mitigation and monitoring guidelines exist in many parts of the world. (Weir and Dolman 2007) In many jurisdictions these guidelines rely on Environmental Impact Assessment (EIA) consideration by decisions makers, yet few jurisdictions stipulate what such assessments should contain.

We articulate the existing commitments for European States, both EU and Non-EU Member States, to conduct EIAs in the Mediterranean region; outline why clear guidelines about the content of EIAs are needed; and propose general principles that should be included in these guidelines.

### **EIAs for Marine Noise in Europe**

A series of important intergovernmental decisions have already determined the direction for regulating anthropogenic marine noise through EIAs in Europe and the Mediterranean Sea.

The Convention on Biological Diversity (CBD) 'CBD Voluntary Guidelines on Biodiversity-inclusive Impact Assessment' urges that environmental impact

assessments should be mandatory for noise-generating activities known to be in habitats for threatened species or in regions that provide key ecosystem services and stipulates important principles about consummation and transparency. (CBD 2006) CBD Decision XII/23 also encourages governments to take appropriate measures, including acoustic mapping with habitat mapping of sound-sensitive species, mitigating and managing anthropogenic noise through the use of spatio-temporal management of activities and conducting impact assessments for activities that may have significant impacts (CBD 2014).

The Convention on Migratory Species (CMS) Resolutions 9.19 and 10.24 each propose the control of anthropogenic marine noise in habitats of vulnerable species, and in areas where marine mammals or other endangered species may be concentrated. EIAs are encouraged prior to approving noise-generating activities (CMS 2008; 2011).

The Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS) Resolutions 4.17 urges governments to '[r]ecogniz[e] that anthropogenic ocean noise is a form of pollution' and conduct 'thorough environmental impact assessments being undertaken before granting approval to proposed noise-producing activities'. The ACCOBAMS Noise Guidelines provide further comprehensive detail-specific considerations relating to military sonar, seismic surveys and offshore drilling, shipping and offshore renewable energy developments. ACCOBAMS Resolutions 5.13 and 5.15 reinforce these commitments (ACCOBAMS 2010; 2013; 2013b).

A number of pieces of European Union legislation on EIAs and nature protection are of direct relevance. Directive 2014/52/EU of the European Parliament and the Council, specifically signals that EIAs should be conducted for specific noise-generating activities and that '[e]xperts involved in the preparation of environmental impact assessment reports should be qualified and competent. Sufficient expertise, in the relevant field of the project concerned, is required for the purpose of its examination by the competent authorities in order to ensure that the information provided by the developer is complete and of a high level of quality.' The Bern Convention, the EU Habitats Directive and EU Birds Directive also articulate that significant disturbance should be assessed and avoided in Natura 2000 sites designated for the protection of features such as marine animal species listed in Annex II of the Habitats directive. This Habitats Directive also includes the obligation to assess the cumulative impacts of different activities on the conservation objectives of the site and prohibits deliberate disturbance of strictly protected species that include all species of cetaceans and a number of marine vertebrates and invertebrates listed in Annex IV(a) (EU 1992; 2010; EC 2007; Bern Convention 1979).

The United Nations Convention on the Law of the Sea (UNCLOS) Article 206 contains provision to assess and communicate the assessment of impacts on the marine environment, including forms of marine pollution. (UNCLOS 1982) The International Maritime Organization (IMO) is developing guidance for the reduction of noise from commercial shipping and its adverse impacts on marine life. (IMO 2013) And, the Espoo (EIA) Convention articulates the principles of public comment and transparency around such assessments (Espoo 2014).

### **Guidelines for Marine Noise**

There are few regions of the world that have so comprehensively articulated the need for EIAs relating to marine noise. Despite this, more often than not, EIAs are either not

conducted or are completed in a cursory manner. They often include misleading or erroneous information, use distance as a simplistic proxy for impact and generalize about noise transmission without fully investigating propagation (Wright et al 2013; Prideaux and Prideaux 2015).

The propagation of sound in water is complex and requires many variables to be carefully considered before the impact of a noise-generating activity can be known. Sound is a physical wave, and has effects on organisms beyond hearing. Sound waves move through a medium by transferring kinetic energy from one molecule to the next. Animals that are exposed to elevated anthropogenic noise will experience passive resonance (particle motion) that may result in direct injuries (barotrauma) that can range from bruising through to death. This damage can also include permanent or temporary auditory threshold shifts, compromising the animal's communication and ability to detect threats. Finally, noise can mask important natural sounds, such as the call of a mate, the sound made by prey or a predator (Urick 1983; Lurton 2010; Prideaux and Prideaux 2015, Aguilar de Soto and Kight 2016).

To present a defensible EIA for any noise-generating activity proposal, proponents should be required to expertly model the noise propagation of their proposed activity. The extent and way that sound propagates is affected by many factors, including the frequency of the sound, water depth and density differences within the water column that vary with temperature, salinity and pressure. Consequently, a sound arriving at an animal is subject to propagation conditions that are complex. (Calambokidis et al 2002; Hildebrand 2009; Lurton 2010; McCauley et al 2000) Modelling should be specific to the region and under the conditions they plan to operate (Clay and Medwin 1997; Etter 2013; Lurton 2010; Wagstaff 1981).

### **Marine Noise EIA Content**

The basic intent of an EIA is to anticipate the significant environmental impacts of a development proposal before any

commitment to a particular course of action has been made. Therefore the detail required within EIAs should be clearly defined. (Cashmore et al 2004; Devlin and Yap 2008; Jay et al 2007). At a minimum, EIAs for marine noise-generating activities should:

- ✓ provide adequate baseline biological and environmental information
- ✓ characterise operations and their acoustic components
- ✓ assess the impact on species and consider cumulative effect from anthropogenic activities
- ✓ describe how impacts are to be mitigated and effectiveness monitored
- ✓ objectively compare the posed risk against alternatives that may cause less impact

To provide this crucial information, expert noise modelling incorporating the cumulative impact of sound exposure over a period of time, should be required. Proponent-funded, independent, peer-review of EIA proposals, before submission to regulators, is also important. Finally, transparency is necessary for well-informed consultation and natural justice.

### *Expert noise modelling*

The objective of noise modelling for EIAs is to predict how much noise a particular activity will generate and how it will disperse. EIAs should present expert modelling of the full frequency bandwidth of a proposed anthropogenic noise source, the intensity/pressure/energy output within the full frequency range of the source(s), not only the main output that is of interest to

the activity. Other parameters that should be considered are water depth, seabed topography, temperature and salinity, and whether spatial variation in the environment is significant (Urlick 1983; Etter 2012; Farcas et al 2016).

Particle motion is commonly not considered in EIA modelling. This is an important area to address, as fish and invertebrates detect sound through particle motion to identify predator and prey, rather than through a tympanic mechanism as with marine mammals. Intense and/or prolonged exposure, particularly to low frequencies, can cause barotrauma in these animal groups (Hawkins 1986; Popper and Fay 2011; Morley et al 2014; Farcas et al 2016).

### *Sound exposure level cumulative (SELcum)*

The next important parameter that must be considered is the cumulative impact of sound exposure over a period of time. This is usually 24 hours, unless specified. EIAs should transparently report the predicted sound exposure level cumulative (SELcum) for all marine species in the area. To illustrate this importance, it is useful to consider the significant susceptibility difference of species to single or short duration noise (represented as dB peak) and SELcum over a period of time. The following table, drawn from the latest NOAA 'Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing' (NOAA 2016) demonstrates this difference and the significantly lower threshold for impact of prolonged exposure.

		Temporary threshold shift		Permanent threshold shift	
		Impulsive	Non-impulsive	Impulsive	Non-impulsive
<b>Bottlenose dolphin</b>	SELcum 24h	140 dB	153 dB	155 dB	173 dB
	dB peak	196 dB	n/a	202 dB	202 dB
<b>Sperm whale</b>	SELcum 24h	170 dB	178 dB	185 dB	198 dB
	dB peak	224 dB	n/a	230 dB	230 dB
<b>Mediterranean monk seal</b>	SELcum 24h	170 dB	181 dB	185 dB	201 dB
	dB peak	212 dB	n/a	218 dB	218 dB

*Adapted from NOAA 2016*

### *Independent peer-review*

Proponent-funded independent peer-review of EIA proposals, before submission to regulators for assessment, is crucial tool and a logical requirement for alignment of EIAs with scientific understanding and standards, and ensuring that scientific understanding takes precedence over short-term benefits and political considerations. (Morrison-Saunders and Bailey 2003, DiMento and Ingram 2005, Sheaves et al 2015)

In the case of marine noise-generating activities, independent peer-reviewers should include species experts, acousticians and expert sound modellers who are able to declare full and verifiable independence from the proposal. Their peer-review reports should be fully transparent and submitted to regulators, without influence from proponents.

### *Transparency*

Finally, transparency is crucial for well-informed consultation and natural justice. Noise-generating activities may have wide-ranging impacts on the environment, affecting many different groups in society. Genuine consultation has two key components: participation in the outcome of a decision and that the burden of proof rests with the proponent. To satisfy the burden of proof, the proponent must provide sufficient evidence to demonstrate that there is limited danger of damaging the marine environment or any species that have been highlighted as having importance. The principle of natural justice, in turn, enshrines a right to a fair hearing so that individuals are not unfairly impacted (penalized) by decisions that affect their rights or legitimate expectations (DiMento and Ingram 2005; O'Faircheallaigh 2010; Glasson et al 2013).

This principle is already in use in the United States (US), where applications for marine noise-generating activities that might harm species protected under US law, including naval activities, require a transparent public consultation process. Elsewhere in the world, including European States, naval activities frequently evade such

transparency and even evade environmental regulations.

In many countries it is common political practise to allow industry proponents to hide behind a veil of commercial sensitivity. While not exposing information that is genuinely commercially or personally sensitive, the extent of transparency should always complement the goals of natural justice and consultation. The technical details of any proposal for activities that generate noise should be fully and transparently available for comment before plans are submitted for approval to regulators (DiMento and Ingram 2005; Costanza et al 2006; Sheaves et al 2015).

### *The Utility of EIAs*

Decision makers or regulators are better equipped to determine if a proposed activity will impact species of concern in a given region if thoroughly developed and transparent EIAs are presented. They can request additional information, make their own assessment about the cumulative impact of the proposed activity with other pre-existing activities in the region; consider the timing and the equipment used. Their decisions can be informed and based on solid information.

For instance, if a noise-generating activity was proposed for the Hellenic Trench, and the expert modelling indicated the noise propagation would extend into critical habitat for Mediterranean monk seals and Cuvier's beaked whales (see illustration 1), there would be justification for restricting and/or rejecting that proposal.

Alternatively, if a noise-generating activity was proposed for the Strait of Sicily, and the expert modelling within the EIA indicated the noise propagation would extend into a noise-cetacean interaction hotspot in the ACCOBAMS area (see illustration 2), there would be justification for restricting and/or rejecting that proposal.

There is solid international agreement that EIAs should be conducted. The detail of what should be requisite is known and available. What is needed is a change of practice: by regulators to insist thorough

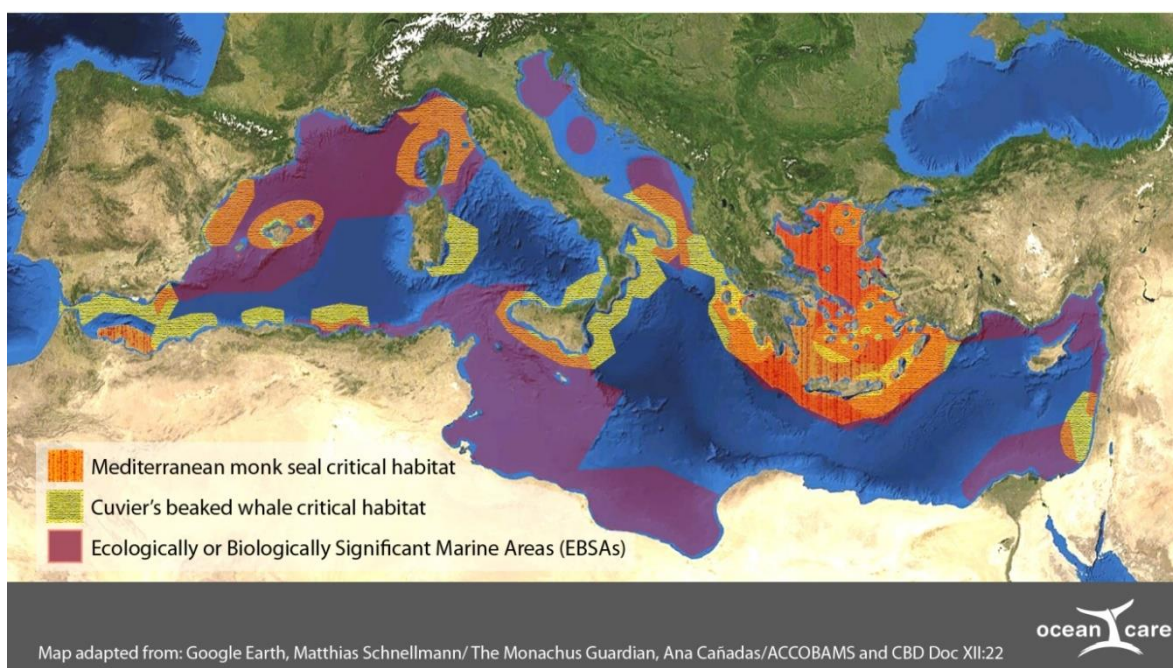


EIAs are presented, and by proponents to accept the same. Only then will there be appropriate assessment of anthropogenic noise in our oceans. Only then will we move from paper to practice.

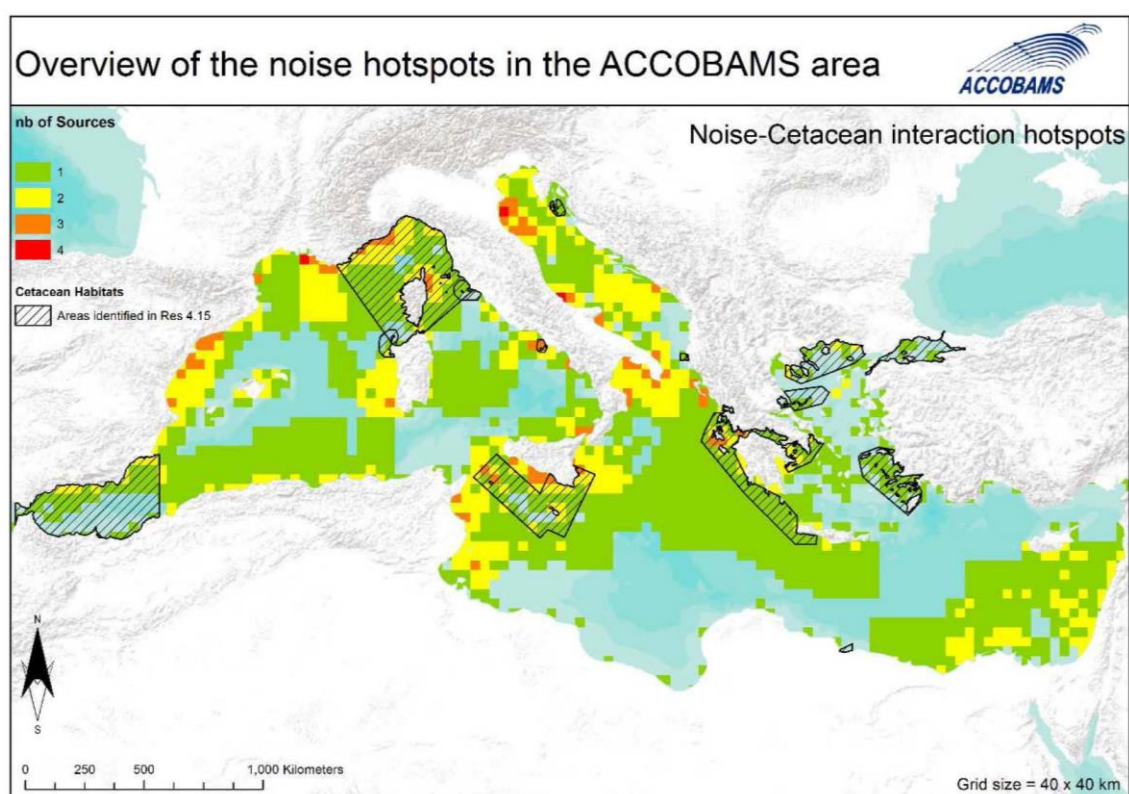
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**Figure 1:** Mediterranean monk seal and Cuvier's beaked whale critical habitats, OceanCare, 2015



**Figure 2:** Noise-cetacean interactions hotspots, ACCOBAMS Secretariat, 2016





# CONTROLLING UNDERWATER NOISE FROM SHIPS

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## Abstract

Underwater noise from vessels is largely unregulated, possibly due to a lack of consensus about the impacts of vessels on marine life. However, the technology required to reduce underwater noise is available today, and can be implemented to reduce noise by 3-5+ dB at a cost that is approximately 1% of the total cost of the vessel.

## Introduction

Concerns about the levels of anthropogenic noise in the world's oceans have risen over the past decade. These concerns have been met with efforts to quantify and characterize sounds produced by vessels, offshore platforms, exploration activities, construction, and the other myriad of activities that humans perform at sea. Various governmental regulatory bodies are also working to perform their own long-term measurements of underwater noise, possibly as a precursor to future regulation. These efforts are important, and provide insights into real-world levels of noise near and far from marine activities. They can also be used for assessments of animal locations, populations, and impacts to marine life as a whole.

Currently, there is limited regulation of underwater noise. Pile driving is the primary exception; multiple European countries apply limits to underwater sound generation from pile driving, and within the USA limits are applied for some projects. Regulation of pile driving noise was likely spurred by a combination of immediate visual feedback of the acoustic impacts (fish have been reported to die nearly instantaneously once pile driving starts in some locations [1]) and the availability of a seemingly effective mitigation method

(bubble curtains). In the many years since initial attempts were made to reduce noise from pile driving, advances have been made in noise control technology and techniques ranging from dewatered cofferdam-barriers to press-in piles [2].

There are very few restrictions currently placed on underwater noise from vessel operations, at least with relation to concerns of impacts to marine life. This may be due in part to a lack of consensus about the impacts of vessel noise on marine life, though it is known that vessels are a major contributor to the rise in low frequency noise throughout the world's oceans as well as local impacts in ports, shipping channels, and other areas where vessel density is elevated [3]. On the other hand, the control of underwater noise from ships is an area that has been studied and implemented for many decades. This is primarily a result of direct military need for quiet vessels. More recently, there has been a drive to design and construct quiet research vessels that provide scientists with a 'stealthy' platform that minimally affects the behavior of the animals being studied.

Reducing vessel noise requires a detailed evaluation of the vessel's design. Even vessels of a certain type (i.e. tankers, container ships, etc.) contain their own nuances, and while there may be commonalities in the major noise sources, methods of controlling noise must be implemented by considering those nuances. For this reason, there is no one-size-fits-all solution to underwater noise. Rather, each vessel design must be acoustically evaluated, and then the appropriate noise control approaches can be implemented.

Underwater noise generation mechanisms from vessels are well understood, and noise reductions could be implemented today. New vessel constructions would benefit the

most, as designing vessels to be quiet is generally more effective than retrofitting treatments.

Costs for such efforts must be considered if vessel noise is to be made inherently quieter worldwide. It is estimated that for most commercial vessels, cost increases of approximately 1% of the current cost of the vessel can be expected for reductions in noise of approximately 3-5 dB. This includes all engineering, manufacturing, material procurement, installation, and validation testing that would be required.

This paper presents an overview of the major sources of underwater noise from vessels, and the means of controlling that noise. Details of cost estimates are also provided.

## Vessel noise sources and solutions

### *Propeller Noise*

- Cavitation and Propeller Design Basics

Propellers create cavitation when operating under moderate to heavy loads. Cavitation is the generation of vapor bubbles ('cavities') within the water when the pressure is reduced below the vapor pressure limit. These bubbles are often visible, especially when cavitation is 'fully developed' (i.e. when there is a lot of it), but can also be present without significant visual cues. Noise is generated when cavitation bubbles collapse; this is a violent, though small scale event that creates noise as well as tremendous heat and even light.

Understanding how cavitation forms requires a basic understanding of how a propeller generates pressures. When a propeller blade rotates through the water, one side creates a suction while the other side creates a positive pressure. This results in a net pressure differential across the blade, creating the thrust that propels the ship. A diagram illustrating this principle for a 2-dimensional blade cross-section is presented in Fig. 1. In this figure, the cavitation occurs in a specific area on the blade face, though the extent and location of cavitation will depend on the pressure

(suction) profile that is specific to the blade and the ship.

- Design

The level of noise produced by cavitation is proportional to the amount of cavitation bubbles that are collapsing during a given time period. Therefore, reducing the amount of cavitation that occurs will reduce the noise in the water. This can be accomplished through modifications to blade geometry, rotation speed, and flow into and out of the propeller.

Blade geometry has a direct impact on the pressure distribution over the blade, which in-turn dictates the degree of cavitation. Many factors can be changed and optimized, including diameter, number of blades, thickness profiles, camber, pitch, skew, rake, and others.

It is the job of the designer to optimize the blade geometry to create sufficient thrust while minimizing cavitation. Ideally, the pressure over a large portion of the suction side of the blade would approach the vapor pressure threshold, while never crossing it. This is difficult to do for practical applications, though using this concept cavitation can be minimized. (Such a design would never occur if noise impacts were not considered.)

The pressure distribution also changes depending on the speed of the water relative to the blades, and therefore rotation rate is an important parameter in propeller design. In general, large, slow-turning propellers will have less cavitation than smaller, higher speed propellers.

The flow distribution into the propeller is another major factor in determining the velocity over the blade, and ultimately in determining the optimal shape for a propeller blade. In open water, the flow into the area occupied by the propeller would be uniform. The real operating environment for a propeller is complex, because the flow into (and out of) the propeller is affected by the presence of the vessel and other appendages. Specifically, the hull displaces the water in front of the propeller, changing

the velocity of water across the propeller area in a non-uniform way.

An example 'wake distribution' is shown in Fig. 2. In this image, the flow is symmetrical about the centerline (left side of the image) and the semi-circle denotes the area occupied by the propeller. The contour lines are boundaries of equal velocity, and the values assigned to each contour are 'wake fractions' which are analogous to an inverse of flow velocity. This contour is an example of how flow velocity presented to a propeller can vary widely with position. The non-uniformity of the wake results in a position-dependent water velocity relative to the blade. This complicates the process of selecting propeller geometries; a particular geometry will generally be optimized for a particular flow, but if that flow is changing as a function of blade position then there is no 'optimal' design other than one that includes many compromises.

For these reasons, reducing noise for any vessel requires an understanding of the wake produced by the vessel, combined with an appropriate analysis of effective blade designs. If performed early in the design, it is possible to combine hull and propeller optimizations using appropriate numerical and physical modeling tools. These tools are currently available and are used in standard practice.

### *Noise from Machinery*

The magnitude of underwater radiated noise caused by machinery will vary depending on the type of machinery, its location in the vessel, and other factors relating to vessel design. Vessels with heavily cavitating propellers will often mask machinery induced noise, with the possible exception of low frequency tones from propulsion and power generation equipment. Conversely, machinery noise will be the dominant noise source when propeller cavitation noise is low.

All machinery items produce local vibration and airborne noise, which can be transmitted to the hull and radiated into the water. These paths can be complex, and again require detailed analysis to determine the dominant path for any particular design.

The tools for assessing and reducing machinery noise exist today. Some of these tools have been implemented for decades, and prediction technology improvements are ongoing. Approaches to prediction and treatment optimization include a range of analytically and empirically based numerical modelling options. Some of these approaches combine fundamental physical principles with practical marine noise control experience and are widely used [5]. Computer programs with 3-D modeling environments have also been developed for improved modeling efficiency and accuracy [6].

### **Costs**

The cost of implementing noise reduction into vessel designs is dependent on the amount of reduction that is required, among many other factors. While this paper does not attempt to assess what noise reduction is needed, it is believed that a 3-5 dB reduction is achievable for many commercial vessels.

When propeller modifications are needed, a reduction in thrust may occur for some designs. This should be expected, particularly for large vessels where the propeller has generally been optimized for thrust. However, these reductions would be minor, estimated to be around 1-2%, and practically speaking would have a small impact on vessel operations especially when compared to imposing speed restrictions to reduce noise. Machinery treatments generally increase weight, though again for a 3-5 dB reduction this increase would be small and should not affect vessel operational efficiency.

The monetary costs for noise control of this magnitude are estimated to be between \$100-500k USD. This would include all increases to cost for design, manufacturing, installation, and verification testing. This would be an increase in cost of around 1% for many commercial vessels. Costs will be lower in cases where noise goals are added to propeller design efforts that already include detailed analyses to optimize thrust. Costs will certainly be on the higher end for existing vessels and when implemented as

an 'add-on'; noise control should be built-in to the design of new vessels at an early stage.

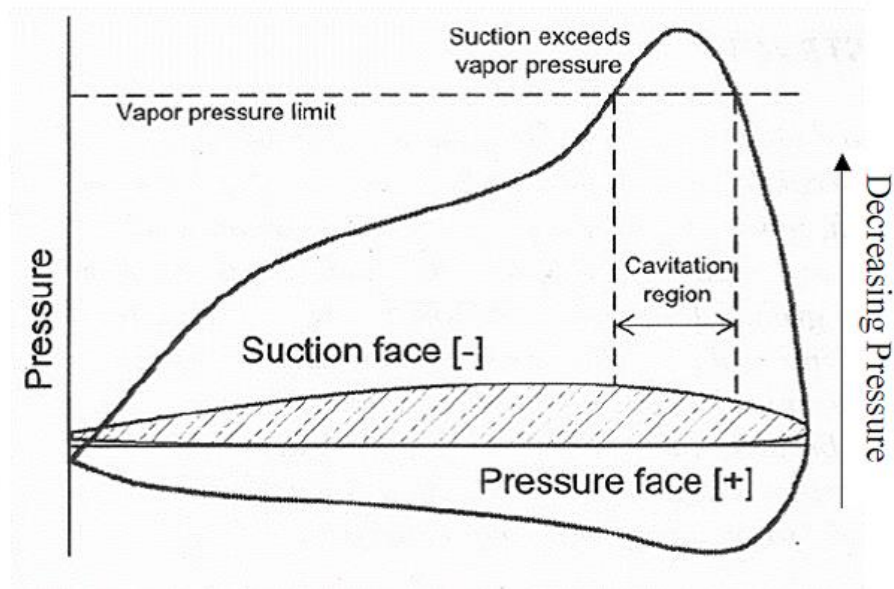
## Conclusions

The vast majority of commercial vessels have been designed without consideration for underwater noise, though the technology required to reduce noise from vessels is available today. Noise control solutions must be designed and implemented on a case-by-case basis. The development of real solutions can only be accomplished with an intimate knowledge of pertinent aspects of each vessel. This is most cost effective when performed during the vessel's design stage. Retro-fitting treatments is possible, but results in additional costs and design limitations.

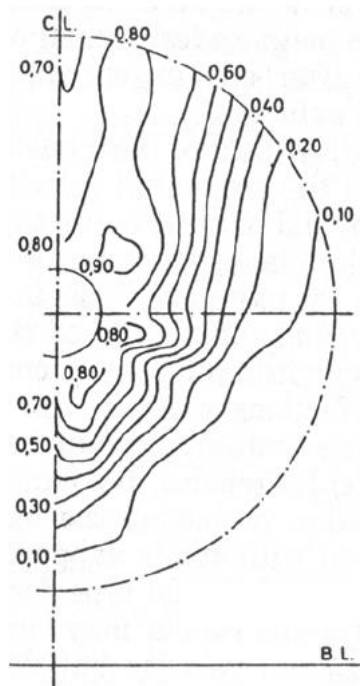
Vessels can be designed to be quiet, but to make a significant impact in local and global underwater noise there would need to be definitive noise goals for each vessel. The increase in cost for many commercial vessels would be around 1% of the total cost of the vessel for a 3-5+ dB reduction relative to existing noise levels.

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**Fig. 1:** Example pressure distribution over propeller blade, with cavitation area noted [4]



**Fig. 2:** Example wake distribution showing flow velocity into the propeller [4]. Contour lines correspond to locations of equal 'wake fraction' which is analogous to the inverse of flow velocity. Note the wide range of flow velocities.





## WHAT MEANS TO PROTECT SENSITIVE MARINE MAMMALS FROM PILING NOISE OF OFFSHORE WINDFARMS FOUNDATIONS INSTALLATION?

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Offshore windfarms (OWFs) have been developing for more than twenty years in Europe at a still increasing pace. A lot of European countries decided to use it to improve the renewable share of their energy mix: wind is more consistent offshore and space is less limited than onshore, making offshore windfarms an interesting solution for renewable energy development.

As of June 2016, 3 344 offshore wind turbines with a combined capacity of 11 538MW are producing electricity in Europe (<https://windeurope.org/wp-content/uploads/files/about-wind/statistics/WindEurope-mid-year-offshore-statistics-2016.pdf>). More than 80% of these wind turbines are installed on monopiles driven in the ground by piling. This installation process is the most commonly used and can produce high level of noise depending on monopile dimensions, water depth, soil conditions on site and installation technics (Figure 1 LEFT). This part of OWF construction is recognized as the noisiest one of all construction activities (even if driving a monopile into the ground can last only a few hours in some cases) and a legal issue in many European countries. For impulsive sounds biological impact measurement the indicator Sound Exposure Level (SEL) is in use. It is a level of acoustic exposure perceived by an animal, a representation of noise accumulation received by a receptor over a period. Noise spectrum of pile driving is usually between 50 Hz to 16 kHz (Figure 1 RIGHT). This underwater noise can impact marine life and more specifically marine mammals either as injury or as disturbance as they are high sensitive species, usually having a large frequencies hearing range.

To prevent and minimize impacts on marine mammals, offshore wind industry has

developed a large variety of methodologies and devices so that effects of piling noise is limited. We propose to discuss here the different means at the disposal of an offshore wind farm developer and understand in which cases they might be preferably used.

1. An approach dedicated at respecting a specific noise level: noise mitigation systems to reduce piling noise
2. Deterrence means focused on taking sensitive species away from impacted zones

### Noise mitigation systems (NMS)

Several noise mitigation systems have been developed to lower piling noise (figure 2).

The most commonly used are Big Bubble Curtains (BBC). It consists of rings of perforated pipes positioned on the sea floor around the foundation to be piled out. The air passes into the water column by regularly arranged holes. They can be used with a single pipe or with two to three layers of pipe, increasing the sound insulation. Depending on site characteristics (current, water depth, soil conditions etc.) and on project parameters (type and diameter of foundation, hammer and installation boats) bubble curtains can achieve a noise reduction from 10 to 18 dB SEL broadband (Bellmann 2014). It usually permits a little decrease in Sound Peak Levels (SPL) noise.

Another noise mitigation system is the Hydro Sound Damper (HSD). It consists of a fisher net where foam plastic or gas-filled balloon of different sizes are included. This fisher net is ballasted by a weighted ring allowing its good deployment around the foundation. The radiated noise from the pile will be reduced by the absorption-reflection of HSD elements. HSD system can reach a

noise reduction of 8-13 dB SEL broadband (Bellmann 2014) depending on the number and type of HSD elements in the fisher net.

IHC has developed a specific NMS, the so called IHC tube consisting of a double-wall steel screen (tube) where monopile is inserted inside the system. Space between the two screens is filled with air and air bubbles can be feed-in between pile and NMS system. The radiated sound crosses the internal bubble curtain as well as the air-filled double-wall steel screen and will be reduced due to reflection (impedance gap). In situ measurements showed this tool may lead up to 43dB reduction in certain frequencies (IHC presentation at 3<sup>rd</sup> workshop of "Racket in the Oceans" on the 17<sup>th</sup> of May 2016 in Paris). An alternative quite similar to IHC's NMS is the cofferdam: it consists of a single wall tube put around the foundation and full of air. The pile is then installed "in air" and the sound of piling is first transmitted to the air before getting transmitted into the water after transiting through the steel screen. Impedence differences between the two will make the sound reflect and decrease it. In order to make Cofferdams work properly, a good gasket needs to be put so that the space between pile and steel tube can be filled with air. This operation can be quite complicated and difficult to set in offshore conditions. If it is done properly, a decrease of up to 20dof SEL broadband can be achieved (Bellmann 2014).

All these noise mitigation systems have been developed to comply mainly with German regulations fixing certain limit to sound emission levels. For example noise should be limited at 160dB SEL or 190 dB SPL at 750m from piling location in Germany, 185 dB SPL in Belgium, 160-170 dB in the Netherlands with periodical restrictions. Those noise limits may not be perfectly adapted to all marine mammal species and were mainly directed at seals and harbour porpoises. NMS can be combined and in many recent OWFs of German EEZ, they were combined in order to comply with the 160 dB limit (Figure 1 RIGHT). Each of these NMS have also their own limits and constraints. For example BBC are poorly working when current is too

important as bubbles are driven away and pipes have difficulties to be stabilized on the ground.

Unfortunately as each project has its own characteristics (depth, current, soil conditions, pile diameter, etc...), each combination of NMS was not established a priori but after a certain time of testing and adjustment at the beginning of each project installation. Therefore it is difficult to establish a standard NMS working for every project: it needs time to find the right and adapted combination. Another important aspect is that NMS are still under development and their reliability is still increasing: some progress is still awaited for future projects. These solutions can represent 10% of the installation costs for foundations, and have to be diminished since the industry is fighting to have a competitive LCOE.

### **Deterrence means take marine mammals away from impacted zones**

In some countries (Denmark, United Kingdom, France) there is no legal limit to noise levels. The law anyway requires to take into consideration the sensitivity of each species of marine mammals located in the construction area during the initial state of the environmental impact assessment. This "species driven" approach uses deterrence means to be sure that marine mammals will not be present in sectors where physical damages of hearing may occur. Mammals usually flee from noisy sectors far before the noise reaches the level of temporary injury (TTS for Temporary Threshold Shift) or permanent injury (PTS for Permanent Threshold Shift). For instance, harbour porpoises detections clicks were observed to decline significantly before any piling or use of deterrence measure to distances of up to 10 km, probably due to an increase in shipping activity related to preparation works (Miriam J. Brandt et. al., 2016).

Several tools have been developed to chase away sensitive marine mammals and to avoid any physical damage.



## Soft starts

A first way of mitigating the effects of the noise generated, is to begin the piling sequence with a gradually increasing energy level, this procedure being termed a "soft start". The mammals have time to flee away from the PTS and TTS sectors. Robinson et al. (2007) for example described precisely the piling sequence (from 80 kJ to 800 kJ) and measured the consequent increase of the noise level (+12 dB peak to peak).

## Seal-scarers or pingers

It was first a need for offshore aquaculture to chase away seals from production facilities and decrease their predation on farmed fish. This was allowed by the use of seal-scarers or pingers. These devices are acoustic repellent. However, seals were shown to habituate quickly to these deterrence devices and could even lead to a "dinner bell" effect (Brandt et al. 2013). With regards to OWFs, seal-scarers have proven their efficiency also for harbour porpoises, scaring them away at up to 7.5km from deterrent device (Brandt et al. 2013).

Even though scientific evidences are lacking for the efficiency of these deterrence systems, many different studies (Dähne et al. 2013) showed that mammals are usually scared away from windfarms during construction. Presence of mammals may be modified until 22 km from piling workshop (Degraer et al., 2013). This distance is significantly higher than the distance where injuries (PTS - TTS) can occur, for example 2.3 km in Southall and al. 2007. Marine mammals observers (MMO) have been classically used in United Kingdom to monitor if a mammal is too close to noisy workshop as for example seismic surveys (JNCC, 2010). But detection range of the MMO for small mammals may be below the impact range. For instance, maximum detection range estimated by Leaper and al. (2015) for Harbour porpoise (*Phocoena phocoena*) is 358 meters in the North Sea conditions. Real time monitoring of the presence of the mammals through hydrophones and adapting piling strategy to the monitoring (i.e. interrupt piling if an animal is detected in the impacted area) can

improve the efficiency of these deterrence system (Nehls et al, 2015).

## Conclusion

We presented in this article different solutions that help minimize pile driving noise and prevent biological impacts related to OWF construction. Some key questions regarding these solutions employment are:

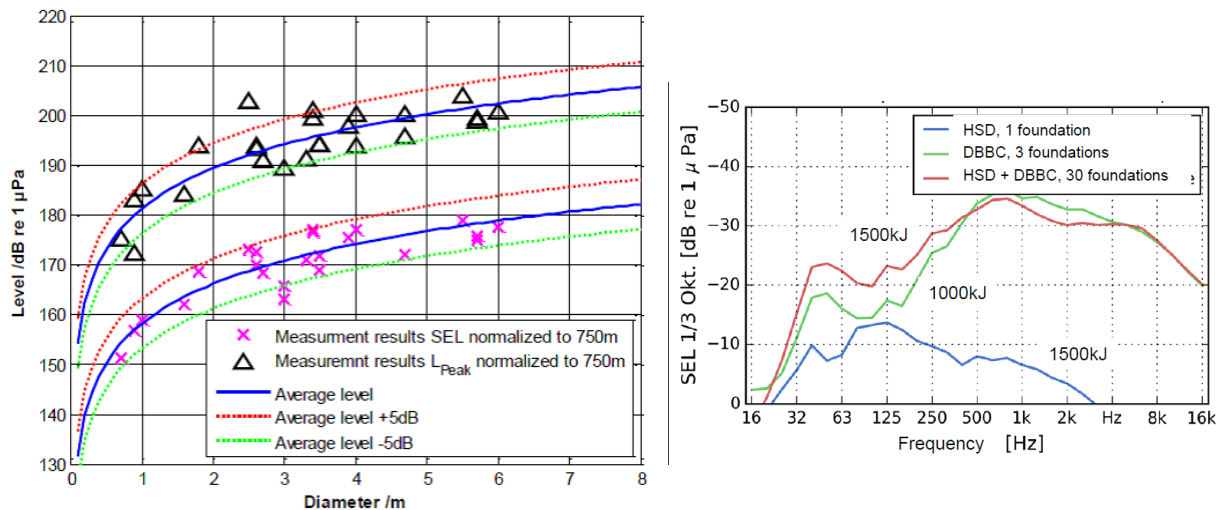
- ✓ Is the solution adapted to the site conditions (depth, current, soil, but also hearing sensitivity of species present on site)?
- ✓ What costs each solution would represent and what implementations constraints would it add (ie extra boat, additional standby due to meteo-oceanic conditions, boat mobilization time increase, etc.)
- ✓ What regulatory constraints do I have to comply with?
- ✓ Is the solution I am going to use reliable (as a lot of research and development are still ongoing and some solutions have been used only in experimental conditions)?

There is no "turnkey" solution neither perfect "state-of-the-art" solution. Each project needs a specific evaluation, based on an initial state to determine which species are present in the area, and on economic and technical assessment of mitigations that can be put in place.

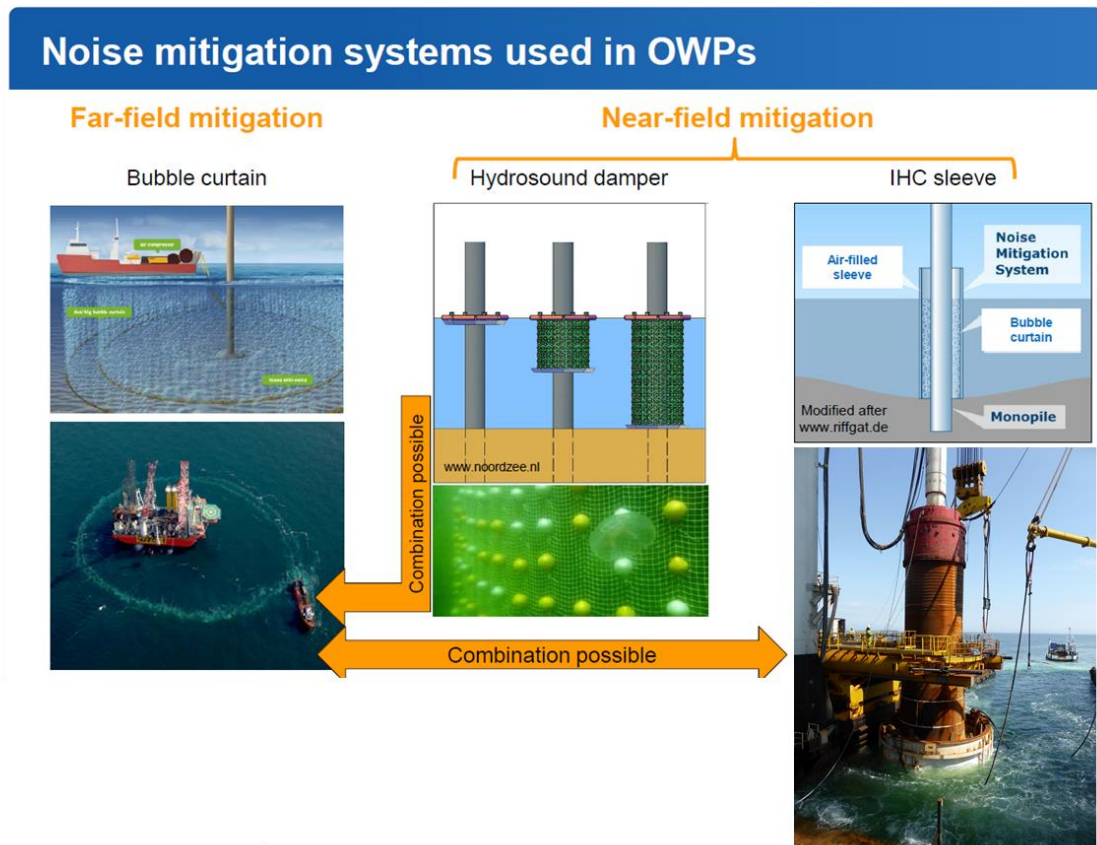
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**Figure 1:** LEFT – Measured Peak Level ( $L_{peak}$ ) and broadband sound exposure levels (SEL50) during pile driving work at diverse OWFs as a function of pile diameter measured by ITAP. (Michael A. Bellmann 2014). RIGHT – spectra of noise mitigation at OWF Sandbank with different NMS



**Figure 2:** Types of Noise mitigation systems (after Dr. Eva Philipp)



# ADDRESSING UNDERWATER NOISE IN MARITIME PROJECTS: IMPORTANCE, CONTROL AND MITIGATION AND FUTURE PERSPECTIVES

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## Importance of the issue for the maritime industry

The increase of anthropogenic activity at the seas and oceans intensifies the pressure on marine ecosystems. Worldwide there is a growing need for protection and conservation of the marine life. Maritime activities such as marine traffic; surveying and exploitation of mineral and hydrocarbon resources; marine construction and the installation of offshore renewable energy projects generate marine pressures and can particularly increase underwater noise. Not only the noise generated by specific anthropogenic activities has been recently studied, there is also increased knowledge on the marine sounds emitted by different species and the ways marine fauna use sound for communication and survival.

On regulations and standards, the European Marine Strategic Framework Directive (MSFD), adopted in 2008, requires member states to monitor the environment and to implement measures to achieve good environmental status by 2020. Qualitative descriptors for good environmental status include underwater noise. The MSFD states 'introduction of underwater noise does not adversely affect the ecosystem' (European Commission, 2016). International standards are currently in development for underwater acoustics and for marine technology. ISO, for example, has two committees on these issues (Audoly *et al.*, 2016).

The rapid development of offshore wind farms at sea requires pile driving for the foundations of the wind turbines in relatively shallow waters. Some classification societies have published rule notes with their recommended measurement procedures and limit values.

In Europe countries such as Germany, Belgium and the Netherlands have established regulations with limit values for pile driving induced underwater noise.

## The need for maritime operating companies to address underwater noise

For operators, it is important to understand and manage the footprint from their projects. For technology providers it is important to recognize the source of the noise and to understand its characteristics. This constitutes the basis for the design of control measures or avoidance from the source. In maritime projects, a noise source could be a specific system or a specific component of a vessel or the operation of auxiliary equipment according to the type of project. The source levels are also depending on the environment where a project takes place. The impact on specific fauna depends on those factors as well as on the resilience and adaptation of specific marine fauna. Understanding these variables allows for better planning of projects, execution, adaptive planning and it provides the basis for the design of control and mitigation measures at the noise source.

Pile driving for renewable energy projects generates high energy sound pressure pulses that could potentially exceed safe sound levels for specific marine species. In response to this, Germany, Belgium and The Netherlands, for example, have opted to establish stringent limit values for Sound Pressure Levels (SPL) as well as for Sound Exposure Levels (SEL) generated by pile driving. Compliance with European thresholds have been a main driver for the development of noise mitigation methods.

## Noise Mitigation System for pile driving: technology and development trajectory

The offshore wind farm construction projects have different type of installations according to the project circumstances and needs. Those can be: mono piles; tripods; tension legs; spar and spread moored; etc. The installation of mono piles requires pile driving. Worldwide, mono-pile installation projects currently occur at water depths of up to 45 m with pile diameters from 1.5 m up to 7.60 m.

Germany established strict legislation on underwater noise for the protection of the marine environment, particularly focused on the protection of the 'harbour porpoise'. Harbour porpoises as well as seals are endangered species in German sea waters. For this, the limits established are maximum 160 dB SEL05 and 190 dB SPL(peak) measured at 750 m from the pile installation. Belgium has established a maximum SPL noise level of 185 dB. The Netherlands has established specific installation windows (three periods of time during the year) and has defined specific SEL levels that vary according to the number of turbines to be installed.

IHC has developed the 'Noise Mitigation System (NMS) in a research and development (R&D) trajectory that has started in 2007 with the initial planning and collaboration with research institutes and the Delft University of Technology. Design, construction and dedicated monitoring of the performance of the NMS during the installation of several offshore wind projects have generated specific knowledge for the development of the mitigation system and its optimisation. Although the development of a noise mitigation system was a sustainability objective within the R&D trajectory, the compliance with the European legislation thresholds has provided insight on the specific SEL and SPL levels to be achieved.

The Noise Mitigation System consists of a double wall steel casing, with stiffeners to reduce water pressure, currents and wave impact. The gap between the inner and

outer screen is a compartment which can be filled with air. To prevent transfer of vibrations, rubber cushioning blocks and a seal are installed between the inner and outer screens. This gap is filled with minimum airflow. Inside the NMS a multi-level and multi-size bubble injector system is used to optimize the bubble mixture and therefore, the mitigation system according to local circumstances and water depth. Several places on the inner and the outer screen are prepared for placement of sensors e.g. for measuring of pressure and acceleration.

The design and optimization of the system requires handling of offshore condition challenges such as weather windows, sea state including waves and currents and handling of equipment on board. A 'Guiding Tool' was designed for the installation of the NMS. This tool is used to launch the NMS and to correct the inclination of the mono pile during its installation. To be successful, the NMS must effectively reduce underwater noise and its installation and retrieval must be both efficient in time and cost savings. Cost savings have been achieved by for example, speeding up the installation sequence by using inclination devices and GPS. The tested inclination devices are widely known and accepted, eliminating the costs from warranty surveyors during installation. Another way of cost savings is by accurate positioning and inclination which reduces the penetration depth and therefore the pilling time. Also, limited human interference during installation reduces pilling time, and therefore improving cost savings.

The NMS has been used in projects in Germany such as Riffgat, Riffgrund, Butendiek OWF, Amrumbank, Gode Wind and Nordsee One. Results achieved during full scale offshore tests have confirmed compliance of pile driving with the NMS with legislation in Germany, Belgium and The Netherlands. A reduction of up to 45 dB is achieved in the frequency band from 10 Hz to 20 kHz (approximate hearing range of harbour porpoises and seals). Results show that when reaching the 160 dB SEL05 level, a parallel maximum SPL level reaches 180 dB.



The design of the NMS depends on the variations in water depth, location, seafloor conditions, weather conditions, diameter of mono piles, hammer size/force, whether the pile is a running or a fixed pile, water temperature, sea level and waves, among others. Other conditions include the background underwater noise. In the North Sea, the background underwater noise is approximately 100-110 dB depending on sea traffic conditions. It has been measured that rain can increase the background noise level up to 15 dB. The total background noise before pile driving and including the installation vessel in stand-by can be approximately 130-140 dB.

#### **Use of additional methods: e.g. deterring systems and bubble screens**

In some projects, the standard mono pile installation procedure starts with the over boarding of the mono pile and with the positioning on the seabed and activation of the deterring system for marine fauna (e.g. seal scare and ping devices). Deterring systems are usually activated for 30 minutes prior to the start of piling. Piling starts with a soft blow, the soft blow is repeated each 30 seconds with limited energy during 30 minutes. Once the starting operation is completed, the energy can be gradually increased up to effective pile driving (standard pile driving frequency is in the order of 40 blows per minute). Sea deterring systems are then turned off. Measurements on site have shown that the use of deterring systems might not be required as similar frequencies are reached at the start of pile driving. See Figure 1.

Figure 2 shows the SEL and SPL levels achieved by the NMS (without additional bubble screen) at the Riffgrund project for a specific pile installation. For the complete installation project, less than 1% of the blows exceeded the 160 dB (SEL05) threshold. Additional bubble screens surrounding the pile driving and the NMS may be used as a complementary mitigation measure. The project Butendiek OWF, was situated in the German nature reserve area 'Natura 2000' and required an additional measure to maintain the noise levels under

the limit. For this project an additional bubble screen around the NMS was installed.

#### **Current developments and future perspectives**

The first versions of the Noise Mitigation System are the NMS-6900, -6000, -6500 and -8000, these vary on diameter and size according to pile hammer specifications as well as environmental conditions such as water depth. The experience and knowledge gained during the development and testing of the system have been used for the design of the next generation NMS versions and have provided future market directions. Results from monitoring demonstrate that 95-100% of the water-borne noise from pile driving can be mitigated by the NMS. However, full scale tests have shown that when using the NMS the ground-borne noise, transferred from the pile into the seabed and from the seabed into the water column, is still an important noise source. This is currently the main challenge for further research and design of control measures. Specialized modelling (Novicos) has been done to further understand this process (Kringelum *et al.*, 2015). Modelling results also showed the effectiveness of the installation of a bubble curtain around the NMS in reducing the ground-borne noise and its propagation into the water.

These insights have been key for the development of a complementary mitigation measure to the NMS, the 'Royal Umbrella Noise Mitigation System' RUNS. The system is situated on hinges at the lower part of the NMS structure. The bubble curtain consists of two hoses which create a total bubble curtain around the NMS at a radius of approximately 30 m. This integrated system eliminates the use of an additional 'external' bubble curtain, which requires a dedicated vessel for installation, large crane capacity and dedicated personnel for launching, operation, and recovery. The integration of a bubble system within the NMS significantly reduces operational costs and project risks while a reduction of the carbon footprint for the project is also achieved.

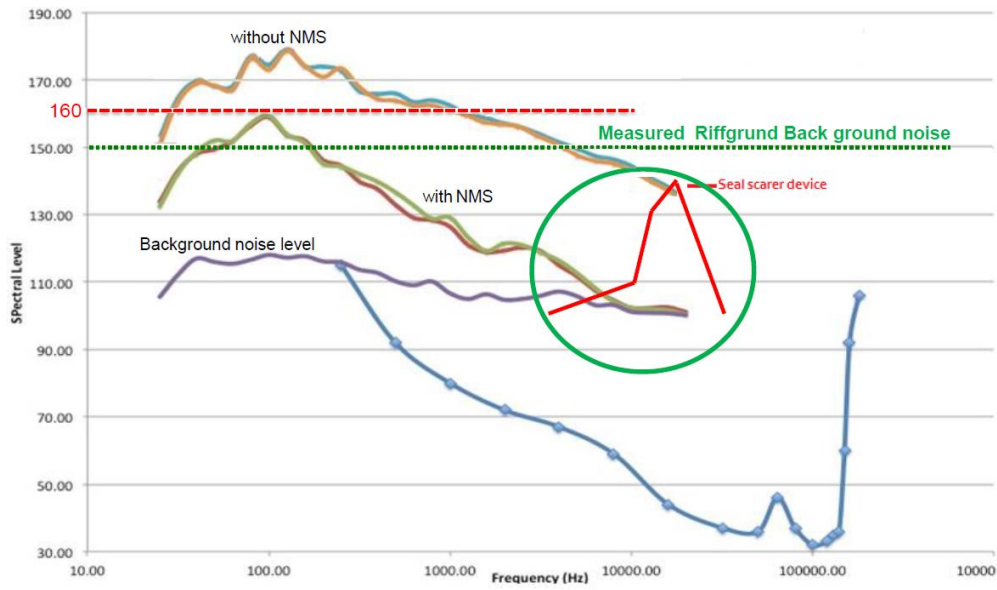


Current developments aim to optimise the RUNS and the NMS. Software and design adaptations are required for the optimisation through real-time monitoring. This provides the possibility for immediate intervention if noise levels are exceeded. The main objectives are to reduce the pile installation time; reduce impact energy and noise levels. An installation method called HiLo consisting of high frequency (increased blow rate) and low energy (use of minimum energy required to break the soil resistance) has demonstrated important reduction in noise generation. Real-time monitoring provides large amounts of data that are used for planning and adaptations in future operations and for product development.

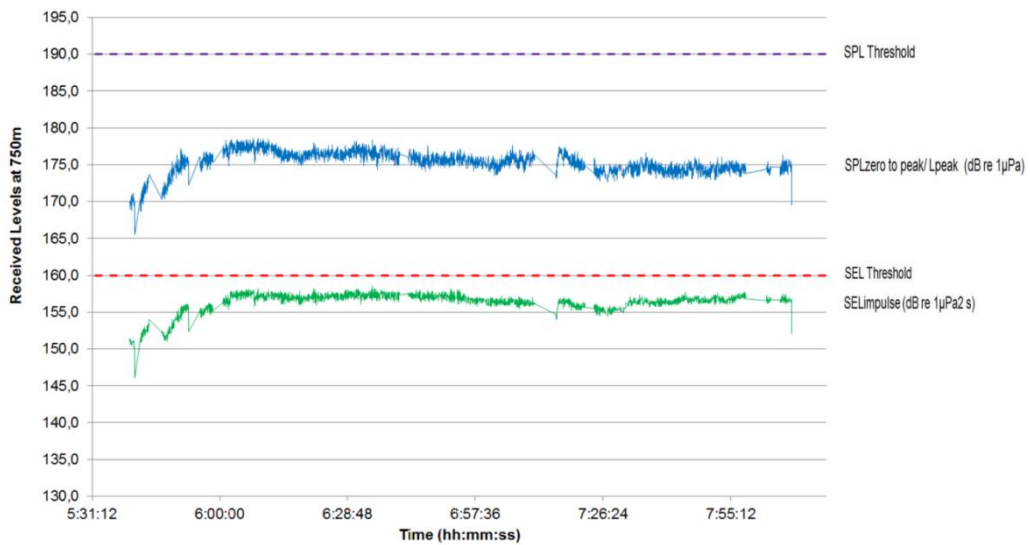
Underwater noise in oceans and seas is currently an important issue. Scientific research has provided more insight on the adverse effects that underwater noise can have on marine ecosystems. Also, European regulations and standards have been an important driver for the development of technology that minimises underwater noise during pile driving of offshore wind farms. Other drivers are cost savings and the reduction of the environmental footprint during installation of the mono piles. Pile driving methods and noise mitigation measures are primarily dependent on the design and specifications of the wind turbines to be installed. Today larger wind turbines are being developed to serve the deeper sea areas and therefore demanding adapted piling methods and systems.

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**Figure 1:** Measured noise levels in Riffgrund project. Background noise (purple); Piling noise level with and without NMS (light green and orange, respectively); hearing range for harbour porpoise (blue) and seal scarer device (red). Source Royal IHC



**Figure 2:** NMS-6000 Riffgrund project. Noise results for Pile 15. Pile driving at reduced energy conditions. Max. 59 blows/min. Measurements using only the NMS-6000 without an additional bubble curtain. Source: Royal IHC



# **THE ENHANCING CETACEAN AND HABITAT (ECHO) PROGRAM: A PORT AUTHORITY-LED COLLABORATIVE INITIATIVE WORKING TO REDUCE CUMULATIVE NOISE IMPACTS OF COMMERCIAL VESSEL ACTIVITY ON AN ENDANGERED KILLER WHALE POPULATION**

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## **Background Context**

The west coast of British Columbia, Canada is a dynamic and growing international trade gateway. It is also a productive coastal ecosystem that sustains populations of whales, porpoises and dolphins (cetaceans). Fisheries and Oceans Canada (DFO) has published Species at Risk Act recovery strategies and action plans for a number of at-risk whale species in the region. Some of the key identified threats to whales in this region include: acoustic disturbance, physical disturbance), environmental contaminants, and the availability of prey.

Much of the commercial vessel activity in the southwest coast of Canada transits DFO-designated critical habitat for endangered southern resident killer whales, as well as areas known to be of importance to other at-risk whales. Currently, the population of southern resident killer whales is just 84 individual whales. These iconic whales have cultural significance for First Nations and all Canadians. The human population of the Metro Vancouver area, currently 2.3 million people, is predicted to grow by one million people by 2040, and with increased trade demands and a number of potential marine projects coming on line in Canadian and American waters, commercial vessel traffic through southern resident killer whale designated critical habitat is predicted to increase over the same time.

Vancouver Fraser Port Authority is committed to ensuring port activities are undertaken in a responsible and sustainable manner that safeguards and promotes continual protection of the environment. For these reasons, the Enhancing Cetacean Habitat and Observation (ECHO) program was developed.

## **ECHO program description and goals**

The ECHO program is a Vancouver Fraser Port Authority-led collaborative initiative aimed at better understanding and managing the impact of cumulative shipping activities on at-risk whales throughout the southern coast of British Columbia. A suite of individual short-term projects, scientific studies and educational initiatives are being advanced by the ECHO program. Between now and 2018 it is intended that these projects will fill knowledge gaps around vessel-related cumulative regional threats and will inform the development of mitigation solutions, threat reduction targets and management options. The long-term goal of the program is to quantifiably reduce threats from commercial vessel-related activities to at-risk whales.

## **A collaborative approach**

Launched in November 2014, the ECHO program aims to engage and involve key regional interests to maximize program success and help ensure that mitigation and management measures developed through the program are informed by social, cultural, economic and environmental interests. Stakeholders include scientists, maritime industries, conservation groups, First Nations individuals and government agencies - who collectively set goals and objectives and help focus program efforts. Along with a core Advisory Working Group, an Acoustical Technical Committee was established to provide technical and scientific advice in the development and execution of ECHO research, mitigation and management projects and is composed of marine mammal biologists, acousticians, naval architects and others with specific technical knowledge around the sources and

impacts of underwater noise. The ECHO program is also an end-user to a number of national and international underwater noise research projects, including the AQUO Project.

### **Projects and studies to inform mitigation and regional management – Acoustic disturbance**

Through consultation with the Advisory Working Group and Acoustic Technical Committee, an acoustic work plan was developed and a number of research projects have been initiated which aim to fill specific data gaps and enhance understanding of regional cumulative vessel noise impacts. These projects include the following, some of which are highlighted in more detail below:

- ✓ Strait of Georgia underwater listening station
- ✓ Regional acoustic model and identification of vessel noise contributors to noise budget
- ✓ Regional ambient noise monitoring network
- ✓ Development of a port incentive program for quieter vessels
- ✓ Comparison of behavioural response of killer whales to shipping vs. whale watch vessel noise
- ✓ Investigation of the effects of ship noise on vocal behaviour of humpback whales
- ✓ Development of an infographic on underwater noise and delivery of educational seminars to vessel owners/operators

The ECHO Program is using the outputs of these acoustic science research projects to help stakeholders better understand and take action on the issue of acoustic disturbance, to inform science based decision making and to inform the development of vessel noise reduction solutions.

### **Regional Management Applications. Project highlight – Strait of Georgia Underwater listening station**

The ECHO program has partnered with Ocean Networks Canada (ONC), JASCO Applied Sciences Ltd (JASCO) and Transport

Canada to install an underwater listening station in the Strait of Georgia on the approach to the Port of Vancouver. The listening station is comprised of JASCO Autonomous Multi-channel Acoustic Recorders (AMAR) 4 element hydrophone arrays and is located at 173m, beneath the inbound shipping lane. The system is connected to ONC's cabled Venus Observatory and is designed to approximate as closely as possible to ANSI/ASA S12.64-2009/Part 1 standard for measurement of vessel underwater radiated noise.

Working with local vessel pilots, the ECHO program is encouraging as many deep sea vessels as possible to accurately transit the underwater listening station. For each vessel that correctly transits the measurement zone an automated vessel source level report will be generated which includes monopole and radiated noise levels; frequency M-weighted (low, mid and high frequency cetaceans) vessel noise emission levels and an "in class" vessel performance ranking. The PortListen software (See Figure 1) developed by JASCO allows ECHO program staff to review which vessels have accurately transited the listening station, view and listen to the vessel sound signature, and generate a report which can be provided to the vessel owner.

As the listening station is continually recording underwater noise, the sound measurements obtained are also being used to generate an ambient noise report for each lunar month, as well as a monthly marine mammal occurrence report.

The outputs of the underwater listening station will be further used to:

- ✓ Help vessel owners/operators understand vessel noise levels and performance in class and identify potential mechanical problems
- ✓ Inform the development of potential incentive or recognition programs for quieter vessels
- ✓ Test potential vessel noise reduction options e.g. hull cleaning, speed variations
- ✓ Build comprehensive vessel source level database

- ✓ Refine vessel source level measurements for future noise modelling

### **Regional Management Applications.** **Project highlight – Regional acoustic modelling and noise budget**

An acoustic model has been developed by JASCO which captures the region where vessel transit routes overlap with southern resident killer whale critical habitat (see Figure 2). The region is represented on a computational grid, with shipping density specified at each grid point through the use of AIS tracks. According to the vessel category and speed, a vessel noise source level is applied to each vessel at each grid point, and noise transmission to surrounding grid locations is calculated using a sound propagation model. The propagation model takes into account the water depth, the sea bottom type and the water sound speed profile.

Using this acoustic model, the ECHO program commissioned a regional noise budget analysis for the months of January and July 2015 to model average, monthly, vessel-generated noise levels for different sub-regions and different vessel categories. Vessel traffic was broken down into general categories including: container ships, oil tankers, other merchant vessels, ferries, tugs, government/research vessels, fishing vessels, passenger/cruise ships, recreational boats, whale watching boats and other/unidentified vessels. The output of this analysis provides an understanding of how and where each of these categories of vessels contributes to the underwater soundscape of the region. With this information, the ECHO program can identify which vessel sectors should be engaged in noise reduction efforts and in which geographical areas, as a means to reduce noise impacts on at-risk whales.

Additionally, the model serves as a powerful tool to simulate different vessel traffic scenarios and evaluate the efficacy of potential mitigation measures. Parameters can be varied within the model to predict

how underwater noise may differ if vessels were to be re-routed, slowed down, if traffic were to increase due to a specific project, or if the mix of vessel sizes and categories transiting the region were to change in the future.

### **Global Applications**

The Vancouver Fraser Port Authority is taking a proactive approach to maintain a healthy ecosystem within a busy and prosperous marine gateway.

The ECHO program aims to enhance understanding of the cumulative impacts of shipping on whales in this region and to develop voluntary mitigation measures and incentives for vessels owners and operators to reduce those impacts. As the issues around underwater noise gain momentum within the global shipping industry, the science and solutions being developed by the program may see global application.

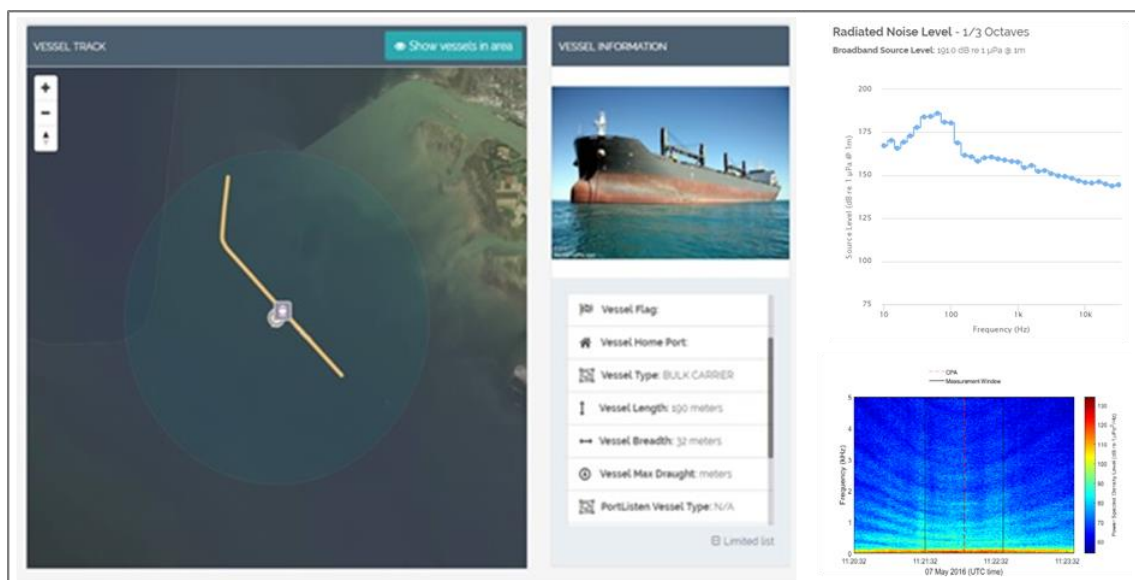
Many of the projects being undertaken through the ECHO program, including the underwater listening station and the regional noise model, are developing new and innovative approaches to understanding vessel underwater noise. These technologies and tools could potentially be applied at other ports worldwide.

The ECHO program serves as an example of how industry, science, environmental groups and local community interests can work together towards a common goal of reducing the impact of shipping. Through early stakeholder engagement, positive collaboration and informed, science-based decision making, the ECHO program could provide a model for other ports to consider when contemplating how to address similar issues.

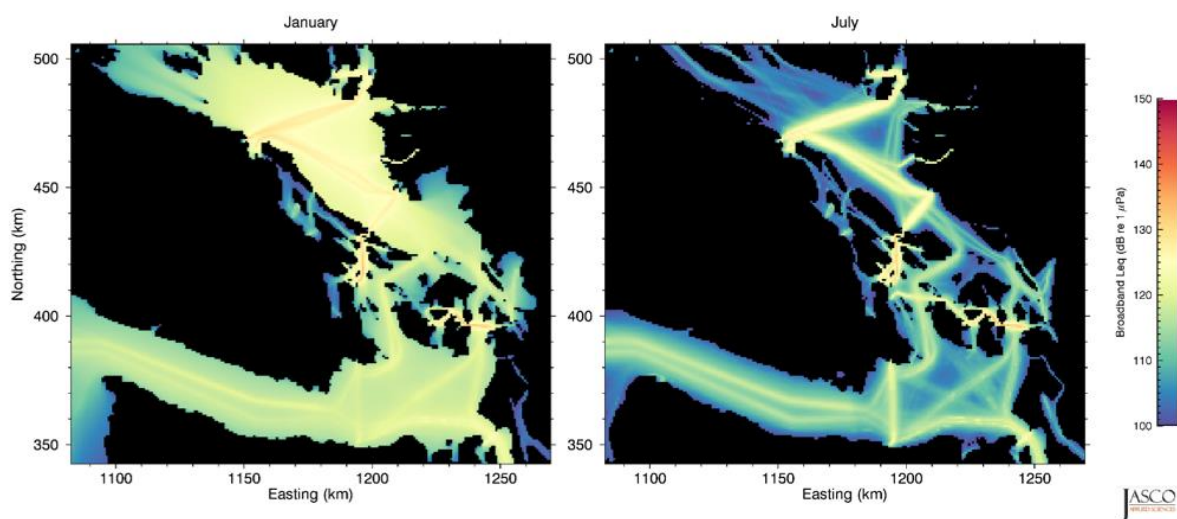
More information on the ECHO program can be found at:

<http://www.portvancouver.com/echo>





**Figure 1:** The PortListen software provides data on the vessel track, acoustic spectrograph, and calculated broadband source levels, and allows the ECHO program to generate a source level report for provision to the vessel owner. Source: JASCO Applied Sciences PortListen software.



**Figure 2:** Monthly average sound pressure level (Leq) for January (left) and July (right) 2015 as calculated by the cumulative shipping noise model (BC Albers projection). Source: JASCO Applied Sciences



## REGIONAL MANAGEMENT OF UNDERWATER NOISE MADE POSSIBLE: AN ACHIEVEMENT OF THE BIAS PROJECT

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### Introduction

The EU LIFE+ project Baltic Sea Information on the Acoustic Soundscape (BIAS) started in September 2012 with the aim to support a regional management of underwater noise in the Baltic Sea, in line with the EU roadmap for the Marine Strategy Framework Directive (MSFD) and the general recognition that a regional handling of ambient noise (Descriptor 11) is advantageous or even necessary for regions such as the Baltic Sea region.

BIAS dealt exclusively with the MSFD Descriptor Criteria 11.2 Continuous low frequency sound (D11.2) with the aim to implement this indicator, by establishing regionally coherent standards, methodologies, and tools that allows for cross-border handling of acoustic data and the associated results. The objectives for BIAS were formulated to form a framework for an efficient joint management of underwater sound in the Baltic Sea by elucidating, and solving, the major challenges related to the implementation of D11.2, specifically in the Baltic Sea region. Nevertheless, the results are often relevant also for other marine regions.

As the first implementation of a joint soundscape monitoring programme across national borders BIAS performed one year of measurements in 2014 with help of 38 acoustic sensors deployed across the Baltic Sea by six nations. The measurements, as well as the post-processing of the acoustic data, were subject to standard field procedures, quality control and signal processing routines, all established within the project [1][2]. The measured acoustic data on continuous low frequency sound

were used to establish modelled noise maps for the project area, providing the first results of the Baltic Sea soundscape on a monthly basis. It deserves to underline that a large number of maps were produced constituting the base for future management of noise. To facilitate an efficient handling of these, and future, results GIS-based online tool was created for visualizing the measured data and the modelled maps in terms of values and quantities recommended for the implementation of the MSFD descriptor within the context of Good Environmental Status (GES).

### Mapping the Baltic Sea

The production of a noise map relies on a number of activities, ranging from field surveys, data processing and data analysis, physical modelling of noise propagation, inversion or calibration algorithms, etc. The BIAS project has gone through all these stages, including highly demanding data control and quality procedures as well as standardization of the data sets and tools.

The BIAS field survey involved all partner nations of the project, and a total of 38 acoustic sensors deployed at fixed position throughout one calendar year as illustrated in Figure 1. The field survey resulted in 38 series of noise level data, each of them describing the cumulative noise at the respective measurement position. These data were brought into the modelling tool Quonops© [3] to ground truth the noise maps according to a patented protocol [4] making use of oceanographic and geological parameters which influence the propagation of the underwater sounds[5][6][7][8], as well as spatio-temporal data of the maritime

activities provided by the Automated Identification System (AIS) and the Vessel Movement System (VMS) [9]. The calibration technique used thereafter was based on the statistical content of the measured data and the three-dimensional modelled data, similarly to techniques used in weather now-casting systems. The acoustic measurements also served to feed a regional model estimating the natural noise caused by wind-generated surface waves forced by the wind, which were incorporated into the final noise maps.

An example of the resulting calibrated maps is shown in Figure 2. The modelling approach produced statistical maps expressed in terms of percentile levels ( $L_n$ ), defined as the sound pressure level exceeded  $n$  percent of the time interval considered. Hence, the series of maps describe not only the noise levels but also the proportion of time subjected to the mapped noise levels. Since there is now a large consensus that not only levels are important but also the duration of noise, this is a key aspect when it comes to interpreting and using the mapped data for the regional management of underwater noise. The advantage of percentiles are illustrated in Figure 2 for the month of February 2014 with the 75<sup>th</sup> percentile soundscape ( $L_{75}$ ) occurring 75% of the time (or, in total 21 days), the median ( $L_{50}$ ) occurring 50% of the time (or, in total 14 days), and the 10<sup>th</sup> percentile ( $L_{10}$ ) occurring 10% of the time (or, in total 3 days) of this particular month. It can be noticed that almost all the time, the major routes across the entire Baltic Sea dominate the natural noise. This can be explained by the permanent high density of the traffic. Shipping routes in the Bothnian Sea (northern basin of the monitored area between Sweden and Finland) emerge from the natural noise less than half of the time. This can likely be explained by the combination of higher ambient noise levels in winter times and relatively limited amount of vessels cruising in the area in winter times.

## Utilizing the noise maps within regional management

Noise maps were produced at a monthly time scale throughout 2014 for the 63 Hz, 125 Hz and 2 kHz third octave bands, for a series of percentile levels (or exceedance levels), and for three depth ranges; the full water-column, depths ranging from the surface to 15 m to assess the noise in the surface layer (roughly the euphotic zone in the Baltic Sea), and depths ranging from 30 m to the bottom to assess the deeper layer.

There was a need to establish how to use this very large quantity of maps for the purpose of regional noise management, way beyond a tool just visualizing the noise maps and measured data. A dedicated tool was developed to aggregate the information from the maps into different perspectives relevant for management. The objectives of the tool were to:

- ✓ Simplify the management of continuous underwater sound in the Baltic Sea Region,
- ✓ Serve as a tool for planning, testing and evaluation - a tool for making decisions,
- ✓ Collect and present information from sound monitoring efforts (BIAS and future ones), including both measured and modelled data,
- ✓ Extract relevant data in user-defined areas of specific interest,
- ✓ Filter between a large number of soundscape maps by selecting particular time periods, frequencies, depths, percentile levels, etc. of interest,
- ✓ Produce graphs, maps and plots based on applied filters.

In practice, the tool is able to deliver ad-hoc plots accustomed by the end-user for their own particular needs, in the range from simple to complex questions, e.g. “what are the sound levels at a certain measurement position?”, “what is the distribution of the most frequent noise in this particular Natura2000 area in June when the harbour porpoises return?”, or “what proportion of the essential spawning area for cod is subject to noise levels comparable at cod communication levels?”

The possibilities offered by the tool are here described using a practical case for the

Atlantic cod (*Gadus morhua*), an important species in the Baltic Sea ecosystem. The above question may then be rephrased as “what is the spatial coverage (in percent of the area) for where masking of their acoustic communication may occur for cod during their spawning period?”. The series of actions for extracting the relevant information in the tool would be to: first, select the relevant geographical polygon delimiting the cod spawning grounds, then chose the 63 Hz third octave band which reflects cod communication and, finally, select the bottom depth interval which is the most relevant for cod. Further, an estimate (a noise threshold level) is needed for the reasonable ambient noise level ensuring that an individual cod can perceive spawning signals emitted by other fish. This threshold level was estimated based on the hearing threshold for the cod, source level of the cod call and a distance between the fish communicating [10]. In addition, it turns out that cod spawning is mostly occurring between July and August in the chosen area.

The tool will provide a composite graph as illustrated in Figure 3. The graph shows the proportion of the Bornholm area (more than 8 300 km<sup>2</sup> total surface) for a series of percentile levels, that is, a series of sound pressure levels exceeded for a particular percentage of time (5, 25, 50, 75, and 95% of time) from March to September 2014. From this plot we would be able to deduct the following:

- ✓ In the sensitive area of Bornholm for cod spawning, there are seasonal fluctuations in the noise levels; all curves,
- ✓ The months of June, July and September are the quietest of this period (all curves), although at rare occasions, the threshold level seems to be surpassed in the entire area independent of the month; 5<sup>th</sup> percentile (L05) – blue curve.
- ✓ During the two-month period essential for cod spawning (July-August), 50% of the area of this critical habitat has noise levels sufficiently low to ensure that the spawning process is carried out in good conditions during a cumulative time of seven to eight days per month; 25<sup>th</sup> percentile (L25) – red curve,
- ✓ During the two-month period essential for cod spawning, 10 to 15% of the area of this critical habitat has noise levels sufficiently low to ensure that the spawning process is done in good conditions during 15 days per month; 50<sup>th</sup> percentile (L50) – orange curve.

## Conclusion

The BIAS project was directed exclusively towards Continuous low frequency sound with the aim to establish a regional implementation plan for this particular MSFD Descriptor Criteria (indicator 11.2). This implied developing regional standards, methodologies, and tools enabling cross-border handling of acoustic data and the associated results. But the BIAS project did not only result in a plan, it also (and more importantly so) resulted in the first practical implementation of the full chain required to monitor and manage this underwater noise indicator.

An extensive field survey of ambient noise was undertaken covering the full year 2014 by collecting noise measurements at 38 fixed positions. The measurements were extrapolated to Baltic Sea full-scale noise maps using underwater noise modelling, resulting in a large quantity of soundscape information. A regional management tool was developed, which demonstrated how the information can be aggregated into a management friendly concept, sufficiently flexible to provide the end-user with relevant information in their decision-making. A number of regional scenarios have been successfully tested and concrete decisions managing the effect of noise on the marine fauna can be made using this innovative and pragmatic approach, bringing the Baltic Sea region one step closer to true management of Good Environmental Status.

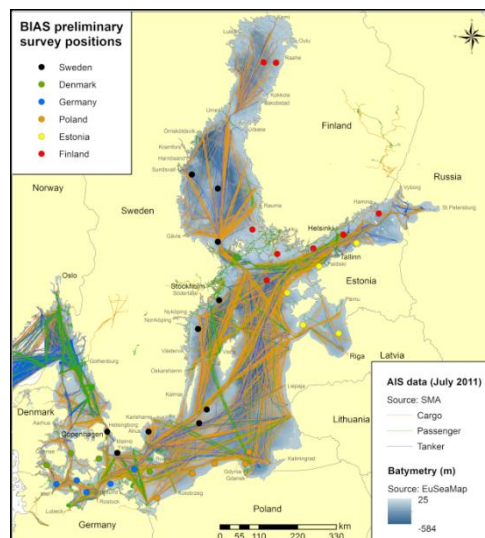
## Acknowledgements

This work was supported by the European Union LIFE program, The Swedish Agency for Marine and Water Management, Ministry of the Environment of Finland, Estonian Ministry of Defence, Environmental Investment Centre (Estonia), Narodowy Fundusz Ochrony Srodowiska I Gospodarki

Wodnej (Poland), and Naturstyrelsen (Denmark)

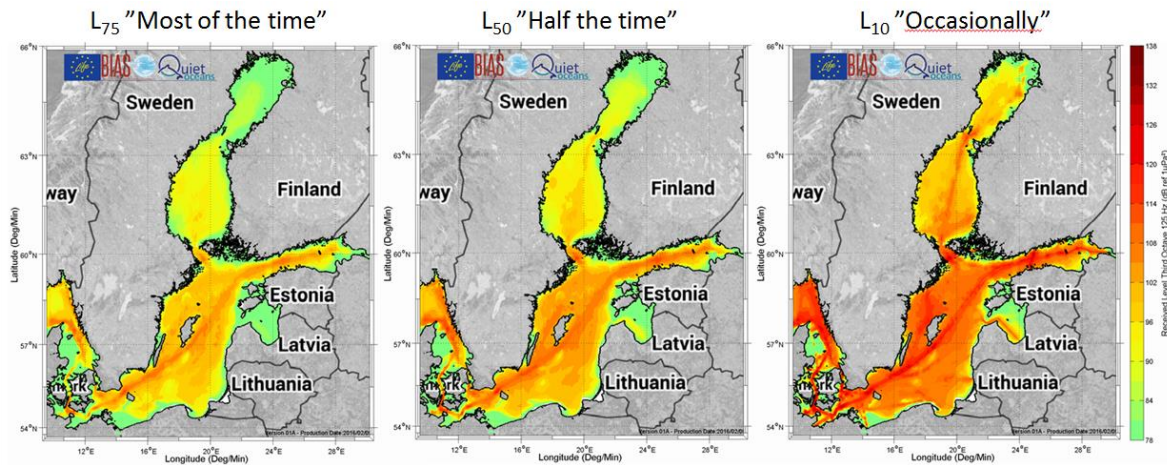
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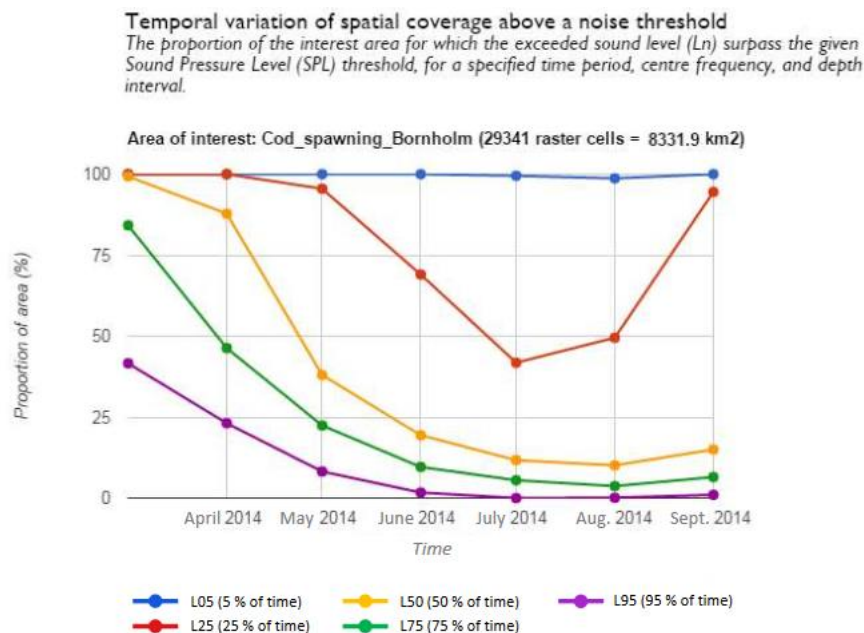


**Figure 1:** Noise monitoring strategy applied during the BIAS project in 2014. Dots represent the sensor positions overlaying the major shipping routes in the Baltic Sea.





**Figure 2:** Three statistical maps of noise in the 125Hz third octave for February 2014. L75 is the 75<sup>th</sup> percentile – or 75% of the time in February, L50 is the median – or 50% of the time in February, and L10 is the 10<sup>th</sup> percentile – or 10% of the time in February



**Figure 3:** Temporal variations of spatial coverage of the noise levels above a user-defined threshold level. The graph is extracted from the series of noise maps as one of three possible graphical options in the BIAS soundscape planning tool.



## EMBEDDED PROCESSING TECHNOLOGIES FOR UNDERWATER NOISE MONITORING: EXPERIENCE FROM THE GERMAN OFFSHORE WINDFARMS

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Internationally, underwater noise impacts on marine life related to offshore wind farms has been a growing issue. Of which, in European shallow waters, the main consideration states around installation of monopiles generating very high-level of impulse noises.

In Europe, the Technical Subgroup on Underwater Noise (TSG noise) provided guidance for member states on meeting the requirements of the Marine Strategy Framework Directive (MSFD) with regards to underwater noise, of which measurement of sounds such as pile-driving, and its potential impact on marine life.

As an example in Europe, leading the way in the area of noise regulations, Germany, via its Federal Maritime and Hydrographic Agency, BSH, defined a threshold limitation of Sound Exposure Level (SEL) at 750 meters from the monopiles for offshore wind farms constructions.

Other regulations are intending to propose a cetacean protected zone (NOAA) where the expectations of the passive acoustic devices are to detect, classify, identify and ideally track the presence of a mammal in a variable surface area.

Therefore, industrials helped by passive acoustic surveyors are requested to provide in a short response time a detailed and accurate reporting following standards and guidelines, this is where it is required to provide a real-time solution to answer regulations.

The first challenge relies in gathering qualitative underwater noise data and provide embedded processing capable of high performance while achieving low power consumption. The second challenge is to rely both on regulation and standardization expectations and to provide

operators a tool with key information feedback and intuitive display so that they will be able to master themselves general understanding in underwater noise monitoring.

After detailing the challenges, we will be present successful experiences and feedbacks from German Wind Farms where a unique innovative solution for real-time pile driving noise monitoring has been implemented and show how such tool can not only meet the regulations expectations but finally also be used as a decisional time-saving tool for operators.

### **Underwater noise embedded processing challenge**

#### *Gathering exploitable calibrated noise data*

With regulations where we can encounter threshold limitations or a +/-1dB difference in measurement and calculation of the underwater noise level can modify a regulation decision and paralyze construction operation. It is then crucial for measurement device to be able to provide qualitative and adapted raw data that will be used for interpretation.

Acquisition of high quality data offers a number of major challenges commonly seen. These include operation across wide dynamic ranges and wide bandwidths (a few Hz – many hundreds of kHz) with low self-noise and great dynamic range.

Nevertheless, gathering high quality of data, autonomous sound recording can represent a considerable amount of data (.wav) in a few day time, representing Tera-Bytes of data per device.



### ***Real time challenge***

In real time, different limitations appear; such as power consumption – especially if an external PC unit is required, or at the contrary self-limitation of embedded processors or DSP such as the memory and computing time integration.

Moreover, the more information we need to extract from processing, the more filtering is required; in that case, filtering data is a time-consuming action: the computing time highly increases as the length of data increases which present the risk of losing real-time capabilities.

### **Real-time noise monitoring**

Real-time (or online) noise monitoring has many advantages in helping offshore wind farm developers to meet both EU- and country-level underwater noise requirements, including increasingly shorter deadlines for reporting schedules.

The main advantage of using real-time monitoring is that the received feedback can be used as a mitigation tool, giving the operator the opportunity to adjust the piling strategy as necessary, and can aid the quick identification of equipment faults, both of which can achieve significant cost savings. Real-time monitoring buoys can also monitor the surrounding area for the presence or absence of target species, such as harbour porpoises, which some countries require.

Real-time monitoring involves deploying a small- to medium-sized buoy connected to a hydrophone (an underwater sensor that detects changes in pressure and translates them into an electrical signal). The buoy both records and stores all the acquired data as well as processing the incoming data stream and transmitting the required noise levels to a receiver unit. This unit can be installed on the piling vessel or any other service vessel. The processed data that is transmitted can be customised to suit specific project needs.

Embedded processing provide significant advantages as it gathers key information together with raw data storage without

increasing power consumption nor requiring external computing unit; which is specifically well suited for remote applications in harsh marine environments where reasonable sized and robust equipment are required. The embedding processing methodology used on the RB-SDA14 buoy developed to calculate noise levels (SEL, Sound Exposure Levels, SPL, instantaneous pressure levels of average levels calculated for each strokes) is designed to be fully approved by authorities and therefore based on international standards on noise level measurement and calculation. Moreover work has been achieved in order to offer solutions allowing regular on-the-field calibration procedures.

### **Real-time noise monitoring benefits: examples**

The integration of autonomous recorders with a live monitoring buoy that permits processing of the required information and transmission of the data to vessels nearby has many benefits.

One of the key benefits of real-time noise monitoring is the ability to effectively use the received feedback as a mitigation tool. This means that the operator on board a piling vessel can view the noise levels that are being recorded a certain distance away in real-time and adjust the piling strategy as necessary.

For instance, the operator can decrease the piling energy to remain below certain noise levels, or increase the energy to minimise the time needed to drive the pile into the substrate if current noise levels are low. Optimising the piling strategy with live feedback from the noise measurements in this way can achieve significant cost-savings.

Finally, real-time noise monitoring buoys can be used to monitor the surrounding area for the presence or absence of target species, such as harbour porpoises, which are a protected species throughout the EU. This is beneficial because, whilst some EU governments have imposed strict thresholds on noise emissions, others instead require monitoring to be conducted

to determine whether marine mammals are present within a certain area during operations. If they are, then mitigation measures must be used to minimise disturbance of marine mammals.

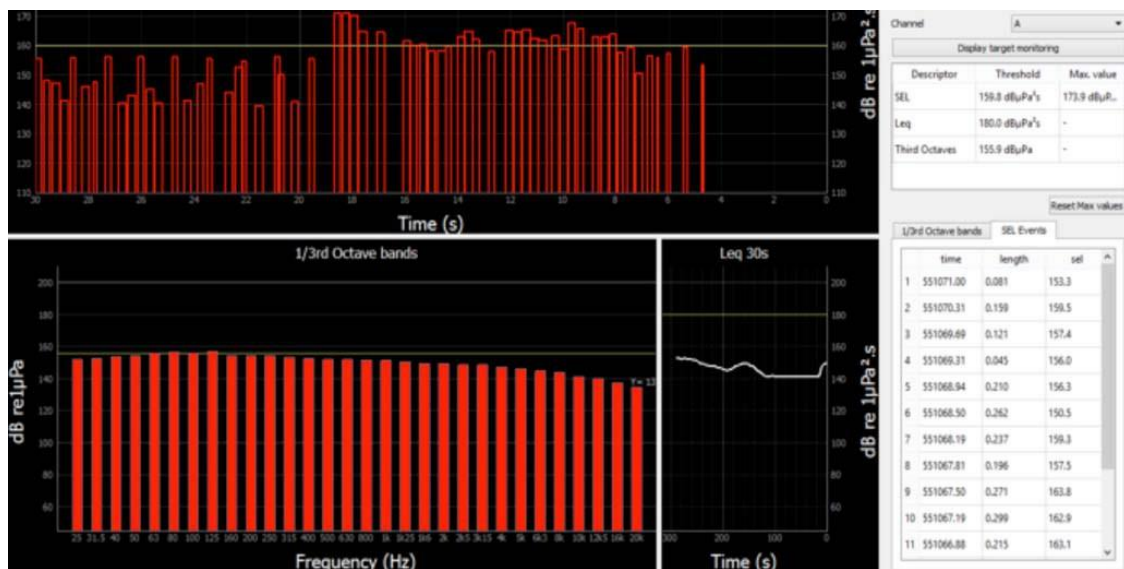
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Standard for measurement and monitoring of underwater noise Part I – TNO, Netherlands



Screenshot of real-time pile-driving noise monitoring interface – Rtsys France



Real-time underwater noise monitoring buoy to be deployed in German Offshore WindFarm – picture credits Baker Consultants



## **PROGRESS IN ADDRESSING MAN-MADE NOISE IN THE MEDITERRANEAN SEA: ASSESSMENT AND REGULATION AT A BASIN-WIDE SCALE**

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### **Introduction**

The Mediterranean region presents a lack of knowledge, monitoring tools and regulation for assessing the use of noise sources and their impact on the marine environment. Within the area, several studies already showed evidence of the impact entailed by anthropogenic underwater noise to sensitive species like cetaceans [1]–[4], while some risk studies were carried out to identify habitats where the use of noise sources could cause harm to cetaceans, especially to beaked whales [5], [6]. On the other hand, little efforts were made to assess levels and effects of maritime human activities. Recent projects providing first data and results at a regional scale are the MEDTRENDS and MEDGIS-MAR project [7], [8]. However, these initiatives do not specifically address the underwater noise issue.

In terms of regulation, the role of Regional Seas Conventions existing in the Mediterranean is of primary importance to promote and spread the adoption of rules concerning the emissions of underwater noise, as they include Contracting Parties which are not Member States of the European Union (EU) and thus are not bound to European directives or regulations (such as the Marine Strategy Framework Directive, MSFD).

In this context, recent efforts have been undertaken within the Agreement on the Conservation of Cetaceans in the Black Sea, the Mediterranean Sea and the contiguous Atlantic Area (ACCOBAMS) aiming at understanding, assessing and regulating

underwater noise inputs into the Agreement area. Such efforts were undertaken with the aim to achieve the global objectives of ACCOBAMS as well as to support the work of the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention). The two bodies share indeed common areas (the Mediterranean Sea) and goals such as implementing measures against pollution and ensuring the conservation of endangered species.

The ACCOBAMS Agreement has addressed the impact of underwater noise on cetaceans since 2004 primarily through Resolutions 2.16, 3.10, 4.17, 5.13 [9]–[12], and by providing expertise to the Barcelona Convention concerning the implementation of an ecosystem based regulation in the basin.

In this paper we present the progress in addressing man-made noise achieved thus far in the framework of two initiatives: the development of a monitoring strategy for underwater noise in the Mediterranean Sea; and the assessment of the spatial and temporal distribution of noise-producing human activities.

### **Initiatives for regulating and assessing underwater noise emissions**

#### ***Ecosystem Approach – Ecological Objective 11***

In 2014 and 2015, ACCOBAMS and the Barcelona Convention cooperated in order to develop a preliminary strategy applying to the whole Mediterranean Sea for

assessing and monitoring underwater noise. This strategy was developed in the framework of the Ecosystem Approach (EcAp) project. EcAp is an initiative of the Barcelona Convention started in 2008 and having the same overall objectives of the MSFD, including the achievement and/or maintenance of the Good Environmental Status (GES) of the marine environment [13]. EcAp and the MSFD share also a similar structure, whereby 11 Ecological Objectives (EOs) of EcAp correspond to 11 Descriptors of the MSFD, the eleventh being in both cases “Energy including underwater noise”. For these reasons and given that some countries are at the same time Member States of the EU and Contracting Parties to ACCOBAMS and the Barcelona Convention, the ACCOBAMS strategy was developed as to be consistent with the guidance from the Task Group on Noise of the European Commission [14]–[16]. It was approved by different technical meetings of the Barcelona Convention in 2015, and finally adopted through Decision IG.22/7 at 19<sup>th</sup> Ordinary Meeting of the Contracting Parties in 2016 [17]

In practice, the strategy is a technical guidance (EO11 Guidance), outlining the indicators related to EO11, and providing information for stakeholders to implement the recommended monitoring and assessment programmes. Two separate indicators are proposed: Common Indicator 26 addresses space-time distribution of impulsive noise sources, while Common Indicator 27 addresses levels of continuous noise through the use of measurements and models as appropriate. The methodology outlined in the strategy proposes some adaptations for the Mediterranean case compared to Descriptor 11 of the MSFD (D11). Particularly, both indicators are more closely related to the acoustic biology of key marine mammal species of the Mediterranean which are known to be sensitive to noise, i.e. the fin whale, the sperm whale and the Cuvier’s beaked whale.

Common Indicator 26 is defined as “Proportion of days and geographical distribution where loud, low and mid-frequency impulsive sounds exceed levels that are likely to entail significant impact on

marine animals”. In the above definition, proportion of days is to be interpreted as the number of days over a calendar year; geographical distribution is defined as the number of grid cells over a 20x20 km grid covering the whole Mediterranean basin; impulsive sounds are to be interpreted as source levels of anthropogenic noise sources; impact is defined as severe and/or sustained and/or long-term avoidance of an area, and/or disruption of acoustic behaviour, i.e. stop calling and/or stop clicking. Finally, the EO11 Guidance defines what impulsive noise sources are to be taken into account for monitoring and assessment: it is recommended to consider all human activities using low frequency noise sources, regardless of their source level, thus accounting for fin whale sensitivity over very long ranges. Furthermore, the EO11 Guidance recommends addressing also human activities using mid frequency noise provided their source levels exceeds a fixed threshold. Thresholds for mid frequency noise sources were set in order to account for Cuvier’s beaked whale sensitivity to mid frequency sounds. So, in order to define GES related to indicator 26, it is recommended to establish a spatial threshold (i.e. a number of cells over a grid) and a time threshold (i.e. a number of days over a calendar year). Exceeding either of such thresholds in a given year means that GES is not attained for that year.

Common Indicator 27 is defined as “Levels of continuous low frequency sound with the use of models as appropriate”. The EO11 Guidance proposes to focus on specific frequency bands, i.e. the third-octave bands centred at 20, 63, 125, 250, 500 and 2000 Hz. Frequency bands were selected where shipping noise is likely to be dominant compared to other sources according to Mediterranean data (63, 125, 250 and 500 Hz), but also where noise potentially masks fin whale calls and sperm whale clicks (20 Hz and 2000 Hz, respectively). Two metrics are recommended for monitoring: the annual arithmetic mean Sound Pressure Level (SPL), expressed in dB re 1µPa (rms); and the annual 33.3% Exceedance Level (or L<sub>33.3</sub>), meaning the noise level exceeded

33.3% of a calendar year.  $L_{33.3}$  is aimed at accounting for possible increase in ambient noise levels due to recreational craft in summer. In fact, it is assumed that recreational craft can cause significant increase in ambient noise levels during the summer period, i.e. June to September, which represents a third (= 33.3%) of a year. So, in order to define GES related to indicator 27, it is recommended to establish a conservative noise threshold. If the annual arithmetic mean SPL is above the noise threshold, GES is not met that year for that region while if the mean is below, the  $L_{33.3}$  is inspected to figure out if during summer the threshold was exceeded. If so, GES is not met again.

### *Identifying hotspots of noise-producing human activities*

A first basin-wide assessment of the spatial and temporal distribution of noise-producing human activities in the Mediterranean Sea was carried out in 2015 [18]. The overall objective of this work was to gather an overview of the occurrence of the activities identified as being of highest risk for marine wildlife and particularly for cetaceans. It is worth noting that this work meant providing data and information of interest also for the E011 and D11 in the Mediterranean area, although the technical guidance related thereto was not followed strictly as the necessary data are currently not available in the Mediterranean region. Main tasks planned for this study included: (i) inventorying noise-producing human activities and (ii) mapping areas where such activities were carried out. Although not exhaustive, this study put together a large amount of data, particularly on activities using impulsive noise sources, for the period 2005 to 2015 and for the next future, i.e. activities scheduled until 2020.

Main results deal with human activities during which impulsive noise sources are usually employed. Data were recorded on the position of 1446 harbours, 228 drilling platforms for hydrocarbon exploitation, 52 wind farm projects, 830 seismic exploration areas, and a number of military areas; whenever possible, the period of occurrence of activities was recorded, but most times

this is limited to the year. Available data for seismic exploration allowed for calculating the surface annually bestowed to this activity in the 2005-2015 period. The highest value was attained in 2013 with seismic survey areas covering around 675 000 km<sup>2</sup>, representing 27% of the surface of the Mediterranean (2.5 M km<sup>2</sup>). On the opposite, 2005 yielded the lowest value with around 67 000 km<sup>2</sup> used (3.8% of the Mediterranean surface). An increasing trend over the study period is highlighted. Furthermore, the position of each category of noise-producing human activities was mapped. Subsequently, summary GIS maps were created using a grid resolution of 40x40 km in order to investigate the accumulation of noise-producing human activities across the study area and to point out overlaps with important cetacean habitats. Areas exposed to multiple noise-producing human activities (noise hotspots) were located in the Italian part of the Adriatic Sea, the Strait of Sicily, the French Eastern coastal waters, the North-eastern part of Corsica, the higher Ionian Sea, and the coast of Campania. These areas accumulated all categories of noise-producing activities considered in this study: harbour activities, commercial and scientific seismic surveys, oil and gas drilling activities, wind farms projects, military exercises. Finally, when overlapping cetacean habitats with identified noise hotspots, potential conflict areas were shown for the Ligurian Sea, the Strait of Sicily and the Northern part of the Hellenic Trench.

### **Discussion and Conclusion**

Initiatives described in this paper outline the work supported by ACCOBAMS in cooperation with the Barcelona Convention in order to develop a regulation framework for underwater noise at the Mediterranean scale and to assess the current status of the spatial and temporal distribution of noise-producing human activities in this area.

Both initiatives are linked to each other as well as to other important processes like the MSFD, and they appear of particular importance as they apply beyond the boundaries of the EU. The overview on the



noise hotspots represents a first discussion ground concerning the need for conservation measures and monitoring/assessment programmes, and can feed the discussions concerning GES definition relative to underwater noise, which is relevant for both the EcAp initiative and the MSFD process.

Difficulties identified during the implementation of such initiatives are the different capacity in implementing noise regulation across Mediterranean countries and the poor quality of many of the available data on the spatial and temporal distribution of noise-producing human activities, particularly for Southern and Eastern Mediterranean countries. Next steps will need to cope with these difficulties to ensure an acceptable balance between marine conservation and human development at sea.

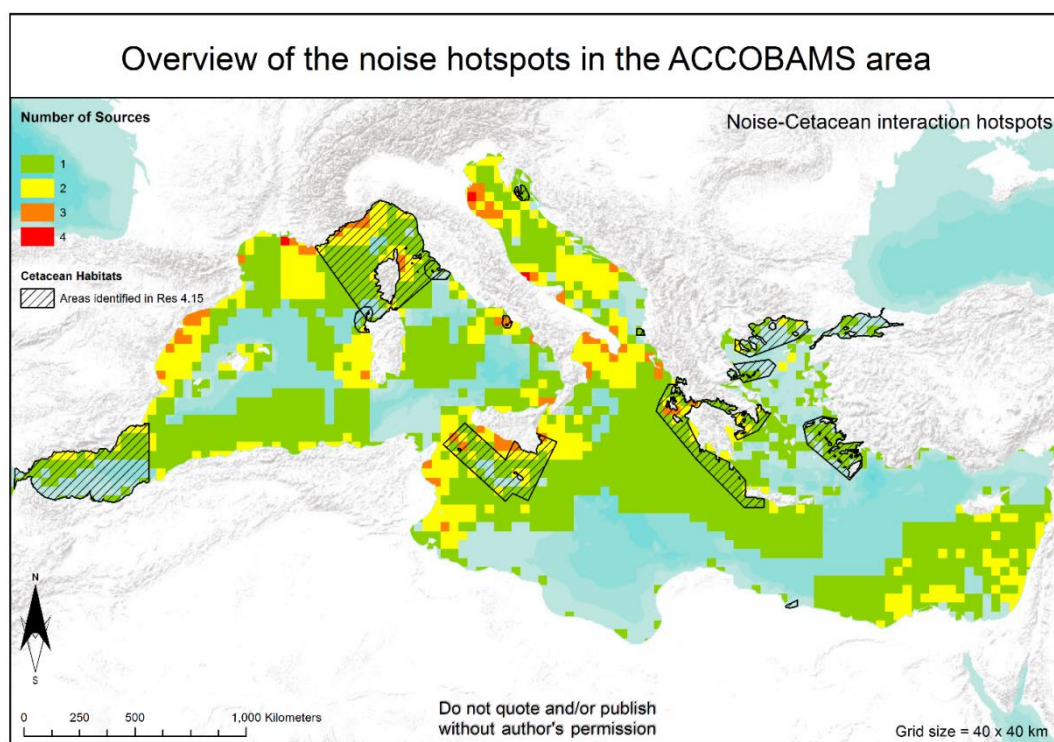
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Indicator N°	Description	Operational objective	State/Pressure	Parameter description	GES assessment	Guidelines
Common Indicator 26	Proportion of days and geographical distribution where loud, low and mid-frequency impulsive sounds exceed levels that are likely to entail significant impact on marine animals	Energy inputs into the marine environment, especially noise from human activities, is minimized	Pressure	Number of days over a year and number of cells over a grid in which activities using loud source levels occur	GES is not achieved or maintained if either the temporal or spatial thresholds are exceeded	Adapted from the Monitoring Guidance for Underwater Noise in European Seas [14]–[16]
Common Indicator 27	Levels of continuous low frequency sound with the use of models as appropriate			Arithmetic mean SPL over a year (dB re 1µPa rms) and $L_{33.3}$ , i.e. 33% exceedance level (dB re 1µPa rms) in the 1/3 octave bands centred at: 20, 63, 125, 250, 500 and 2000 Hz	GES is not achieved or maintained if the $L_{33.3}$ index, calculated over a year, is above the threshold	

**Table 1:** Synthesis of the technical guidance for the Ecological Objective 11 of the EcAp initiative



**Figure 1:** Noise-cetacean interaction hotspots: Accumulation of noise-producing human activities (4 categories considered: harbour activities; offshore works including Oil & Gas drilling sites and windfarm projects; seismic surveys, military exercises) and overlaps with important cetacean habitats



# Appendix

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## PRESENTATION OF THE PROJECT

This position paper results from a project carried out at the Observatory for Responsible Innovation. The Observatory for Responsible Innovation is an independent international think tank created to reflect on and discuss new concepts, measures and methods for encouraging responsible innovation. The Observatory is based in Mines ParisTech and is part of i3, the Interdisciplinary Institute of Innovation (CNRS UMR 9217). This Institute was founded by the CNRS, in collaboration with Mines ParisTech, Ecole Polytechnique and Telecom Paris.

### The Observatory for Responsible Innovation and i3

This think tank views innovation as a process that is both full of promises and fraught with dangers, with negative externalities. Its philosophy is rooted in the question of technical democracy as understood by Michel Callon. Its main goal is to organize debate around innovation, to animate a political discussion, and attract media attention to it. To do so, the Observatory mostly provides human resources.

The Interdisciplinary Institute of Innovation (i3, CNRS UMR 9217), founded in 2015, brings together:

- ✓ the Mines ParisTech economics, management and sociology research teams (CERNA, CGS and CSI),
- ✓ those of the Department of Economics and Social Science (DSES) at Télécom ParisTech,
- ✓ and the Management Research Center (CRG) at Ecole Polytechnique,

and thus comprises more than 200 people, including 60 permanent academic researchers.

It pursues high-level research, combining academic excellence and relevance for the end users. Through its teaching and research activities, i3 takes an active part in addressing main contemporary challenges:

the diffusion of communication technologies, health, innovation, energy and sustainable development. These activities are organized around four main topics:

- ✓ Transformations of innovating firms
- ✓ Theories and models of design
- ✓ Regulations of innovation
- ✓ Uses, participation and democratization of innovation

For more information:

- ✓ <http://www.i-3.fr/>
- ✓ <http://www.debatinginnovation.org>

### Organization of the project

The project started at a time when it was possible to take advantage of the work of two European projects focusing on shipping noise (SONIC, AQUO) and of the oil & gas industry initiative on sound measure, but also at a point when it had become crucial to think about implementing innovative solutions.

A working group was organized and coordinated by Héloïse Berkowitz and Hervé Dumez, and involved: Eric Baudin from BureauVeritas, Christian Audoly and Céline Rousset from DCNS; Aldo Napoli, researcher in risk modeling at Mines ParisTech, and Fabian Muniesa, chairman of the Observatory for Responsible Innovation.

The objective of the project was to explore with scientists, industry representatives, and national and European public officers the best way to develop solutions. The position paper you are reading was prepared thanks to three one-day workshops on the following topics:

- ✓ **Noise measurement:** two ISO groups worked on this topic. The workshop highlighted the problems and stakes linked to the definition of an efficient standardized measurement instrument;
- ✓ **Noise impact on marine life:** This workshop tried to delineate the state-of-the-art about the impacts of underwater

noise on marine (mammals, fish, invertebrates, etc.);

- ✓ **Innovative solutions and management devices:** industrial actors are developing many innovations to reduce the

underwater noise footprint of ships. This workshop sought to summarize and present the most innovative solutions being implemented in different sectors.





### Workshop 1: Measuring noise in oceans: towards a convergence?

*Coordinators: Héloïse Berkowitz and Hervé Dumez (Ecole polytechnique, i3)*

Underwater noise is becoming a major environmental issue. To act and protect the marine life, the first step is to measure that noise, both the noise sources and the status of underwater noise in the maritime areas. Different approaches have been developed. The objective of the workshop is to synthesize and to give a state of the art of these different methods, and to investigate how we could converge to a standardized measurement systems and techniques, efficient and cost effective.

#### *Provisional Program of the Workshop*

The workshop is scheduled over one day (9<sup>th</sup> of February, 2016)

8h00: welcoming participants and coffee

8h30-8h45: i3 presentation

8h45-9h: European officer presentation of the challenges for regulation (Lydia Martin-Roumégas, *European Commission, Environment*)

#### **1st session**

9h-9h20: AQUO Project presentation (Raul Salinas, *TSI*, and Thomas Folégot, *Quiet Oceans*)

9h20-9h40: BIAS Project presentation (Peter Sigray, *FOI-BIAS*)

9h40-10h00: SONIC Project presentation (Victor Humphrey, *University of Southampton, UK*)

10h00-10h15: Comments from moderator (Jean-Philippe Pagot, *EDF EN*)

10h15-10h45: General discussion

*10h45-11h00: break*

#### **2nd session**

11h00-11h20: JIP E&P Sound and Marine life presentation (Roy Wyatt, *Seiche Measurements*)

11h20-11h40: NeXOS (Eric Delory, *Plocan-NeXOS*)





11h40-11h50 : Comments from moderator (Céline Rousset, *DCNS*)

11h50-12h15: General discussion

*12h15-13h30: Lunch*

### **3ème session**

13h30-13h50: IEC presentation (Brian Polagye, *to be confirmed*)

13h50-14h10: ISO presentation (Christian Audoly, *DCNS*, and Stephen Robinson, *National Physical Laboratory, UK*)

14h10-14h20: Comments from moderator (Guillaume Babin)

14h20-14h50: General Discussion

*14h50-15h00: Break*

15h00-16h00: Final discussion and synthesis

A presentation is meant to last 20 minutes. Each session is followed by a commentary from a moderator (20-30-minute long) and concluded by a general discussion with the attendees (15-minute long).

The aim of the workshop is to address the three following points: measurement of the source levels, local measurement of underwater sound, and mapping models of the sound in a zone. The presentations will have to address at least one of these three issues.

Moderators can be from the regulating bodies (Ministry of the Environment, European Commission), from industries (oil & gas industry, marine renewable energies, shipping, etc.) or experts.

The final session is introduced by a presentation synthesizing the discussions of the day and outlining the way ahead for a possible convergence. The debate then consists of transversal issues.





## Racket in the oceans and responsible innovation

*Coordinators: H  lo  se Berkowitz and Herv   Dumez (Ecole polytechnique, i3)*

### Workshop 2: The Impacts of Underwater Noise on Marine Life

*Scientific coordinator: Michel Andr   (Technical University of Catalonia, BarcelonaTech)*

To reduce anthropogenic sounds' impacts on marine fauna such as cetaceans, fish, invertebrates, we need to better understand these impacts, and especially how underwater acoustics can affect animals' behaviours and life. This workshop, by welcoming international, recognized scientists and experts, aims to give a state of the art on these questions.

#### *Program of the Workshop*

The workshop is scheduled over one day (10<sup>th</sup> of March, 2016), at Mines ParisTech, 60 Boulevard Saint-Michel, 75006 Paris, room Vend  me:

8h30-9h00: welcoming participants and coffee

9h00-9h10: i3 and Michel Andr   presentation and introduction of the day

9h10-9h30: **What does MaRVEN have to say about noise? A large-scale study of the environmental impacts of noise from marine renewables**, Frank Thomsen (*Ecology and Environment, DK-EED, DHI Denmark*)

9h30-9h50: **Use of at-sea experiments to describe how cetaceans respond to naval sonar signals**, Patrick Miller (*University of St Andrews, UK*)

*9h50-10h10: Break*

10h10-10h30: **Contrasting behavioural responses to noise and predator presentations to assess biological significance**, Charlotte Cur   (*Cerema Dter Est, Laboratory of Strasbourg, Acoustics Group, Strasbourg, France*)

10h30-10h50: **A fish's life in a changing soundscape**, Mathias Andersson (*FOI, Swedish Defence Research Agency, Sweden*)

10h50-11h05: **Discussant**

11h05-12h05: **Morning General Discussion**





**12h05-12h30: Press conference**

*12h30-13h30: Lunch Break*

**13h30-13h50: Effects of noise on invertebrates: non-auditory specialists present acoustic trauma when exposed to low-frequency sounds**, Michel André (*Technical University of Catalonia, BarcelonaTech, UPC, Spain*)

**13h50-14h10: Quantifying biological risks from anthropogenic noise**, Thomas Folegot (*Quiet-Oceans, Brest, France*)

*14h10-14h30: Break*

**14h30-14h50: The view of the industry (Oil and Gas)**, John Campbell (*International Association of Oil & Gas Producers, UK*)

**14h50-15h05: Discussant**

**15h05-15h25: From paper to practice: the challenge to effectively address anthropogenic noise in our oceans**, Nicolas Entrup (*Consultant to NRDC & OceanCare, Austria*)

*15h25-15h45: Break*

**15h45-16h45 : Final Round Table**

The aim of the workshop is to give a state of the art on the impacts of marine sound on all forms of marine life. A presentation is meant to last 20 minutes. A discussant will discuss each session of four presentations. The morning session will be concluded by a general round table with the audience and with a press conference before lunch. The final session concludes the day with a presentation synthetizing the discussions of the day and outlining the main issues that the third workshop (on management solutions) might try to answer.

**Global calendar:**

Workshop 1 on measurement: **9th February 2016**

Workshop 2 on impacts on marine life: **10 March 2016**

Workshop 3 on solutions and regulation issues: **May 2016**

International conference: **Sept 2016**





## Racket in the oceans and responsible innovation

*Coordinators: H  lo  se Berkowitz and Herv   Dumez (Ecole polytechnique, i3)*

### Workshop 3: Innovative solutions: technologies and management & regulatory tools

Many innovations are under development or deployment to reduce underwater noise footprint of ships, oil and gas exploration or pile driving. This workshop aims to summarize and present most innovative technologies in different sectors. It will also present management and regulatory tools designed to better implement these innovations.

#### *Program of the Workshop*

The workshop is scheduled over one day (17<sup>th</sup> of May, 2016), at Mines ParisTech, 60 Boulevard Saint-Michel, 75006 Paris, room V115-V116:

8h30-9h00: welcoming participants and coffee

#### **1<sup>st</sup> session: Innovations in ships**

9h00-9h20: "Noise & Vibration Comprehensive Management: The proven engineering tool to built silent ships", Publio Beltr  n (*TSI*)

9h20-9h40: "Reducing Underwater Noise from Ships – An Overview of Basic Requirements and Estimated Costs.", Jesse Spence (*NCE*)

9h40-10h00 : "Mitigation of Propeller Cavitation Noise with Air Ejection", Marko Hyensj   (*RollsRoyce*)

10h00-10h20 : "STX approach to ship underwater radiated noise management", St  phane Cordier (*STXFrance*)

*10h20-10h40: Break*

#### **2<sup>nd</sup> session: Renewable Marine Energies**

10h40-11h00: Managing noise during construction work in offshore wind farms C  line Dam Hieu (*EDF EN*)

11h00-11h20: IHC Noise Mitigation System, R&D trajectory and regulatory issues, Henk van Vessem (*Royal IHC*)







**3<sup>rd</sup> session: Oil and Gas industry**

11h20-11h40: **Continual improvement in Exploration and Production**, John Campbell (*IOGP*)

11h40-12h30: **Morning General Discussion**

*12h30-13h30: Lunch Break*

13h30-14h00: Visit of the Minerals Museum

14h00-14h20: **Real-time automated noise monitoring and marine mammal detection to mitigate anthropogenic sound sources**, Michel André (*UPC*)

14h20-14h40: **A methodology to quantify underwater noise mitigation solutions**, Eric Baudin (*Aquo, Bureau Veritas*)

*14h40-15h00: Break*

15h00-15h20: **A French Nature conservation perspective on underwater sound and marine species: from anthropogenic threats to mitigation techniques and indicators of ecosystem health**, Sylvain Michel (*AMP*)

15h20-15h40: **“Implementing MSFD Descriptor 11 at OSPAR and in the UK”**, Nathan Merchant (*Cefas*)

15h40-16h30 : **Final Round Table**

The aim of the workshop is to give a state of the art on the innovative solutions, both technologies and management & regulatory tools. A presentation is meant to last 20 minutes. The morning session will be concluded by a general round table with the audience. The final session concludes the day with a presentation synthetizing the discussions of the day and outlining the main issues.

**Global calendar:**

Workshop 1 on measurement: **9th February 2016**

Workshop 2 on impacts on marine life: **10th March 2016**

Workshop 3 on solutions and regulation issues: **17<sup>th</sup> May 2016**

International conference: **Sept 2016**





## **RACKET IN THE OCEANS: INTERNATIONAL CONFERENCE ON UNDERWATER NOISE**

Coordinators: Heloise Berkowitz & Hervé Dumez

**Paris, September the 20<sup>th</sup>**

*The Observatory for Responsible Innovation organized three workshops in February, March and May on the issues of underwater sound measurements and standardization, impacts on marine fauna and innovative solutions, with the final objective to produce a position paper.*

The conference is scheduled over one day (20<sup>th</sup> of September, 2016), at Maison des Océans, 195 rue Saint Jacques, 75006 Paris (RER: Luxembourg, metro Cardinal Lemoine or Place Monge)



[Register here to the conference](#)

*To find out more about the Observatory for Responsible Organization and the Marine Sound working group please [visit our website](#).*



### *Program of the Conference*

8h30-9h00: welcoming participants and coffee

9h00-9h10: **Introduction to the conference**

9h10-9h40: **Contrasting whale behavioral responses to anthropogenic noise and predator presentations to assess biological significance**, Charlotte Curé (*Cerema*)

9h40-10h50: **Discussion panel on “From noise measurement to impact assessment”:**

Christian Audoly (*DCNS*)  
Arthur Finez (*Microdb*)  
Nicolas Entrup (*Consultant to NRDC & OceanCare*)  
Moderator: Eric Baudin (*BureauVeritas*)

10h50-11h10: *break*

11h10-12h30: **Discussion panel on “Deploying innovation to mitigate noise in oceans”:**

Phil Johnston (*Seiche*)  
Jesse Spence (*NoiseControl*)  
Yohan Weiller (*wpd Offshore France*)  
John Campbell (*IOGP*)  
Moderator: Christian Audoly (*DCNS*)

12h30-13h30: *Lunch break*

#### **SESSION Regulating noise in oceans: experiences and feedbacks**

13h30-14h00: **How Marine Strategy Framework Directive protect European oceans from under water noise?** Lydia Martin-Roumégas (*European Commission/DG ENV*)

14h00-14h30: **Regional management of underwater noise made possible: an achievement of the BIAS project**, Thomas Folégot (*Quiet-Oceans*)

14h30-15h00: **Embedded processing technologies for underwater noise monitoring: experience from the German Offshore windfarms**, Luc Simon (*RTSys*)

15h00-15h30: *Coffee Break*

15h30-16h00: **The ECHO Program: A port led collaborative initiative working to reduce cumulative noise impacts of commercial vessel activity on an endangered killer whale population**, Orla Robinson (*Vancouver Harbor*)

16h00-16h30: **Presentation of the position paper “Racket in the oceans: why underwater noise matters and what we can do about it”**, Héloïse Berkowitz & Hervé Dumez (*Ecole polytechnique*)

16h30-17h00: **Open discussion on future steps**



## LEXICON/GLOSSARY

**Anthropophony:** chorus of sounds produced by humans, whether coherent such as music or dialogue, or incoherent such as those generated by electromechanics.

**Biophony:** chorus of sound from living organisms.

**Geophony:** chorus of natural sounds such as noise from the rain, waves, seisms, or even storms for instance.

Good environmental status:

**Masking:** noise pollution interferes with an animal's use of sounds to detect other animals, to interpret, to hunt etc.

**Particle Motion:** sound is actually vibratory energy that propagates through oscillating particles that then move close particles which in turn move particles next to them. Particles in a medium such as water do not actually travel; they only transmit oscillation, which is called particle motion.

**Sound pressure:** local variation in pressure caused by a sound wave.

**Sound pressure level (SPL):** acoustic pressure level is a logarithmic measure of the effective pressure of a sound relative to a reference value.

**Soundscape:** set of elements in the acoustic environment that life beings can perceive. Human soundscape vary from fish soundscape. Soundscape is distinct from acoustic environment that covers the whole range of sound sources, from natural biophony to geophony and anthropophony.

**Underwater acoustic pollution:** anthropic introduction of energy in the form of acoustic emission that negatively affects marine fauna's behaviors, physiologies or population.