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FAUNAGUARD: A SCIENTIFIC METHOD FOR DETERRING MARINE FAUNA

ABSTRACT

Regulators, funding agencies and proponents worldwide are imposing increasingly strict environmental regulations to minimise the potential impact of marine construction activities, and more specifically, the underwater sound generated by such activities. Marine fauna may be adversely affected by marine construction as a result of physical interaction with construction equipment and/or exposure to high levels of underwater sound. Physical interaction can cause injury or death, exposure to high sound levels may cause physiological effects (e.g., permanent or temporary hearing threshold shifts), behavioural effects or masking.

To minimise the potential impact of marine construction projects on marine fauna worldwide Van Oord and SEAMARCO have developed the FaunaGuard, an Acoustic Deterrent Device, to safely and temporarily deter various marine fauna species from marine construction sites with specialised underwater acoustics. The underwater acoustics that are implemented in the FaunaGuard have been designed and tested scientifically for specific marine fauna species, or species groups. A variety of signals is already available or under development, i.e., for various species of marine fish, mammals and reptiles. A number of practical applications are described. The FaunaGuard is a successful member of a broader family of environmental Guards (FaunaGuard, PlumeGuard, ReefGuard).

INTRODUCTION

Regulators, funding agencies and proponents worldwide are imposing increasingly strict environmental regulations to minimise the potential impact of marine construction activities, and the sound generated under water by such activities.

Marine fauna may be adversely affected by marine construction works as a result of physical interaction with construction equipment and/or exposure to high levels of underwater sound. Physical interaction can cause injury or death, exposure to high sound levels may cause masking, physiological effects (e.g., temporary or permanent hearing threshold shifts), behavioural effects or masking.

Above: Schools of fish are typically encountered at marine construction sites. FaunaGuard, an Acoustic Deterrent Device, can safely and temporarily deter various marine fauna species from these sites using specialised underwater acoustics.

Legislation for underwater sound, as it emerges internationally (e.g., following the EU Marine Framework Directive), increasingly takes an ecosystem-based approach aiming to keep sound levels in a sensitive habitat within acceptable levels. The philosophy is not to scare animals away from their known foraging and breeding grounds, but to allow human activities in that habitat only when impact remains below maximum acceptable levels. This triggers mitigating measures, such as air bubble screens, that focus on reducing the propagation of sound energy from the source.

When dealing with temporary high energetic activities producing high peak levels of underwater sound, sound suppressing mitigation measures might no longer be effective at acceptable cost. In order to protect marine fauna from Temporary Threshold Shift (TTS) and Permanent Threshold Shift (PTS), Acoustic Deterrent Devices (ADDs or pingers) still remain a viable option in order to temporarily deter the animals away to a distance where underwater sound levels have dropped to safe values.

Many ADDs and pingers are commercially available. An issue around such devices remains that their effectiveness is often not scientifically validated. As an alternative to existing approaches Van Oord and

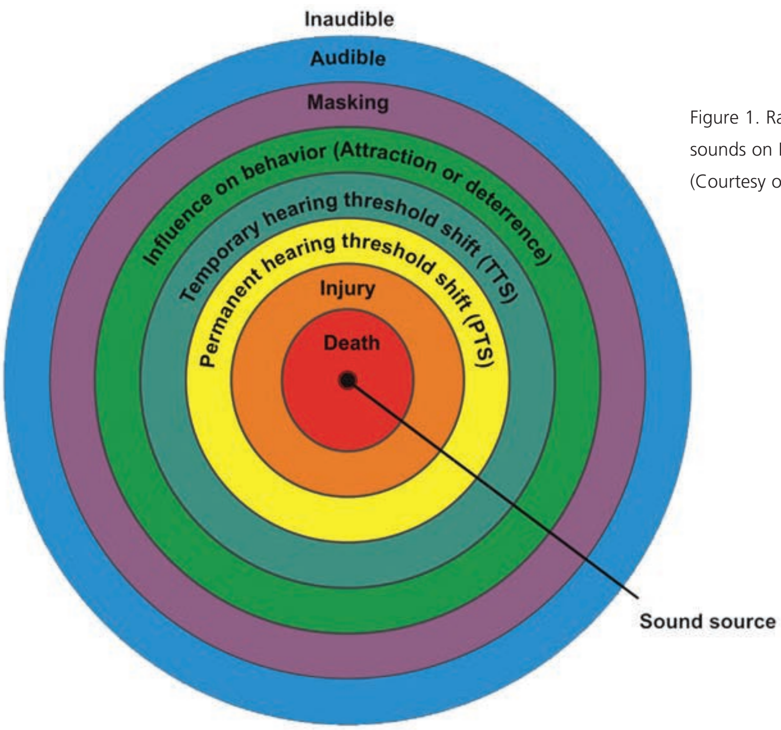

Figure 1. Ranges of effects of sounds on Marine Mammals (Courtesy of SEAMARCO).

SEAMARCO have developed the FaunaGuard, an Acoustic Deterrent Device to safely and temporarily deter various marine fauna species from marine construction sites with specialised underwater acoustics.

The underwater acoustics that are implemented in the FaunaGuard have been designed and tested scientifically for specific marine fauna species or groups of species. A variety of signals is already available or under development for modular application to various species of marine fish, mammals and reptiles. The most recent module added to the FaunaGuard (2014) has been designed for the harbour porpoise (*Phocoena phocoena*).

This article describes important aspects of marine fauna and (anthropogenic) underwater sound, the philosophy behind the FaunaGuard, its infrastructure and signal library and its application scope.

MARINE FAUNA AND UNDERWATER SOUND

Sound can be described as a moving wave in which particles of the medium are forced together and then move apart. This creates changes in pressure that propagate with the speed of sound. The speed of sound in water is more than four times higher than the speed of sound in air because the medium 'water' supports the propagation of sound better than the medium 'air'. In water, the attenuation is less than in air.

Sound is produced under water by natural and anthropogenic sources. Natural sources of sound can be vocalisations of marine life, e.g., the elaborate songs of humpback whales or the snapping of shrimp. Wind, rain, waves, and subsea volcanic and seismic activity all contribute to ambient sounds in bodies of water. Anthropogenic sound comes from construction of marine infrastructure (including dredging) and industrial activities such as drilling or aggregate extraction, shipping, military activities using various types of sonar, geophysical exploration using seismic surveys, and a variety of other activities.

As sound propagates very well under water, many marine species use it for a variety of purposes. Both fish and marine mammals communicate with underwater sound. Some whales even communicate over distances as large as hundreds of kilometres. Marine fauna also uses sound for navigation, finding prey and detecting predators.

HAZARDS OF ANTHROPOGENIC SOUNDS

Anthropogenic sound interferences can have a variety of effects on aquatic life (see Figure 1). Once sounds of anthropogenic origin are loud enough to be in the audible range of marine fauna, they may first mask biologically important signals such as communication calls between animals. When sound levels increase, the severity of the response also increases ranging from subtle, such as a startle response, to strong behavioural reactions, such as complete avoidance of an area. When sound levels received by marine fauna are even higher, they can affect hearing either temporarily or permanently and extremes can lead to injury or even death. The latter, however, occurs only when animals are very close to a very high intensity sound source.

Like many other activities, dredging and marine construction activities produce underwater sound. The Central Dredging Association (CEDA) has published a position paper on this topic and encourages the development of a standardised monitoring protocol for underwater sound, to facilitate evaluations of reasonable and appropriate management practices to reduced underwater sound production during dredging (CEDA, 2011).

FAUNAGUARD PHILOSOPHY

The philosophy of the FaunaGuard, developed by Van Oord and SEAMARCO, is to make optimal use of the behavioural effects induced by specific sounds with different species or species groups. By deliberately making an area in and around a dredging or marine construction site (temporarily) unattractive to marine fauna, more serious effects related to high peak energy events may be prevented. As such the FaunaGuard aims to utilise mild behavioural effects (moving from an area) *just before* construction, to prevent more serious physiological effects on marine fauna *during* construction.

The careful use of underwater sound has some additional advantages. Traditional mitigating measures rely on visual observations, e.g., by Marine Fauna Observers (MFOs), or physical contact, such as turtle deflectors and physical relocation. Both methods, though effectively used in practice, have limitations:

- Visual observations are less effective when marine fauna are not at the water surface, when turbidity levels are higher or visibility is low in general (such as during bad weather or at night).

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received an MSc (1998) and subsequently a PhD degree (2003) in Civil Engineering from the University of Twente, Enschede, the Netherlands. His PhD research, executed at WL|Delft Hydraulics, later Deltares, focussed on Matching Specialist Knowledge with End User Needs. After several years working at Deltares he joined Van Oord (2008) where he is currently the manager of the Environmental Engineering Department. He aims to proactively provide clients with state-of-the-art solutions.

- Methods that rely on physical contact (like a turtle deflector or re-location of species by divers / nets) may still cause stress and impact to the fauna.
- Physical devices may adversely affect the efficiency of dredging operations or even cause safety issues.

A modern alternative mitigation technique is to make use of Passive Acoustic Monitoring (PAM) to acoustically detect the presence of marine mammal species such as whales and porpoises. The use of PAM systems alone is often insufficient, as it is difficult to discern between different species as well as to establish the exact location of the detected animal in relation to the position of the PAM.

Last but not least it is good to realise that PAM systems can only work when animals vocalise.

The FaunaGuard is an Acoustic Deterrent Device (ADD), albeit one with customised hardware specifications to allow for the emission quite specific signals at the appropriate levels of intensity. ADDs, as they are available on the market, vary greatly in source level, spectrum (and thus the effective range), duty cycle, proven effectiveness and durability. The most innovative aspect of the FaunaGuard is the fact that it deters marine fauna with species specific or group specific (safe) acoustics that are tested scientifically for their effectiveness. This means that the acoustic signals that are emitted by the FaunaGuard have been specifically selected (frequency spectrum, loudness, temporal structure, duty cycle) for specific species of marine fauna. The tailor-made sounds enable a more focussed deterring approach, which minimises impacts on the target species, as well as on other species, and improves the likelihood for fauna to survive.

FAUNAGUARD HARDWARE

The FaunaGuard consists of sound-emitting equipment and sound-receiving equipment (to allow users to check that the device is working). In principle each FaunaGuard module is purpose-built for a target species, although it is possible to combine several modules into one device.

The FaunaGuard randomly emits sounds that are all designed to fit specific requirements for the target species. The different sounds are based on the hearing range and sensitivity of the species (frequency spectrum) and the reaction threshold levels, based on known literature and extensive behavioural response experiments.

The frequency spectrum of the deterring sounds of the FaunaGuard have been designed to be within the functional hearing range of the target animals, and within the range of best hearing, so that the sensation level (number of dB above the hearing threshold for a particular frequency) is as high

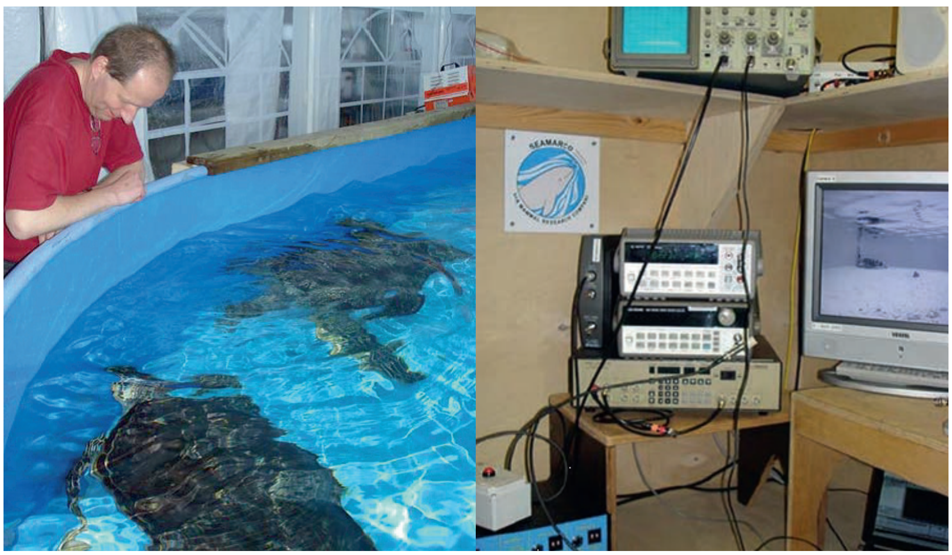

Figure 2. Sounds tested on sea turtles at Rotterdam Zoo (Courtesy of SEAMARCO).

as possible (thus creating a deterring range that is as large as possible).

Furthermore, if possible, the signal duration and frequency spectrum takes into account the species directional hearing abilities, as to assure that the species know where to move away from (i.e., in which direction to go to minimise the sound level).

For almost all animals, sounds with complicated spectra have a greater deterring effect than pure tones. Therefore, the FaunaGuard emits a variety of complex sounds such as sounds with harmonics, sweeps, and impulsive sounds. In addition, sounds have various durations and are emitted with random inter-pulse intervals, to reduce the habituation process.

Figure 3. Fish tests at SEAMARCO Institute in Zeeland (Courtesy of SEAMARCO).

The higher the level of the sounds emitted, the greater the effective range of the FaunaGuard. To allow sounds of high level to be produced, a transducer is selected that has:

- a high output level in the desired frequency range (i.e., in the hearing range of the target species), and
- omni-directionality for the higher frequencies (for this purpose a ball hydrophone is used, transmitting the sounds in 3 dimensions).

The sound level emitted by the FaunaGuard can be adjusted depending on the required effective range. Additionally, for the safety of the animal's hearing the sound level is slowly ramped up after the FaunaGuard is activated. It takes 5-10 minutes to reach the maximum output level. This gives marine fauna time to swim away before maximum output of the FaunaGuard is reached.

FAUNAGUARD TESTED SOUNDS

Since 2010, Van Oord has commissioned SEAMARCO to test and compose the FaunaGuard modules for different species of marine fauna. The following behavioural response experiments have been performed under laboratory conditions at the SEAMARCO facilities in Wilhelminadorp, Rotterdam Zoo and the Arsenaal Aquarium in Vlissingen, all located in the Netherlands.

Responses to sound and light stimuli by Atlantic green turtles (Chelonia mydas) and Hawksbill turtles (Eretmochelys imbricata) in a pool at Rotterdam Zoo, 2010

A study on the effects of sound and light stimuli on the behaviour of Atlantic green turtles (*Chelonia mydas*) and Hawksbill turtles (*Eretmochelys imbricata*) was conducted in an indoor pool at Rotterdam Zoo, the Netherlands (see Figure 2). The pool was set up in the quarantine area of the zoo's aquarium department which is not open to visitors and therefore relatively quiet. The turtles were kept in pairs in an oval pool (7.6 m (l) x 5 m (w) x 1 m (d)). Two 1-m-long male Atlantic green turtles (*Chelonia mydas*) and two 1-m-long Hawksbill turtles (*Eretmochelys imbricata*) were subjects for this study.

The FaunaGuard experiment at Rotterdam Zoo produced several signals that triggered a clear behavioural response with the turtles in the test facility. The experiment furthermore produced a number of helpful lessons learnt regarding the type of signals that were effective, which aspects to take into account when deterring turtles and the optimal signal duration in order to elicit a behavioural response.

Figure 4. Shark and fish pilot study at 'The Arsenaal' in Vlissingen, the Netherlands (Courtesy of SEAMARCO).

Differences were observed in responses to sound between individuals in the pool. Owing to the small sample size, it cannot be determined if these differences were individual, age related, or species specific. When the turtles were in a sleep phase, they were very difficult to "wake up". As a result, the exposure level required to elicit behavioural responses in turtles needs to be high. However, above a certain level, it is the spectrum which determines whether a turtle responds to a sound. Responses were mainly seen to sounds below 1 kHz. This is in agreement with the literature about the frequency range of hearing in turtles. Typical

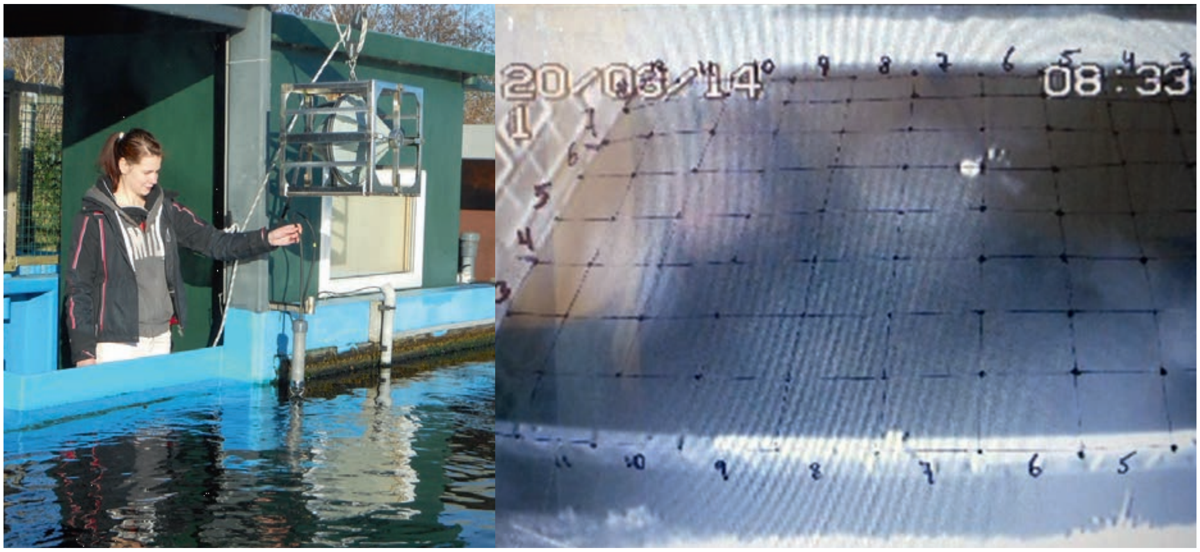

Figure 5. Harbour porpoise behavioural response study at SEAMARCO Institute in Zeeland, the Netherlands (Courtesy of SEAMARCO).

behavioural responses were an increase in activity and a change in swimming pattern.

Even though the experimental setup had some limitations (relatively small basin size, limited size test population), the overall results are useful. Additional tests are planned to further refine the signals found so far, apply these under various field conditions and test them on more sea turtle individuals.

Responses of captive North Sea fish species to underwater sounds produced by the FaunaGuard, 2011

The FaunaGuard Fish Module was designed to produce (safe) sounds to deter fish from areas where harmful sounds are about to be made. Though qualitative evidence from deployment on a dredging project in Sweden suggests that the FaunaGuard effectively deters fish, no scientific data on the behavioural responses of fish to the sounds produced by the FaunaGuard was available.

Therefore the behavioural responses of two captive marine fish species to sounds produced by the FaunaGuard were observed, recorded and quantified (see Figure 3). The 20 sounds of the FaunaGuard Fish Module were tested on five schools of sea bass (*Dicentrarchus labrax*) falling into three size classes and on three schools of thicklip mullet (*Chelon labrosus*) of one size class.
Although the two fish species responded slightly differently to the sounds, several generalisations on the effectiveness of the 20 sounds on the fish in the facility could be made. Ten of the 20 sounds were very effective in causing behavioural responses in the fish. These responses were classified according to type and duration. The sounds that caused little or no effect were outside the most sensitive hearing range of most fish species and outside the resonance frequency range of the transducer (meaning that they were produced at a lower source level). These 10 sounds produced by the FaunaGuard have been replaced by other, more effective, sounds.

Responses of 4 shark species, stingrays and 3 bony marine fish species to underwater sounds produced by the FaunaGuard, 2012

The effectiveness of the FaunaGuard on bony fish (Teleosts; skeletons are made of bone) has been shown qualitatively during several field deployments at marine construction projects in Sweden and Brazil in 2011 and 2012. The exact effectiveness was established in studies under laboratory conditions in a pool at SEAMARCO (2011) (see Figure 3). Next, the effectiveness of the FaunaGuard Fish Module on sharks (Elasmobranchs; skeletons made of cartilage; sharks, rays and dogfish) was studied.

Because sharks are more dependent on their electro-magnetic and olfactory senses, the likelihood of them reacting to sounds was expected to be smaller than for bony fishes. A pilot study on whether behavioural responses from sharks could be elicited with sound was performed in a public aquarium (Figure 4). If the sharks would react to the emitted sounds, a larger study was envisioned.
Four shark species, one stingray species, and three bony marine fish species were exposed to the sounds of the fish module of the FaunaGuard (duration of sounds: 10 seconds, once every 5 minutes). The sharks often showed a change in swimming pattern after exposure to the sounds (during and often after signal presentation). The sharks reacted relatively strongly to three signal types (square waves, white noise and down-sweep) and strongly to one signal type (down-sweep). Also, the sharks reacted relatively strongly to several of the high frequency down-sweeps. Most of the shark species reacted to the high frequency sounds with a slightly higher activity level and a change in swimming pattern.

All bony fish species reacted to the FaunaGuard sounds (Sea bass and Yellowtail Kingfish reacted both equally strong to the sounds, and they reacted stronger than Cod). None of the bony fish species reacted to sounds above 1 kHz. Whether the sharks reacted to the FaunaGuard sounds directly, or to the response of the bony fish to the FaunaGuard sounds indirectly, could not be established conclusively. However, sharks at sea are likely to follow fish (their prey) that behave abnormally (such as during flight), and this response may lead them to follow the fish and thus out or harm's way. When an opportunity arises this aspect will be investigated in greater detail.

Figure 6. FaunaGuard in Norrköping (Sweden) hanging off the drilling and blasting barge before deployment.

Behavioural response study of porpoise on underwater sounds produced by the FaunaGuard, March – May 2014

To estimate the mean received behavioural threshold level of harbour porpoises for the sounds of the FaunaGuard Porpoise Module, and establish an acoustic dose-behavioural response relationship, a porpoise in a pool was exposed to the sounds at seven mean received Sound Pressure Levels (SPLs). Two behavioural parameters were recorded during control and test sessions: the number of respirations (stress indicator) and the animal's distance to the transducer. The experimental setup that was used to test this is shown in Figure 5.

The number of respirations differed significantly between control and test sessions at mean received test levels of 104 dB re 1μPa and above. The porpoise's distance to the transducer was significantly greater during test sessions than during control sessions when mean received levels in test sessions were 86 dB re 1μPa and above. The results show that harbour porpoise will respond to the FaunaGuard by swimming away from it.

The FaunaGuard Porpoise Module is effective at deterring harbour porpoises, in part owing to the high frequency sounds it produces. This allows the porpoise to localise the sound source more easily. To calculate the deterring distance or effective range of the FaunaGuard for harbour porpoises at sea, information on the Source Level, the behavioural threshold level for distance established in the present study, and modelled information on the local propagation conditions and ambient noise need to be combined. For a specific construction site in the North Sea (Eneco Luchterduinen wind turbine park), TNO has calculated the effective distance (~1.3 km). The effective distance was far enough to prevent Permanent Hearing Threshold Shift (PTS) in harbour porpoises caused by pile driving sounds.

FAUNAGUARD PRACTICAL APPLICATIONS

In order to deter marine fauna from its marine construction sites, Van Oord has applied the FaunaGuard in different projects worldwide. Key to effective deployment is the careful design of a management framework in which a mitigating measure such as the FaunaGuard, can be embedded. Garel et al. (2014) illustrate the applicability of the Frame of Reference (FoR) approach in the design of such management frameworks for offshore renewable energy projects.

The FoR approach was developed to help researchers from various fields of expertise to use one generically applicable method to embed their results in a practical decision context (Van Koningsveld et al., 2003; Van Koningsveld and Mulder, 2004; Van Koningsveld et al., 2005). The approach is characterised by the coherent definition of clear objectives at strategic and operational (or tactical) levels and an operational phase where indicators are defined to verify whether or not these objectives are met. A simple example that involves the deployment of a FaunaGuard is discussed below (see Table I).

Let's assume that a virtual offshore wind energy project in Europe is considered, for

Table I. Example of Frame of Reference (FoR) approach on one effect (impact on mammals) of wind energy projects.

Environmental issue	Strategic objective	Tactical objective	Quantitative State concept	Benchmarking desired state	Benchmarking current state	Intervention procedure	Evaluation procedure
Harbour porpoise protection	To preserve the regional harbour porpoise population given the planned construction activity	To prevent individual porpoise being present in the area with high risk for Permanent Hearing Threshold Shift (PTS)	Number of individuals within 1000 m from source 15 min. prior to start of piling activities	No individuals in 1000 m radius 15 min. prior to start of piling activities	Observed number of individuals in 1000 m radius 15 min. prior to start of piling.	If observed number of individuals exceeds the benchmark, activate the FaunaGuard. Observations may be a combination of MMOs and PAMs	If intervention procedure does not achieve the benchmark adapt the setup (change signal, adjust loudness, increase number of devices).

which the Environmental Impact Assessment (EIA) has reported the following environmental concern: "Mammals: Harbour porpoises (Phocoena phocoena) are abundant in the area and may suffer hearing injuries and death as a result of the emission of underwater sound from devices and vessel." One might select "to preserve the regional harbour porpoise population given the planned construction activity" as the strategic objective for the management framework for Mammals. As a subsequent tactical objective one might choose "to prevent individual porpoise being present in the area with high risk for Permanent Hearing Threshold Shift".

Let's say that research for the EIA has shown that the zone with Permanent Hearing Threshold Shift (PTS) risk is a circle with a radius of 1000 m around the sound source. A common first step would then be, to assess the number of individuals that are present in the area and compare that number with the benchmark value. For this either Marine Fauna Observers (MFOs) or Passive Acoustic Monitoring (PAM) or a combination of these two may be utilised. A management measure could be that piling should not start as long as there are still porpoise present in the area. Properly implemented this framework should prevent any harbour porpoise suffering PTS. However, as discussed above under "Faunaguard philosophy", MFOs and PAMs alone are not always sufficient. An additional management measure could be to activate the FaunaGuard and make the area of potential risk temporarily unattractive to porpoise.

As the FaunaGuard provides an evidence based approach, theoretically other measures could be omitted. It is good practice, however, to establish at the start of each project that the anticipated effectiveness and effective range are indeed achieved. Once this is confirmed other monitoring efforts may be reduced. The reasoning described in the above example has been applied to several practical applications. First field application of the FaunaGuard was in Norrköping, Sweden (Figure 6), where drilling, but mainly the blasting, activities were possibly a hazard to the fish and a threat to the fishing industry within the fjord. By introducing low frequency specialised sounds from the FaunaGuard (fish module), the impact on fish in the blasting area was minimised. Owing to minimal preparation time, SEAMARCO had included sounds in the fish module of the FaunaGuard that were chosen based on literature study and experience. During the project the effectiveness of the FaunaGuard was confirmed with observations made on site. After the project finished the FaunaGuard was shipped to the SEAMARCO facilities for service and for further testing of the fish module.

After the field application in Sweden and the lab tests for the fish module, drilling and blasting operations in a more tropical region, Brazil (Figure 7), called for an addition in species representation: the dolphin module was added to the FaunaGuard. Because of the limited information about the responses of dolphins (toothed whales) to sounds, the sounds produced by the dolphin module are based on studies with harbour porpoises. Many studies have been conducted on this species in relation to the development of pingers to deter the porpoises from gill nets (Kastelein et al., 1995-2014). In Brazil, the FaunaGuard has been applied for drilling and blasting operations on two projects in different regions. The successful application was confirmed on site and even reported in a technical certificate from the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA) stating that "… the use of a probe for scaring off fish and dolphins, is worthy of note, for it has proved to be very efficient in scaring fish before detonations".

The latest research and successful application for harbour porpoises has been performed during the construction phase of the Eneco Luchterduinen Wind Farm (a partnership between Eneco and the Mitsubishi Corporation) in the Dutch North Sea (Figure 8). In this case the FaunaGuard has been used as a mitigation measure to deter harbour porpoises sufficiently far away (about 1 km) from piling activities to prevent permanent hearing threshold shift (PTS).
For this measure to be acceptable to the regulator, its effectiveness had to be validated by means of behavioural response study. The effective range of the FaunaGuard should be larger than the distance at which piling can cause PTS (based on sound propagation modelling). Based on the above described research and practical experience, the FaunaGuard (porpoise module) has been accepted by the regulatory agency of the Dutch government and has been employed during the construction of the Eneco Luchterduinen Wind Farm.

Figure 7. FaunaGuard transducers and hydrophone in São Francisco do Sul, Brazil.

Figure 8. Installation vessel Aeolus at work during the construction phase of the Eneco Luchterduinen Wind Farm in the Dutch North Sea.

CONCLUSIONS

The FaunaGuard is an Acoustic Deterrent Device (ADD), albeit one with customised hardware specifications to allow for the emission quite specific signals at the appropriate levels of intensity. It makes optimal use of the scientifically confirmed behavioural effects induced by specific sounds with different species or species groups.

By deliberately making an area in and around a dredging or marine construction site (temporarily) unattractive to marine fauna, more serious effects related to high peak energy events may be prevented. As such the FaunaGuard utilises mild behavioural effects (moving from an area) just before construction, to prevent more serious physiological effects on marine fauna during construction.

As the FaunaGuard provides an evidence based approach, additional monitoring and mitigating measures may be reduced after the predicted effectiveness and effective range have been confirmed for a specific project site. Several field applications have been described to illustrate the approach.

Van Oord will continue to further develop the FaunaGuard (hardware as well as signal library) in collaboration with SEAMARCO and other marine fauna specialists worldwide. Additional laboratory studies are foreseen to improve and extend the signal library.

Further field verification tests are foreseen to better understand how site conditions influence the FaunaGuard's effectiveness. The ruggedness of the equipment, a requirement for offshore conditions, will be improved. Practical applications will be used to improve the environmental management framework in which the FaunaGuard is used.

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