THEME 4: Noise

This is a deliverable from the BalticBOOST project that was coordinated by HELCOM and co-financed by the European Union in 2015-2016 as part of the programme DG ENV/MSFD Action Plans/2016.

WP 4.1 Deliverable 5: Compilation of internationally available mitigation measures and Baltic Sea country specific information

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Contents

1 Introduction

One of the aims of BalticBOOST theme 4 is to survey possible measures to manage and mitigate relevant impacts of underwater noise from different sources of relevance in the Baltic Sea.

This document aims to compile available international information and national experiences on mitigation measures to address anthropogenic sources of noise with the understanding that mitigation measures aim to keep marine mammals at a distance from noise sources that have the potential to harm or kill them (ASCOBANS, 2009).

A preliminary version of this document was submitted to PRESSURE 5-2016 and MARITIME 16-2016. This improved version of the document accommodates comments as provided by those meetings (Outcome of PRESSURE 5-2016, par. 4.24-4.25 and Outcome of MARITIME 16-2016, par. 12.1-12.3).

2 Sources of underwater noise

Sound present in the underwater environment can be categorized as either natural or anthropogenic sound where the first encompasses all kinds of events produced by either animals or geophysical processes such as rain and waves, ice breaking, while the second is produced by mankind.

Sound is generally defined as noise when it clutters and masks other sounds of interest (Richardson et al. 1995), and anthropogenic sound will most often be considered noise in the natural environment. Anthropogenic noise can largely be divided into two categories; continuous noise such as noise from ship traffic or impulsive noise such as noise from piling or sonars, though there often is some overlap between the categories.

In a report from the TG Noise group 2014 (Dekeling et al., 2014) different impulsive sound sources were defined together with sound pressure levels and a corresponding estimate from very low to high on the strength of the source (Table 1). To our knowledge, a similar table for continuous noise has not been established. However, an open access to data from measurements of radiated noise from ships is available as part of the SONIC project (Suppression of Underwater Noise Induced by Cavitation project).

Table 1. Impulsive noise levels caused by human activities as defined by the TG Noise group (Dekeling et al., 2014).

Sound source	
Sonar or acoustic deterrents (source level, rounded to nearest decibel)	• Very low: 176-200 dB re 1 µPa m • Low: 201-210 dB re 1 µPa m • Medium: 211-220 dB re 1 µPa m • High: above 220 dB re 1 µPa m
Generic explicitly impulsive source (energy source level, rounded to nearest decibel)	• Very low: 186-210 dB re 1 µPa² m² s • Low: 211-220 dB re 1 µPa² m² s • Medium: 221-230 dB re 1 µPa² m² s • High: above 230 dB re 1 µPa² m² s
Airgun arrays (zero to peak source level, rounded to nearest decibel)	• Very low: 209-233 dB re 1 µPa m • Low: 234-243 dB re 1 µPa m • Medium: 244-253 dB re 1 µPa m • High: above 253 dB re 1 µPa m

Sound source	
Explosions (equivalent TNT charge mass, rounded to nearest 10 g if less than 10 kg and to nearest 1 kg otherwise)	• Very low: 8 g to 210 g • Low: 220 g to 2.1 kg • medium: 2.11-21 kg • high: 22-210 kg • Very high: above 210 kg
Impact pile driver (hammer energy, rounded to nearest 10 kJ)	• Very low: less than 280 kJ • Low: 290 kJ-2.80 MJ • Medium: 2.81-28 MJ • High: above 28 MJ

In the past decades, concern has been raised on how the underwater noise generated by human activities affects marine life since it has been recognized that both continuous and impulsive noise may have a negative impact on marine life (Richardson et al., 1995; Popper and Hawkins, 2012 and 2016). In order to decrease the environmental impact due to this, it is necessary to take measures to mitigate the emission of underwater noise. In a report presented by the OSPAR Commission in 2014, an inventory of measures to mitigate noise emission was presented (OSPAR, 2014). The report gives an overview of different mitigation options, especially to certain human activities that are considered of prime concern.

These are or will be listed in 7 annexes to the OSPAR report:

- Annex 1: pile driving
- Annex 2: seismic surveys
- Annex 3: explosions
- Annex 4: high frequency (HF) impulsive sources (e.g. echo sounders)
- Annex 5: dredging
- Annex 6: sonar
- Annex 7: shipping

Annex 1, pile driving, is the only finished annex so far. However, a draft report covering measures and techniques to mitigate the impact of seismic surveys was compiled by the Department of Energy & Climate Change and presented at an ICG-Noise meeting in January 2016 (Genesis, 2015), and a further updated version was presented to OSPAR in June 2016 where it was agreed to publish it pending study reservation by Denmark. The report will form the base of Annex 2 mentioned above. Mitigation measures for the the remaining activities: explosions, HF impulsive sources, dredging, sonar and shipping, will be completed in due time, and will also be described below in some detail.

In the Baltic Sea many of the human activities listed in the OSPAR report occur, but some might not be as widespread as in the North Sea or the Atlantic Ocean (e.g. seismic surveys). These activities should however still be included in this report since events might increase in the future and noise mitigation thus become an important issue.

3 Mitigation measures

Generally noise mitigation can be divided into the following categories of measures; 1) measures that reduce the noise produced (e.g. pile caps in pile-driving or small focused charges in explosions), 2) measures that attenuate the noise produced (e.g. bubble curtains) or, 3) measures reducing the likelihood of animals encountering a noise event (e.g. marine mammal observers, or moving the event in space or time) (Richardson et al., 1995; Weilgart, 2007; Jefferson et al., 2009; Andre et al., 2011).

As previously mentioned the report by the OSPAR Commission (OSPAR, 2014) also considers the need to mitigate the noise generated by different kind of human activities, but has so far only finished Annex 1: piling.

This section takes into account measures to mitigate piling, seismic surveys and shipping and recreational boating in detail, as well as some possible mitigation measures for naval sonars, high frequency impulsive sources, marine aggregate dredging operations, and explosives.

Note that the listed mitigation measures are described in more detail in the referenced reports and publications.

3.1 General considerations

In principle it is possible to reduce the environmental impact of emitted noise by restricting the activities that generate noise to certain locations and time periods where and when it is known that sensitive species are avoided (Jefferson et al., 2009; Weilgart, 2007). General considerations such as this one are listed in Table 2.

Table 2. General considerations for underwater noise mitigation.

Activity	Mitigation measures
General considerations (OSPAR, 2014)	☐ **Refraining** from applying activities generating harmful noise; ☐ **Exclusion of noise generating activities** for a certain time of the year (e.g., prohibition of pile driving in the Dutch part of the North Sea within the first 6 month of a year to protect fish larvae from being killed [as food basis for protected seabirds], in particular); ☐ **Restriction** of anthropogenic underwater noise to **a certain level** (e.g., limitation of impulsive noise during offshore wind farm construction to 160 dB SEL in the German part of the North Sea to protect especially harbor porpoises from being injured); ☐ **Exclusion** of noise generating activities **from certain areas** (e.g., by transferring of shipping lanes); ☐ **Spatio-temporal exclusion or limitation** of noise causing activities (e.g. to protect harbor porpoises from disturbance at most sensitive time of their life cycle); ☐ Usage of **alternative techniques** with lower sound emissions; ☐ **Modification** of operational state of noise source, e.g., reducing ship speed.

3.2 Pile driving

To mitigate sound from pile driving, several methods have been explored. Reducing the sound pressure levels produced has been tested by e.g. using pile caps (Laughlin, 2006) and vibratory hammers (e.g. Nedwell and Edwards, 2002; Betke et al., 2010). Another method is attenuating the produced sound through the use of bubble curtains, confined bubble curtains, bubble sleeves, hydro sound dampers, de-watered cofferdams etc. These methods have been tested in several constructions (e.g. Anonymous, 2001; CALTRANS, 2009, Carlson and Wieland, 2007; Lee et al., 2011; Lucke et al., 2011; Reyff, 2003), and Bellmann (2014) reviewed the tested effectiveness of secondary sound attenuators used in windfarm construction in German waters.

Measures to mitigate pile driving of off-shore wind turbines as well as alternative low-noise foundation concepts are presented below as described in Annex 1 in the OSPAR Commission report (OSPAR, 2014).

Table 3. Measures to mitigate pile driving.

Activity	Mitigation measures
Pile driving (Annex 1 in the OSPAR, 2014)	☐ **Big bubble curtain (BBC**): Freely rising bubbles injected by perforated pipes encircling the pipe; ☐ **Little bubble curtain (LBC)** (also Small BC, BC confined and Layered BC): Same as BBC but smaller dimension; ☐ **Isolation casings**: Different types, either steel pipe or foam or composites or rising bubbles surrounds the pipe; ☐ **Dewatered cofferdams**: Pile is isolated from the water, noise is reduced in the airgap between pile and water; ☐ **Hydro Sound Dampers** (Encapsulated bubbles: Small air-filled elastic balloons fixed to nets or frames are placed around the pile. Alternatives to Impact Pile Driving which emit less noise: ☐ **Vibratory Pile Driving** (Vibropiling): Makes piles oscillate at low frequency (20 Hz). Can work in combination with impact pile driving; ☐ **Drilled foundations**: Instead of impact pile driving, drilling is an option; ☐ **Gravity base foundation**: Large box girders with stability from self-weight of the structure; ☐ **Floating Wind Turbines**: Tethered in different way using suction anchors, driven piles or counterweights; ☐ **Bucket foundations** (suction bucket/caisson/can): Founded to the seabed using suction pumps. Additional noise mitigation concepts: ☐ **High frequency – low energy piling** – 90 blows/min instead of 40; ☐ **Mandrel piles;** ☐ **Slit piles** (theoretical approach); ☐ **Silent pile driving** – prolonged pulse duration (theoretical approach).

3.3 Seismic surveys

Measures to reduce the noise from seismic surveys as well as possible alternatives have been reviewed based on available information by the Department of Energy & Climate (Genesis, 2015). For a detailed description of each mitigation measure, see the report available online (Genesis, 2015).

Table 4. Mitigation measures for seismic surveys.

Activity	Mitigation measures
Seismic surveys (airgun array) (from Genesis, 2015)	**Mitigation during the planning phase** ☐ Collection **of baseline data** of the marine species present within the area; ☐ **Avoidance of sensitive areas** including/excluding buffer zones; ☐ **Avoid surveys** during sensitive time periods; ☐ Consider simultaneous and cumulative impacts; ☐ Assess the **impact on marine mammals;** ☐ Determine the **size of the exclusion zone** (safety/mitigation zone) o E.g. border at the 180 dB isopleth; o Specified distance such as 500 m; ☐ Minimise airgun sound and sound propagation o Use lowest practicable volume of the airgun; o Reduce high frequency component; **Mitigation during operations** ☐ Pre shoot watch during specified time interval (e.g. 60 min); ☐ Use acoustic deterrent devices; ☐ **Soft start** (ramp up); ☐ Restrict the usage of airguns during line changes; ☐ Use **marine mammal observers;** ☐ Define visual monitoring procedures o Restrict surveys during night; o Determine the range to the animal; o Restrict airgun use when sighting an animal; ☐ Use **passive acoustic monitoring** systems; ☐ Use active acoustic monitoring; ☐ Make aerial surveys before and after the seismic survey; ☐ Sound baffling using screens of air bubbles; ☐ Mitigation for Other Species; **Post Survey Measures** ☐ MMO reports and sharing of data; ☐ Post survey monitoring (in areas where baseline data is poor); ☐ Impulsive noise monitoring (noise registry); **Alternatives to seismic** ☐ Marine Vibroseis / marine vibrators: frequency sweep between 5-90 Hz; ☐ "Teles" – a Marine Siren; ☐ Low-frequency Acoustic Sources; ☐ Deep-towed Acoustic/Geophysical System; ☐ Low Impact Seismic Array; ☐ Underwater Tuneable Organ-pipe; ☐ Electromagnetic Surveys; ☐ Gravity and Gravity Gradiometry; ☐ Shear Wave Generators.

3.4 Sonar

Mitigation measures used for naval sonars have been surveyed by Dolman et al. (2009). They identified three main standard mitigation methods; 1) avoidance of marine mammals through planning in time and space, 2) operational procedure implementation such as soft start, and 3) using marine mammal observers and passive acoustic monitoring to maintain "exclusion zones".

Table 5. Mitigation measures for naval sonar.

Activity	Mitigation measures
Naval sonar (from Dolman et al., 2009)	**Mitigation during the planning phase** ☐ **Avoidance of sensitive areas** including/excluding buffer zones; ☐ **Avoid surveys** during sensitive time periods; **Mitigation during operations** ☐ **Soft start** (ramp up); ☐ Restrict sonar use during night time, in adverse weather conditions and during higher risk oceanographic and meteorological conditions; ☐ Use **marine mammal observers;** ☐ Use **passive acoustic monitoring** systems

3.5 High frequency (HF) impulsive sources (e.g. echo sounders)

O'Brien et al. (2005) surveyed best practice mitigation measures in relation to the use of multibeam echo sounders in various areas, where such equipment had been in use. Common for all instances was the measure to use marine mammal observers, though several other measures were also suggested in some cases.

Table 6. Mitigation measures for multibeam echo sounders.

Activity	Mitigation measures
Multibeam Echo sounders (from O'Brien et al., 2005)	**Mitigation during the planning phase** ☐ **Avoidance of sensitive areas** including/excluding buffer zones; ☐ **Avoid surveys** during sensitive time periods; ☐ **Planning surveys** to minimize repeated risk of exposure in an area in consecutive years; **Mitigation during operations** ☐ **Soft start** (ramp up); ☐ Restrict multibeam echo sounder use during night time and in adverse weather conditions; ☐ Use **marine mammal observers;** o Interrupt operation in case of appearance of one or more animals; ☐ Use **passive acoustic monitoring** systems

3.6 Marine aggregate dredging operations

Sound mitigation for dredging activities seems mostly to focus on temporal and geographical restrictions, as the noise produced is largely similar to that of shipping, being the overall noise output level is partially dependent upon the aggregate being extracted, and results indicate that extracting gravel is noisier than extracting sand (Robinson et al., 2011; CEDA, 2011; Todd et al., 2015). Further mitigation measures could therefore be similar to those proposed to reduce shipping noise. Additionally, one very effective sound-mitigation measure might simply be adequate maintenance of the dredge plant, including lubrication and repair of winches, generators, propulsion components, and other potential sources, because well-maintained dredgers are much less likely to be "loud" dredgers (WODA, 2016).

3.7 Explosives

Several studies have evaluated mitigation measures to minimize the effects of explosions. The most effective mitigation methods for the protection of marine mammals seems to be the use of marine mammal observers and acoustic deterring devices (ADD) to establish safety zones (Continental, 2004; dos Santos et al., 2010; Jordan et al., 2007). Keevin and Hempen (1997) found that the use of bubble curtains can significantly reduce

the risk of injury in fish. Further mitigation measures include reducing blasting activity to an absolute minimum, and in instances were blasting cannot be avoided to use small focused charges (Reverse Engineering, 2004; Continental, 2004).

Table 7 Mitigation measures for explosives

Activity	Mitigation measures
Explosives (from Continental, 2004; dos Santos et al., 2010; Jordan et al., 2007; Keevin and Hempen, 1997; Reverse Engineering, 2004)	**Mitigation during the planning phase** ☐ **Only use explosives as a last resort**; ☐ **Avoidance of sensitive areas** including/excluding buffer zones; ☐ **Avoid** sensitive time periods; **Mitigation during operations** ☐ Use **marine mammal observers;** o Refrain from blasting in case one or more animals appear in or in the vicinity of the "safety zone"; ☐ Use **ADD** systems; ☐ Use small focused charges

3.8 Shipping and recreational boating

Underwater noise from ships originates mainly from the propulsion system (McKenna et al., 2012; Arveson and Vendittis, 2000; Trevorrow and Vasiliev, 2008) and particularly the propeller of the ship due to cavitation (Ross, 1976). Mitigation systems that focus on reducing noise of the propulsion system will thus reduce the emitted noise to a large extent. However, there are also other considerations when it comes to mitigating ship noise. Speed reduction as well as temporal or geographical restrictions can also be effective means to mitigate noise from shipping (Weilgart, 2007; Merchant et al., 2012).

The International Maritime Organization (IMO) considered the issue of reducing underwater noise pollution from commercial shipping already in 2010 (IMO, 2010), which formed the base of the non-binding IMO Guidelines for the reduction of underwater noise from commercial shipping that was presented in 2014 (IMO, 2014). The IMO guidelines lists several mitigation measures either by considering the design of the ship or when operating the vessel, and these are presented in Table 8**Error! Reference source not found.**.

Veirs & Veirs (2007) found that recreational vessels on average increased background noise 5 – 10 dB higher than the average of large commercial ships, but more importantly their frequency range is much higher (1 kHz - 15 kHz).

Ice-breaking ships are a source of noise in the Baltic Sea. Two types of noise have been identified during ice breaking: bubbler system noise and propeller cavitation noise (Hildebrand, 2005). Some ships are equipped with bubbler systems that blow high-pressure air into the water around the ship to push floating ice away. The noise is continuous while the bubbler system is operating, with a broadband spectrum below 5 kHz. A source level of 192 dB re 1 µPa at 1 m has been reported for bubbler system noise. Icebreaker propeller cavitation noise occurs when the ship rams the ice with its propeller turning at high speed. The spectrum of propeller cavitation noise is broadband up to at least 20 kHz, and has a source level of 197 dB re 1 µPa at 1 m (Hildebrand, 2005).

Table 8. Measures to mitigate ship noise.

Activity	Mitigation measures
Shipping (IMO, 2014)	**Design considerations** ☐ **Ship design** where the hull of the ship has influence on the inflow of water to the propeller. Hull and propeller design should be adapted to each other; ☐ **Propeller design:** should be designed to minimize cavitation by optimizing propeller load, enabling uniform water flow, carefully selecting propeller characteristics such as diameter, blade number, pitch and skew; ☐ **Hull design:** should be designed so that the wake field is as homogenous as possible. **Onboard machinery** ☐ **Select onboard machinery** and vibration control measures, proper location of equipment and optimize foundation structure; ☐ **Request information on airborne sound levels**; ☐ **Use of diesel-electric propulsion** so that it is possible to isolate the diesel generator; ☐ **Use of four-stroke engines** instead of two-stroke; ☐ **Use of vibration isolation mounts** where applicable. **Additional technologies for existing ships** ☐ **Install new propellers;** ☐ **Install wake conditioning devices;** ☐ **Install air injection to the propeller.** **Operational and maintenance considerations** ☐ **Clean the propeller** to reduce the surface roughness and thus the cavitation; ☐ **Maintain smooth hull surface;** ☐ **Reduce ship speed** if this reduces the noise; ☐ **Optimize the combination of shaft speed and propeller pitch** if a decreased speed does not reduce the noise (controllable pitch propellers).

4 Survey by HELCOM countries

This section contains a survey filled in by HELCOM countries indicating which of the listed measures are nationally implemented, or planned to be and also measures that have the potential to be implemented in the future. The measures already listed in the questionnaire are the ones found in the referenced reports (IMO, 2014; OSPAR, 2014; Genesis, 2015); if other measures not listed have been applied, countries were invited to provide them in a separate document.

The questionnaire was submitted to PRESSURE 4-2016 (document 3-5) where the procedure to refine and then fill in the questionnaire was considered. The meeting agreed to provide comments on the questionnaire from both and Pressure and Maritime and the Secretariat to collate them and post the questionnaire at the HELCOM website by 20 May 2016. The Contracting Parties were to fill in the questionnaire by 10 June 2016.

Comments on the questionnaire were provided by Denmark and the questionnaire was amended accordingly (see Underwater noise mitigation measures questionnaire).

The questionnaire was filled in by representatives from Denmark, Finland[1], Germany, Lithuania, Russia and Sweden (see all replies provided compiled in Annex 1).

4.1 Analysis of national feedback

From reporting countries, Denmark, Germany and Sweden have **general considerations** implemented regarding mitigation sound, whereas Lithuania is currently establishing the legal basis required and Finland is to implement them in the future. Preferences differ from one country to another being Sweden the country where more diverse mitigation options are implemented.

Exclusion of noise generating activities for a certain time period	DK*, FI*, SE
Exclusion of wind farms in Nature Conservation Areas (Maritime Spatial Planning)	DE
Restriction of anthropogenic underwater noise to a certain level	DE, DK, SE
Exclusion of noise generating activities from certain areas (e.g. wind farms)	DE, SE
Spatio-temporal exclusion or limitation of noise causing activities	DK*, SE
Usage of alternative techniques	SE
Modification of operational state of noise source, e.g., reducing ship speed	SE
Refraining from applying activities (e.g. by refrain from using explosives when decommissioning offshore constructions)	SE
The environmental courts may impose any of these restrictions as conditions for granting a project license. For shipping over 500 tonnes, the Swedish Transport Agency may propose "Areas to be avoided" through the IMO. Two such areas were implemented in the Baltic in 2005. No speed restrictions for larger vessels have been proposed, though regional authorities have implemented coastal "Consideration Areas" which include speed restrictions for motorboats. The Swedish Armed Forces use a marine biological calendar when planning exercises to minimize environmental disturbance.	SE

**Potential measure*

Regarding specific mitigation measures, Lithuania and Russia potentially contemplate mitigation measures from **ship traffic** following IMO Guidelines (IMO, 2014), whereas they are already implemented on a voluntary basis by shipping companies in Sweden in order to improve fuel economy and maintenance issues. There are no general regulations in Germany where only research vessels need to comply with the state of the art.

In Denmark and Germany the approach to counter act **pile driving** activities differs: in Germany a long list of mitigation measures is implemented, ranging from bubble curtains to acoustic deterrent devices, whereas in Denmark, the concession to pile driving activities for offshore windfarms is to decide which mitigation measures to use to fulfill the related Danish regulation. Both Denmark and Germany have established threshold values for pile driving activities: 190 dB re. 1 µPa2s (PTS) for pile driving exposures longer than 1 hour (computed as the cumulated SEL over all pulses) in Denmark and 160 dB in 750m in Germany. In Sweden, there is a combined approach, where the environmental court determines the limits on maximum allowed sound pressure level together with any other mitigation measures required as a

[1] Info from Finland to be updated once the on-going reporting is finished.

condition of licensing on a case-by-case basis. Finally, in Lithuania, proposals are made to establish the national register along with legal basis for the regional impulsive noise register.

Regarding **seismic surveys** information is only available from Denmark and Sweden, since there is no experience with seismic surveys in the German EEZ in the Baltic Sea. In Denmark, the approval to carry out offshore seismic activities holds terms in relation to soft start and monitoring with possible requirements for MMO's and PAM. An application is subject to an approval process considering the possible impact on protected species and areas such as natura2000 areas, on a case by case process. Thus, there are different options of mitigation measures during the planning, operation and post phases of the seismic surveys, although no maximum sound pressure level is established. In Sweden, mitigation measures can be suggested both for the planning and operation phase of the seismic surveys as part of the license requirements aiming at a maximum sound pressure level (SPL) of 15 000 Hz.

For **explosions** in relation to military activities there are no direct mitigation measures affecting the sound level of the activity in Denmark, but a set of instructions to be followed in order to avoid permanent damage on the marine environment. Protection of species and habitats during military activities is implemented nationally in the Danish Order no. 1458 of 14/12/2010.

Mitigation measures for explosions are currently under consideration in Finland being already implemented in Germany i.e. use of acoustic deterrent devices, pre-detonation and big bubble curtains.

High frequency (HF) sonars used for military activities are to follow a set of instructions in Denmark aiming at avoiding permanent damage on the marine environment. There is no Danish order aimed directly at mitigating sound from HF sonars, however protection of species and habitats during military activities are implemented nationally in the Danish Order no. 1458 of 14/12/2010.

In the case of **dredging** activities, Lithuanian regulations allow dredging activities during the spawning migration of key fish species in estuarine areas only with appropriate permits. The compensational scheme is established regarding fish stocks. However the regulative noise levels are not established. . Although explicit legislation covering noise does not exist in Sweden, courts have the right to impose requirements as appropriate (e.g. time limits, geotextile and bubble curtains, limits on suspended sediment levels at appropriate distances and dredging technique). In Finland, this issue is currently under consideration.

No reporting country contemplates mitigation measures for **sonar** activities. However, limitations in regards of frequency can be considered in Denmark.

Finally, regarding mitigation measure for any other noise generating activity, the Swedish Armed Forces have ordered an investigation into their marine environmental impact. It will be delivered in 2017 and will provide further tools for future planning of exercises in sensitive areas.

5 Discussion

The selection of the most appropriate mitigation measure to counteract the sound to be generated by an anthropogenic activity is a complex issue where the feasibility of the measure, its adequacy and its implementation costs are relevant factors to bear in mind. Unfortunately, social cost benefit analysis on the implementation of underwater mitigation measures is at its early stage (Meulendijk-de Mol, 2015). From the information compiled in this report it can be extracted that mitigation measures to address pile driving are the most advanced ones in the Baltic Sea region where experiences are to be shared between HELCOM countries. This is to be welcomed bearing in mind that pile driving is one of the most frequent activities in the Baltic Sea as reported in the HELCOM registry of impulsive events. Further work may be needed to mitigate sonar activities, since these activities do also take place in the Baltic Sea and there are no

restrictions on the use of sonar or any other mandatory measures to mitigate underwater noise generated by them, apart from possible frequency limitations in Denmark.

Shipping has a crucial role in the economy of the Baltic Sea region and mitigation measures of this sound generating activity are linked to the implementation of the non-binding IMO Guidelines. In this regard, it is to be highlighted that reduction of propeller cavitation is a measure which serves several purposes: it reduces noise but also increases energy efficiency. However, the proposal to use four stroke engines instead of two stroke engines may not feasible as a general recommendation as the choice between these two depends on a complex set of conditions. To clear out this issue and other open questions that may arise it is recommended to work with the maritime industry to develop support for vessel noise reduction. Small boats represent a particular challenge to maritime surveillance due to their ubiquity, low radar cross-section, and absence of AIS transmission (Pollara et al., 2016). Therefore, to address underwater noise generated by recreational boating, the application of alternative methods enabling the extraction of acoustic signatures of different types of boats may be applied. In parallel, a dialogue with the leisure boating community is needed to promote good boating behaviour (slow speeds, good engine maintenance and lower engine noise).

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7 Annex 1. Compilation of the feedback received on the questionnaire

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Are there any general considerations when it comes to mitigating sound?	Yes	Yes	Yes	Yes	No	Yes
General considerations (choose measures)	- Exclusion of noise generating activities for a certain time period[2] - Spatio-temporal exclusion or limitation of noise causing activities[3]	- Exclusion of noise generating activities for a certain time period	- Restriction of anthropogenic underwater noise to a certain level - Exclusion of noise generating activities from certain areas (e.g., by transferring of shipping lanes) - Exclusion of wind farms and shipping in Nature Conservation Areas (Maritime Spatial Planning)	- Due to date the proposals are made to establish the legal basis for mitigation measures	-	- Refraining from applying activities (e.g. by refrain from using explosives when decommissioning offshore constructions) - Exclusion of noise generating activities for a certain time period - Restriction of anthropogenic underwater noise to a certain level - Exclusion of noise generating activities from certain areas (e.g., by transferring of shipping lanes) - Spatio-temporal exclusion or limitation of noise causing activities

[2] Potential measure.
[3] Potential measure.

						- Usage of alternative techniques - Modification of operational state of noise source, e.g., reducing ship speed. - Comments (or other mitigation measures): Under Swedish Environmental Law, the environmental courts may impose any of these restrictions as conditions for granting a project license. For shipping over 500 tonnes, the Swedish Transport Agency may propose "Areas to be avoided" through the IMO. Two such areas were implemented in the Baltic in 2005. No speed restrictions for larger vessels have been proposed, though regional authorities have implemented coastal "Consideration Areas" which include speed restrictions for motorboats. The Swedish Armed Forces use a marine biological calendar when planning exercises to minimize environmental disturbance.

General considerations: What is the status of the general mitigation measures in May 2016	Measures are implemented, and considered on a case by case basis, furthermore requirements for application content and terms for preinvestigation activities for oil and gas are currently being evaluated for a possible update.	- Status: potential measure - We are carrying out a study on Rauma fairway deepening project, where the underwater noise is measured during the construction works to determine the possible influences and mitigation measures in future	- Status: implemented - Threshold for Pile driving noise (160 dB in 750m)	N/A	-	- Status: Implemented - Noise limitation has been required by courts in several piling projects. 'Consideration areas' are implemented. Military exercises are conducted with consideration. Two IMO Areas to be avoided have been implemented in 2005, affecting vessels over 500 tonnes.
Comments on general considerations	-	-	-	-	-	-
Is there any measure aiming at mitigating the noise from ship traffic?	No	No	No	Yes	Yes	Yes
Shipping Design	-	-	-	-	- Measures regarding ship design - Measures regarding propeller design - Measures regarding hull design	- Measures regardingship design, - Measures regardingpropeller design, - Measures regarding hull design
Shipping Onboard machinery	-	-	-	-	-	- Onboard machinery and vibration control measures - Request information on airborne sound levels - Use of diesel-electric propulsion - Use of four-stroke engines - Use of vibration isolation mounts
Shipping Additional technologies for existing ships	-	-	-	-	- Measure to install new propellers - Measure to install wake conditioning devices - Measure to install air injection to the propeller	- Measure to install new propellers, - Measure to install wake conditioning devices, - Measure to install air injection to the propeller

Shipping Operational and maintenance considerations	-	-	-	It is proposed for governmental bodies to cooperate in the Region on questions of possibility to implement IMO MEPC. 1/Circ.833 recommendation	- Measures on cleaning the propeller - Measures on maintaining a smooth hull surface - Measures on reducing the ship speed - Measures on optimizing the combination of shaft speed and propeller pitch	- Measures on cleaning the propeller - Measures on maintaining a smooth hull surface - Measures on reducing the ship speed - Measures on optimizing the combination of shaft speed and propeller pitch
Shipping, what is the status of measures for noise from ship traffic in May 2016?	N/A	-	-	N/A	Potential measure	Implemented
Comments on shipping	-	-	No general regulations. Only Research vessels need to comply with the state of the art.	-	All mentioned measures are included in the MEPC.1/Circ.833 on Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life, which was adopted in 2014 as a voluntary, non-binding “guiding document”.	Measures related to shipping have been implemented, but have been made voluntarily by shipping companies in order to improve fuel economy and maintenance issues. Noise reduction legislation (apart from that related to the working environment) has not driven these changes. It can be debated therefore whether these are ’measures’. Information provided by Swedish Transport Agency.
Is there any measure aiming at mitigating the noise from pile driving?	Yes, to mitigate to a certain noise level.	No	Yes	No	-	Yes

Pile driving Impact piling mitigation measures	-	-	- Big bubble curtain (BBC) - Little bubble curtain (LBC) - Hydro Sound Dampers - Use of acoustic deterrent devices - Soft-Start - Limitation of piling energy - Assess the impact on marine mammals - Passive acoustic monitoring of marine mammals - Monitoring of impulsive noise - Noise registry	-	-	- Big bubble curtain (BBC) - Little bubble curtain (LBC) - Isolation casings - Dewatered cofferdams - Hydro Sound Dampers
Pile driving Alternatives to Impact Pile Driving which emits less noise	-	-	-	-	-	- Vibratory pile driving (Vibropiling) - Drilled foundations - Gravity base foundation - Floating wind turbines - Bucket foundations
Pile driving Additional noise mitigation concepts	-	-	High frequency – low energy piling	-	-	- High frequency – low energy piling - Mandrel piles - Slit piles - Silent pile driving with prolonged pulse duration
Pile driving: are there any limits on maximum allowed sound pressure level (SPL)?	Yes, in relation to pile driving activities for offshore windfarms. The Danish regulation is developed to protect marine mammals from permanent hearing damage, and is based on the work from an expert group. The regulation is specially developed for pile driving activities for installation of OWF. The regulation is revised in 2016 including some new studies and fieldwork on harbour porpoises and	No	Yes Threshold: 160 dB in 750m	-	-	Yes These can (and have been) required as a condition of licensing, for example in the Kattegat Offshore project, with the express aim to protect porpoises. Limits (and all other measures) are determined in each separate case by the environmental court in accordance with need.

	seals. The Danish regulation and the background reports can be requested at the Danish Energy Agency. The Danish threshold value is 190 dB re. 1 µPa2s (PTS), for pile driving exposures longer than 1 hour (computed as the cumulated SEL over all pulses)					
Pile driving: What is the status of the measures to mitigate noise from pile driving in May 2016?	See text above and below	-	Implemented	-	-	Implemented. Implemented on a case-by-case basis. Official guidance to the Environmental Courts (and operators) about pile driving will be published soon. Explicit legal instruments do not however exist.
Comments on pile driving	Regarding pile driving for windfarm activities, the Danish regulation is developed to protect marine mammals from permanent hearing damage. The regulation contains a threshold value, and the concession holder must demonstrate how he intends to fulfil the requirements and finally perform control measurements. Therefore it is the concession holder that decides which type of mitigation measures are to be used. The next OWF to be established in DK is the Horns Rev 3 in 2017. It is expected, that	-	-	Proposals are made to establish the national register along with legal basis for the impulsive noise register	-	Information from the Swedish Agency for Marine and Water Management

	bubble curtains have to be used by Vattenfall					
Is there any measure aiming at mitigating the noise from seismic surveys?	Yes	No	No	No	-	Yes
Seismic surveys Mitigation during the planning phase	- Avoidance of biologically sensitive areas - Consider simultaneous and cumulative impacts - Assess the impact on marine mammals - Determine the size of the exclusion zone (safety/mitigation zone). This is not up to the applicant. Currently a 500 meter safety zone is to be used.	-	-	-	-	- Avoidance of biologically sensitive areas - Avoid surveys during sensitive time periods
Seismic surveys Mitigation during operations	- Pre shoot watch during specified time interval (e.g. 30 or 60 min) - Soft start (ramp up) - Restrict the usage of airguns during line changes - Use marine mammal observers - Use passive acoustic monitoring systems	-	-	-	-	Use acoustic deterrent devices

Seismic surveys Post Survey Measures	- Marine mammal observer reports and sharing of data - Impulsive noise monitoring e.g. in a noise registry	-	-	-	-	-
Seismic surveys Alternatives to seismic	-	-	-	-	-	-
Seismic surveys: Is there any maximum sound pressure level (SPL) for seismic surveys?	No	No	-	-	-	Yes Maximum 15 000 Hz
Seismic surveys: What is the status of the mitigation measures for seismic surveys in May 2016?	See above	-	-	-	-	N/A
Comments on mitigation measures for seismic surveys	Approval to carry out offshore seismic activities in Denmark holds terms in relation to soft start and monitoring with MMO's, terms in regards of PAM is also used. Furthermore Denmark adheres to the marine framework directive. An application is subject to an approval process considering the possible impact on protected species and	-	No experience with seismic surveys in the German EEZ in the Baltic Sea	-	-	SwAM sees license applications from operators and can suggest conditions to prevent harm to, e.g. porpoises. The Swedish Geological Survey can then insert this requirement in the operator's license. Information provided by SwAM and the Swedish Geological Survey.

	areas such as natura2000 areas, on a case by case process. Requirements for application content and terms is currently being evaluated for a possible update.					
Explosions: Are there any mitigation measures for explosions?	No For explosions in relation to military activities there are no direct mitigation measures affecting the sound level of the activity, but there is a set of instructions which are to be followed in order to avoid permanent damage on the marine environment. In the planning phase an evaluation of possible environmental consequences of the planned explosion in a certain area in a certain time period is performed, and it is assessed weather the activity is of such damage to local populations of bird or marine mammals that it should be placed in another time period or in another area. The instructions also set up some ground rules to follow when executing the explosions. Firstly a visual inspection is performed and if any mammals or birds are spotted in the ”safety zone“ (defined as the	Yes	Yes Acoustic deterrent devices, predetonation, Big Bubble Curtain	No	-	No

	zone wherein mammals will suffer permanent physical damage) the explosions are not to be carried out before the animal(s) are no longer observed in the safety zone. Thereafter follow a "rampup" procedure to scare away animal life before the explosions are executed. If marine mammals are spotted within the safety zone the activity is stopped immediately					
Explosions: What is the status of mitigating measures for explosions in May 2016?	N/A There is no Danish order aimed directly at mitigating sound from explosions, however protection of species and habitats during military activities are implemented nationally in the Danish Order no. 1458 of 14/12/2010; Bekendtgørelse om administration af internationale naturbeskyttelsesområder samt beskyttelse af visse arter for så vidt angår forsvarets aktiviteter "https://www.retsinformation.dk/Forms/R0710.aspx?id=134796 . In this order it is among other things stated that the Minister of Defence should take the appropriate measures in order to avoid	Potential measures, We are carrying out a study on Rauma fairway deepening project, where the underwater nois is measured during the construction works to determine the possible influences and mitigation measures in future	Implemented	N/A	-	N/A

	disturbance of protected species or habitats as specified in the Habitats directive. Furthermore the instructions described under point 29 are in use for most activities already.					
High Frequency sonars: Are there any mitigation measures for high frequency sonars e.g. echo sounders?	Yes For high frequency sonars (20-180 kHZ) used for military activities there is a set of instructions which are to be followed in order to avoid permanent damage on the marine environment (however if the sonar activity is assessed to be fundamental for ship safety these procedures do not apply). In the planning phase an evaluation of possible environmental consequences of the planned sonar use in a certain area in a certain time period is performed, and it is assessed whether the activity is of such damage to local populations of bird or marine mammals that it should be placed in an another time period or in another area. The instructions also set up some ground rules to follow when using sonar. Firstly a visual inspection is performed and if any mammals or birds are	No	No	No	-	No

	spotted in the "safety zone" (defined as the zone wherein mammals will suffer permanent physical damage) the activity is not to be carried out before the animal(s) are no longer observed in the safety zone. Thereafter follow a "rampup" procedure to mitigate possible hearing damages before the activity is executed. Furthermore where possible it is attempted to minimize the sound exposure by requesting as few sonar system active at once as possible, the highest frequency and most low sound level, together with avoidance of beaming towards certain areas if possible, while still achieving the goal of the operation. The later recommendations are usually only given when dealing with sonar systems operating below 20 kHz					
High Frequency sonars: What is the status of mitigating measures for HF sonars in May 2016?	N/A There is no Danish order aimed directly at mitigating sound from HF sonars, however protection of species and habitats during military activities are implemented nationally in the Danish Order no. 1458 of 14/12/2010;	-	-	-	-	N/A

	Bekendtgørelse om administration af internationale naturbeskyttelsesområder samt beskyttelse af visse arter for så vidt angår forsvarets aktiviteter" https://www.retsinformation.dk/Forms/R0710.aspx?id=134796. In this order it is among other things stated that the Minister of Defence should take the appropriate measures in order to avoid disturbance of protected species or habitats as specified in the Habitats directive. Furthermore the instructions described under point 31. are in use for most activities already					
Dredging: Are there any mitigation measures for dredging activities?	No	Yes	No	Yes National regulations allow dredging activities during the spawning migration of key fish species in estuarine areas only with appropriate permits. The compensational scheme is established regarding fish stocks. However the regulative noise levels are not established	-	Yes Courts may impose requirements such as time limits, geotextile and bubble curtains, limits on suspended sediment levels at appropriate distances and dredging technique.
Dredging: What is the status of mitigating noise from dredging activities in May 2016?	N/A	Potential measures We are carrying out a study on Rauma fairway deepening project, where the underwater noise is measured during the construction works to determine the possible influences and mitigation measures in future	-	Implemented National regulations allows dredging activities during the spawning migration of key fish species in estuarine areas only with appropriate permits	-	Implemented Explicit legislation covering noise does not exist, but courts have the right to impose requirements as appropriate

Sonar: Is noise from sonars mitigated, are there any restrictions on using sonars?	No	No	No	No	-	No
Sonars: What is the status om mitigation measures on sonars in May 2016?	N/A	-	-	N/A	-	N/A
Are there any mitigation measure for any other noise generating activity?	No	No	No	No	-	Yes. The Swedish Armed Forces have ordered an investigation into their marine environmental impact. It will be delivered in 2017 and will provide further tools for future planning of exercises in sensitive areas.
Are there any other comments to this survey, please write them below	-	-	Only little data available (one windfarm) in the German EEZ in the Baltic Sea	-	-	The Swedish Agency for Marine and Water Management prepared these answers with the help of the Swedish Transport Agency, the Swedish Geological Survey and the Swedish Armed Forces.