Consultation within TSG 3: Construction Activities in the Sea and on the Seashore and Achieving good environmental status of the Sea

Mitigation measures to reduce underwater noise in marine water generated by anthripogenic activities

Omilitveni ukrepi za zmanjšanje podvodnega hrupa v morski vodi, ki ga povzročajo antropogene dejavnosti

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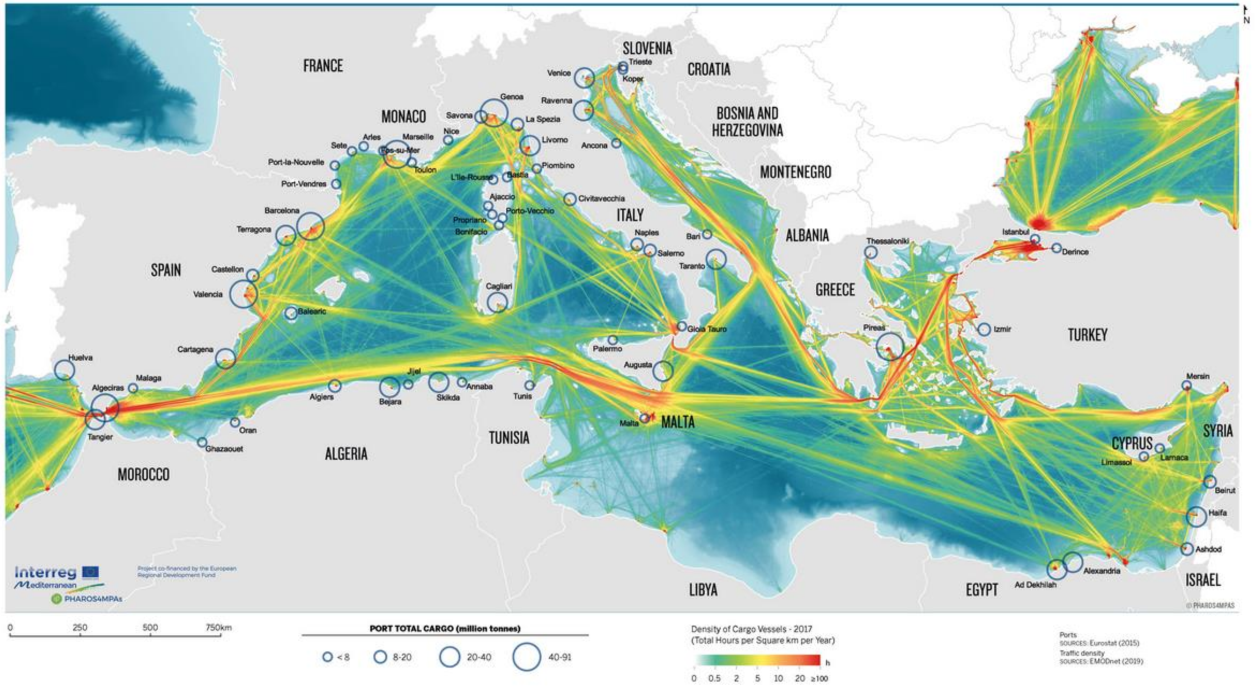
Undrewater noise (continuous and impulsive)

Continuous noise: maritime transport (merchant, passenger, fishing and military ships and recreational vessels), construction activity (deepening of the seabed with an excavation dredger, drilling piles into the seabed) and industrial activity (operating oil rigs and offshore wind farms).

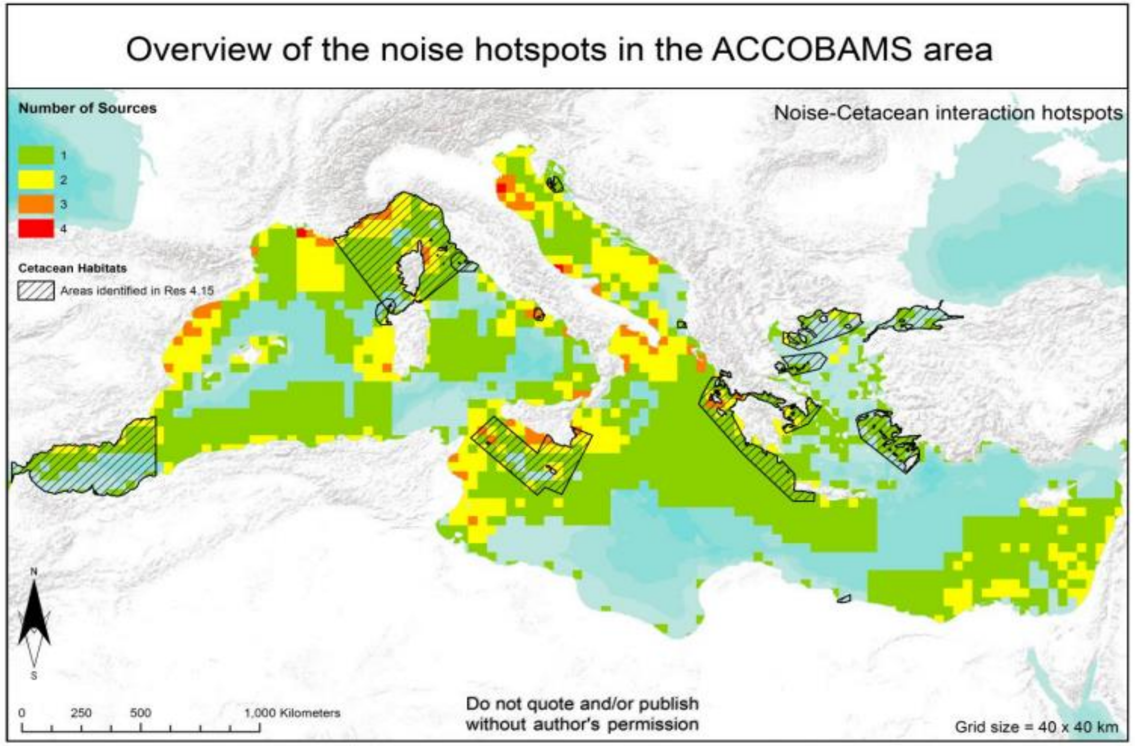
Density of cargo ships in the Mediterranean sea in 2017 (Emodnet data)



Undrewater noise (continuous and impulsive)

Impulsive noise: pile driving (for construction of docks, oil rings, foundations for windfarms), use of low- and mid-frequency sonars, seismic exploration (use of air guns), explosions, acoustic deterrents.

Impulsive noise hot spots in the Mediterranean sea. Important cetacean habitats are marked on the map (Maglio et al., 2016).



Mitigation measures for
the reduction of underwater noise from shipping

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1) **Mitigation measures used in design of the ship (propeller and hull design)**

- Mitigation measures used in propeller design
- Mitigation measures used in hull design

2) **Mitigation measures used in design, selection and installation of on board machinery**

- Mitigation measures used in the selection of on board machinery
- Mitigation measures used in the selection of location, where machinery is installed in the ship hull
- Mitigation measures to control vibrations and optimization of foundations

3) **Mitigation measures based on the use of additional technologies on existing ships**

- Design and installation of new state-of-the-art propellers
- Installation of wake conditioning devices
- Installation of air injection to propeller

4) **Mitigation measures used in ship operation and maintenance**

- Cleaning of propeller
- Maintenance of the ship hull surface
- Operational mitigation measures – selection of the proper speed
- Re-direction and operational measures for reduction of harmful effects on marine organisms

Mitigation measures for
<u>the reduction of underwater noise from shipping</u>

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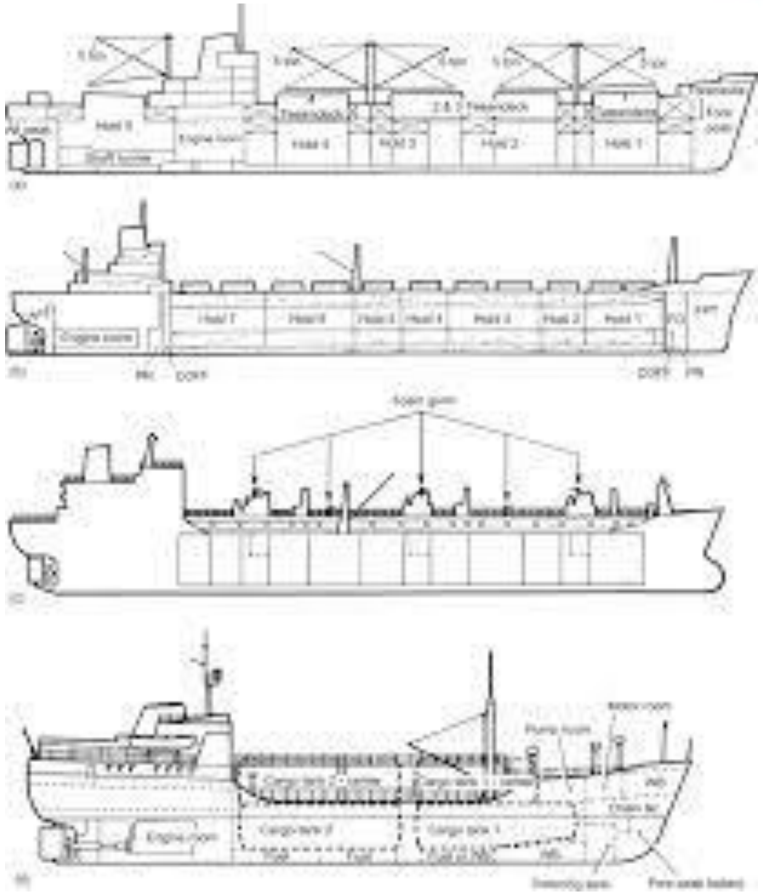
1) Mitigation measures used in design of the ship

- Mitigation measures used in propeller design
- Mitigation measures used in hull design



Mitigation measures for the reduction of underwater noise from shipping: propeller design

Propeller design affects underwater radiated noise through the following factors:

-**Number of propellers**: distribution of the thrust over more than one propeller can reduce propeller loading and cavitation. Moreover, the wake flow into the propeller can be more uniform if the propellers are placed off the centre line of the vessel.

-**Fixed or Controllable pitch**: propeller blades can have fixed blade angles (fixed pitch) or adjustable blade angles (controllable pitch). Pitch control enables adjusting the thrust (and hence ship speed) independent of the rate of rotation (rpm). Consequently, reducing the speed of a ship equipped with controllable pitch propellers does not necessarily result in a radiated noise reduction. When the shaft speed can be controlled as well, the combination of shaft speed and propeller pitch can potentially be optimized with respect to cavitation performance and noise.

-**Number of blades, blade area and shape (pitch and skew)**: no general guidelines can be given for these design parameters, since they need to be optimized against multiple requirements. However, it is advised to include cavitation behavior and noise control as essential boundary conditions for the design process.

Mitigation measures for the reduction of underwater noise from shipping: propeller design

Propeller design affects underwater radiated noise through the following factors:

-**Hub**: hub cavitation should be avoided using technical solutions, such as propeller boss cap fins.

-**Azimuth thrusters**: marine propellers can be placed before or after underwater pods that can be rotated to any horizontal angle (azimuth), increasing manoeuvrability and making a rudder unnecessary. A (diesel or diesel-electric) motor can either be inside the ship and connected to the outboard unit by gearing (L- or Z-drive), or the motor may be diesel or diesel-electric. Depending on the shaft arrangement, an electric motor is fitted in the pod itself. ('podded propulsion'). This drive type allows for a more uniform inflow into the propeller, leading to improved cavitation behavior, at the cost of a more direct connection between the motor and the water, leading to higher machinery noise radiation.

-**Air injection**: can be used for either reducing propeller cavitation by air injection directly into the cavitating region, or attenuating noise radiation by generating an isolating bubble curtain around the propeller and its downstream flow.

Solutions
in propeller design

<u>ACCOBAMS proposed the following technologies for reduction of propeller cavitation</u>:

- **Schneekluth duct** – device installed on the hull of the ship in order to improve the flow on the upper part of the propeller and decrease cavitation;

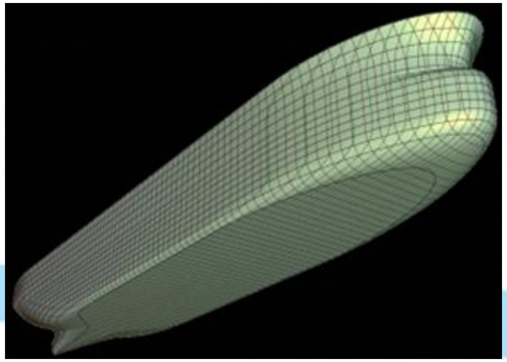
- **Becker Mewis Duct** – a duct positioned in front of the propeller along with an integrated fin system;

- **Propeller boss cap fins** – improves the propeller performance characteristics via minimising the hub vortex and resultant rudder cavitation;
- **EnergoProFin (Wartsila)** – an energy saving propeller cap with fins that rotate together with the propeller;
- **ECO-Cap (Nakashima)** – propeller cap for propeller hub reduction

Solutions
in propeller design

Optimal propeller with regard to underwater noise reduction cannot always be employed due to technical or geometrical constraints (e.g. icestrengthening of the propeller). It is also acknowledged that design principles for cavitation reduction (i.e. reduce pitch at the blade tips) can cause decrease of efficiency.

Mitigation measures for the reduction of underwater noise from shipping: in hull design

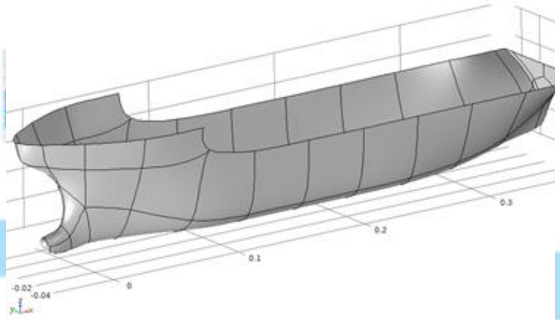


Uneven or non-homogeneous wake fields are known to increase cavitation. Therefore, the **ship hull form** with its appendages **should be designed** such that **the wake field is as homogeneous as possible**. This will reduce cavitation as the propeller operates in the wake field generated by the ship hull.

Hull design affects underwater radiated noise through the following factors:

- **Resistance**: optimization of the hull form and the application of anti-fouling and low-friction coatings, for reduced resistance will reduce the required propulsion power at the same speed, which will generally lead to reduced propulsion noise (less propeller cavitation). Reduced resistance is also beneficial for energy efficiency and reduces emission of greenhouse gases.
- **Wake field**: optimization of the hull form with its appendages such that the wake field (in the propeller plane) is as homogeneous as possible, which will reduce propeller cavitation. Various technical solutions (fins, ducts) to improve the inflow into the propeller are proposed as propulsion improving devices, since these are generally beneficial for energy efficiency as well.
- **Structure**: optimization of the hull structure (mass, stiffness and damping) can potentially reduce the underwater radiation of structure-borne and air-borne machinery noise. Only relevant when machinery noise exceeds propeller noise.

Mitigation measures for the reduction of underwater noise from shipping: in hull design



Hull design affects underwater radiated noise through the following factors:

- **Hull treatments**: air emission systems can be installed to reduce resistance (air lubrication), which likely reduce machinery noise radiation as well (decoupling the vibrating hull from the surrounding water). Decoupling can also be achieved by application of a flexible hull coating (de Jong, 2002). Such decoupling techniques are used on naval vessels (submarines as well as surface ships) with stringent acoustic signature requirements.

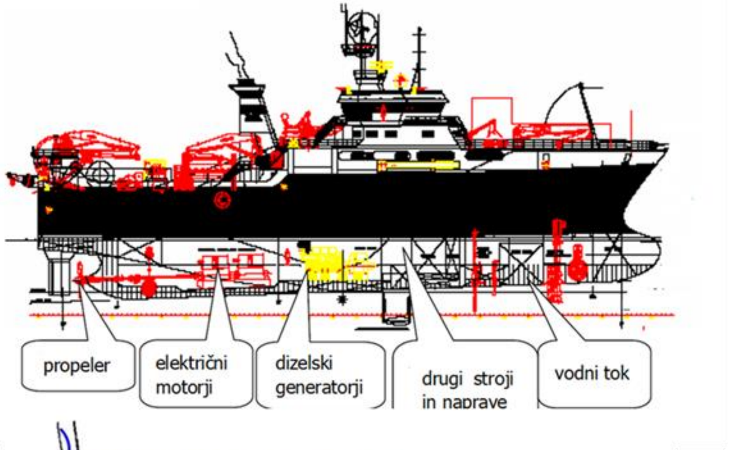
- **Appendages and openings (sea chests)**: improper design of appendages and hull openings (e.g. for cooling water intake) can lead to local cavitation or flow induced noise.

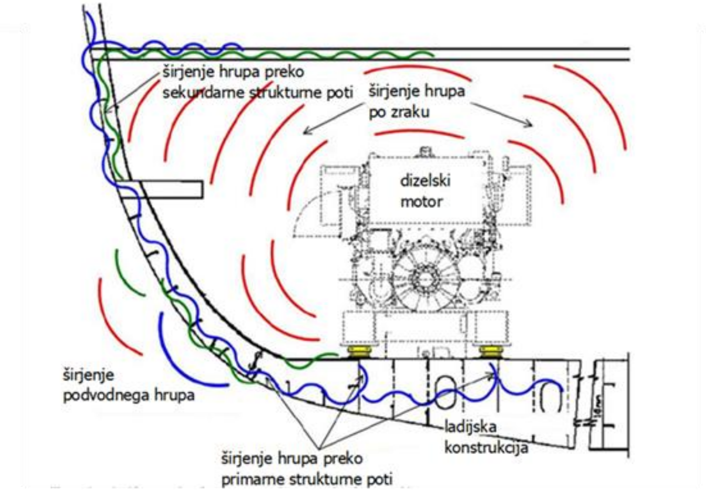
Consideration can be given to the investigation of structural optimization to reduce the excitation response and the transmission of structure-borne noise to the hull.

Mitigation measures for the reduction of underwater noise from shipping

2) Mitigation measures used in design, selection and installation of on board machinery

- Mitigation measures used in selection of on board machinery
- Mitigation measures used in selection of location, where machinery is installed in the ship hull
- Mitigation measures to control vibrations and optimization of foundations





Mitigation measures for the reduction of underwater noise from shipping

3) Mitigation measures based on the use of additional technologies on existing ships

The following technologies are known to contribute to noise reduction for existing ships:

- design and installation of new state-of-the-art propellers;
- installation of wake conditioning devices;
- installation of air injection to propeller.

Mitigation measures for the reduction of underwater noise from shipping

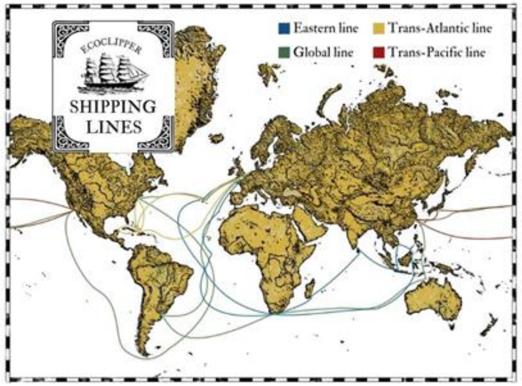
4) Mitigation measures used in ship operation and maintenance

- cleaning of propeller

- maintenance of the ship hull surface
- Operational mitigation measures:

selection of the proper speed

- Re-direction and operational measures for reduction of harmful effects on marine organisms



Mitigation measures for the reduction of underwater noise from shipping

Measures to reduce propulsion power and propeller thrust loading are beneficial for energy efficiency, emission reduction and underwater radiated noise reduction.

Measures to optimize hull design and execute regular maintenance, aimed at reducing hull resistance, are effective for reduced emissions and underwater noise.

Design measures to reduce propeller cavitation are effective for underwater radiated noise reduction. In particular, the hull and propeller need to be designed together, as a unit, such that a uniform wake field is created to reduce propeller cavitation. To some extent these will also increase energy efficiency, and reduce emissions.

Speed limits ('slow steaming') have a potential to be effective to control shipping underwater noise as well as energy efficiency and emission reduction, but different ship types have different optimum speeds and not all ship types can slow down to the same extent.

Mitigation measures for the reduction of impulsive underwater noise

1) Mitigation measures to be used for pile driving
2) Mitigation measures to be used in seismic explorations
3) Mitigation measures to be used for explosive use
4) Mitigation measures to be used for sonar use

Mitigation measures for impulsive noise

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Mitigation measures to be used for pile driving:

Mitigation Framework for pile driving, drilling and dredging	
Planning phase (expected outcomes of the EIA)	1. Review the presence of cetaceans in the candidate periods for the works and carry out or fund research where the information is non-existent or inadequate 2. Select periods with low biological sensitivity 3. Use sound propagation modelling results, verified in the field, to define the extension of the exclusion area (EZ) 4. Plan the lowest practicable source power 5. Consider alternative technologies (p. 11) 6. Plan Noise Mitigation Technologies in case no alternatives are possible (p. 8-9-10)
Real-time mitigation practices (p. 12)	1. Use Acoustic Mitigation Devices prior to the beginning of the work 2. Use the soft start protocol 3. Use the visual monitoring protocol* 4. Use the acoustic monitoring protocol*
Post-activity	1. Detailed reporting of real-time mitigation**

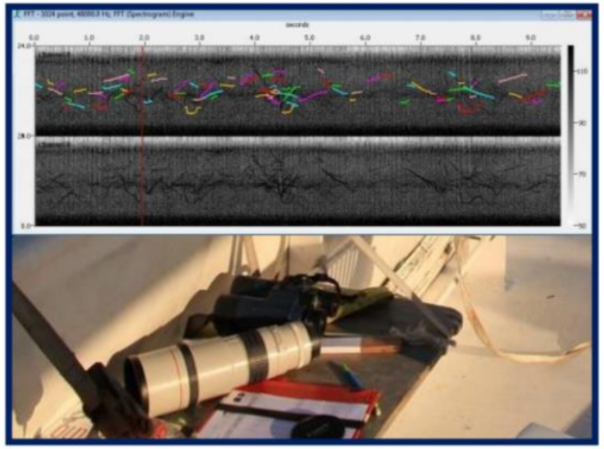
Source level *228 dB re 1µPa m (Peak) or 243 – 257 dB re 1µPa m (P-to-P)*
Bandwidth *20 Hz – 20 kHz*
Major amplitude *100 Hz – 500 Hz*
Duration *50 ms*
Directionality *Omnidirectional*

ref: CEDA 2011; OSPAR 2009

Noise mitigation technologies

Real time mitigation measures

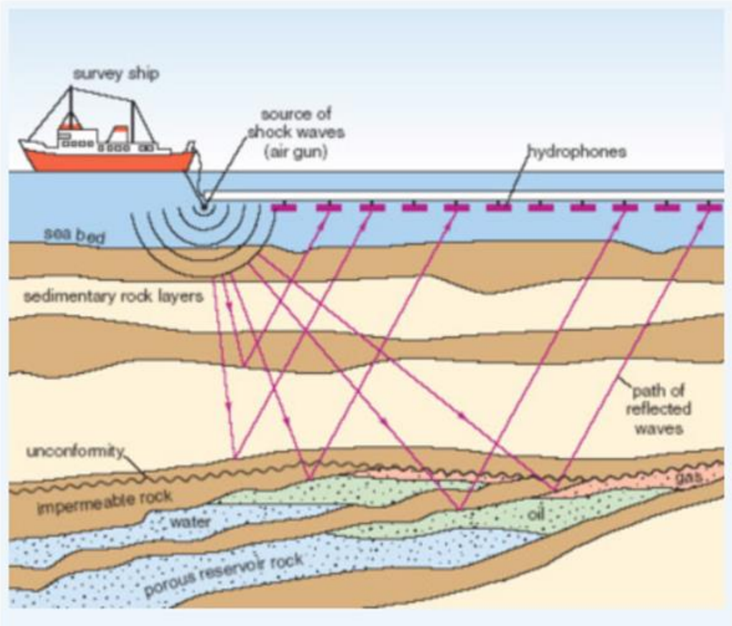
MITIGATION PROTOCOLS
Use of Acoustic Mitigation Devices (AMD)
- Prior to the beginning of the work, AMD should be used to drive away groups or individuals of marine mammals - Only AMDs allowed in the ACCOBAMS area are to be employed (see ACCOBAMS Resolution 4.9, 2010 for cetacean devices)
Soft start protocol
- Noise emissions should begin at low power, increasing gradually until full power is reached - The soft start procedure should be of 20 min duration at least
Marine Mammal Observation protocol
- Dedicated and independent Marine Mammal Observers (MMO) should watch the Exclusion Zone (EZ) for 30 min before the beginning the soft start procedure (120 min for highly sensitive species). - The soft start procedure should be delayed if cetaceans enter the EZ - Continuous watch should be kept for the entire duration of noise emission - The activity should be stopped (or powered down) if cetaceans enter the EZ - In case of a halt in noise, a new 30 min watch should be kept without animals in the EZ before re-starting noise emissions (120 min for highly sensitive species)
Passive Acoustic Monitoring protocol (PAM)
- Acoustic monitoring should be used to alert the observers (MMO) to the presence of cetaceans - Continuous acoustic monitoring should be performed for the entire duration of the noise emission - If activities are carried out at night or during bad weather conditions, acoustic monitoring is to be used as the main monitoring tool - In such conditions, noise emissions should be stopped, or powered down, if acoustic detections of cetaceans occur



Mitigation measures for impulsive noise

Mitigation measures to be used in seismic exploration:

Mitigation Framework for seismic surveys	
Planning phase (expected outcomes of an EIA)	1. Consider the adoption of alternative technologies (p. 11) 2. Review the presence of cetaceans in the candidate periods for the survey and carry out or fund research where the information is non-existent or inadequate 3. Define no-survey zones (biological reserves, especially protected areas etc.) 4. Select periods with low biological sensitivity 5. Use sound propagation modelling to define the extent of the exclusion area (EZ)
Real-time mitigation practices (p. 12)	1. Use the visual monitoring protocol* 2. Use the acoustic monitoring protocol* 3. Use the soft start protocol
Post-activity	1. Detailed reporting of real-time mitigation**



Source level* *220 – 262 dB re 1μPa m (P-to-P)*
Bandwidth *5 Hz – 100 kHz*
Major amplitude *10 Hz – 120 Hz*
Duration *10 – 100 ms*
Directionality *Downwards*

ref: CEDA 2011; OSPAR 2009

Mitigation measures for impulsive noise

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Mitigation measures to be used for explosive use:

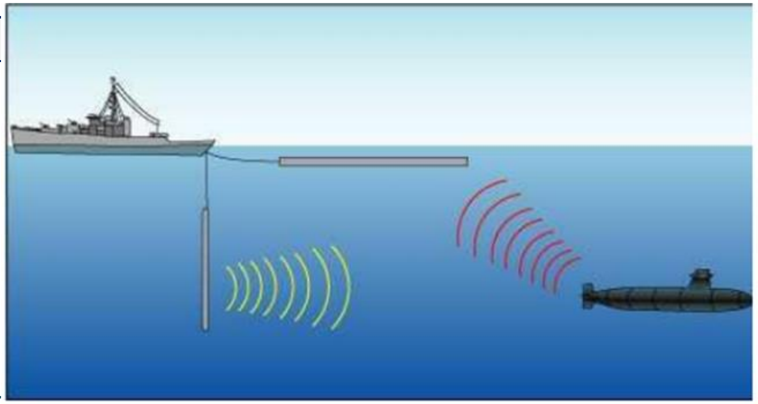
Mitigation Framework for use or disposal of explosives	
Planning phase (expected outcomes of the EIA)	1. Review the presence of cetaceans in the candidate periods for the work and fund research if information is inadequate 2. Select periods with low biological sensitivity 3. Use sound propagation modelling results to define the extent of the exclusion area (EZ) 4. Plan the lowest practicable charge
Noise Mitigation Technologies	1. Use noise mitigation technologies: • Big Air Bubble Curtain (p. 8) • HydroSound Damper net (HSD-net, p. 9)
Real-time mitigation practices (p. 12)	1. Use Acoustic Mitigation Devices prior to the work 2. Use the soft start protocol (small charges prior to operational charges) 3. Use the visual monitoring protocol 4. Use the acoustic monitoring protocol
Post-activity	1. Detailed reporting of real-time mitigation*

Source level (0.5 – 50 kg)	*272 - 287 dB re 1μPa m (Peak)*
Bandwidth	*2 Hz – 1 kHz*
Major amplitude	*6 Hz – 21 Hz*
Duration	*1 – 10 ms*
Directionality	*Omnidirectional*

Mitigation measures for impulsive noise

Mitigation measures to be used for sonar use:

Mitigation framework for military and civil sonar use	
Planning phase (expected outcomes of an EIA)	1. Review the presence of cetaceans in the candidate periods for the survey/exercise and fund research if information is inadequate 2. Define no-exercise zones (biological reserves, especially protected areas etc.) 3. Define buffer zones 4. Select periods with low biological sensitivity 5. Use sound propagation modelling to define the extent of the exclusion area (EZ)
Real-time mitigation practices (p. 12)	1. Use the visual monitoring protocol* 2. Use the acoustic monitoring protocol* 3. Use the soft start protocol
Post-activity	1. Detailed reporting of real-time mitigation**



	NAVAL SONAR	ACADEMIC and INDUSTRIAL SONAR
Source level	*235 dB re 1µPa m (Peak, LFAS)* *223 – 235 dB re 1µPa m (Peak, MFAS)*	*203 – 240 dB re 1µPa m (rms)*
Bandwidth	*100 Hz – 500 Hz (LFAS)* *2 kHz – 8 kHz (MFAS)*	*1 kHz – 400 kHz*
Major amplitude	*3.5 kHz (MFAS)*	*Various*
Duration	*6s – 100s (LFAS)* *0.5s – 2s (MFAS)*	*0.2 ms – 100 ms*
Directionality	*Horizontally focused*	*Depends on sonar type*

ref: (CEDA 2011; Lurton and Antoine 2007; OSPAR 2009)

Noise mitigation technologies

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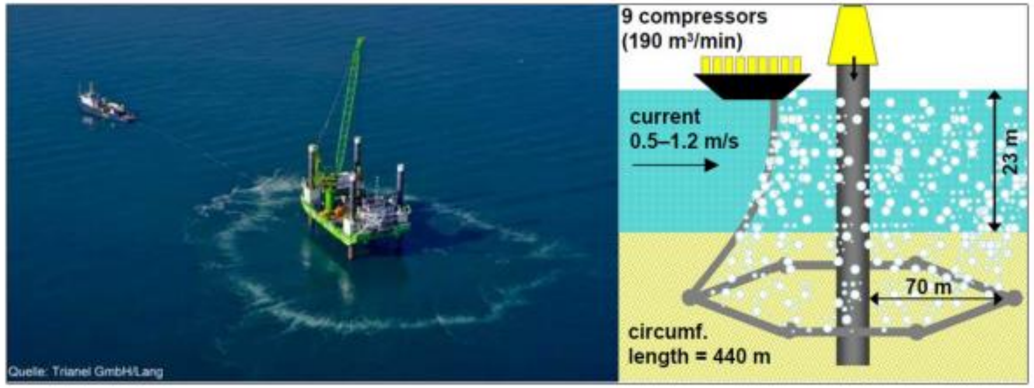
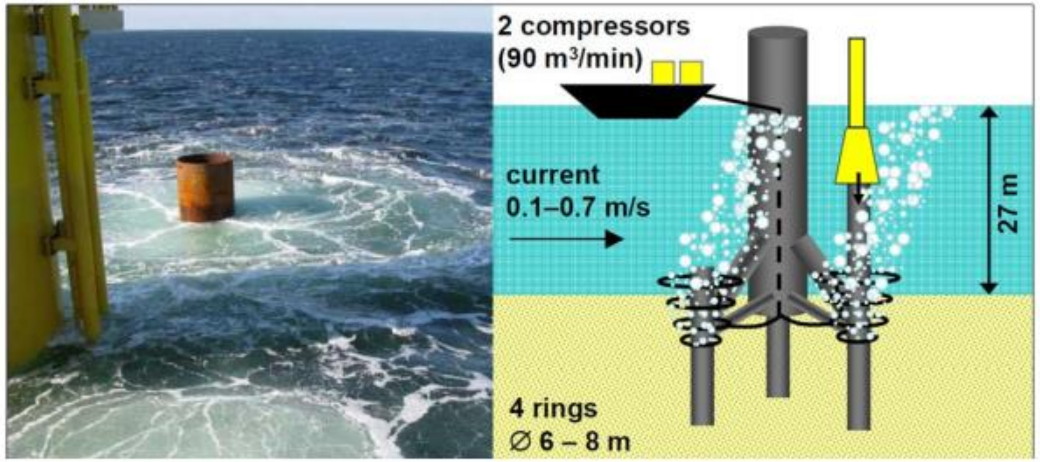
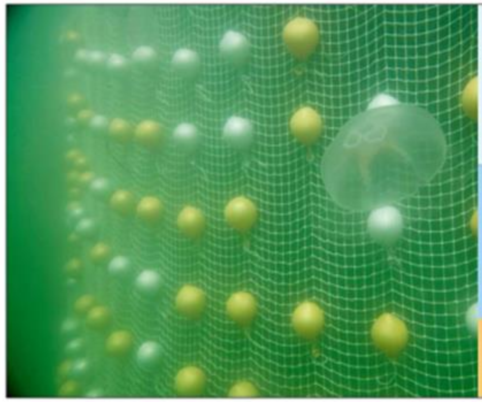
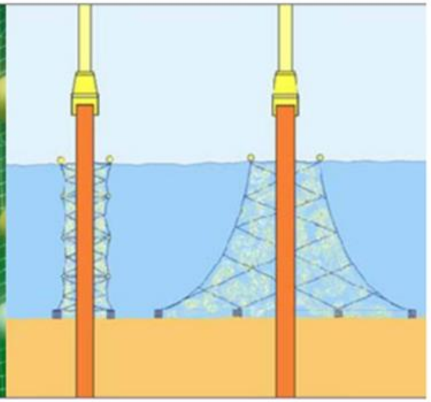
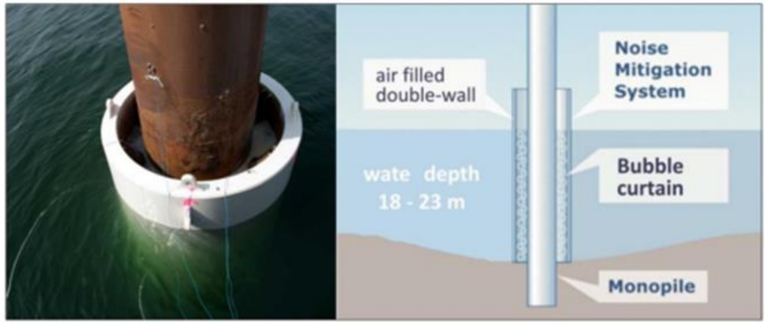
MITIGATION TECHNOLOGY	NOISE REDUCTION	APPLICATION	OVERVIEW
Big Air Bubble Curtain. A large bubble curtain consists of a hose with drilled holes, supplied with compressed air. The hose is placed on the sea bed and the air escaping from the holes forms the bubble screen. (Photo : Trianel GmbH/Lang ; Reférence: (Verfuß 2012, Koschinski & Lüdemann 2013, Bellmann 2014)	Single bubble curtain : - 12 dB (SEL), 14 dB (peak) - 11 dB (SEL) 15 dB (peak) - 10 – 15 dB (SEL) Double bubble curtain : - 17 dB (SEL), 21 dB (peak) - 15 – 18 dB (SEL)	Pile driving Drillng Dredging Detonations	
Little Air Bubble Curtain A little bubble curtain can be customized and placed much closer to the noise source than the big bubble curtain. It may consist of a rigid frame placed around the source. Several configurations are possible. Reférence: (Verfuß 2012, Koschinski & Lüdemann 2013, Bellmann 2014)	Several tests : - 12 dB (SEL), 14 dB (peak) - 11-13 dB (SEL) - 4-5 dB (SEL) - 14 dB (SEL), 20 dB (peak)	Pile driving Drilling	

Noise mitigation technologies

MITIGATION TECHNOLOGY	NOISE REDUCTION	APPLICATION	OVERVIEW
Hydro Sound Damper. This technology consists of fishing nets with small balloon filled with gas and foam - tuned to resonant frequencies- fixed to it. It can be applied in different ways. Photo: Patrice Kunte; Reférénce: (Verfuß 2012, Koschinski & Lüdemann 2013, Bellmann 2014)	4 - 14 dB (SEL) 8 – 13 dB (SEL)	Pile driving Drillng Dredging Detonations	 
Cofferdam. The cofferdam consists of a rigid steel tube surrounding the pile. Once the pile is stabbed into the cofferdam, the water is pumped out Photos: Kurt Thomsen; Reférénce: (Verfuß 2012, Koschinski & Lüdemann 2013, Bellmann 2014)	up to 22 dB (SEL) and 18 dB (Peak) 10 – 20 dB (SEL)	Pile driving Drilling	 

Noise mitigation technologies

MITIGATION TECHNOLOGY	NOISE REDUCTION	APPLICATION	OVERVIEW
Noise Mitigation Screen. The NMS is a double layered screen, filled with air. Between the pile and screen there is a multi level and multi size bubble injection system. Photo: Patrice Kunte; Reférence: (Verfuß 2012, Koschinski & Lüdemann 2013, Bellmann 2014)	5 – 20 dB (SEL) 10 – 14 dB (SEL)	Pile driving Drilling	
BEKA_shells - Double steel wall with polymer filling - Inner and outer bubble curtain - Acoustic decoupling (vibration absorber) (Photos: Patrice Kunte; Reference: Verfuß & Jülich 2012, Koschinski & Lüdemann 2013)	6-8 dB (SEL)	Pile driving Drilling	

Noise mitigation technologies

ALTERNATIVE TECHNOLOGIES	EMISSIONS	RELEVANT ACTIVITIES	REFERENCES/COMMENTS
Drilled foundation Drilling can be done within a concrete pile. The drill head can be placed outside the pile if there is resistance. The pile will sink within the drilled hole	Not information available	Any activity that would require pile driving (offshore wind farms, harbour extensions, bridges etc.)	(North Sea Foundation 2012, Verfuß 2012, Koschinski & Lüdemann 2013)
Vibro-drilling. Vibro-drilling combines a vibrator tandem PVE and a drill head in one unit. The pile is driven into the sea floor by vibrating. Drilling is applied when there is resistance with vibrating	Less than 130 dB @ 750 m expected (not measured yet)	Any activity that would require pile driving (offshore wind farms, harbour extensions, bridges etc.)	(North Sea Foundation 2012, Verfuß 2012, Koschinski & Lüdemann 2013)
Concrete Gravity Foundations. These structures are reinforced, self buoyant concrete structures. They are towed to a site and directly placed to the seabed.	No emissions	Any activity that would require pile driving (offshore wind farms, harbour extensions, bridges etc.)	(North Sea Foundation 2012, Verfuß 2012, Koschinski & Lüdemann 2013)
Bucket foundation. A bucket foundation is a large steel caisson which is founded in the seabed by suction pumps. The water is pumped out of the cavity underneath the caisson. The vacuum in combination with the hydrostatic pressure makes the caisson penetrate into the seabed up to its final depth	Very low noise expected (not measured yet)	Any activity that would require pile driving (offshore wind farms, harbour extensions, bridges etc.)	(North Sea Foundation 2012, Verfuß 2012, Koschinski & Lüdemann 2013)
Marine Vibroseis (MV). Hydraulic and electromechanical MVs can be towed in the same configuration as airgun arrays or operated in a stationary mode much like land vibrators; MV's will have lower source signal rise times, lower peak pressures, and less energy above 100 Hz	Source Level : 203 dB re 1μPa; 6-100 Hz	Seismic surveys (p. 15)	System from Geokinetics licenced for shallow water available mid 2014 (CSA Ocean Sciences Inc. 2013, Weilgart 2013, Castellote, pers. comm.)
Low level Acoustic Combustion Source (LACS) The LACS system is a combustion engine producing long sequences of acoustic pulses at a rate of 11 shots/s with low intensity at non-seismic (>100 Hz) frequencies. The system is suitable for shallow-penetration, towed-streamer seismic surveys or vertical seismic profiling	Source Level : 218 dB re 1μPa Peak-to-Peak	Seismic surveys (p. 15)	Market available (Askeland et al. 2009, CSA Ocean Sciences Inc. 2013)

Conclusion: A need to connect science and industry

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Scientific knowledge on UWN.

↓

Mitigation measures.

↓

New approaches, solutions and technologies.

↓

New business opportunities.

Thank you!