Explosions' remediation: accounting for cost efficiency and nature conservation needs

Sven Koschinski, Meereszoologie, Nehmten, Germany

Introduction (some physics)

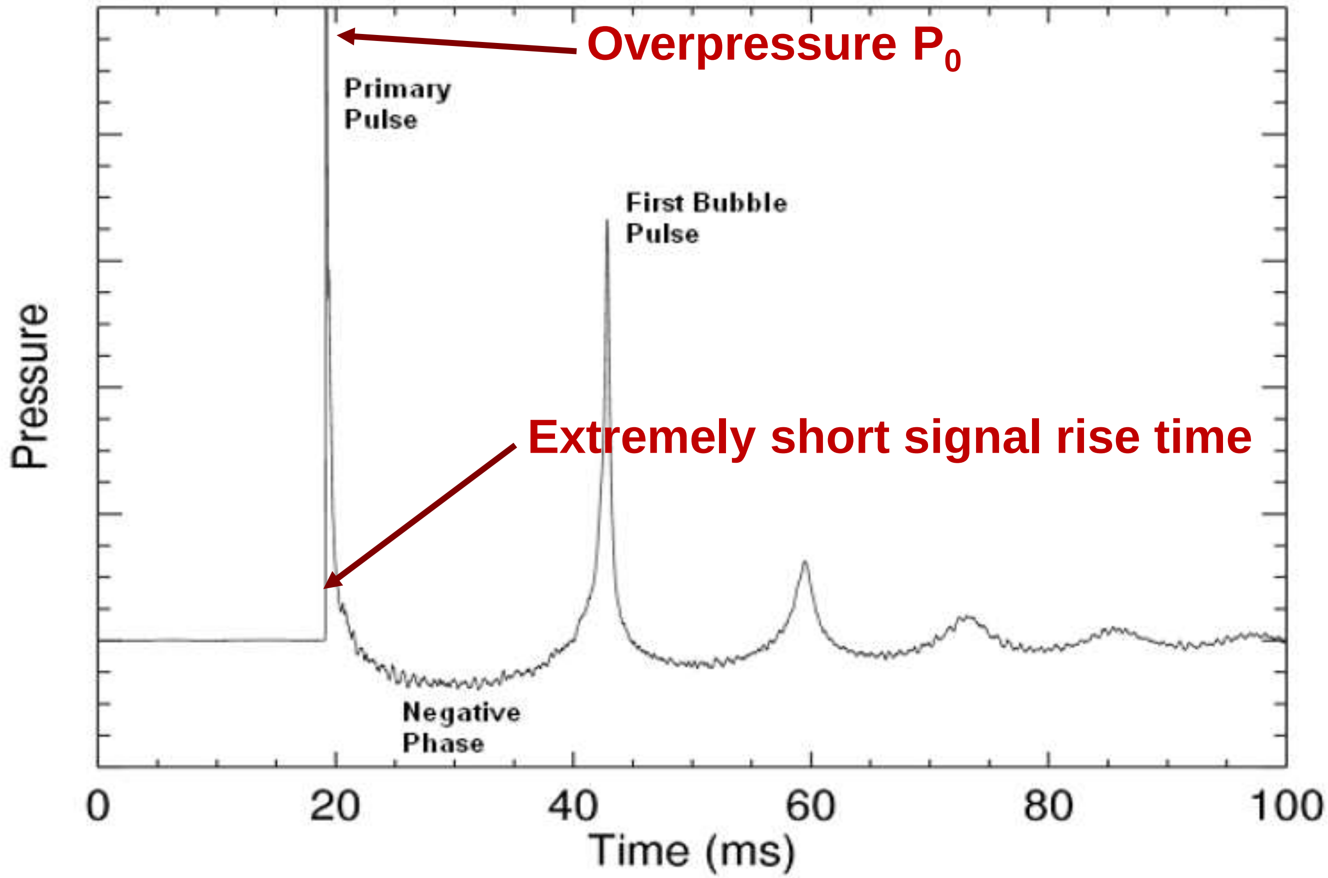
Modelling of shock wave propagation

Implications for marine life

Mitigation: Big bubble curtain

bubble curtain experiments of the German Navy

Additional mitigation measures



The shock wave propagates into the (water saturated) body.

Compressibility of air, but not water leads to:

- extreme shear forces at air/water interface, tissue rupture (lung, intestines), internal bleeding
- compression of chest, blood pressure rise, rupture of blood vessels (e.g., brain), fat embolism

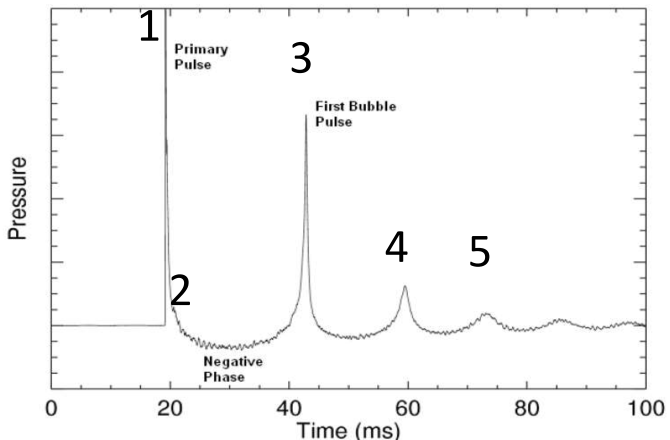
Further: displacement of hearing bones

Shock wave –theory

Energetic conversion of explosive creates a gas bubble. Dimensions depend on charge weight.

1. Explosive with a high detonation velocity (e.g. TNT): Gas bubble expands faster than underwater sound speed and thus creates a shock wave
2. Doubling of gas bubble requires to displace 8 times more water volume

3. to 5. Multiple collapses of bubble during its rising (pressure pulses) – counteracting hydrostatic pressure

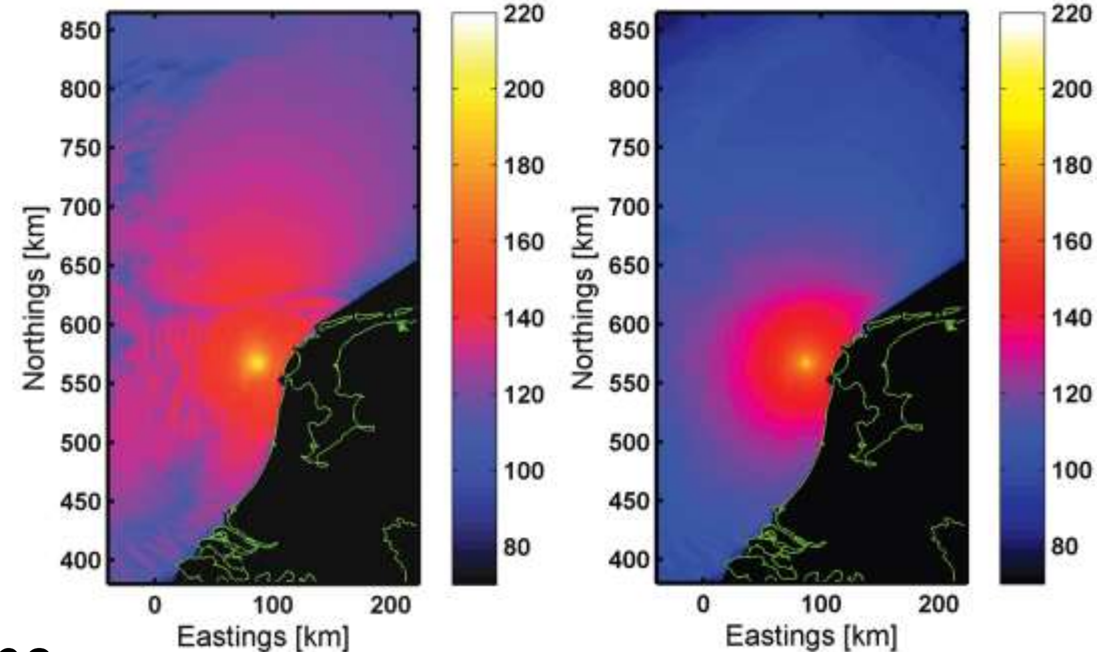


Modelling of shock wave propagation

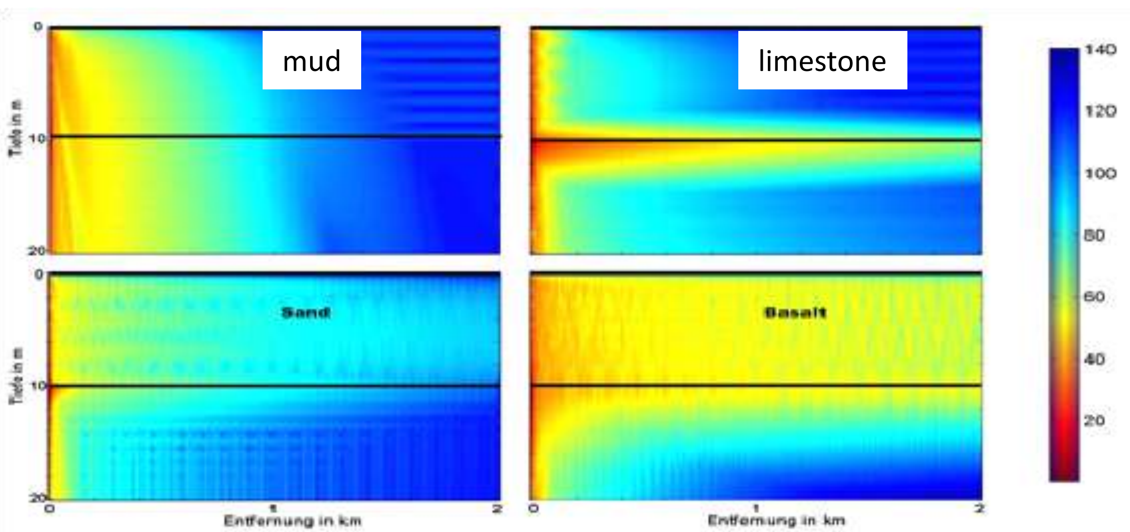
Influence of water depth

Left 1 m above seafloor, 263 kg TNT

Right 1 m below surface, 263 kg TNT



Influence of sediment type



Sources: von Benda-Beckmann et al. 2015, Nuetzel 2008

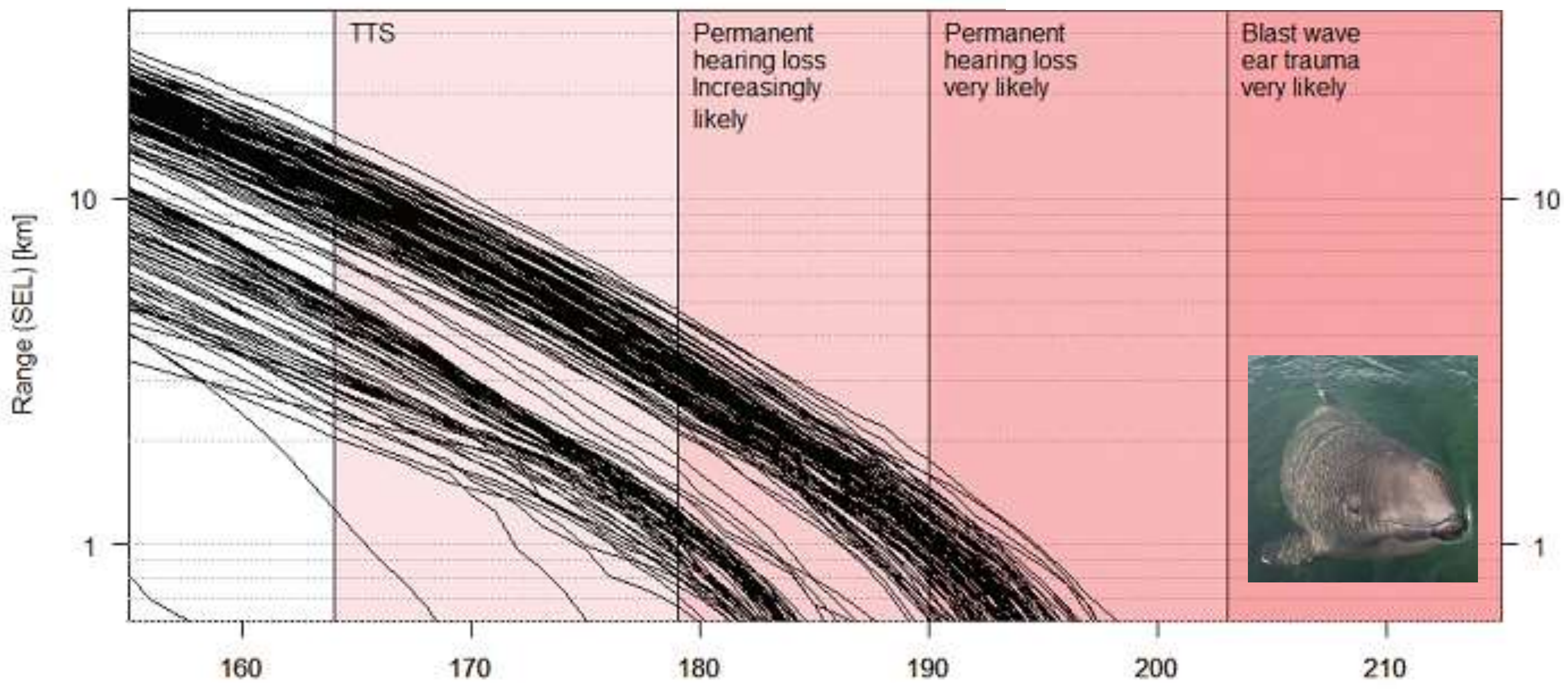
Implications for marine life

From thresholds to effect distances

Example for situation 1 m above seafloor
with respect to harbour porpoises
Calculations for underwater detonations in the Dutch North Sea with specific charges and for specific places

<table>
<tr><th>SEL (unweighted) (dB re 1 μPa²s)</th><th>Noise-induced TTS</th><th>Noise-induced PTS</th><th>Blast wave-induced ear trauma</th><th>Permanent hearing loss</th></tr>
<tr><td>> 203</td><td rowspan="4">Very likely</td><td rowspan="2">Very likely*</td><td>Very likely</td><td rowspan="2">Very likely</td></tr>
<tr><td>190-203</td><td>Increasingly likely</td></tr>
<tr><td>179-190</td><td>Increasingly likely</td><td rowspan="3">Unlikely</td><td>Increasingly likely</td></tr>
<tr><td>164-179</td><td rowspan="2">Unlikely</td><td rowspan="2">Unlikely</td></tr>
<tr><td>< 164</td><td>Unlikely</td></tr>
</table>

*Based on expert judgement



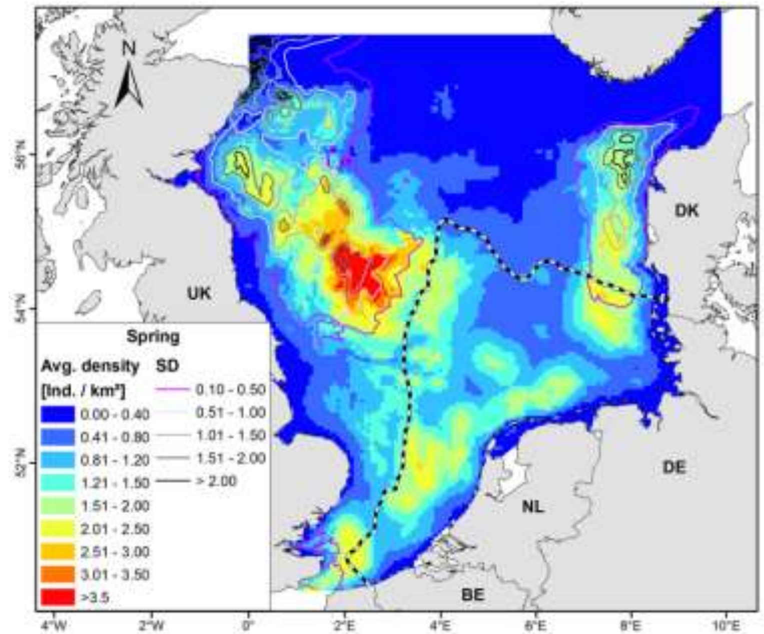
Source: von Benda-Beckmann et al. 2015

Implications for marine life

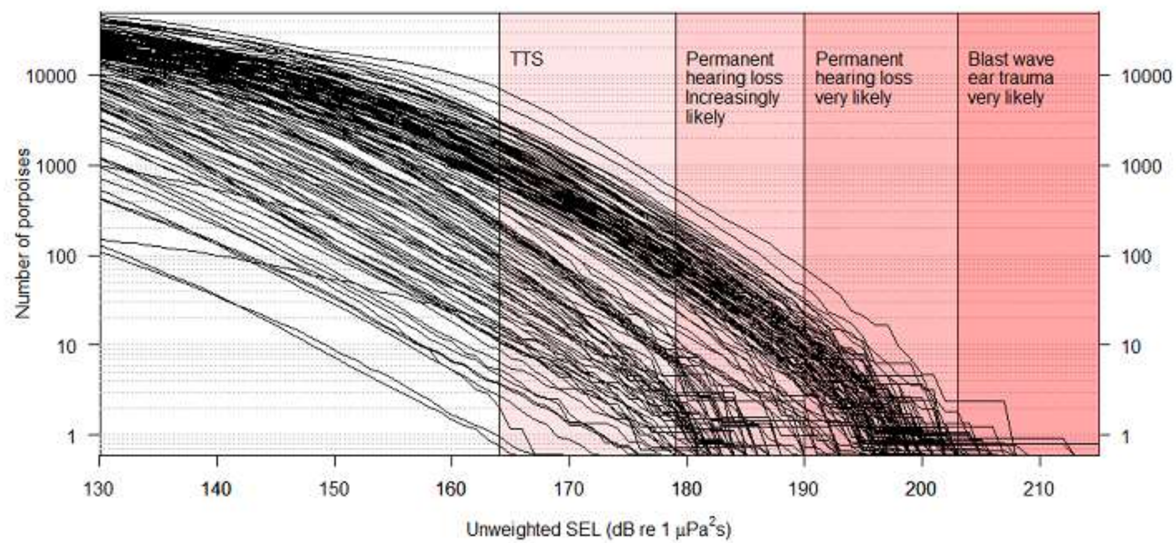
From effect distances to risk

Seasonal habitat-based density model

- Based on 2005-2013 harbour porpoise surveys
- Porpoises are where the food is
- But: Incomplete fisheries data (e.g. sandeel beds as explanatory variable)
- Dynamic environment (productivity linked to e.g. frontal patterns, mixing, river plumes, upwelling) does not allow for “exact” predictions
- Year-to-year changes likely



Estimated auditory impact of detonations



Source: Gilles et al. 2016

Implications for marine life

From risk to mitigation

Avoid detonations! If unavoidable:

- Identify species/populations at risk
- Threatened and protected species require better mitigation
- Collate available biological data
- Avoid sensitive times and areas
- Consider specific behaviour (such as attraction to debilitated fish)
- Identify effect distance (modelling of shockwave propagation)
- Consider use of deterrent devices (choose efficient method, e. g., „seal scarers“ work for porpoises but not for seals)
- Compare scaring range and effect distance
- If scaring distance is not sufficient, additional mitigation measures are required
- **Always** make use of observers and passive acoustic monitoring!

Mitigation measures

<u>Big bubble curtains (BBC)</u>

General principles:

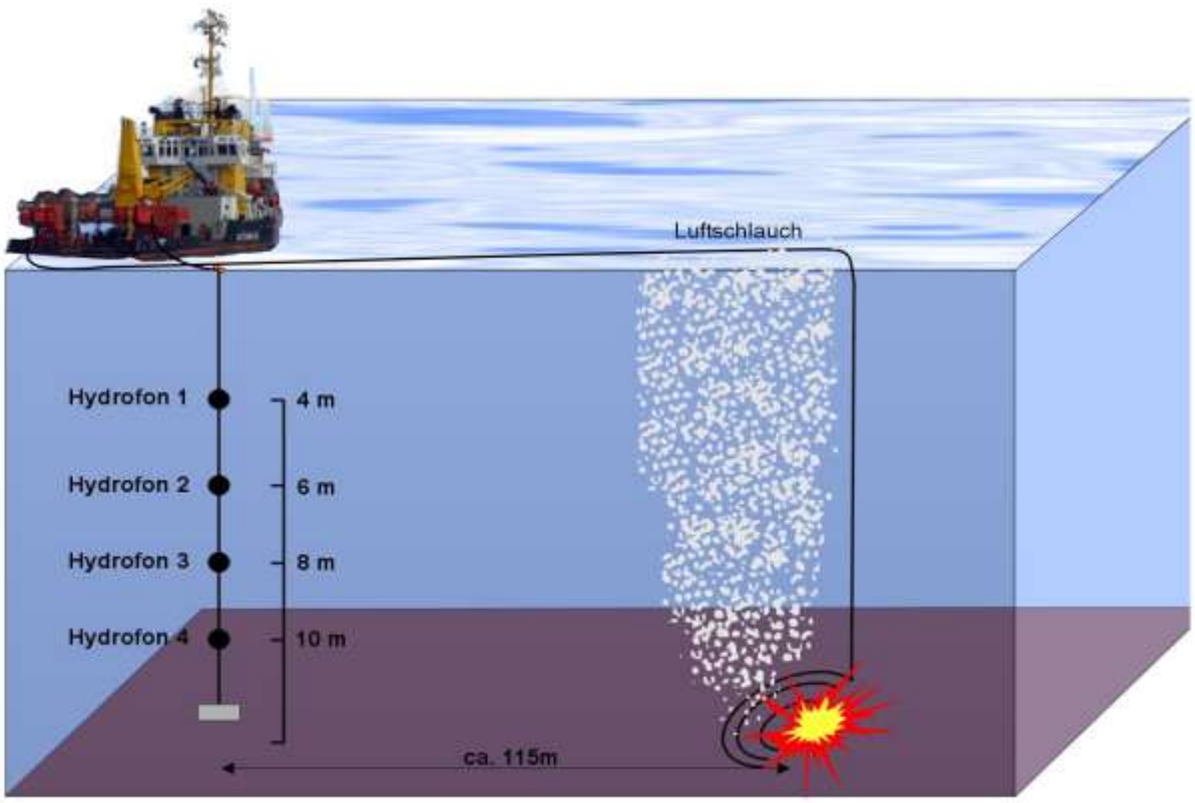
- Air bubbles in water act as Helmholtz resonators and take up energy from the pressure wave (increase the temperature)
- Additional scattering and reflection of acoustic energy inside the bubble curtain

German government: „BAT, BEP for detonations in munitions clearance "

illustration: Hydrotechnik Lübeck

Bubble curtain experiments by the German Navy 2008

- General features of explosions 0.1 kg, 1 kg and 15 kg
- First BC trials with 1 kg charges: Single, double, tripple BC, radius 4 to 6 m
- Single BC with different air volume streams



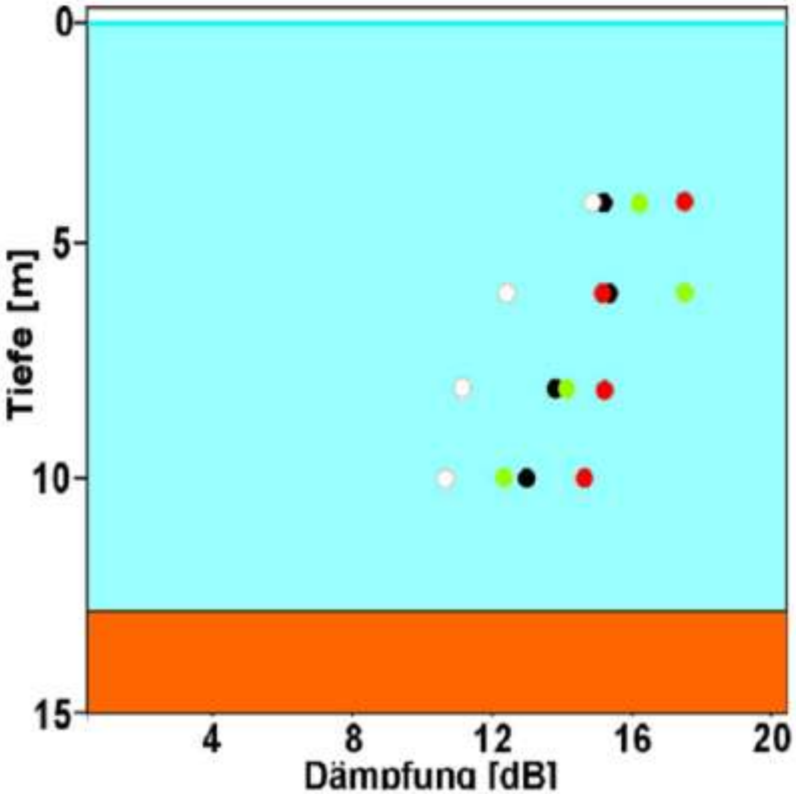
Source: Nuetzel 2008

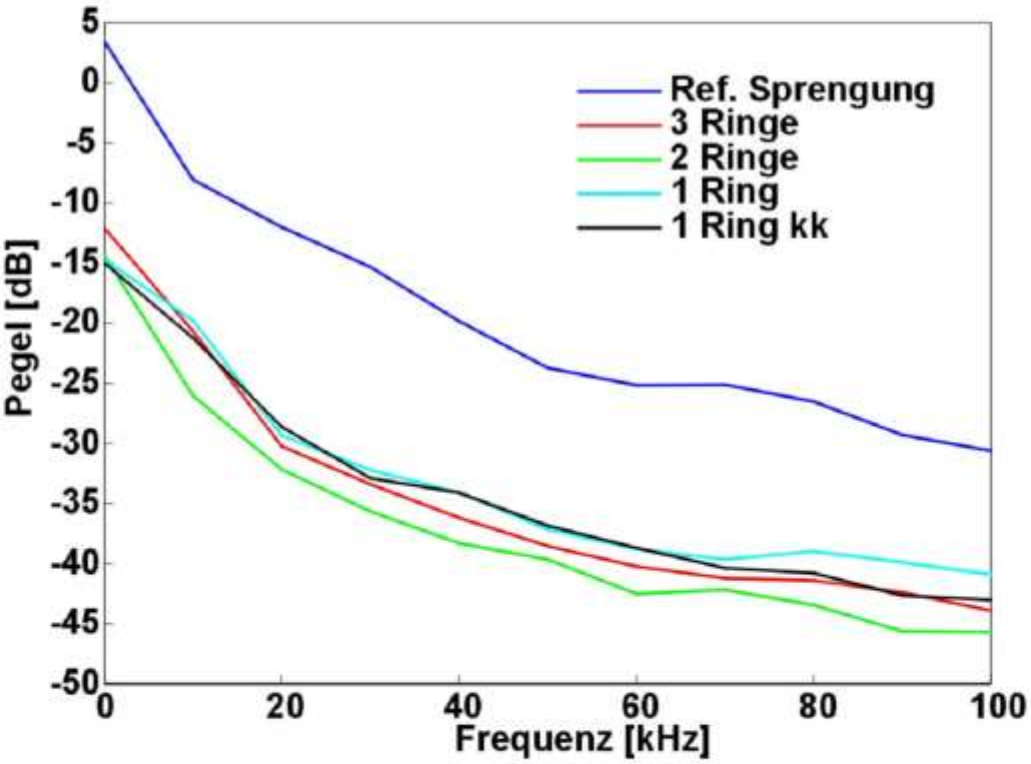
Bubble curtain experiments by the German Navy 2008

- General features of explosions 0.1 kg, 1 kg and 15 kg
- First BC trials with 1 kg charges: Single, double, tripple BC, radius 4 to 6 m
- Single BC with different air volume streams

Results:

- Attenuation 11.1 dB to 17.3 dB
- Double BC more effective than triple BC – density of bubbles in water matters





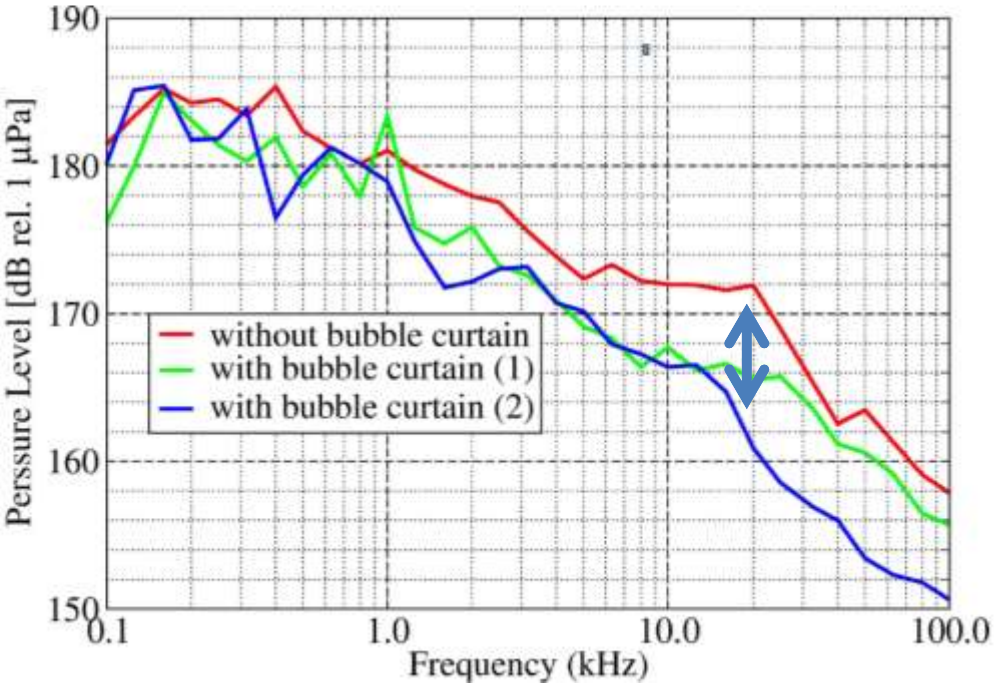
Source: Nuetzel 2008

Bubble curtain experiments by the German Navy 2008

- General features of explosions 300 kg
- Single BC trials with radius 22 m

Results:

- Attenuation up to 8 dB
- Mainly at high frequncies (ultrasonic expansion of gas globe)
- At lower frequencies (water pushed away by gas globe) no reduction possible because BC radius was too small

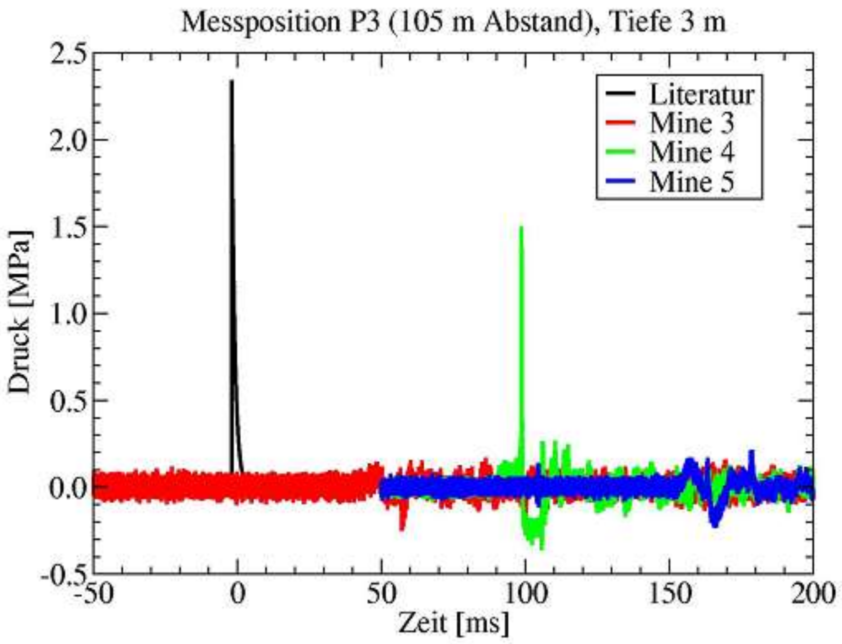


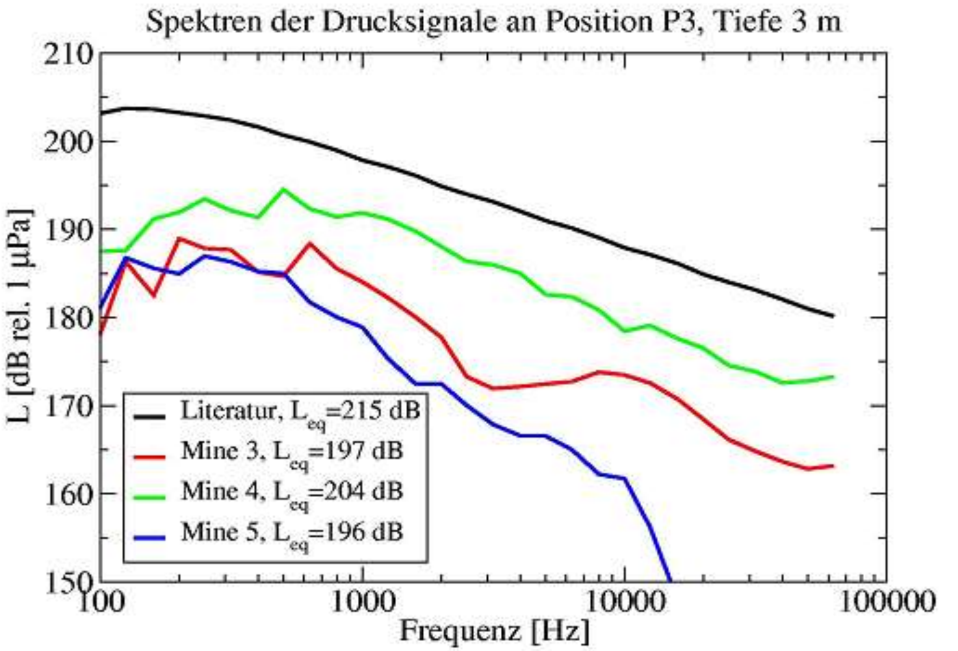
Source: Schmidtke et al. 2009

Bubble curtain experiments by the German Navy 2010

Radius of bubble curtain = 70 m
Semicircle for practical reasons (for mitigation: full circle required!)

Results
Attenuation of peak pressure = 19 dB, (6 dB), 16 dB
Mine 4: Bubble curtain not fully closed





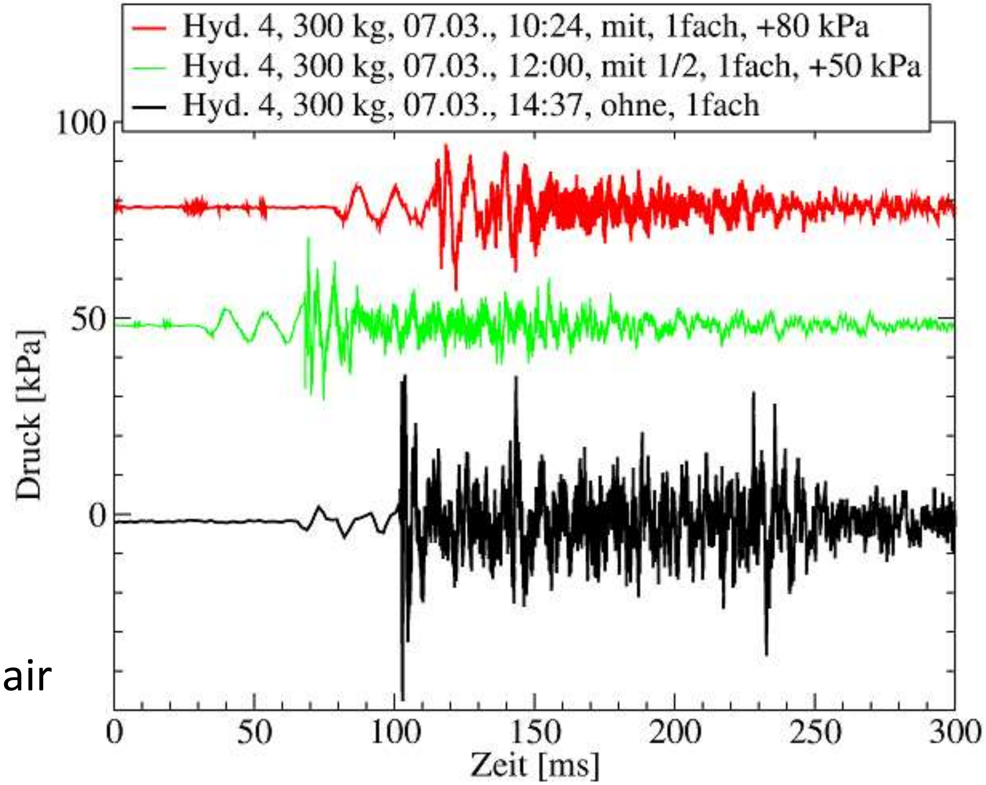
Bubble curtain experiments by the German Navy 2011

BC completed to full circle

Main question: How much air is needed?

20 g and 300 kg charges

- full air volume stream (1.0m³/min/m)
- Half air volume stream (0.5m³/min/m)
- no BBC



Results:

- Hardly any difference between full and half air volume stream
- 20 g „scare“ charges attenuated by 24 dB (peak)
- 300 kg mines attenuated by 6 dB
- Peak pressure of unattenuated blast was only 1/10 of the expected value
- Explosion in detonation crater
- Large contribution of seismic wave coupling back to water?

How to make a bubble curtain cost efficient

- Use of own platforms saves renting costs for a vessel
- Good preparation saves stand-by costs
- Serial remediation at the same place saves vessel mobilisation costs
- Make bubble curtain diameter as large as necessary but as small as possible to save compressor costs
- Make air volume stream as large as necessary but as small as possible to save compressor costs
- Experience from bubble curtain deployment in the German EEZ of the North Sea: starting from 12.000 Euros for 3 explosions
- Important: Use oil-free compressors (make no compromise, even if cheaper)

Further mitigation measures

Mitigation at source	Mitigating the creation and propagation of the shockwave	Mitigating at the receiver (animal)
Move to different location (shallow, less populated areas)	Shielding, bubble curtain	Timing, season with low animal density
Detonate in air at sea	Shielding, air pocket (e.g., expanded clay pebbles)	Monitoring (visual/ acoustic)
Detonate close to surface	Shielding, burying with sand	Deterrent devices (are they efficient enough?)
„shockwave shaper“	Shielding, air pocket due to small charges	~~Scare charges~~ are not an option!
Multiple sequential explosions (assuming long-term deterrence)	Shielding, resonant air-filled spheres	
(Jet-cutting)	Timing, low tide	
~~Deflagration~~ is not an option!	Change policy to avoid detonation	
Place charge in crater	HydroSound Dampers, encapsulated bubbles	

Source: von Benda-Beckmann et al. 2014, amended

Further mitigation measures

Hydro Sound Dampers

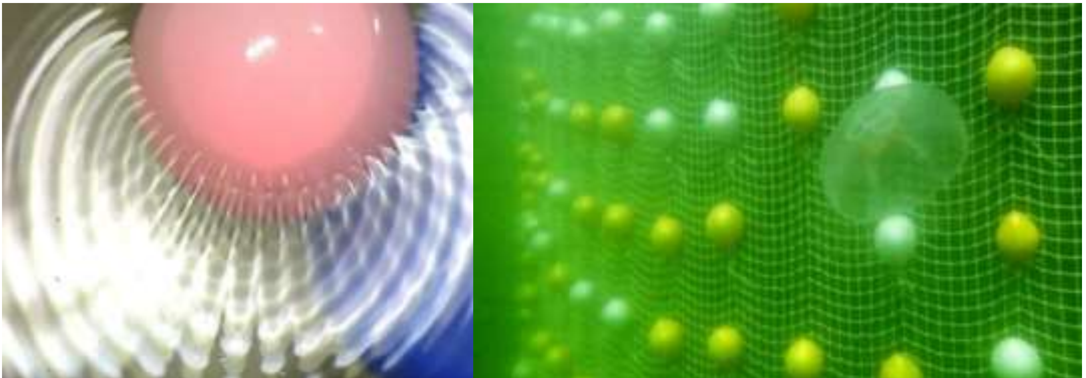
Resonators in nets (ballons and foam elements)

In ballasted basket at gripper

Leightweight system (< 70 t)

No compressors needed

At water depths up to 50 m include larger bubbles at the bottom due to increasing hydrostatic pressure



Photos: K.-H. Elmer, Patrice Kunte


Questions?