Evaluating Ultrasonic Antifouling Technology: Effectiveness Against Biofouling and Potential Impact on Marine Mammals

DEN DANSKE MARITIME FOND

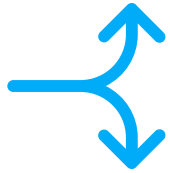
Micaela Machado Querido
Pernille Bohn
Torben Madsen
Rémi Maguet

DHI

Introduction

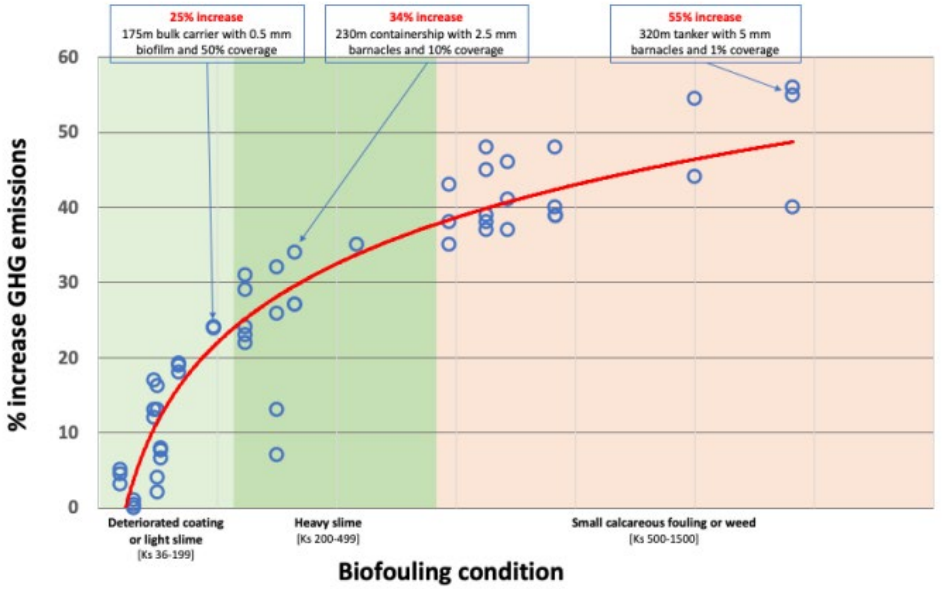
Shipping : 3% of global GHG emissions

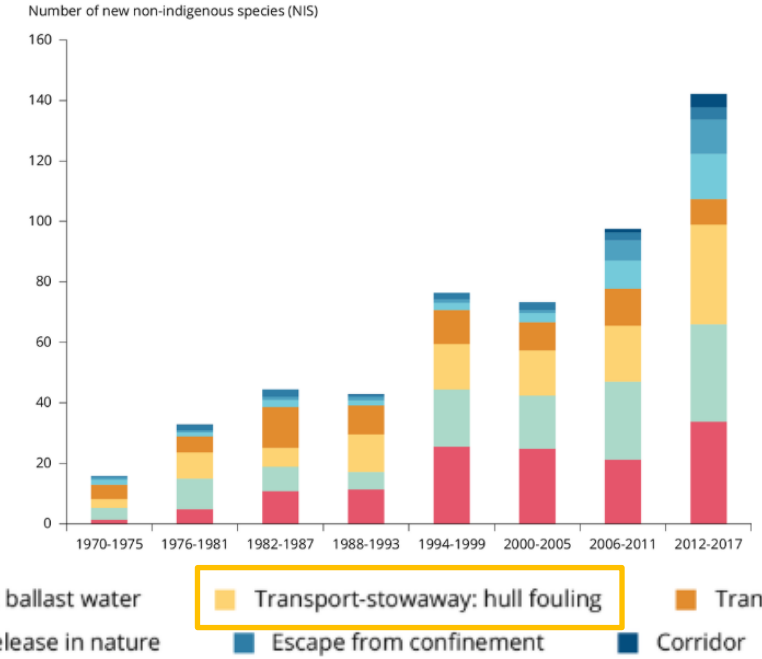
Biofouling consequences



reduction of vessel speed
increase of ship fuel consumption
rise of operational costs
damage to critical components

transfer of non-indigenous species
invasion and disruption of ecosystems





Introduction

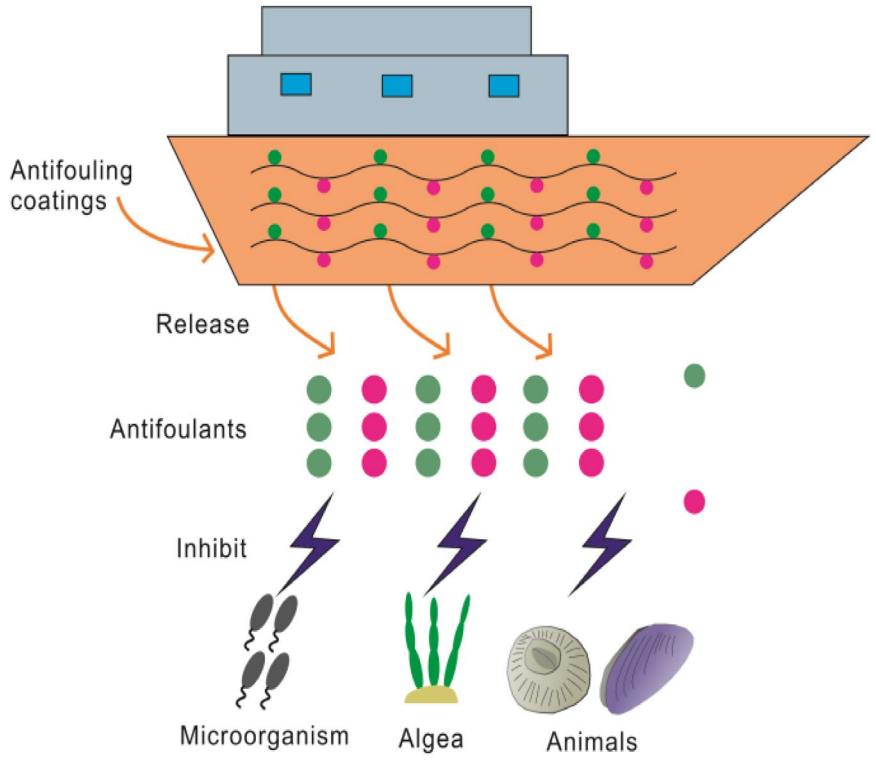
Biofouling consequences

reduction of vessel speed
increase of ship fuel consumption
rise of operational costs
damage to critical components

transfer of non-indigenous species
invasion and disruption of ecosystems

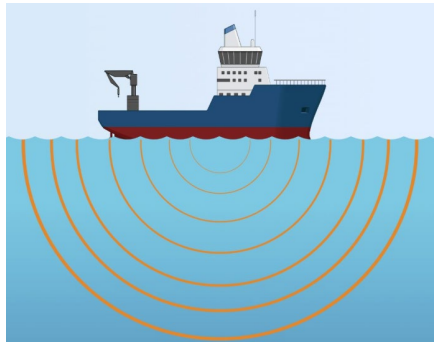
Antifouling coatings

release toxic chemicals
contribute to marine pollution and
harm aquatic life



Increasing regulations demand sustainable alternatives

Introduction



Ultrasonic antifouling systems

produce sound waves that induce micro-vibrations in ship surfaces

prevent organisms from attaching and colonizing surfaces

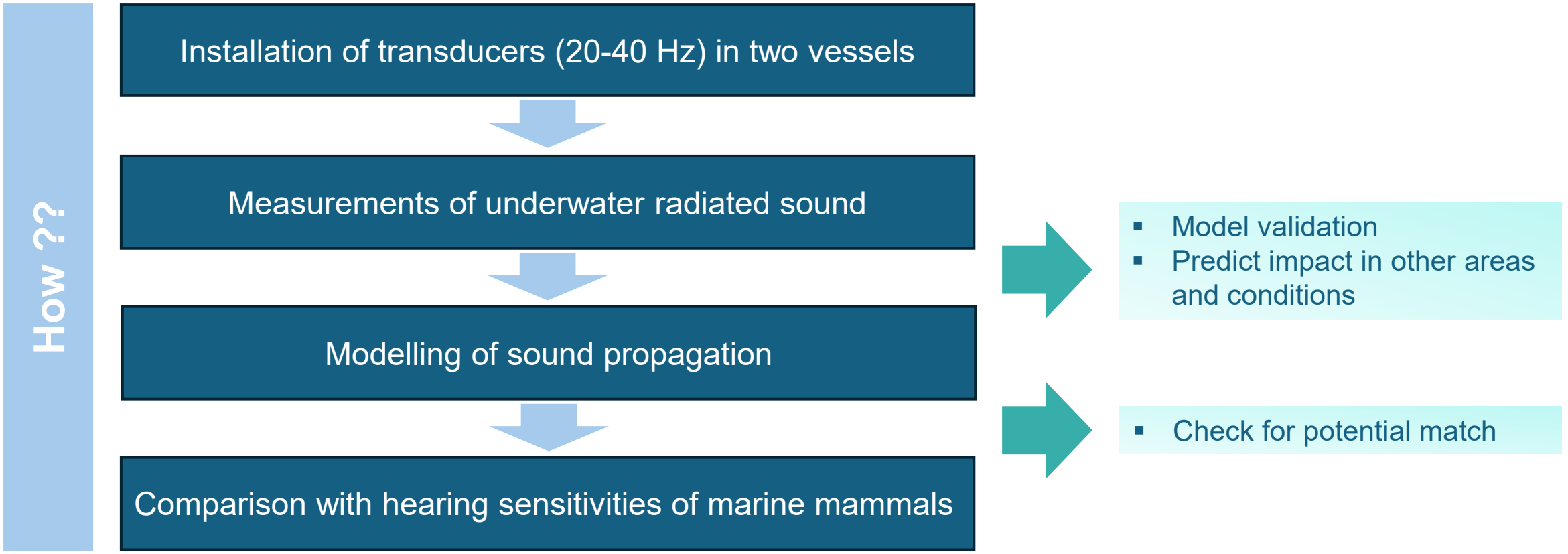
can be combined with traditional antifouling coatings

advantage : installation in niche areas of vessels

can generate underwater noise affecting marine animals

Objectives

Evaluate potential **biological side effects** related to the **underwater sound** emitted from **ultrasonic antifouling systems** installed onboard an oil tanker and a diving vessel.



Biological risk assessment of underwater radiated noise

- Focus on determining impact ranges for behavioral response and impaired hearing
- Species-specific thresholds

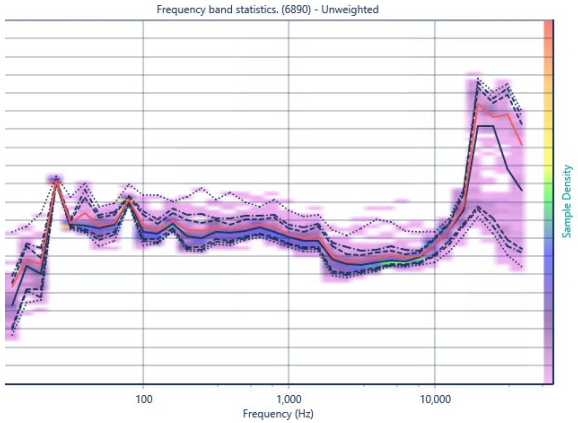
Generalized hearing ranges for marine mammal hearing groups

Hearing group	Generalized hearing range *
Low-frequency cetaceans (example: humpback whale)	7 Hz to 35 kHz
High-frequency cetaceans (example: killer whale)	150 Hz to 160 kHz
Very high-frequency cetaceans (example: harbour porpoise)	275 Hz to 160 kHz

Note: * Generalized hearing range for the entire group including all species within the group. Individual species' hearing ranges are typically not as broad; for details, see Southall *et al.,* 2007. Reference: NMFS, 2024.

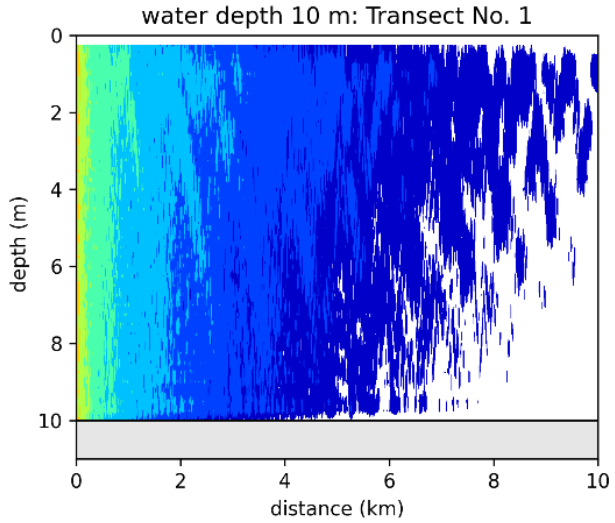
Biological risk assessment of underwater radiated noise

Source definition



Measurements in the field

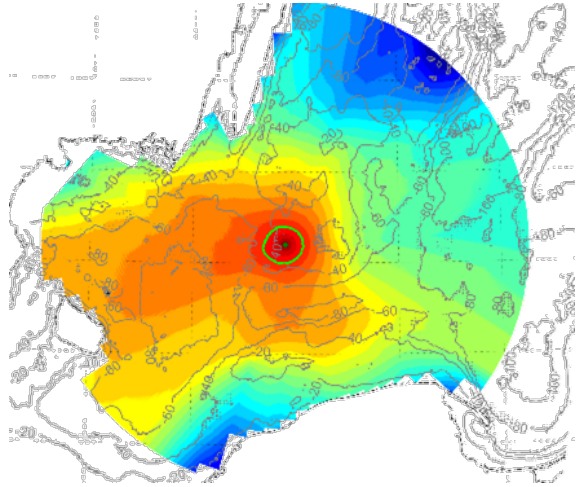
Propagation model



DHIs modelling

Results validated within the project

Impact



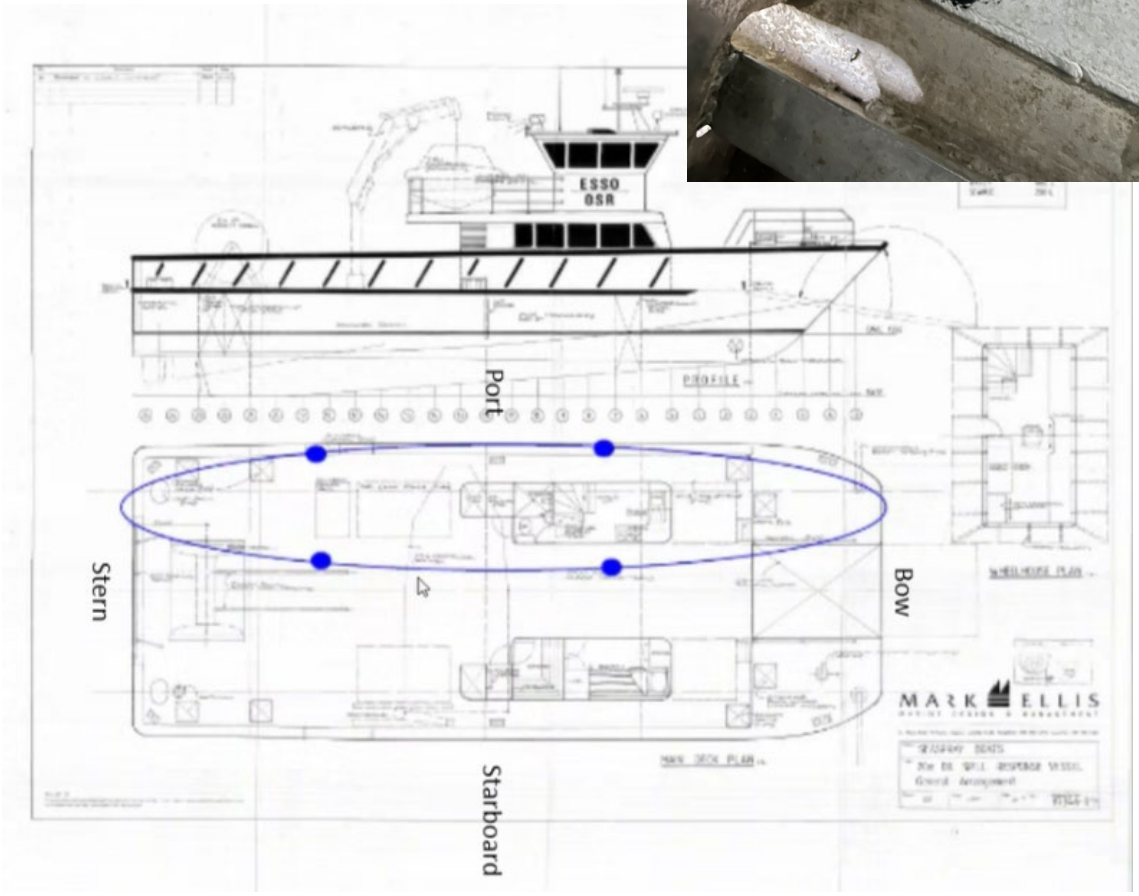
Combination of accoustical results and species specific thresholds

Methodology-Installation in Oil Tanker

- 34 ultrasonic transducers installed in seawater intakes, coolers, condensers, inner hull.
- Electrochemical antifouling disabled to isolate ultrasonic effects.

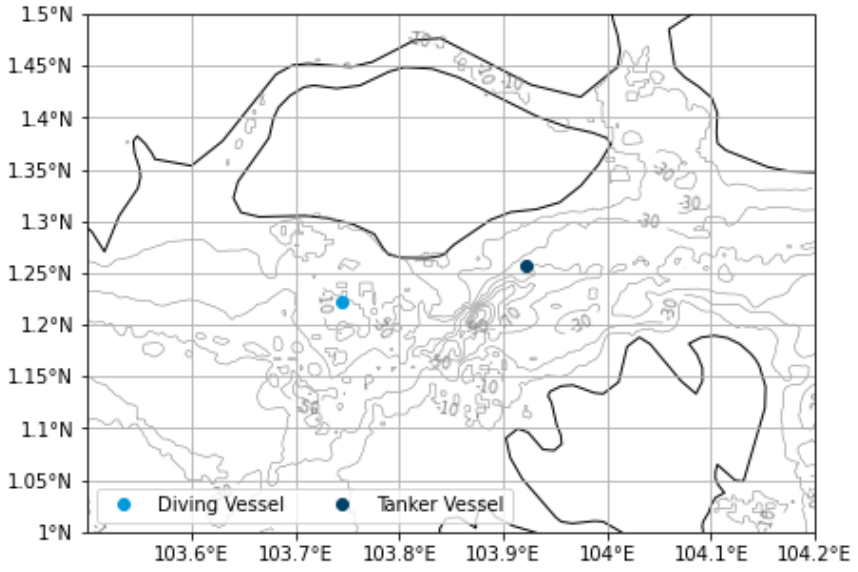
Methodology-Installation in Diving Vessel

- 4 ultrasonic transducers installed along port-side hull
- Smaller system with reduced output levels



Field Measurments

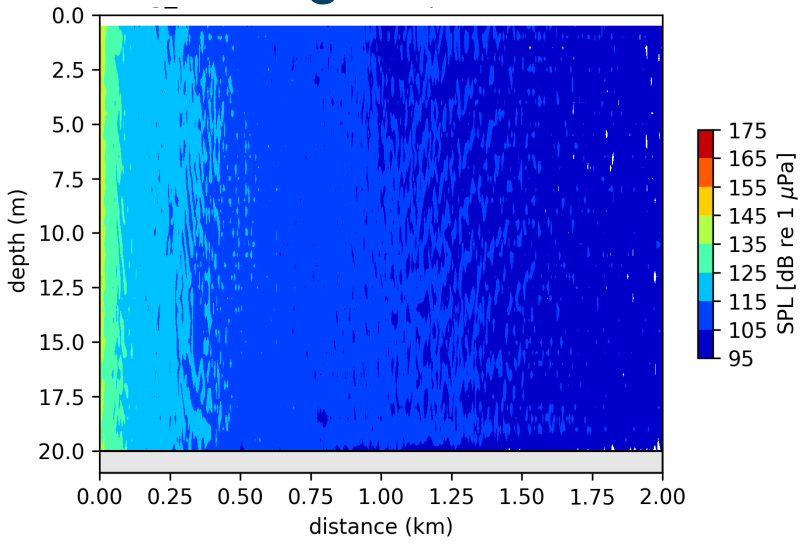
- Field measurements in **Singapore Straight**
- Hydrophones recorded SPL at multiple distances and depths:
  - Oil Tanker: distance from **50m** to **100m** at **5m** deep
  - Diving Vessel: distance from **20m** to **1800m** at **2m** and **5m** deep
- Sampling frequencies: 192/384 kHz
- Ocean instruments ST600 HF Hydrophone/Recorder: Recorded while vessels anchored with engines off.



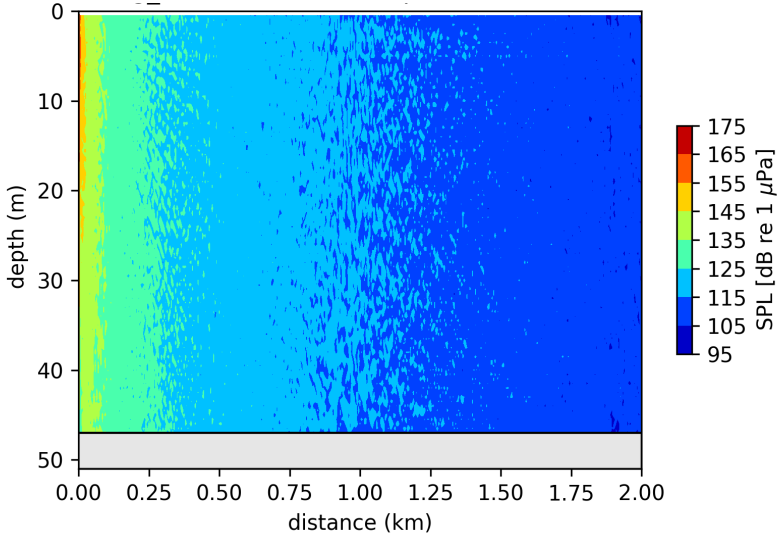
Modelling of underwater noise propagation

- Tool: DHI´s MIKE Underwater Acoustic Simulator (MIKE UAS)
- Locations: Singapore Strait & Skagerrak (Denmark)
- Water properties (pH, T, S) measured, assumed constant over depth
- Factors: frequency-dependent attenuation, bathymetry, seabed

Diving vessel



Oil Tanker



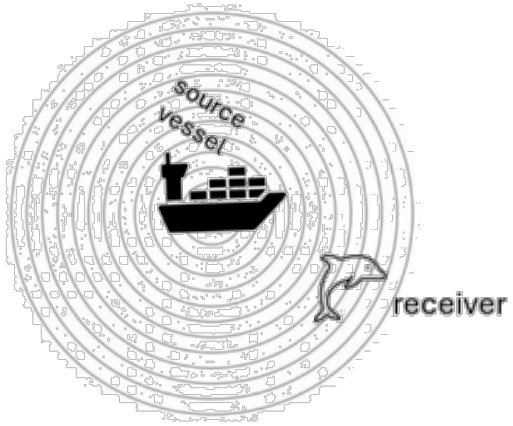
Modelling-Exposure Scenarios

Static vessel scenario vs **Moving** vessel scenario

- Static: 15 min constant exposure overtime
- Moving: vessel passig by a static animal at constant speed

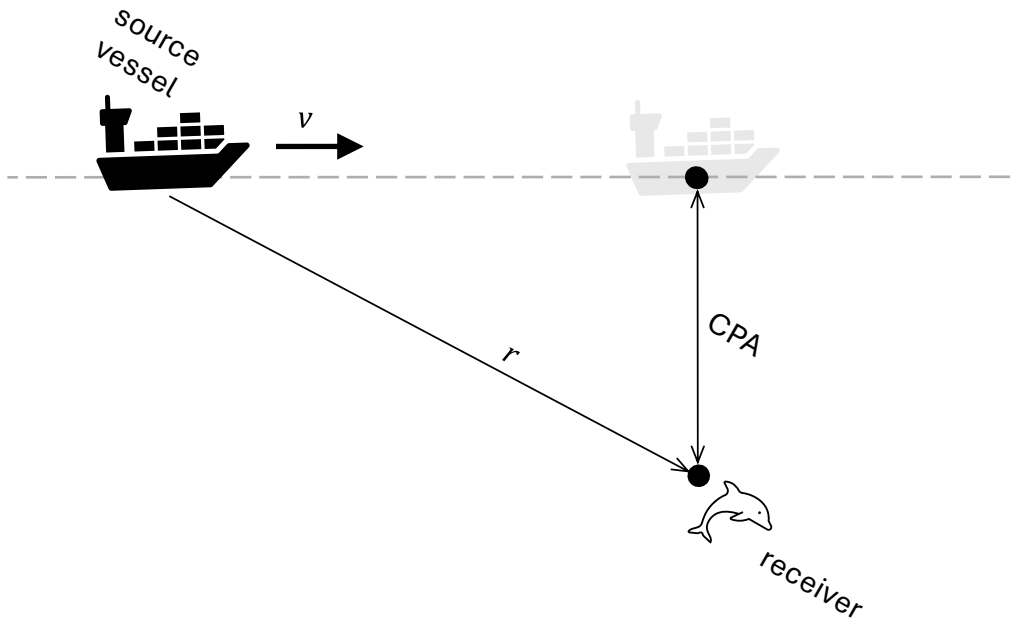
- Diving Vessel: Static Scenario
- Oil Tanker: Static and Moving Scenarios

Static vessel scenario



Moving vessel scenario

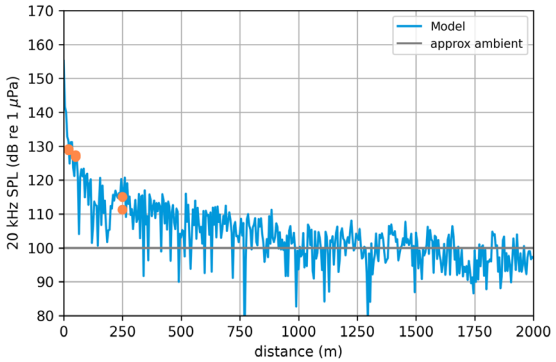
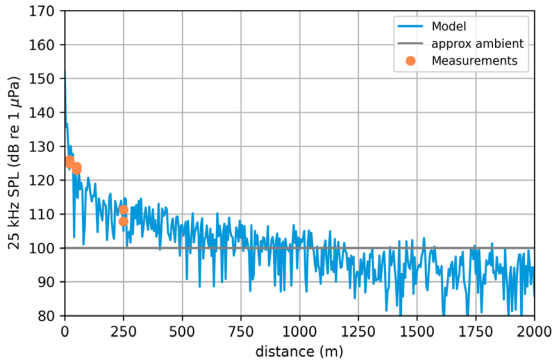
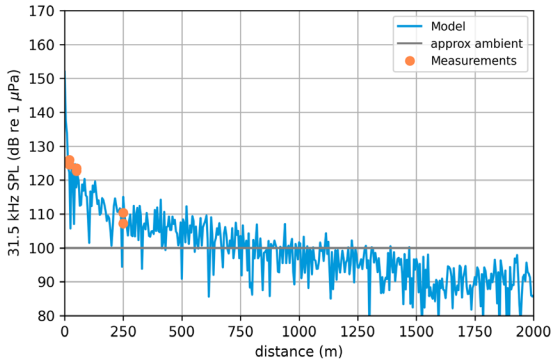
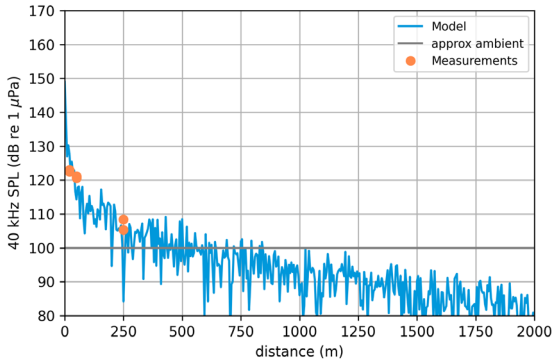
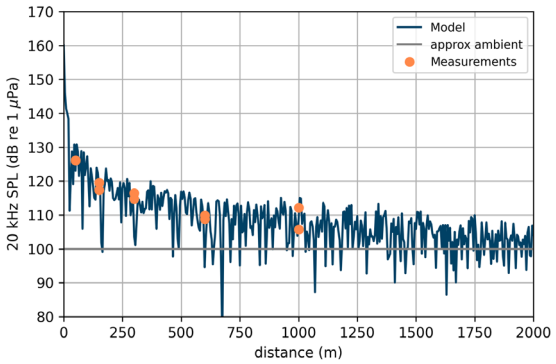
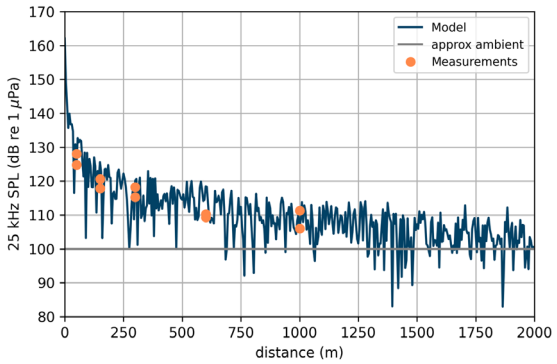
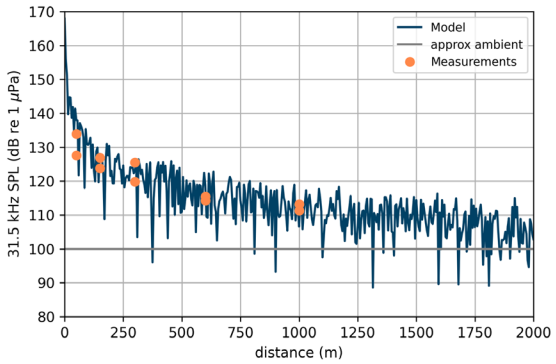
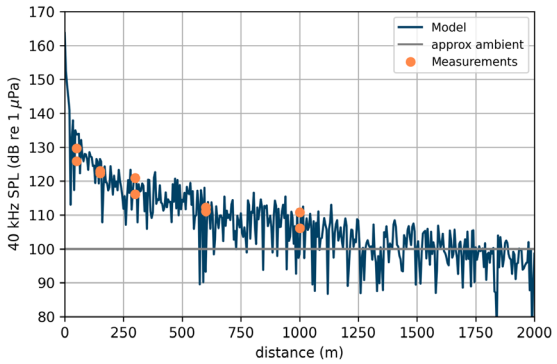
Assumed vessel track and closest point of approach (CPA)



Validation of the propagation model

Comparison between field measurements and modelling (Singapore Straight)

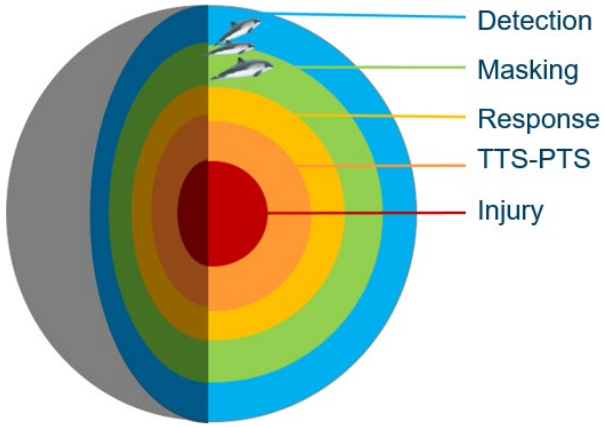
Good agreement between measured and modelled data considering environmental uncertainties

	20 kHz	25 kHz	31.5 kHz	40 kHz
Diving Vessel				
Oil Tanker				

Impact threshold for each hearing group

Overview of impact thresholds used to calculate the impact ranges.

Hearing group	Effect	Sound pressure level [dB re 1 µPa] or Sound exposure level [dB re 1µPa²s]
Low-frequency cetaceans	Onset of behavioural response	*SPL: 130 dB re 1 µPa (1) (2)
	Temporary threshold shift	***SEL: 177 dB re 1µPa²s (3)
	Auditory injury	***SEL: 197 dB re 1µPa²s (3)
High-frequency cetaceans	Onset of behavioural response	*SPL: 130 dB re 1 µPa (1) (2)
	Temporary threshold shift	***SEL*: 181 dB re 1µPa²s (3)
	Auditory injury	***SEL: 201 dB re 1µPa²s (3)
Very high-frequency cetaceans	Onset of behavioural response	**SPL: 103 dB re 1 µPa (4) (5)
	Temporary threshold shift	***SEL: 161 dB re 1µPa²s (3)
	Auditory injury	***SEL: 181 dB re 1µPa²s (3)



- **SPL-Sound Pressure Levels**: A measure of the **instantaneous intensity of sound** at a specific moment or averaged over a short time window. Tell us How *loud* a sound is at a given point in space.
- **SEL-Sound Exposure Levels**: A measure of the **cumulative energy** in a sound over a defined time period. Accounts for both the **loudness (SPL)** and the **duration** of exposure.

Temporary threshold shift (TTS)

Notes: * unweighted SPL; **very high-frequency weighted SPL (based on the weighting function in reference 5); ***weighted cumulative SEL.
References: (1) Southall et al. 2007; (2) Southall et al. 2021; (3) NMFS, 2024; (4) Tougaard, 2021; (5) Southall et al. 2019.

Results–Diving Vessel (Static Scenario)

Static Scenario

- **Location: Singapore Strait**
- **Behavioural responses:**
  - Low- & high-frequency cetaceans: up to 65 m.
  - Very-high-frequency cetaceans : up to **1725 m**.
- **Hearing effects:**
  - **Temporary threshold shift (TTS)** for very-high frequency cetaceans: up to **300 m**.
  - Auditory injury: within 20 m.
  - Low/high-frequency cetaceans: TTS within 5–20 m.

Results–Oil Tanker (Static Scenario)

Static Scenario

Location: Singapore Strait & Skagerrak (modelled)

•Behavioural responses:

- Low- & high-frequency cetaceans (whales, dolphins): up to 230 m (Singapore), 410 m (Skagerrak).
- **Very high-frequency cetaceans:** up to **3075 m** (Singapore), **3210 m** (Skagerrak).

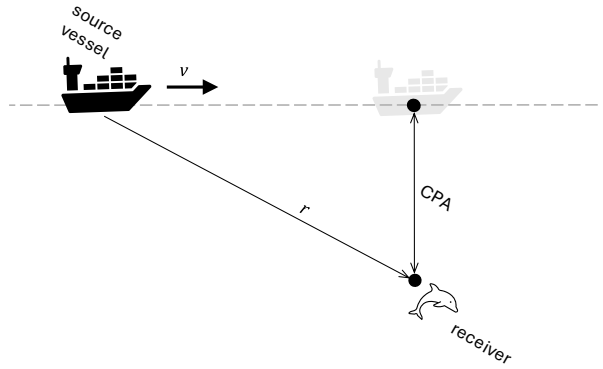
•Hearing effects:

- **Temporary threshold shift (TTS)** for very-high frequency cetaceans: up to **905 m (Singapore)**, **1040 m (Skagerrak)**.
- Auditory injury (permanent damage) for very-high-frequency cetaceans : within 80–90 m.
- Low/high-frequency cetaceans: TTS only at very close range (5–20 m).

Results compilation–Static Scenario

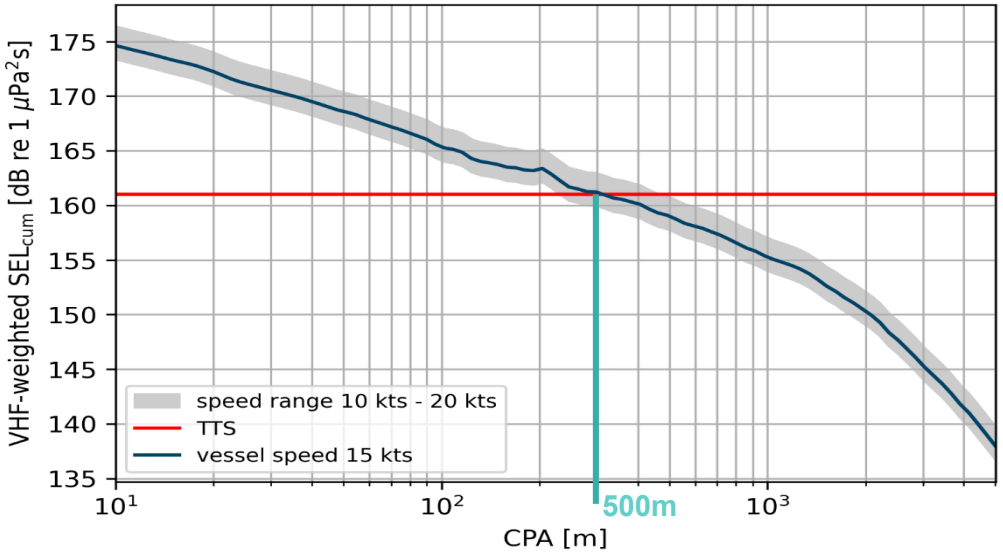
Hearing Group	Effect	Impact range [m]		
		Oil Tanker Singapore	Oil Tanker Skagerrak	Diving Vessel Singapore
Low-frequency cetaceans	Behavioural response	230	410	65
	Temporary threshold shift	5	5	-
	Auditory injury	-	-	-
High-frequency cetaceans	Behavioural response	230	410	65
	Temporary threshold shift	20	20	5
	Auditory injury	-	-	-
Very high-frequency cetaceans	Behavioural response	3075	3210	1725
	Temporary threshold shift	905	1040	300
	Auditory injury	80	90	20

Results–Oil Tanker (Moving Scenario)

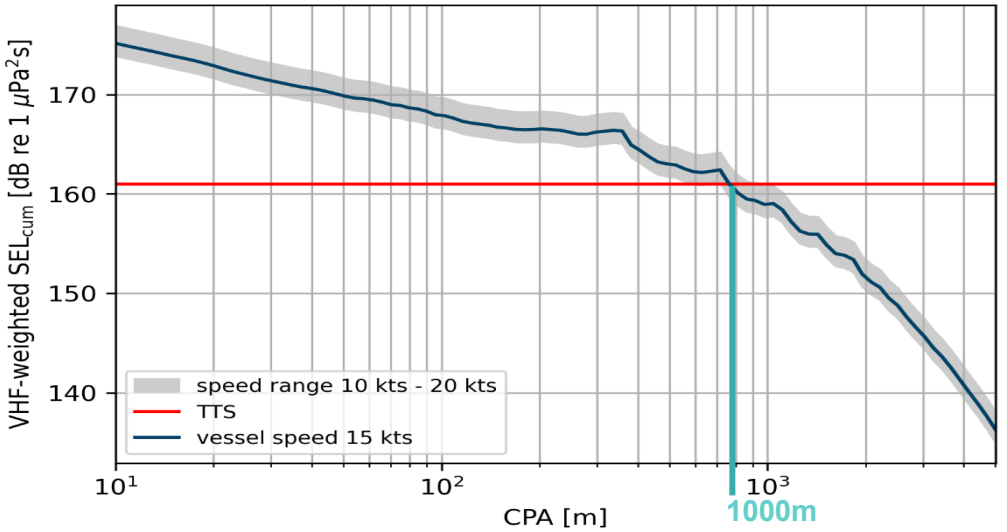


Moving Scenario

- **Location: Singapore Strait & Skagerrak**
- **Results:**
  - For very-high-frequency cetaceans, the temporary threshold shift was exceeded at closest point of approach (CPA):
    - Up to **500m (Singapore)**.
    - Up to **1000m (Skagerrak)**.
  - Behavioural responses expected at similar or larger ranges.



Cumulative SEL$_{cum}$, weighted for very high-frequency cetaceans in the Singapore Strait resulting from ultrasonic transducers as affected by the CPA.



Cumulative SEL$_{cum}$, weighted for very high-frequency cetaceans) in Skagerrak resulting from ultrasonic transducers as affected by the CPA.

Conclusions

- **Oil Tanker:** Broader impact zones (behaviour effects up to 3 km, hearing effects up to 1 km for very-high-frequency cetaceans).
- **Diving Vessel:** Smaller but still considerable zones (behaviour effects up to 1.7 km, hearing effects up to 300 m for very-high-frequency cetaceans).
- **Very high-frequency cetaceans** (such as porpoises) are the most affected in all cases.

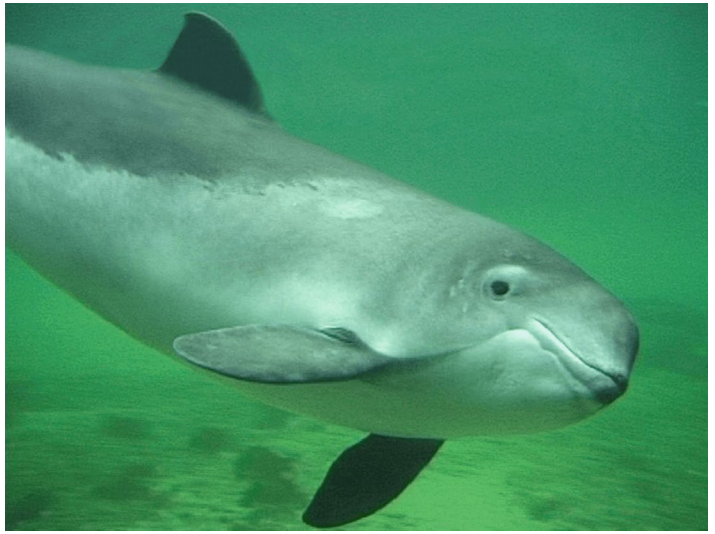
Take home message

•Ultrasonic antifouling systems **may cause adverse effects** on the **behaviour** and **hearing hability** of cetaceans.

•**Very-high frequency cetaceans** seem to be the most sensitive group.

•To **reduce biological impact**, shipping industry may consider **route planning** to avoid:

- •Feeding or breeding areas;
- •Habitats populated with endangered species;
- •Sensitive or protected areas.



Muller et al. (2014)

Thank you

DEN DANSKE MARITIME FOND

Micaela Machado Querido
miqu@dhigroup.com / +45 45 16 92 16

DHI