Ocean noise and the role of offshore wind energy

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Sound under water

Sound travels **far and fast** under water

Sound speed in air: ~340 m/s

Sound speed in water: ~ 1500 m/s

⇩

Dependens on environmental- and sound properties

- If sound speed is constant, it travels straight through the water
- Sound speed is faster with increasing temperature, salinity, and pressure
- Sound waves are refracted when encountering changes of sound speed

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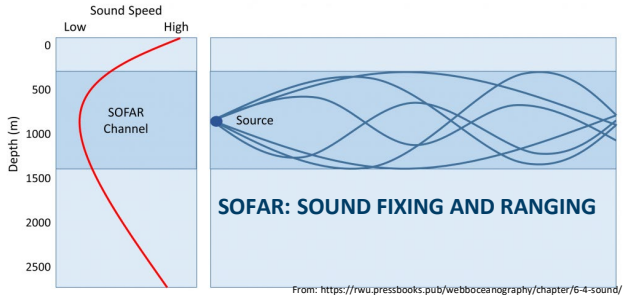
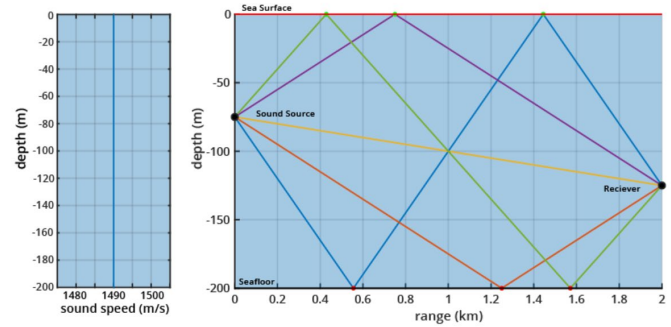
Especially low frequency sound travels far, e.g. in the sound speed minimum layer ~1000 m: SOFAR channel

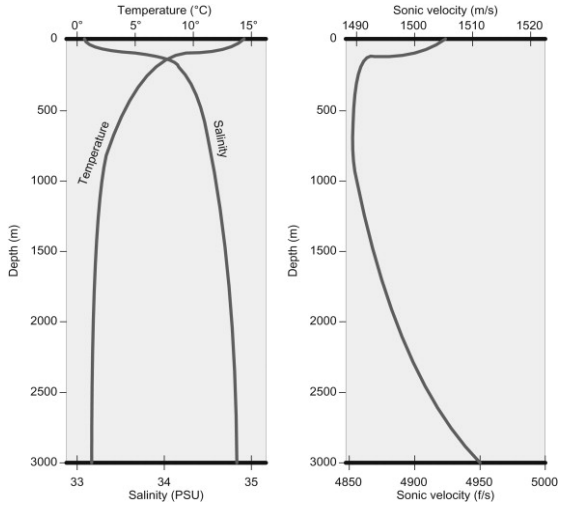


From: https://rwu.pressbooks.pub/webboceanography/chapter/6-4-sound/



Left: Constant speed of sound through the water column. Right: Illustration of the paths between a mid-depth source and a mid-depth receiver at a constant sound speed. Only the sound waves reaching the receive are shown. Credit DOSITS.

From: https://dosits.org/science/advanced-topics/shallow-water-propagation/



From: https://www.sciencedirect.com/topics/engineering/sound-velocity

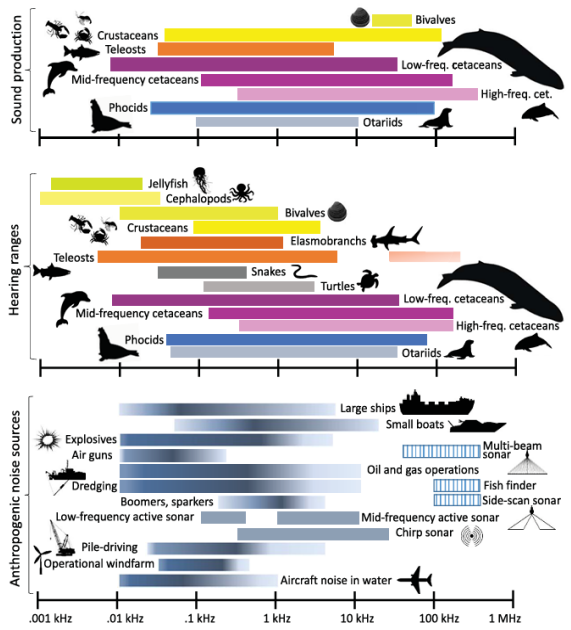
Underwater sound sources

Natural soundscape

- Weather: wind/waves/sea state/rain/ice
- Tides and other currents: turbulence and vortices around objects; sediment movement
- Earthquakes and other geological events
- Organisms

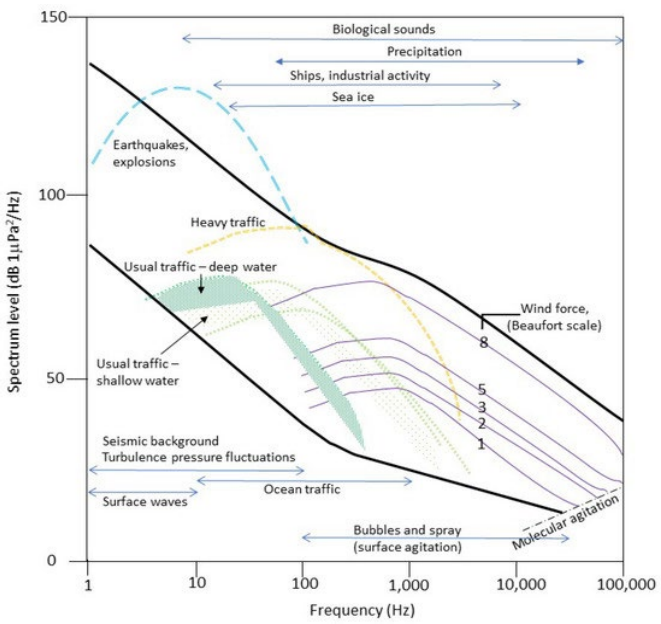
Anthropogenic sounds/noise

- Sonar
- Explosions
- Construction of marine structures (e.g. piledriving)
- Ships/boats



From Duarte et al. 2021: DOI: 10.1126/science.aba4658

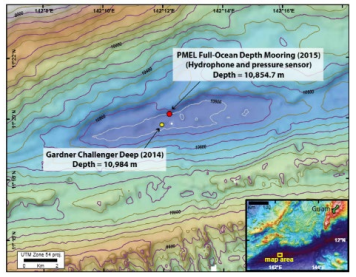
Wenz diagram



From: https://doi.org/10.3390/su151310178

Continuous increase of ocean noise

- Anthropogenic noise is continuously increasing
- “Shipping may be responsible for 90% of the sound energy we add to the ocean, ….” Ship noise has increased >32 fold in some areas over the past 50 years, doubling every 10 years, …. (Malakoff, 2010)
- Global underwater noise emissions from shipping has doubled in the last decade (Jalkanen et al. 2022)



Anthropogenic sounds recorded at the Challenger Deep (> 10 000 m)

“… percentage of the year 2019 the predicted anthropogenic noise dominates the natural ambient noise by 20 dB or more…”

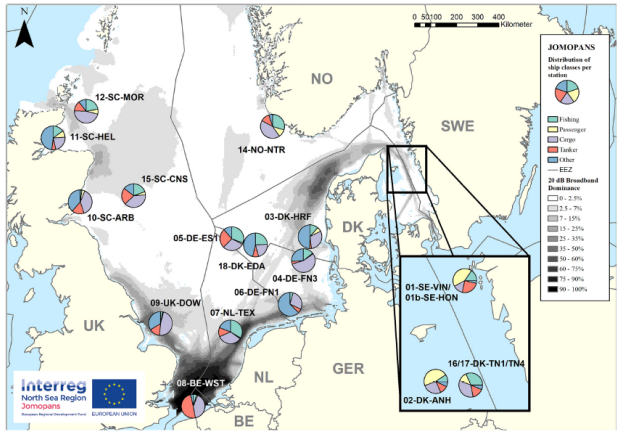
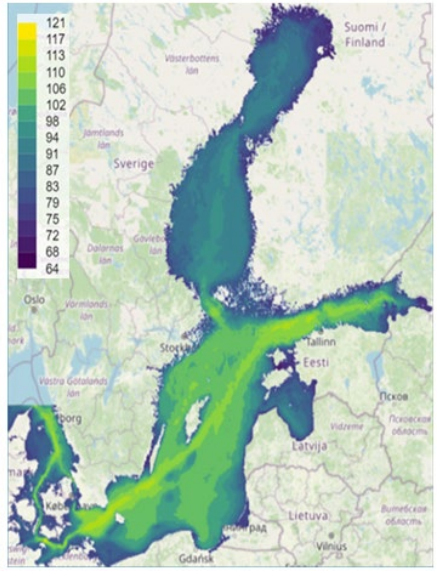


Fig. 1. Positions of 10 measurement stations indicated by pie charts depicting the share of ship classes on total traffic within 35 km of each station; contour map in the background exhibits over what percentage of the year 2019 the predicted anthropogenic noise dominates the natural ambient noise by 20 dB or more (broadband 10 Hz - 20 kHz), underlying sound map adopted from (de Jong et al., 2022); note that the 13-NO-LOV station is not depicted in the figure as it is outside the modelled region; its coordinates are given in Table 2.

From: Basan et al. 2024 https://doi.org/10.1016/j.marpolbul.2023.115891



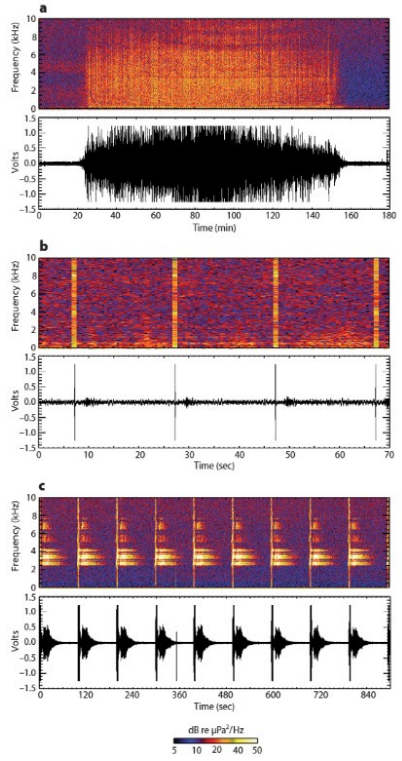
Continuous underwater noise in the Baltic Sea, SPL for the third octave band 125 Hz in March 2028.

From HELCOM: https://stateofthebalticsea.helcom.fi/findings/pressures/pollution/underwater-noise/

Ship propeller noise (10-24 h/day)

Airgun bursts

Sonar pings



From: Dziak et al. 2017 DOI: 10.5670/oceanog.2017.240

Underwater noise as pollutant of concern

Underwater noise is recognised as pollutant in the EU Marine Strategy Framework Directive (MSFD) and member states now need to assess and manage continuous and impulsive noise to ensure a good environmental status (GES).

- **Continuous noise**: Long-lasting, lower-energy sound without a sharp pulse characteristic, e.g. shipping, dredging. Can mask communication and other important signals, leading to chronic stress and behavioural issues. **No more than 20% of a marine area can be exposed to continuous underwater noise above the LOBE in any given month.**
  - MSFD Regulation: Assessed under Descriptor 11, Indicator 11.2.1.MSFD.
- **Impulsive noise**: Short, high-energy pulses, e.g. pile driving, seismic surveys (airguns), explosions, low frequency sonar. Impacts: Can cause injury, acute behavioural changes, or death. **For a single day, no more than 20% of a habitat can be exposed to levels above the LOBE. Over a year, no more than 10% of a habitat can be exposed to levels above the LOBE, on average.**
  - MSFD Regulation: Assessed under Descriptor 11, Indicator 11.1.1.MSFD.

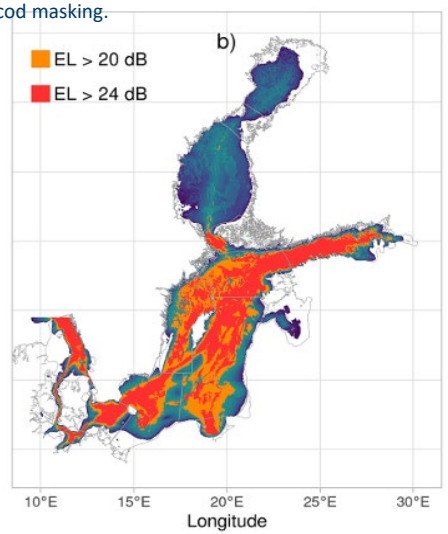
LOBE: **Level of Onset of adverse Biological Effects**
Definition: The noise level at which individual animals start to have adverse effects that could affect their fitness.
Effect examples: behavioural disturbance, stress, reduced communication space, and temporary or permanent habitat loss.

Levels of Onset of Biologically adverse Effects (LOBE) for the chosen Baltic Sea indicator species.

Marine species	Decidecade	Risk for disturbance	Risk of masking	References and comments
	Hz	dB re 1µPa		
		SPL	(excess level) EL	
Seals	500	110	20	Mikkelsen et al. (2019), EG Noise advise
Porpoise	500	110	n/a	EG Noise advise
Herring	125	110	20	[Olsen, 1971] [van der Knaap et al., 2022]
and Cod				

From: Klauson et al. 2024 https://doi.org/10.1016/j.marpolbul.2024.117105

Soundscape map of the Baltic sea (March 2018) showing areas where the sound excess level is predicted to be above the LOBE for herring and cod masking.



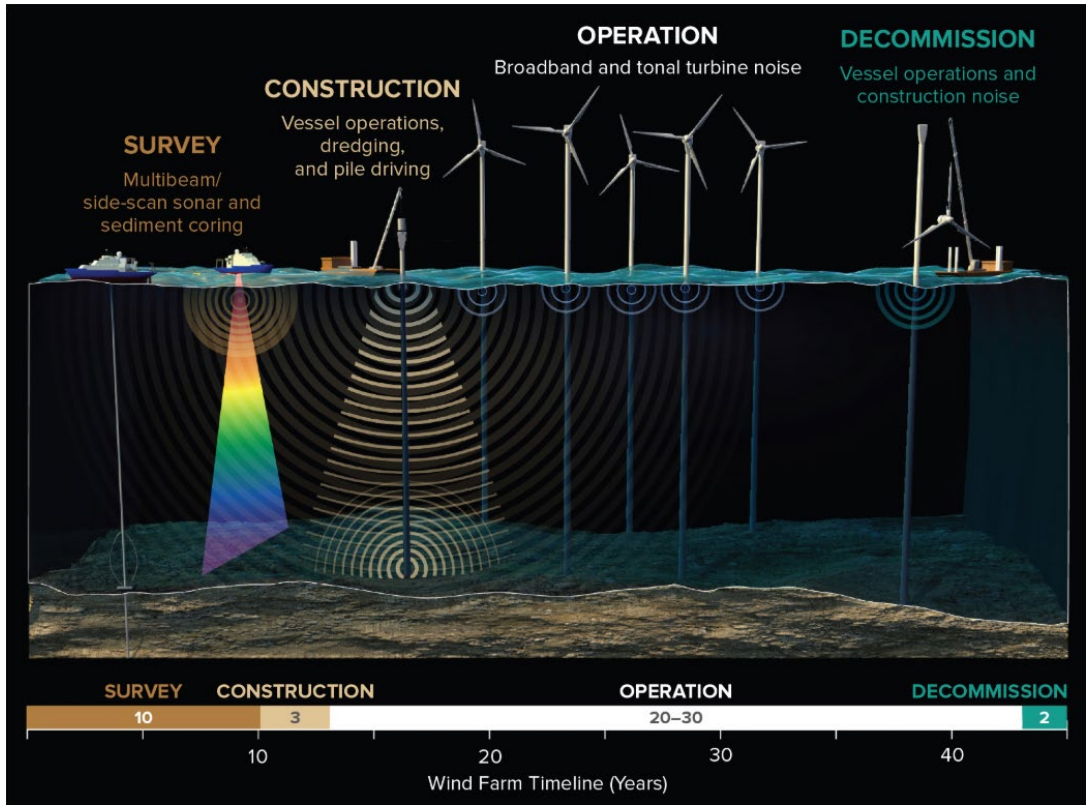
Offshore wind (OSW)

OSW causes underwater noise at **different phases:**

- Seismic surveys (weeks to months ++)
- Piledriving (days to weeks)
- Other construction such as bottom preparation (drilling, dredging, trenching, scour protection…) and assembly (days to weeks)
- Operational noise, e.g. generator noise, vibrations, chains … (during lifetime)

Ship noise from OSW

- Surveys, construction, maintenance ships, and decommissioning



From: Mooney et al 2020 https://doi.org/10.5670/oceanog.2020.408

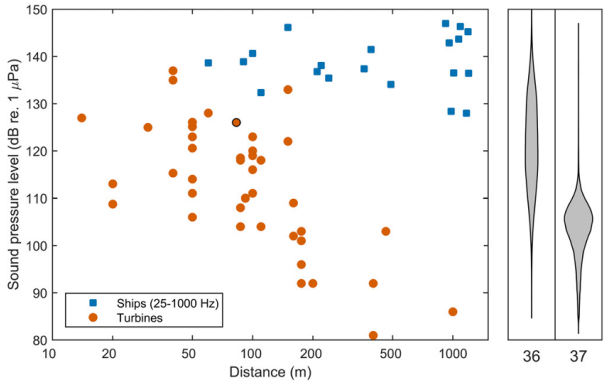
Monitoring studies

Some (approximate) numbers:

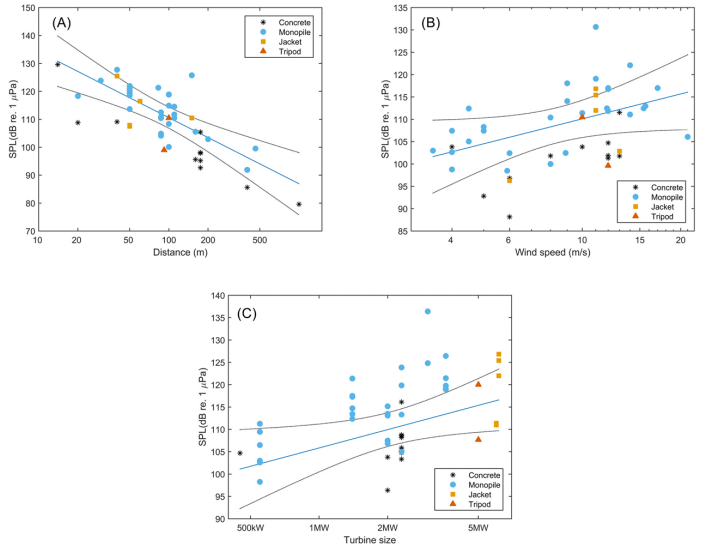
	Frequency (range) Hz	Sound pressure (SPL)	Distance "audible"	Notes
Piledriving	< 1 kHz (100 – 500 Hz)	> 200 dB re 1 µPa	several km	Impulsive noise during foundation installation
Operational noise	20 Hz – 1 kHz (20 – 250 Hz)	– 160 dB re 1 µPa	some 100 m to few km	Continuous tonal and broadband noise from drivetrain (hum); low-frequency tonal noise, wind-speed dependent (floating)
Maintenance (vessels)	50 – 1 kHz	> 100 dB re 1 µPa	several km	Engine, propeller and thruster noise during routine visits

Summary of SPL from literature (+ ship noise; Tougaard et al. 2020):

- Ships are louder than turbines
- Factors explaining SPL: distance > wind speed and turbine size
- OWF could cause elevated noise (km distance) under very low ambient noise
- Under high ambient noise: no impact with distance



From Tougaard et al. 2020 https://doi.org/10.1121/10.0002453



Not possible to draw conclusions on the effects of foundation (related to turbine size and depth).
Data was normalised to 100 m, a wind speed of 10 m/s, and a turbine size of 1 MW

Impacts

Findings vary between studies - it depends!

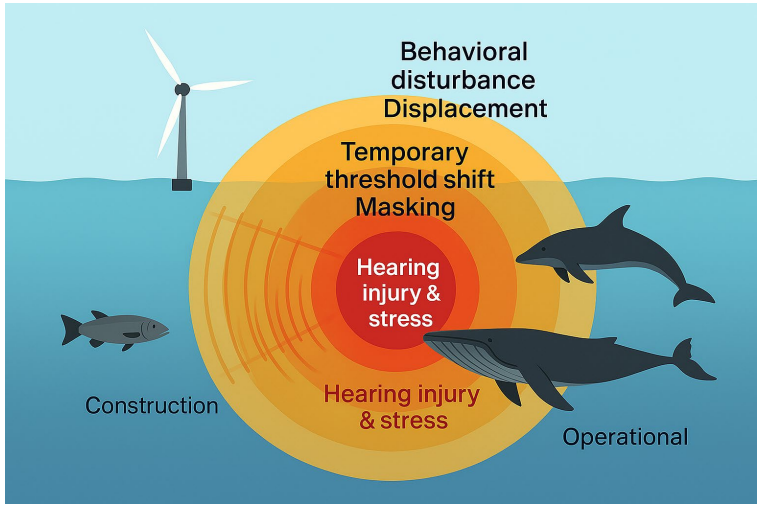
- Piledriving: mammals show avoidance behaviour/temporary displacement (seals, dolphins, harbour porpoise); seabass altered schooling behaviour and swimming speed; cod was found to change depth but not leave the area

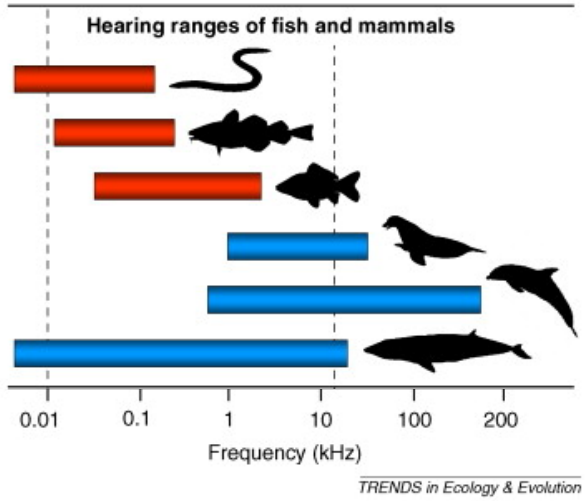
  Cuttlefish eggs: might be affected within a range of around 500 metres from pile driving

- Operational noise: audible for cod, herring, seal … also at distance

  Cod larvae were found to be attracted to wind park sound

  Masking of fish communication!

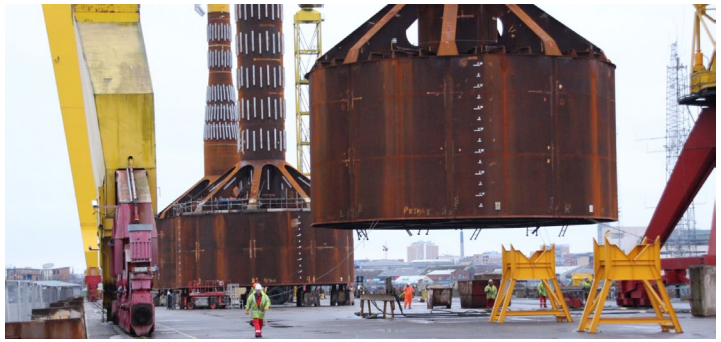




Modified from: Slabbekoorn et al. 2010 https://doi.org/10.1016/j.tree.2010.04.005

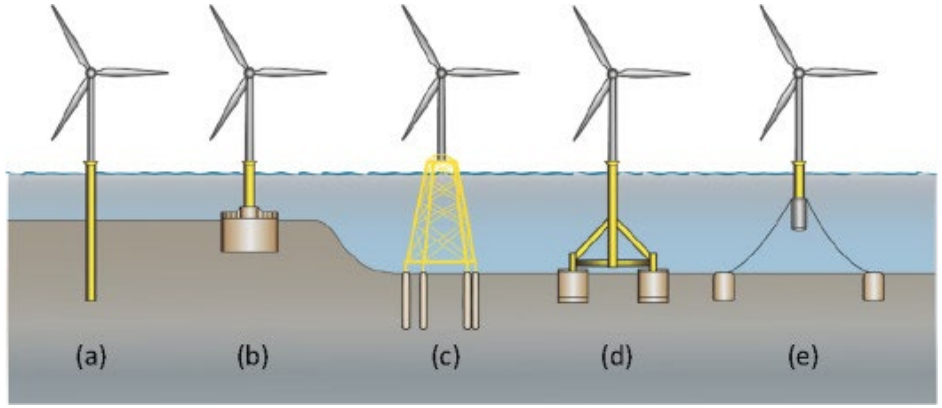
Mitigation options

- Adapt duration/timing of seismic surveys
- Measures during pile driving (bubble curtains; deterrence, …)
- Avoid pile driving by using e.g. suction buckets



https://psmag.com/news/could-giant-suction-cups-turn-lake-erie-into-a-regional-energy-hub/

- Marine spatial planning!
- Consider number of turbines
- Consider cumulative effects with other noise sources (shipping lanes) – “already noise polluted areas”?
- Distance to MPA, reproduction areas (vocalisation)
- Maintenance schedule
- Prolong lifetime
- …



From Kaynia 2019 https://doi.org/10.1016/j.soildyn.2018.04.038

Summary

- Continuous underwater noise from individual wind turbines is low (lower than ship noise)
- Cumulative sound from (larger) windfarms can be significant
- Cumulative sound levels from windfarms could disturb sensitive species especially in low ambient noise areas

  -should be included in impact assessment and marine spatial planning

SINTEF

Teknologi for et bedre samfunn