Vulnerability of North Sea fish species to underwater noise

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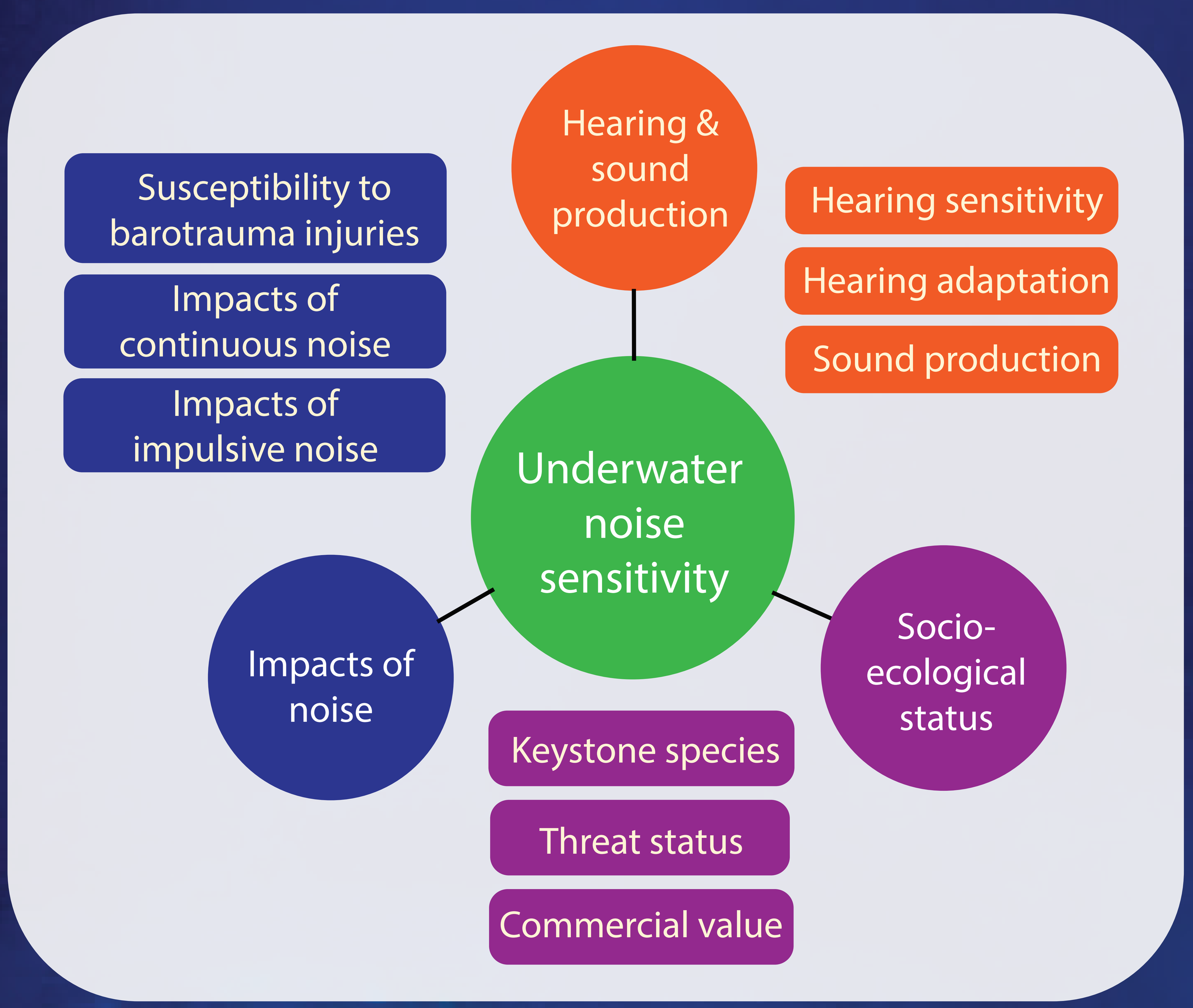


BACKGROUND OF THE STUDY

Fish are anatomically diverse.

Therefore, different species exhibit varying levels of sensitivity to underwater noise.

How do fish perceive sound?

Fish primarily detect particle motion[1]. The swim bladder plays a role in fish hearing. It serves as an acoustic transformer, translating sound pressure into reradiated particle motion[2]. Some species developed special adaptations that mechanically link the swim bladder to the ear[3].

Why do sounds matter to fish?

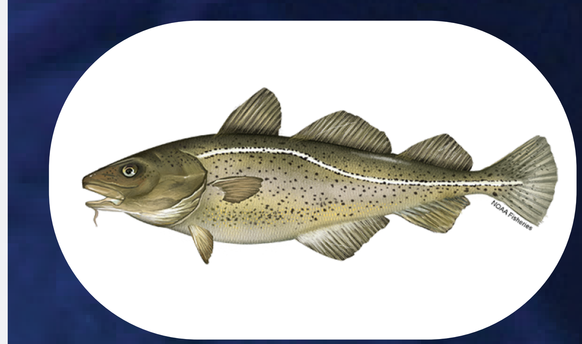
Fish use sounds to navigate, communicate, detect prey/predators, migrate, mate and select habitats[4]. Intensifying anthropogenic sounds can interfere with the survival and fitness of animals through masking of biologically relevant sounds[5,6,7]. Anthropogenic sounds can also result to physiological or behavioral changes[3].

The North Sea is one of the most heavily used areas in the world![8] The hearing ranges of fish, in most cases, completely overlap with low-frequency anthropogenic sounds, such as pile driving, airgun, operational wind farm and shipping noise[5].

1 Development of a vulnerability scoring system

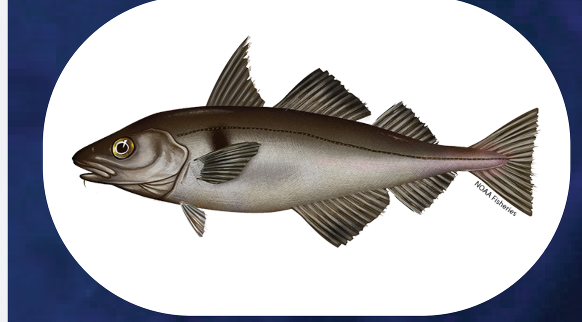
2 Identify the most vulnerable species and select indicator species for the North Sea

Based on literature and an expert consultation survey



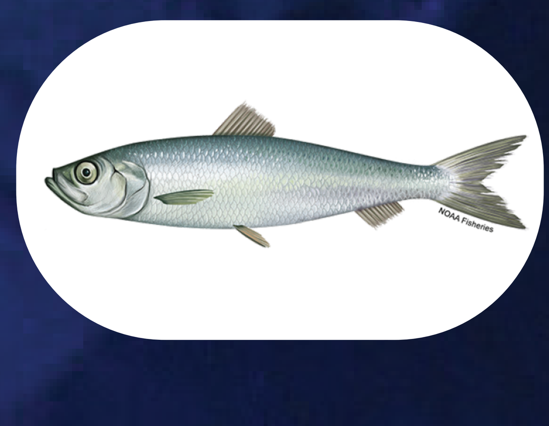
Atlantic cod (*Gadus morhua*)

Total vulnerability score: 24.6
Hearing range: ~30 - 470 Hz[9]
Hearing adaptation: Swim bladder has anterior extensions in proximity to the ears, making it sensitive to both particle motion and sound pressure[10]
Sound production: below 1 kHz related to courtship and spawning[11]
Impact of impulsive noise: reduced heart rate[12], loss of ciliary bundles[13]
Impact of continuous noise: masking of behaviorally significant calls[7]



Haddock (*Melanogrammus aeglefinus*)

Total vulnerability score: 24.0
Hearing range: ~30 - 500 Hz[9]
Hearing adaptation: no accessory hearing organs
Sound production: 50 to 260 Hz during spawning[14]
Impact of impulsive noise: negatively affected foraging behavior[15]
Impact of continuous noise: masking of behaviorally significant calls[7]



Atlantic herring (*Clupea harengus*)

Total vulnerability score: 23.2
Hearing range: up to 4 kHz[17]
Hearing adaptation: Tubular connection between its swim bladder and its air-filled otic bullae in proximity to its inner ear[18]
Sound production: 1.7 – 22 kHz, social mediation appears likely[19]
Impact of impulsive noise: damage to hair cells[20]
Impact of continuous noise: significant diving reactions[21], avoidance reaction[22]

Ling (*Molva molva*)

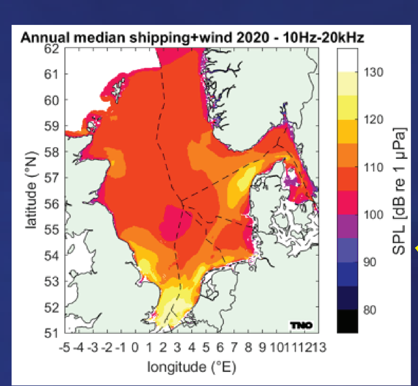
Total vulnerability score: 21.0
Hearing range: ~30 - 500 Hz[9]
Hearing adaptation: no accessory hearing organs
Sound production: Likely but unconfirmed[14]
Impact of impulsive noise: increased swimming activity[15]
Impact of continuous noise: potential masking of calls[16]

Atlantic salmon (*Salmo salar*)

Total vulnerability score: 20.0
Hearing range: up to 580 Hz[23]
Hearing adaptation: No accessory hearing organs[23]
Sound production: 300 - 2000 Hz[24]
Impact of impulsive noise: no overt reactions[25]
Impact of continuous noise: masking of behaviorally significant calls[26]

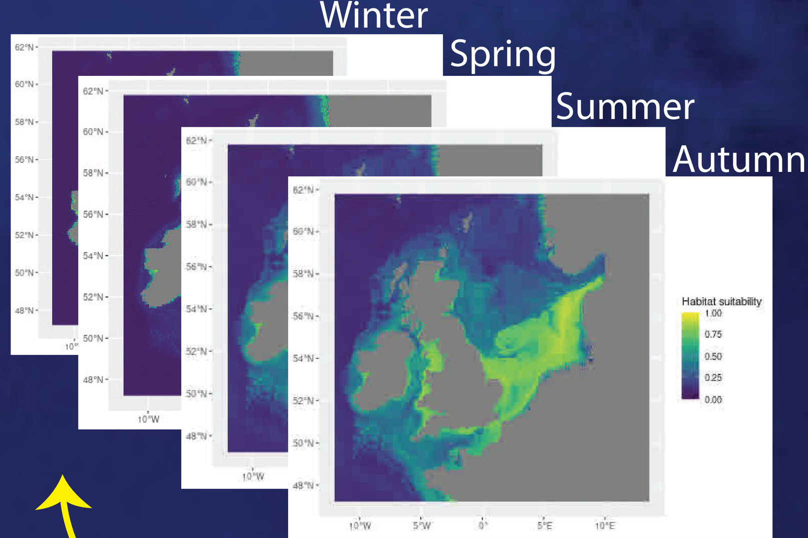
3 Evaluate the distribution of indicator species and assess the impacts of noise

Field measurements of underwater sound in offshore wind farms



de Jong et al., 2021

Predictions of future soundscapes for maritime zones



Habitat suitability mapping of selected indicator species

Collection of 190+ references related to fish hearing, sound production and impacts of noise.

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