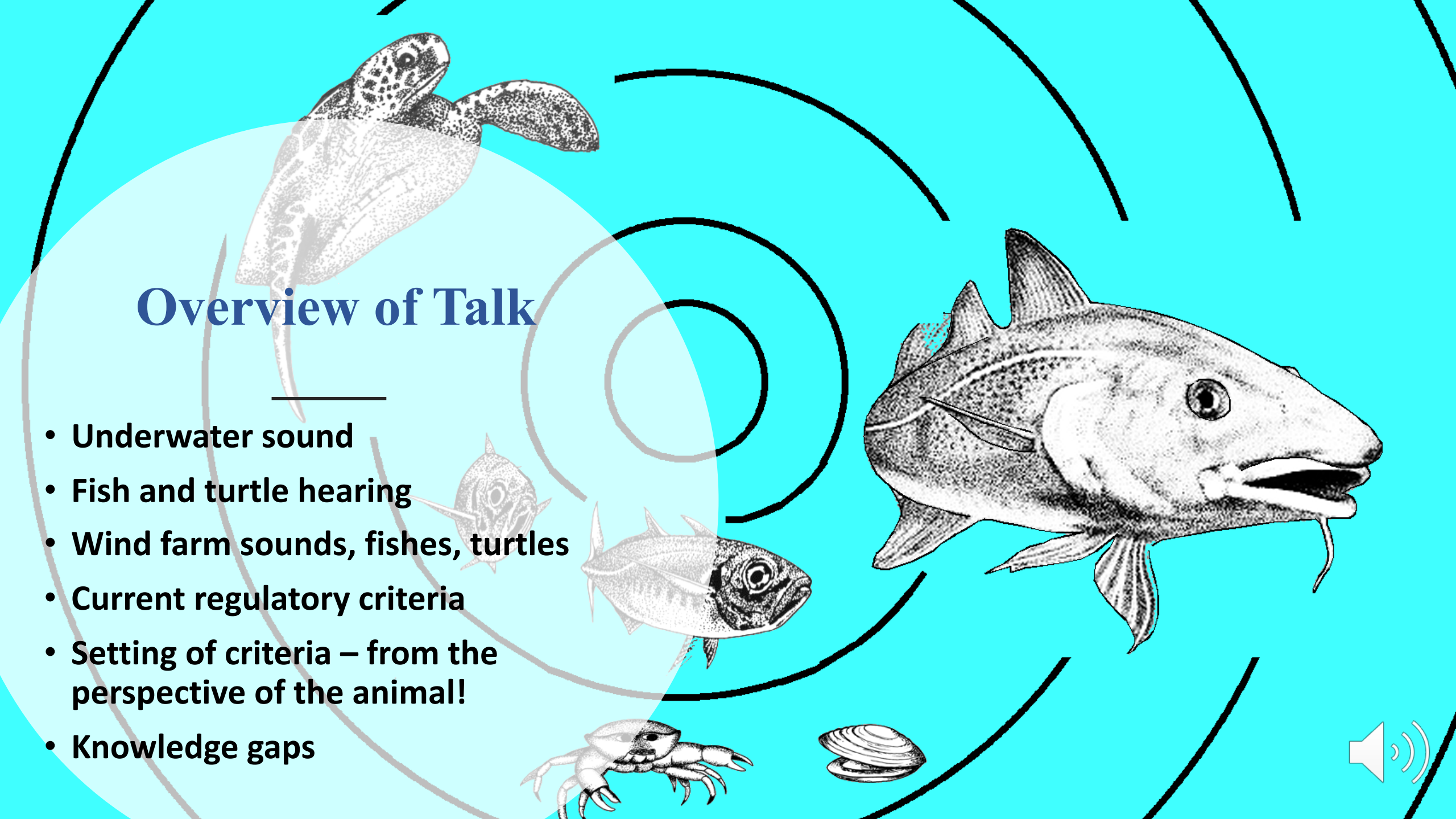
Cumulative Noise Impacts Upon Fishes (and Turtles) from Offshore Wind Farm Construction and Operation

Arthur N. Popper and Anthony D. Hawkins

apopper@umd.edu, www.Ahukini.net

a.hawkins@btconnect.com

Tony Art

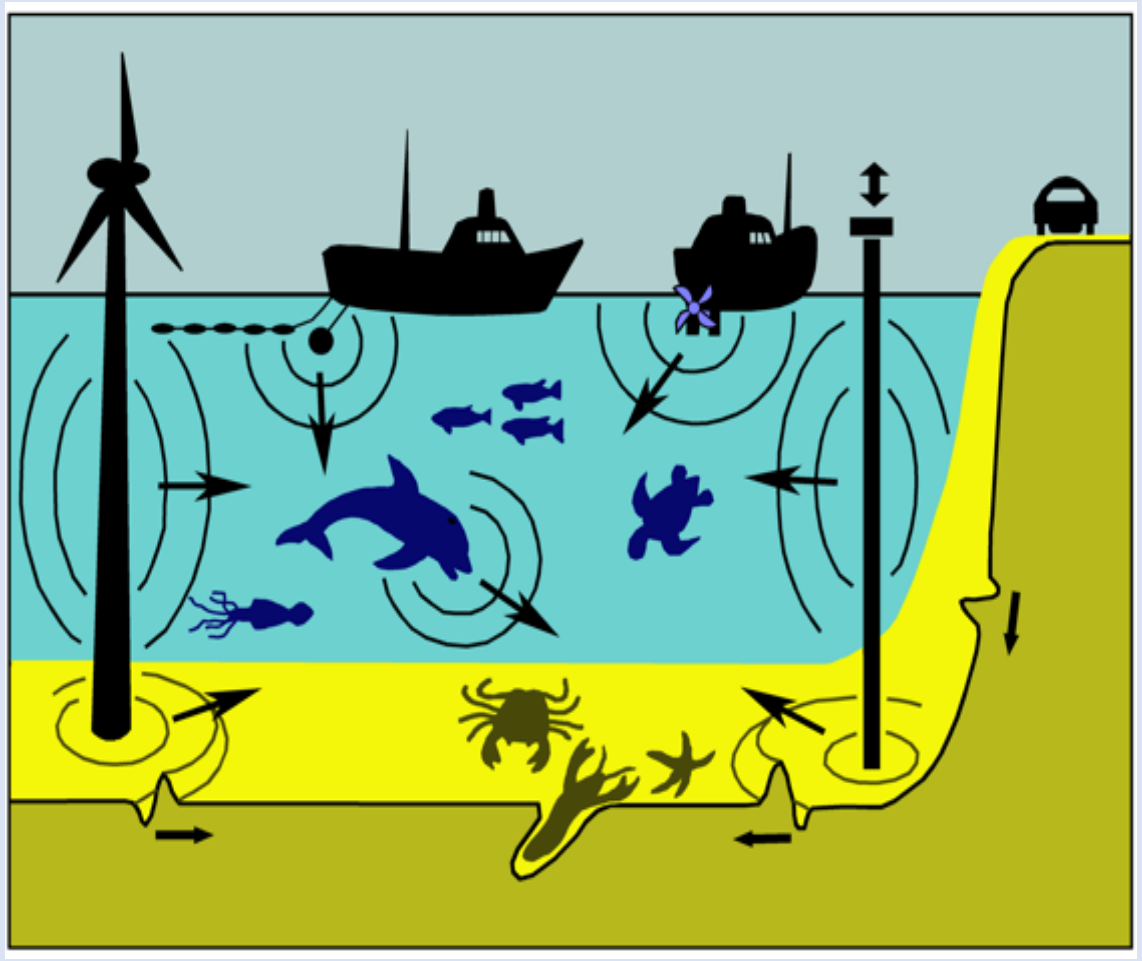


Overview of Talk

- Underwater sound
- Fish and turtle hearing
- Wind farm sounds, fishes, turtles
- Current regulatory criteria
- Setting of criteria – from the perspective of the animal!
- Knowledge gaps

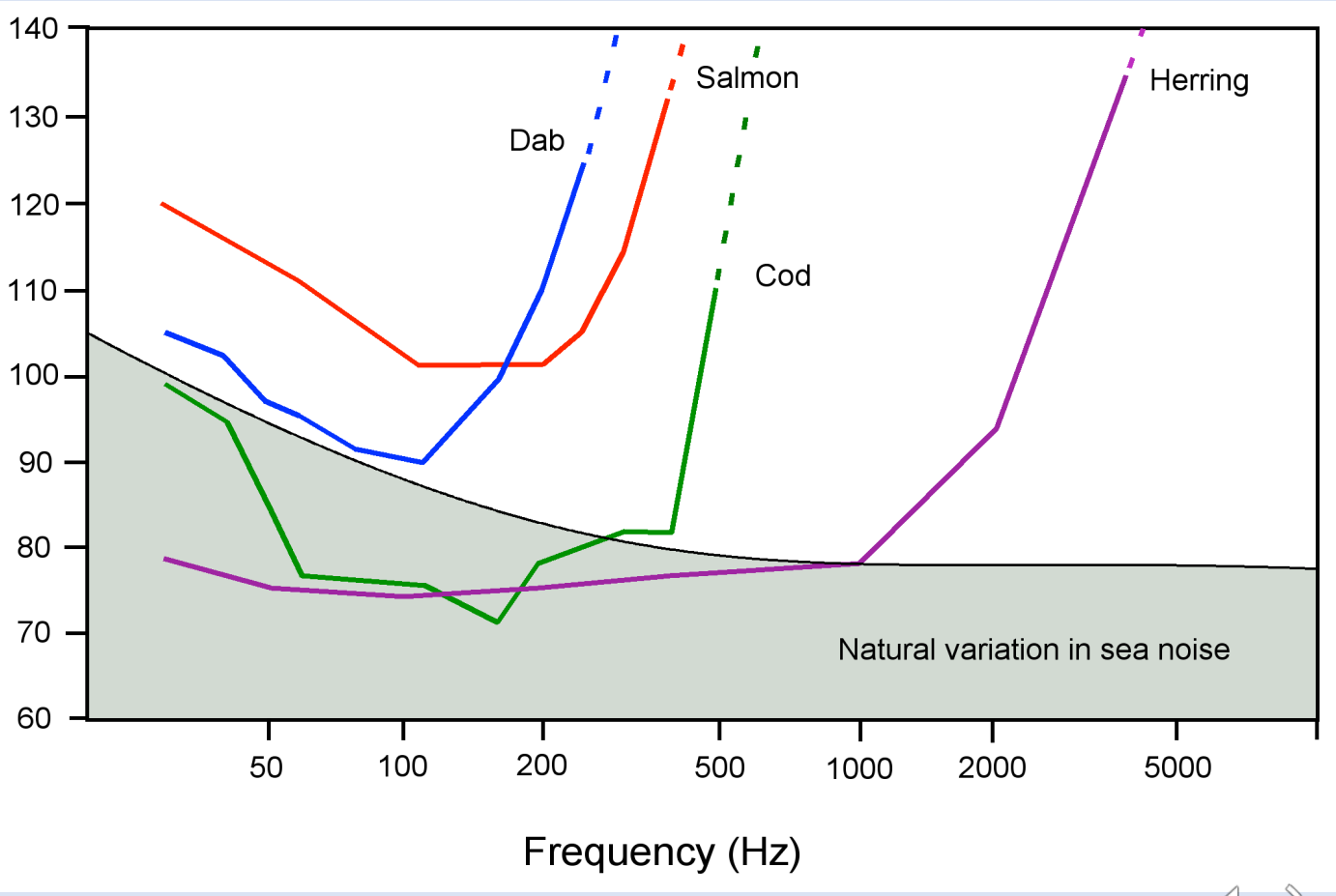
Underwater Sound

- Water is denser than air, and sound travels faster in water, with the speed depending on the pressure, temperature, and salinity (see www.dosits.com)
- Underwater sound has two elements:
  - Sound pressure
  - Particle motion
- In air, pressure is the dominant stimulus
- In water, due to density, particle motion is also substantial
- Additional issue: sounds in substrate and that emanate from it



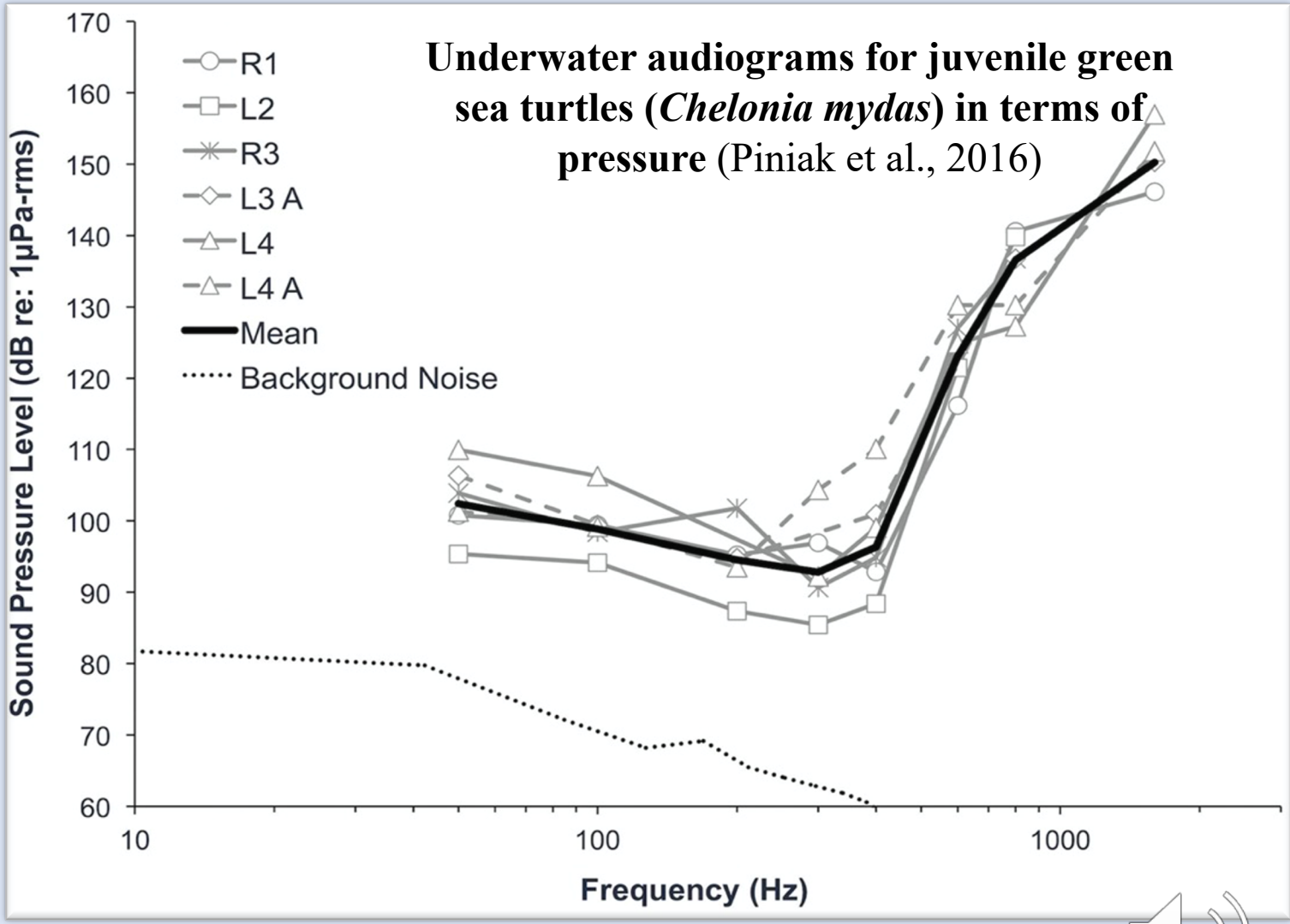
Hearing Capabilities – An Overview

- All fish can hear
- Hearing capabilities varies by species
- Fish hearing capabilities include:
  - Detection of sound in the presence of noise
  - Determination of the direction of a sound source
  - Discrimination between sounds of different frequency and intensity
- **All fishes detect particle motion**
- Some species also detect pressure – increases bandwidth & sensitivity



Turtle Sound Detection

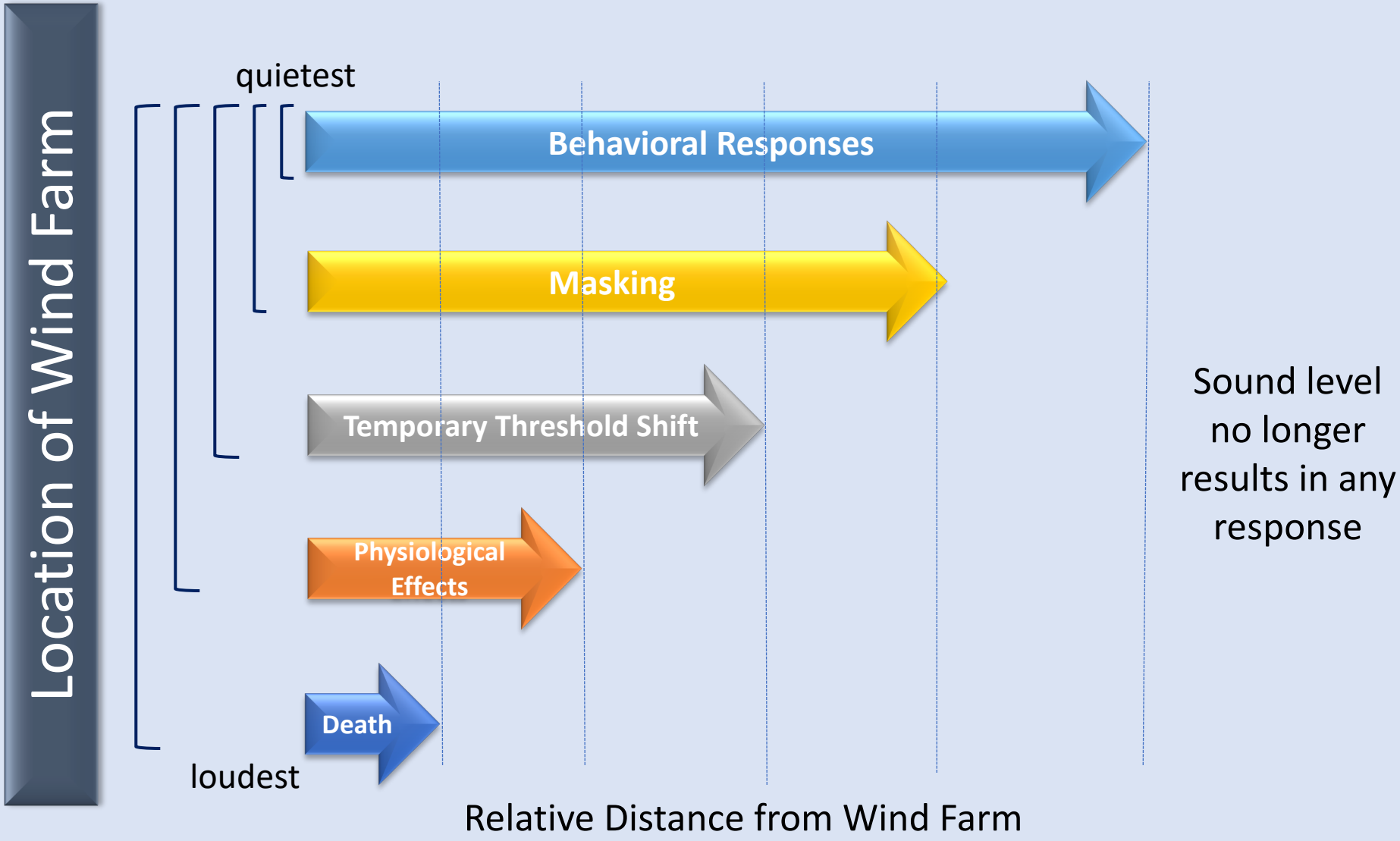
- Much less is known about turtle hearing than for fishes
- We do not know:
  - If they detect sound pressure or particle motion, or both
  - If they detect substrate vibrations
- Green sea turtle data are similar data from other marine turtle species studied
- With so few data, predictions of effects, both physical and behavioral effects are not currently possible



Wind Farm Sounds, Fishes (and Turtles)

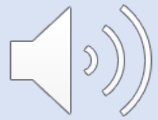
- Likely that most species of fish will detect pile driving (and other construction) sounds up to some (unknown) distance from source. Depends on source level
- Issue is how far from the source will they detect the sounds. Depends upon:
  - Lowest sound level the fish can detect
  - How much other sounds interfere (mask) with detection
- Some species also may detect operational windfarm sounds
  - Likely only those fishes with best hearing
  - Likely only relatively close to the source
- Unknown in both cases is sound that travels through the substrate and then into the water column at different distances from the source
- Can say nothing about turtles, but perhaps same conclusions as for fishes

Potential Effects of Sounds on Fishes (and Turtles)



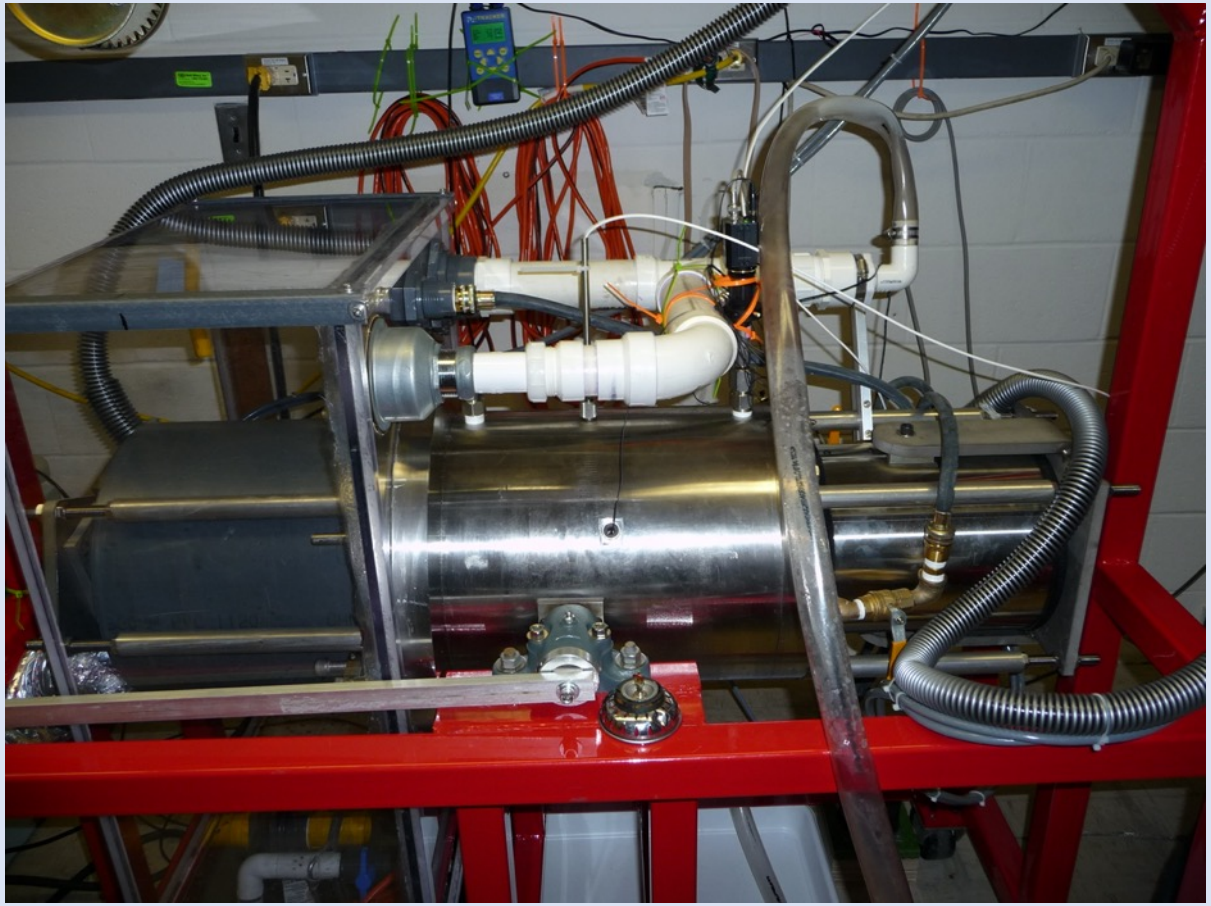
Potential Effects from Wind Farms

- During construction
  - Mortality (if close to the source)
  - Physical damage (if close to the source) & potential delayed mortality
  - TTS, masking, behavioral effects
- Cumulative effects if animals stay near the source
- During operation
  - Mortality and physical effects unlikely since sounds are much quieter, and not impulsive
  - TTS also unlikely since sounds so low
  - Only likely effects are masking and behavioral changes
  - However, depends on if the animal even hears the sound
  - Also depends on whether animal stays around or moves away



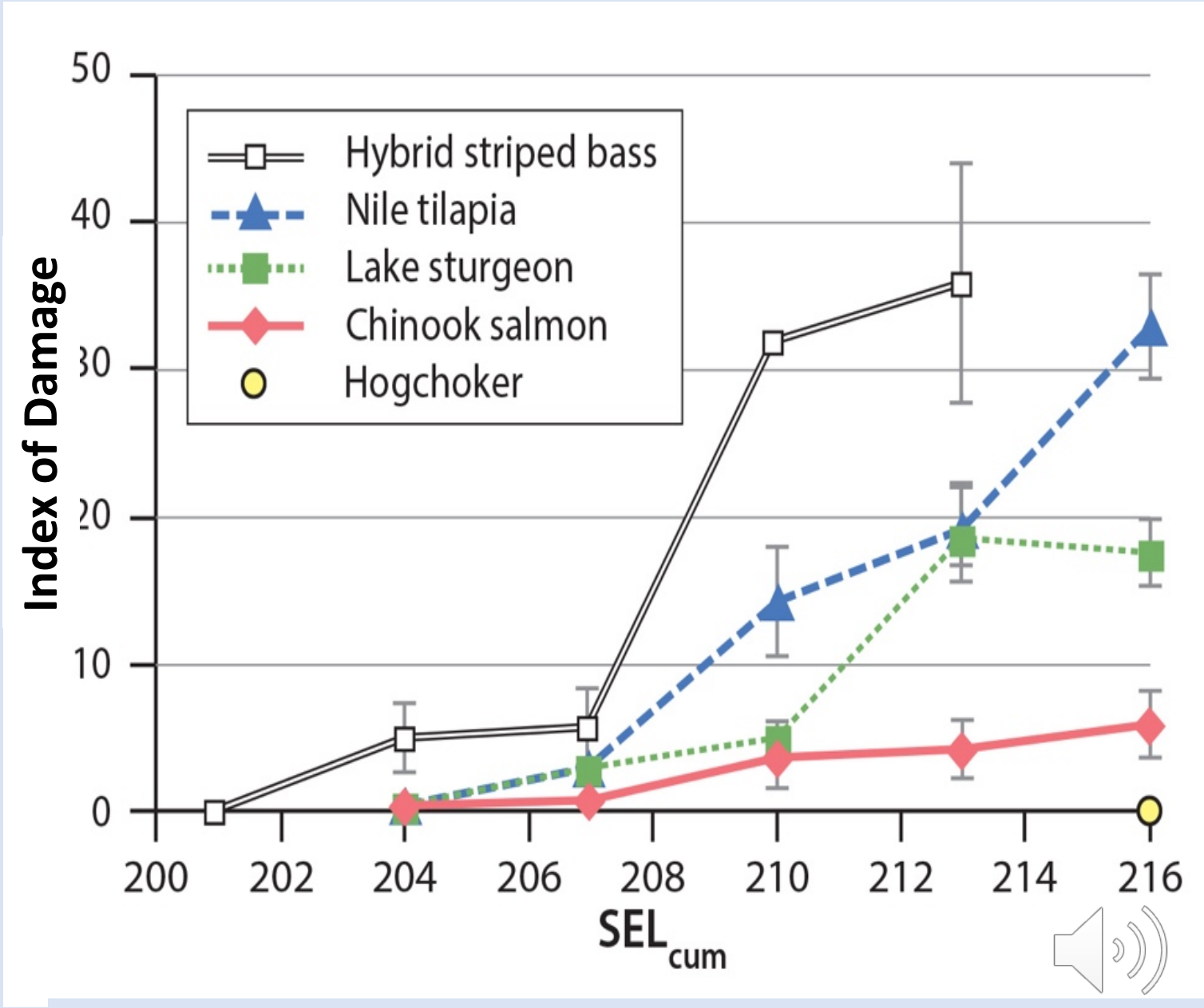
Construction Sounds (Pile Driving): Potential Physical/Physiological Effects

- Can say nothing about turtles
- Conclusions for fishes based on work done in Popperlab (references Halvorsen et al.; Casper et al.) (www.Ahukini.net)
- Studies exposed several different species to pile driving sounds at levels comparable to those that might occur near an actual field site
  - Used 960 or 1920 pile strikes
  - Different sound levels
  - Examined for physical damage externally and internally
  - Did recovery studies
  - Goal was to help develop criteria for potential effects of pile driving sounds on fishes



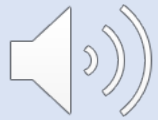
Cumulative Effects

- Nothing known about turtles, but likelihood is that if sounds bothered them, they would leave areas
- Fishes could suffer effects of pile driving if stay in area
  - Data suggests there is accumulation of effects
  - But NOT a simple accumulation (not 1:1)
- Species differences

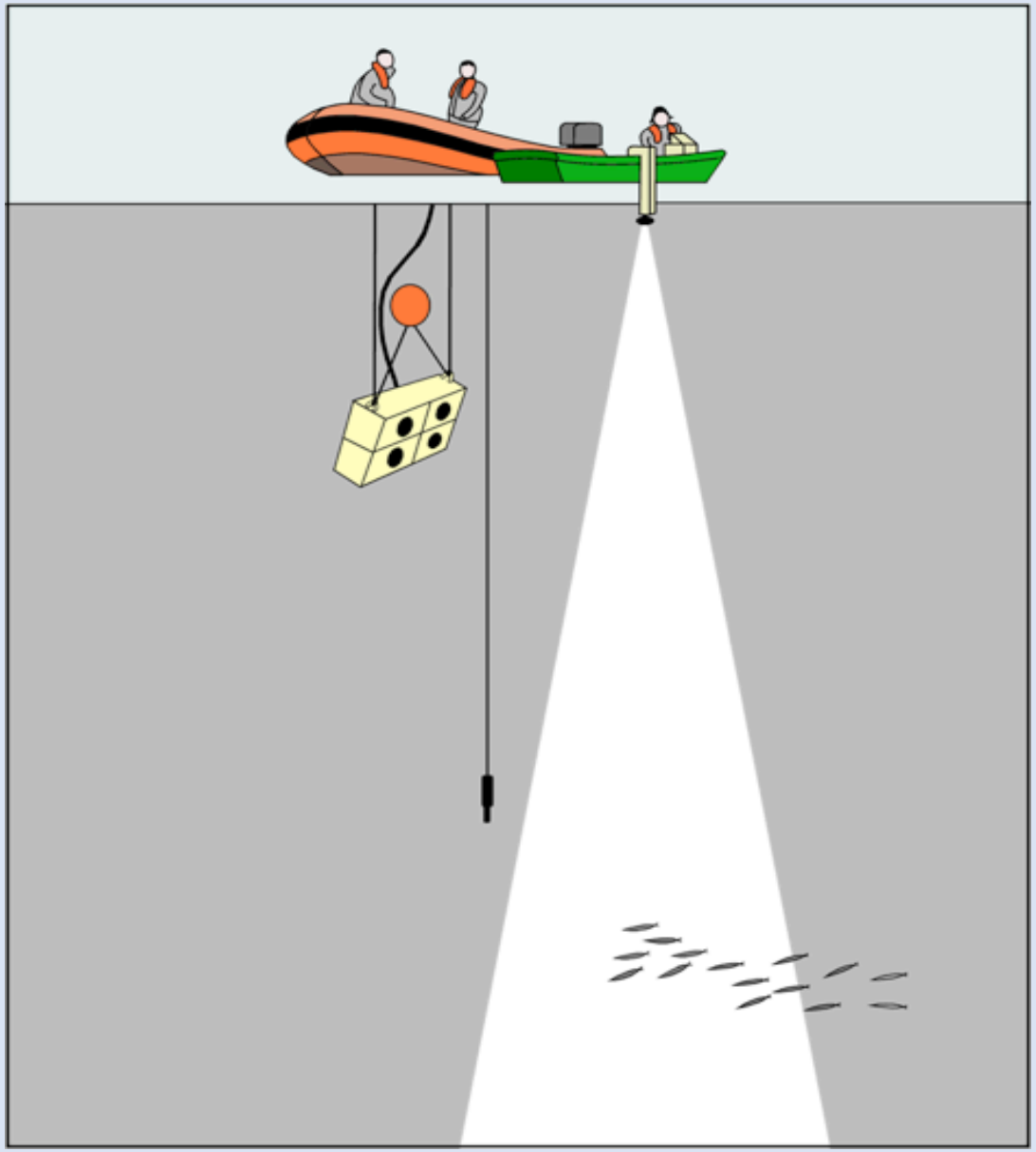


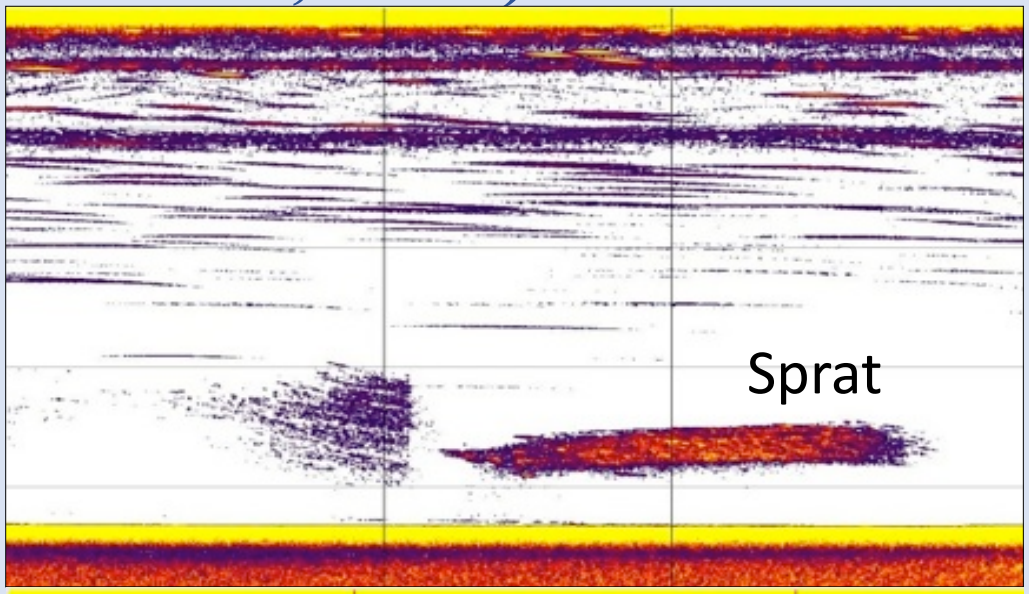
Operational Wind Farm: Potential Behavioral Effects

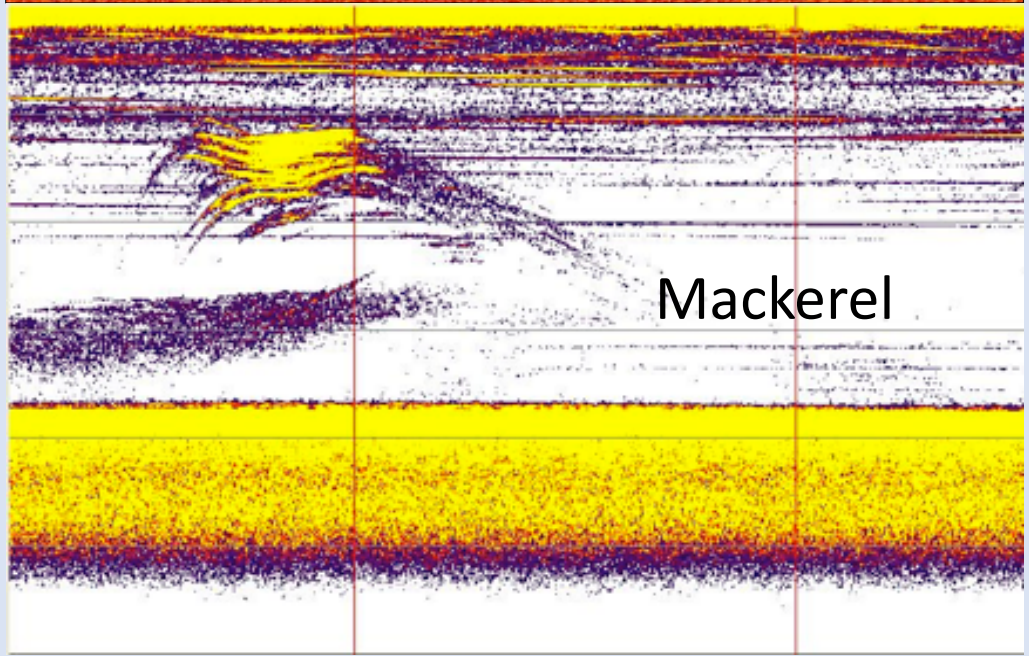
- Not much data about effects of sounds operational windfarm on fishes, but:
  - Long-term exposure to continuous sounds in lab shows some temporary hearing loss in fishes that hear well. However,
  - Operational sounds are lower than those used in the lab
  - The only fishes that showed hearing loss are those that hear very low intensity sounds
  - Not representative of most (if not all) fishes exposed to operational wind farm
- There is also possibility that sounds will mask detection of biologically important sounds
- Most studies done in the lab and in tanks where there are issues on meaning of data.
- Need field studies

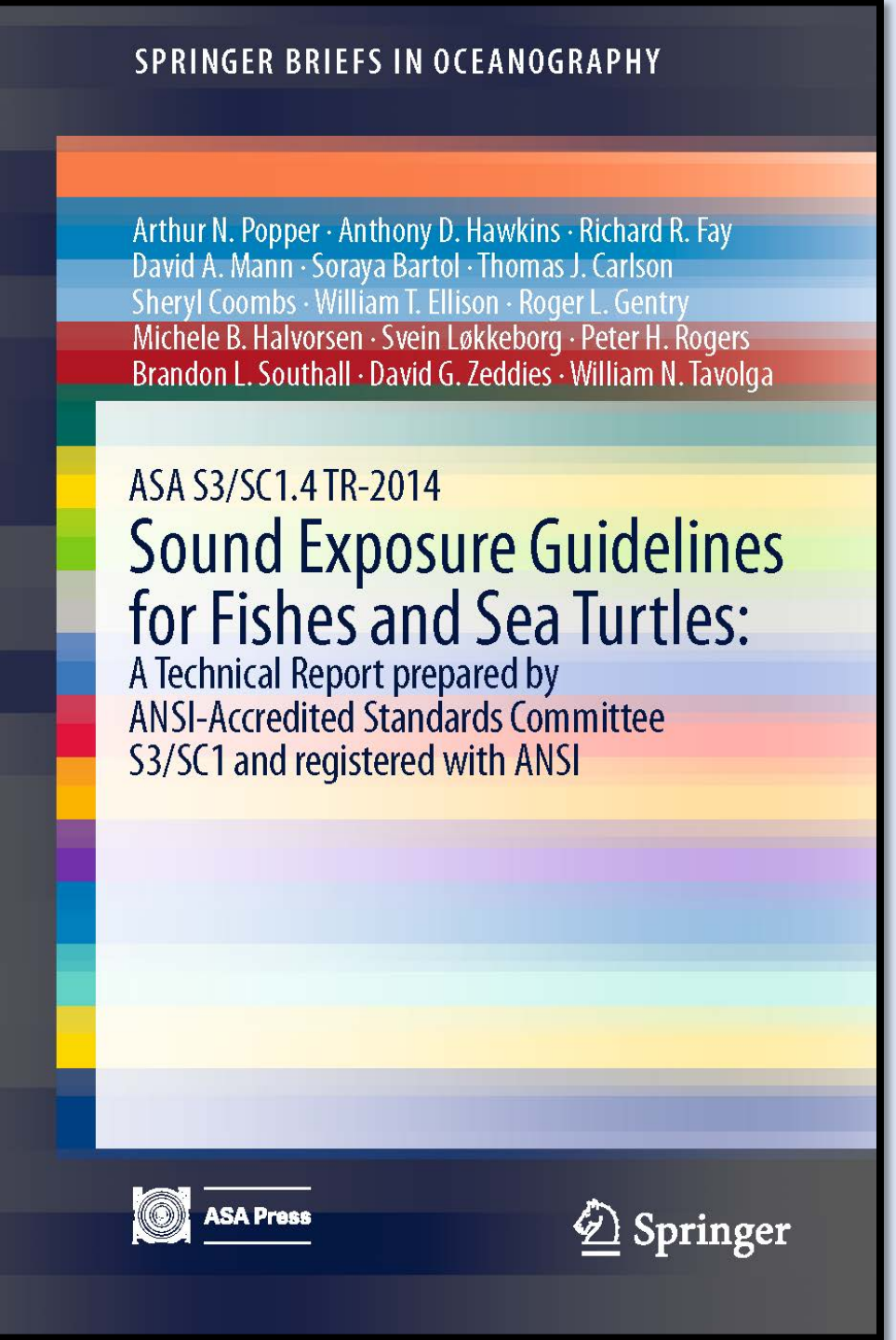


Responses of Wild Fishes to the Playback of Pile Driving Sounds (Hawkins et al., 2014)









Sound Exposure Criteria

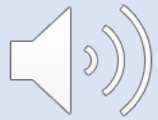
- Currently used criteria developed in 2008 – not science base
- In 2014 developed for fishes and turtles as interim guidelines
  - Based on most recent data
  - Interim guidelines being adopted in Europe and other parts of the world
  - Recently reviewed literature post 2014 and showed that the interim criteria are still appropriate since no relevant data since
- HOWEVER
  - Guidelines still only in terms of sound pressure and not particle motion or substrate vibration

Example: Pile Driving Guidelines

Type of Animal	Mortality and potential mortal injury	Impairment			Behavior
		Recoverable injury	TTS	Masking	
Fish: no swim bladder (particle motion detection)	>219 dB SEL_{cum} or >213 dB peak	>216 dB SEL_{cum} or >213 dB peak	>>186 dB SEL_{cum}	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder is not involved in hearing (particle motion detection)	210 dB SEL_{cum} or >207 dB peak	203 dB SEL_{cum} or >207 dB peak	>186 dB SEL_{cum}	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder involved in hearing (primarily pressure detection)	207 dB SEL_{cum} or >207 dB peak	203 dB SEL_{cum} or >207 dB peak	186 dB SEL_{cum}	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate
Sea turtles	210 dB SEL_{cum} or >207 dB peak	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) High (I) Moderate (F) Low
Eggs and larvae	>210 dB SEL_{cum} or >207 dB peak	(N) Moderate (I) Low (F) Low	(N)Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low

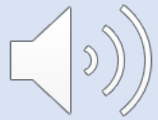
A New Approach to Developing Criteria

- *Popper, A. N., Hawkins, A. D., and Thomsen, F. (**2020**). "Taking the animals' perspective regarding underwater anthropogenic sound," Trends in ecology & evolution **35**, 787-794.*
- Argue that in thinking about regulation, mitigation, and criteria we need to ask what affects the animals, and how
  - If no effect, then no need to regulate or mitigate
  - Too often today, regulation and mitigation is based on "best guesses" of how animals might respond
  - Problem is that there is a severe lack of data on potential effects of anthropogenic sound (of any type) on fishes, invertebrates, and turtles (and even marine mammals)



Major Knowledge Gaps

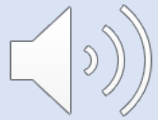
- Hearing sensitivity, determined behaviorally, of fishes that are likely to be exposed to sounds from wind farm
- Behavioral responses of wild animals to both construction and operation of wind farms – this is the major question!
- Physical & physiological effects of exposure to wind farms during construction and operations
- Effects on eggs and larve of construction and operation of wind farms
- CAVEATS
  - Behavioral studies must be done in the field
  - Hearing studies must us behavioral methods
  - Data for several different species – there is no one “right” species
- Gaps for turtles the same as for fish – except we know even less about fish



Some of Our Recent, Relevant, Papers

- Hawkins, A. D., Pembroke, A., and Popper, A. N. (2015). Information gaps in understanding the effects of noise on fishes and invertebrates. Reviews in Fish Biology and Fisheries. 25:39-64. DOI 10.1007/s11160-014-9369-3
- Popper, A. N. and Hawkins, A. D. (2018). The importance of particle motion to fishes and invertebrate. The Journal of the Acoustical Society of America, 143: 470-488. https://doi.org/10.1121/1.5021594
- Popper, A. N. and Hawkins, A. D. (2019). An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. Journal of Fish Biology, 94:692-713. https://doi.org/10.1111/jfb.13948
- Popper, A. N., Hawkins, A. D., and Halvorsen, M. C. (2019). Anthropogenic sound and fishes. A Report Prepared for the Washington State Department of Transportation, Olympia, WA. http://www.wsdot.wa.gov/research/reports/800/anthropogenic-sound-and-fishes
- Hawkins, A. D., Johnson, C., Popper, A. N. (2020). Setting of sound exposure criteria for fishes. The Journal of the Acoustical Society of America, 147:1762-1777. https://doi.org/10.1121/10.0000907
- Popper, A. N., Hawkins, A. D. and Thomsen, F. (2020). Taking the animals' perspective regarding underwater anthropogenic sound. Trends in Ecology and Evolution. 35:787-794. https://doi.org/10.1016/j.tree.2020.05.002
- Hawkins, A. D. and Popper, A. N. (2020). Sound detection by Atlantic cod: An overview. The Journal of the Acoustical Society of America, in press.

EMAIL us for copies of these or other papers



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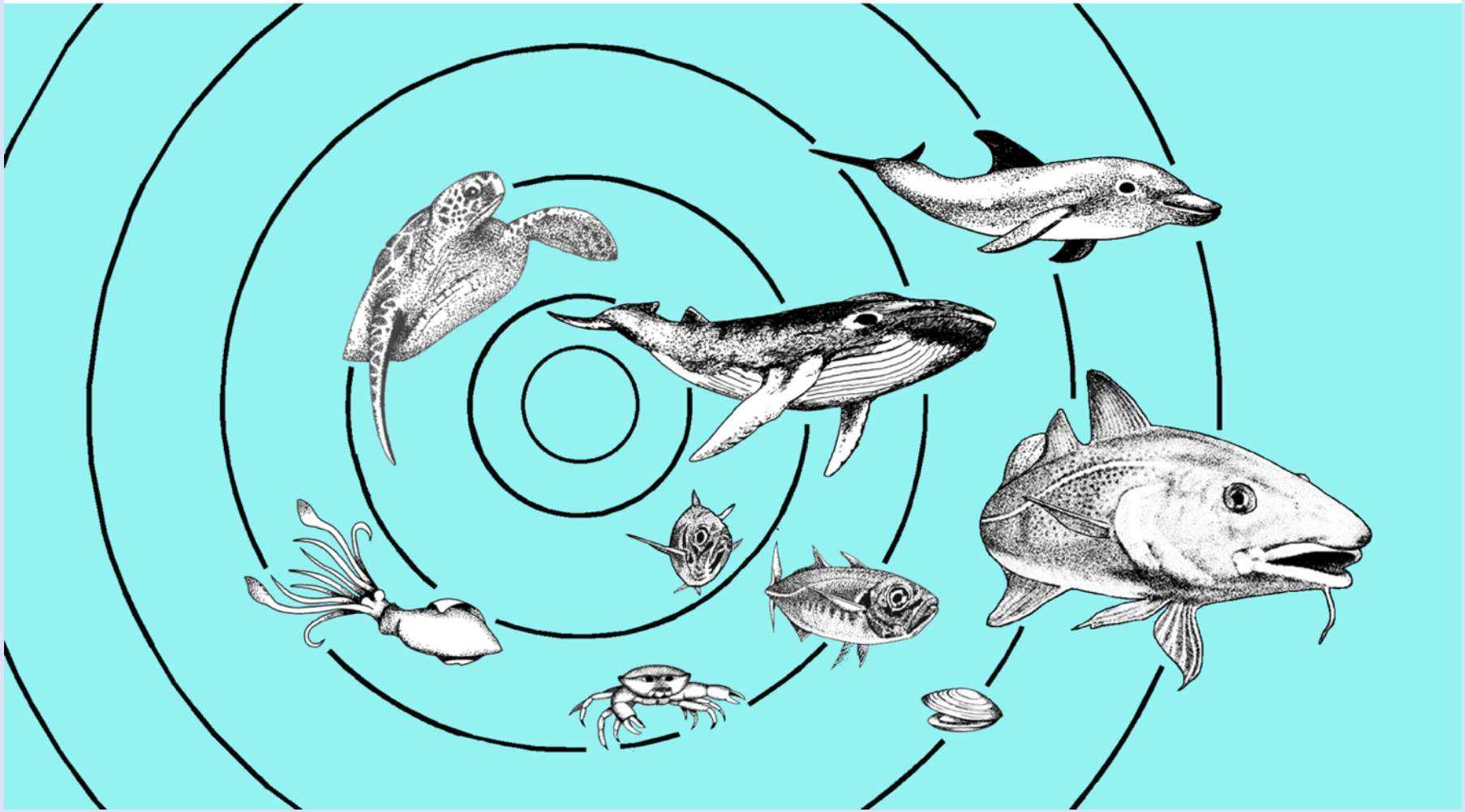
The Effects of Noise on Aquatic Life

Berlin, Germany, 10-15 July 2022



Contact us:

Arthur Popper
apopper@umd.edu
www.Ahukini.net

Anthony Hawkins
a.hawkins@btconnect.com