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Laboratory Evaluation of the Effects of Turbine Noise on Fish

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Recent Developments in Research on the
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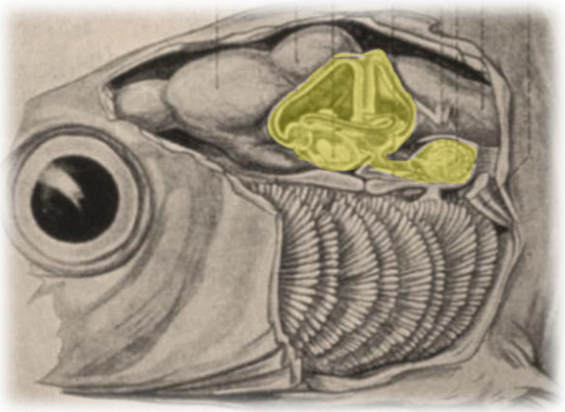
Components of Underwater Noise

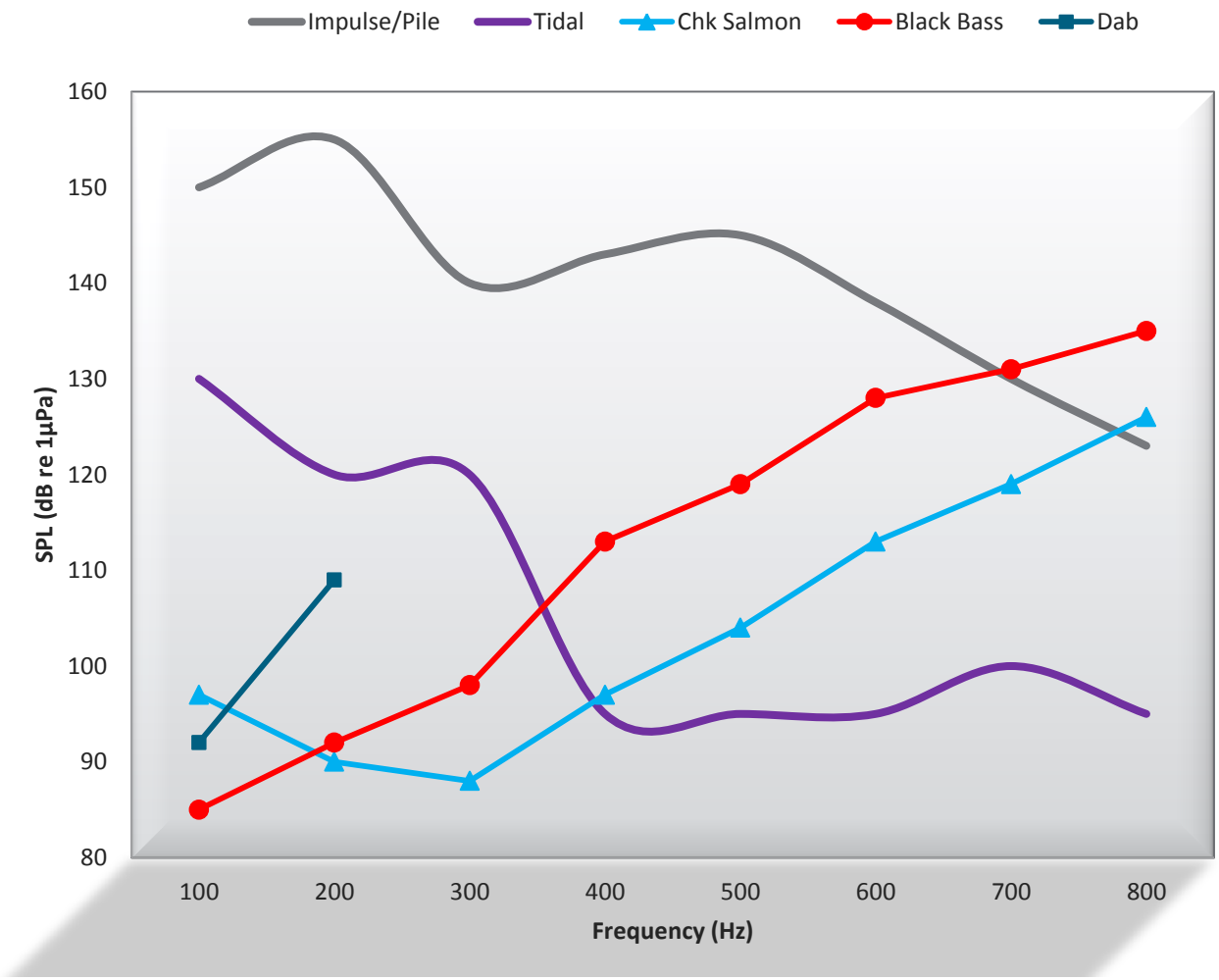
- Sound energy can cause damage based on:
  - Frequency
  - Intensity
  - Spectrum
- Two components of any sound wave:
  - Pressure
  - Particle motion
- Near field (pressure & particle motion)
- Far field (mostly pressure, but some motion)
  - All fish can acoustically detect particle motion
  - Some fish are acoustically sensitive to pressure

- Marine energy development raises concerns about noise impacts on fish:
- Typical assessments to determine harm include:
  - Auditory – hearing shift
  - Barotrauma – tissue/organ damage

Underwater Noise Effects - Auditory



- Auditory
  - Changes in hearing threshold
  - Masking



Salmon: Halvorsen et.al., 2009; Bass: Holt et.al., 2010; Dab: Chapman & Sand 1973;
Karl von Frisch- ear

Underwater Noise Effects - Barotrauma

Barotrauma is tissue injury caused by rapid pressure changes

Impulsive Sounds

- Pile driving
- Seismic exploration
- Explosions

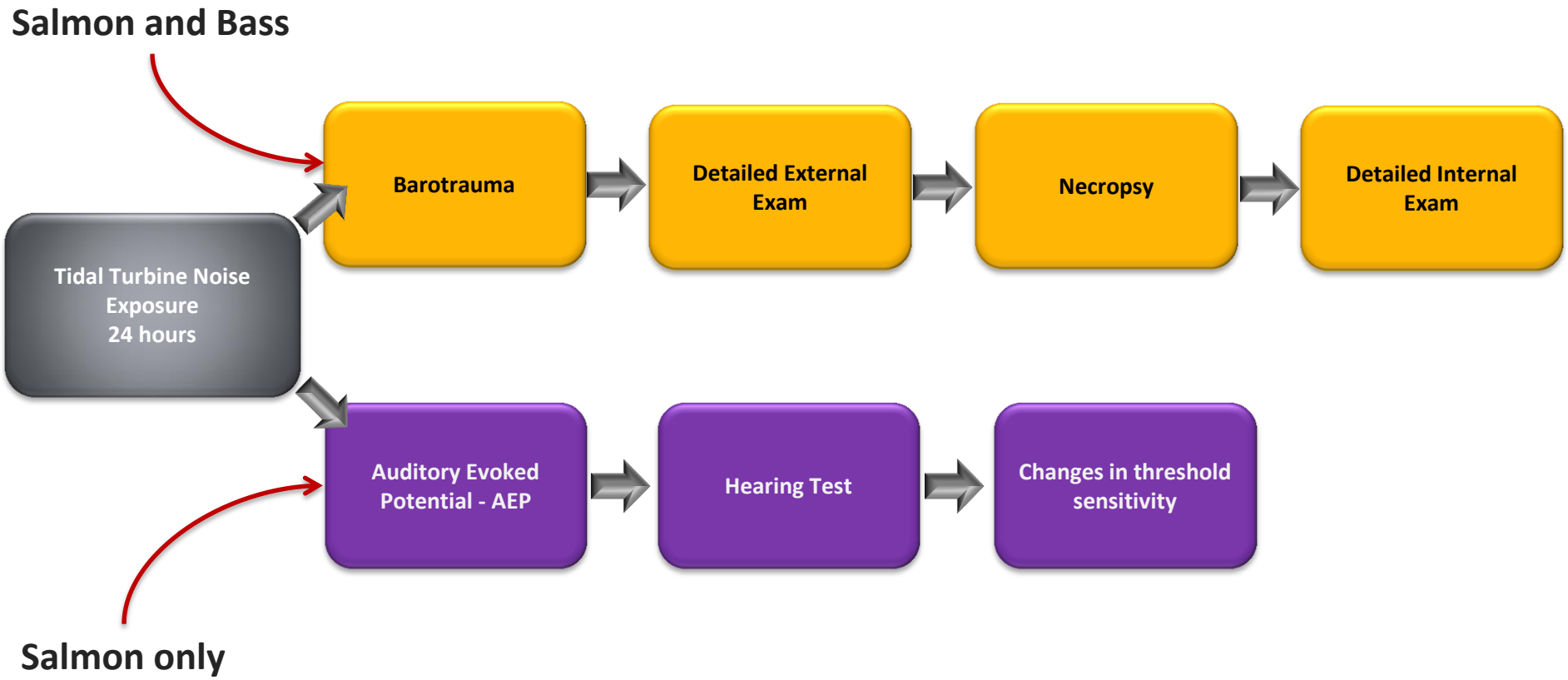
Intermittent and Continuous Sounds

- Low- and mid-frequency sonar
- Shipping
- Wave energy converters
- Tidal turbines

Underwater Noise Effects - Barotrauma

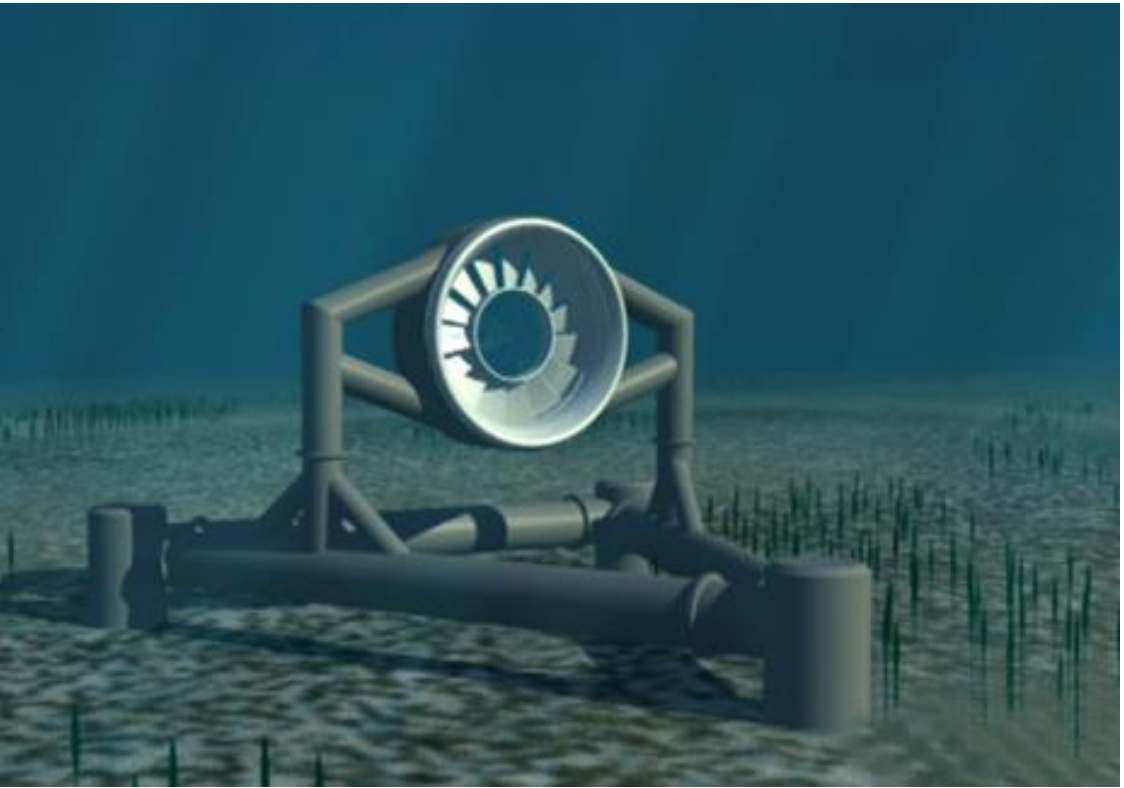
- Swim bladder
  - Contracts and expands
  - Rupture
  - Damages surrounding tissues
- Dissolved blood gasses come out of solution
  - Bubbles form in blood and tissues
  - Damages tissues, vessels, organs
- Equilibration state of animal is important
  - Neutrally buoyant fish
  - Tissue-gas equilibration with surrounding water
  - Physiological state of fish at exposure is critical (mimic state of wild fish)

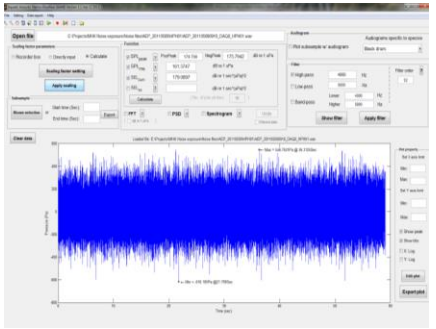
Testing Methods

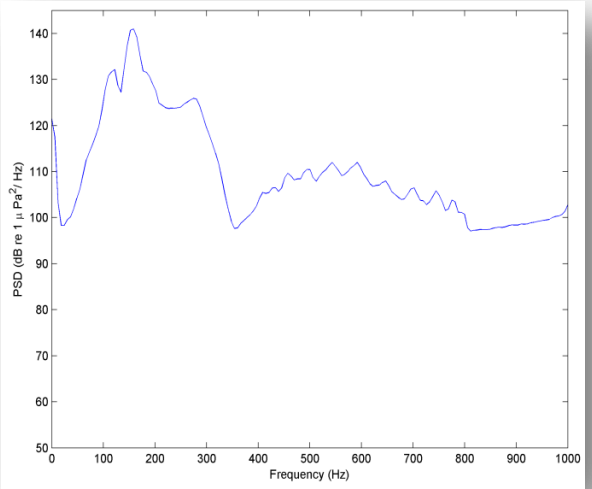


Noise from OpenHydro tidal turbine

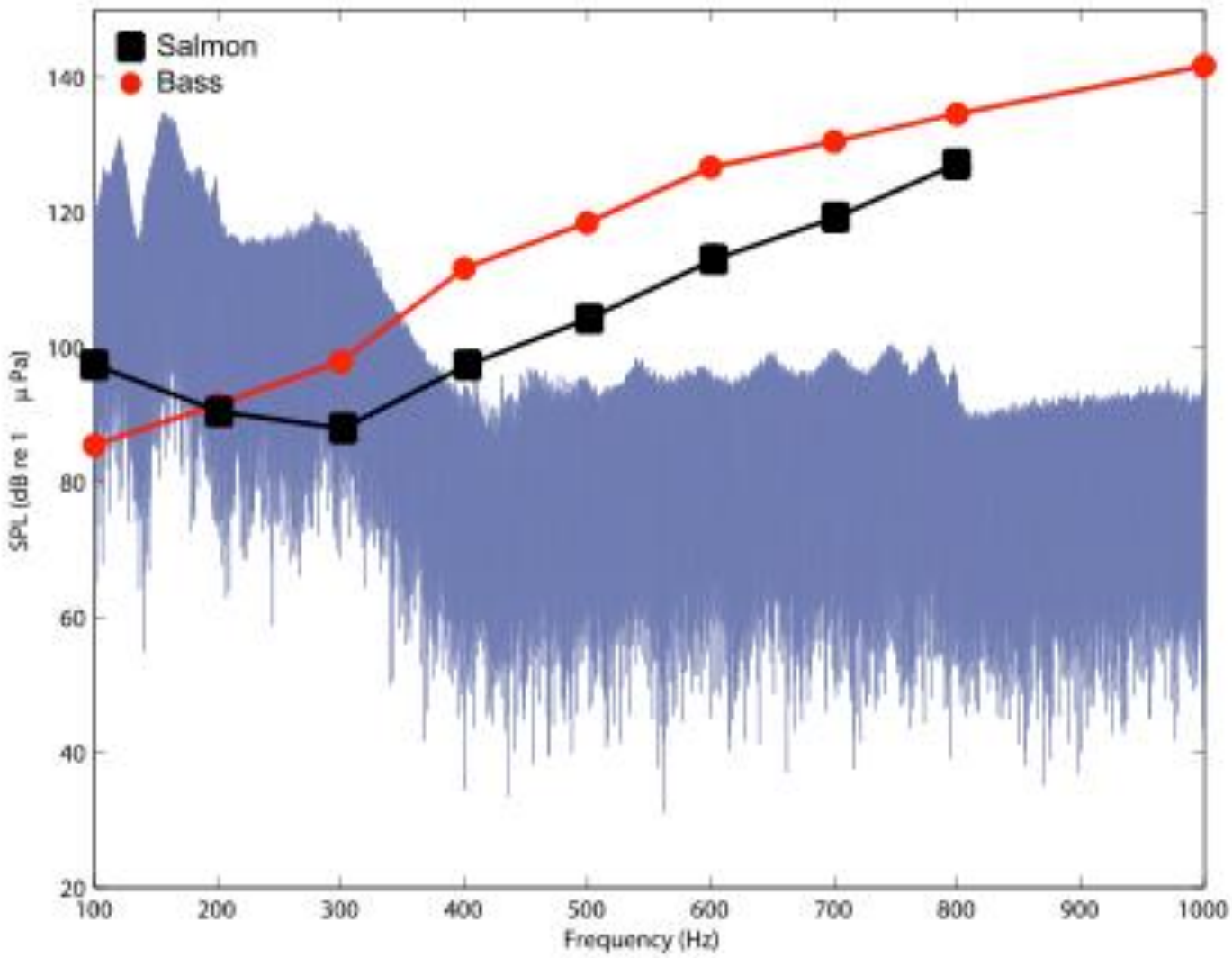
- Turbine spectrogram
  - Measured at EMEC
- Laboratory experiments
  - Continuous noise exposure
  - Physiological response of fish to sound exposure







Tidal Turbine Noise and Fish Audiograms



Tidal Turbine- Hearing Tests

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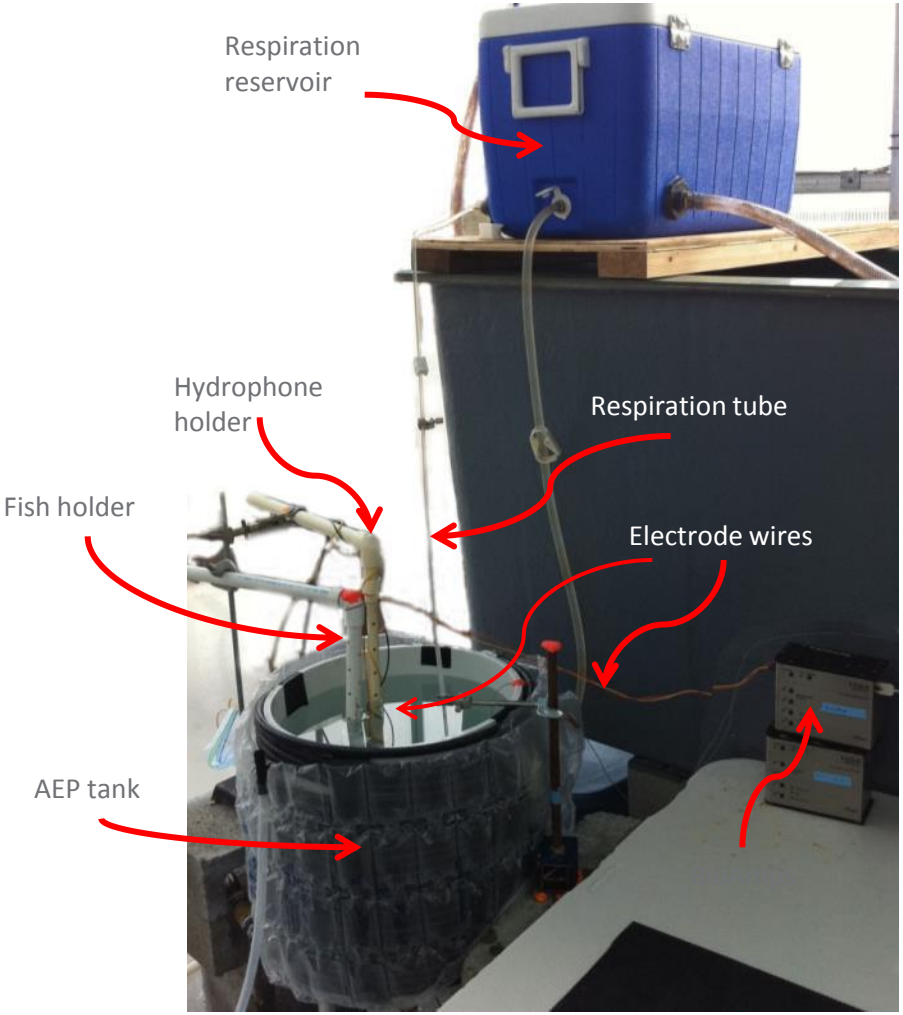

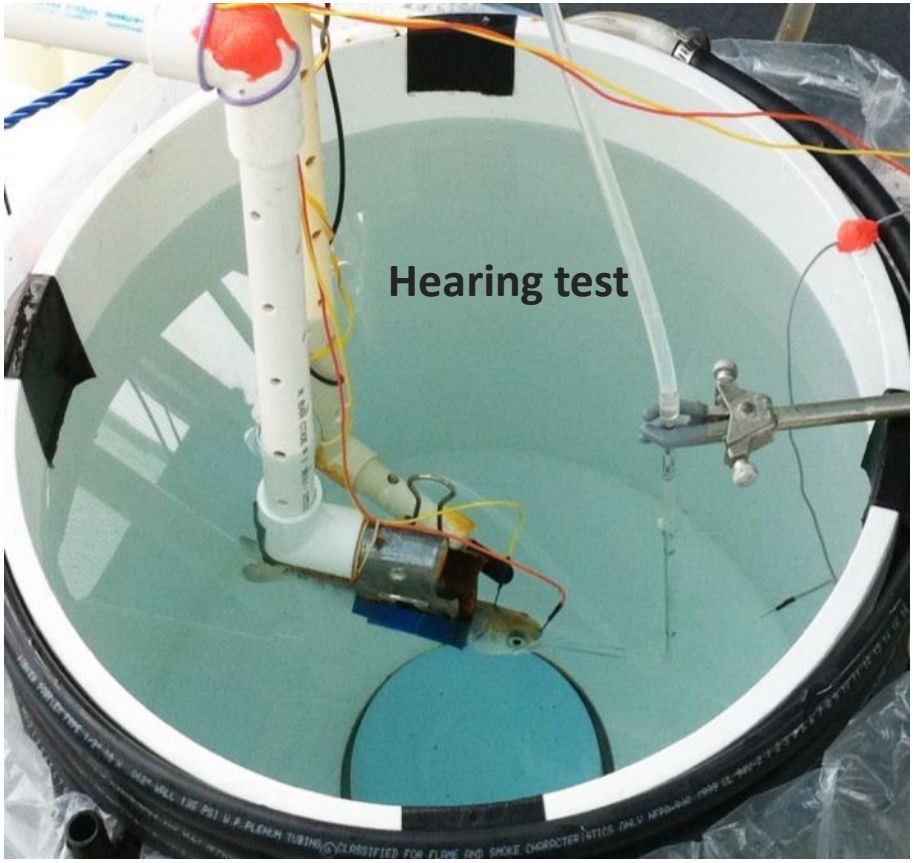

Tidal Turbine - Auditory Evoked Potentials

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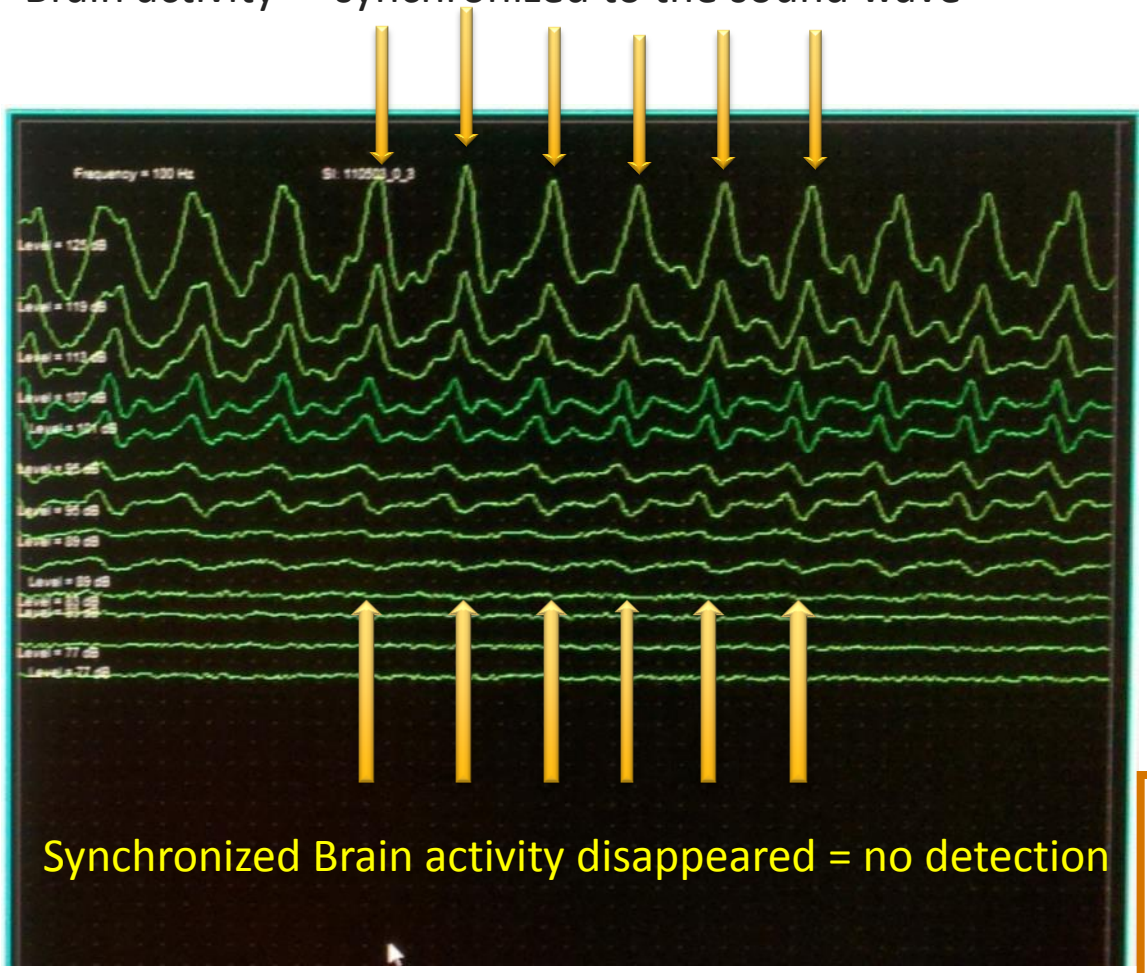
Brain activity - synchronized to the sound wave



Louder level

Softer level

Outcome for juvenile salmon:

NSS difference between test and control exposures @ 158-162dB

Barotrauma Exposure and Effects Response Model

- Barotrauma
  - Used panel of 72 injuries to assess biological effects
  - Purpose “Quantify a qualitative assessment”
  - Focused on physiological ‘meaning’ of observed injuries

- Fish Index Trauma - FIT
  - List of 72 injuries
  - Physiological Rank
  - 3 Injury classes
  - Weight

Response Weighted Index (RWI)

$$RWI = \sum (W \times T_i)$$

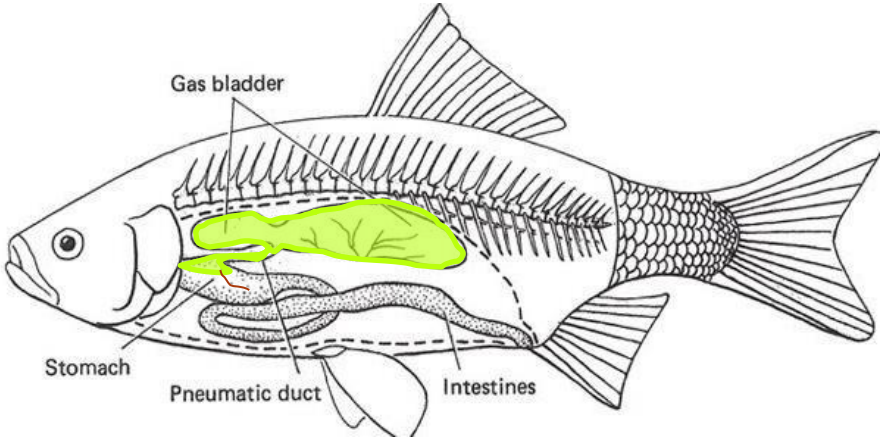
Mortal Injury	Wt
Dead within 1 hr	5
Hemorrhage: heart	5

Moderate Injury	Wt
Hemorrhage: intestine	3
Hemorrhage: wall capillaries	3

Mild Injury	Wt
Hematoma : vent	1
Hematoma: dorsal fin	1

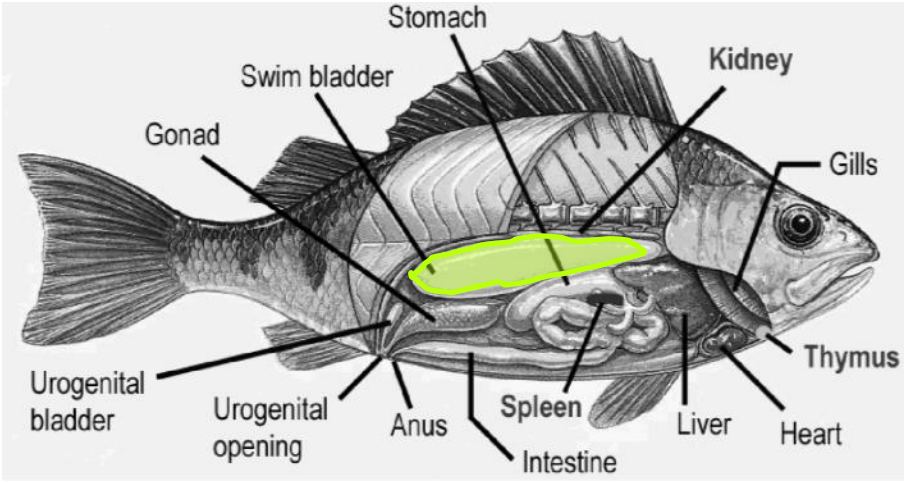
Fish Physiology Groups

Physostomous



- Connection between gut and swim bladder
- Gulp or burp air
- Need access to air to increase swim bladder volume

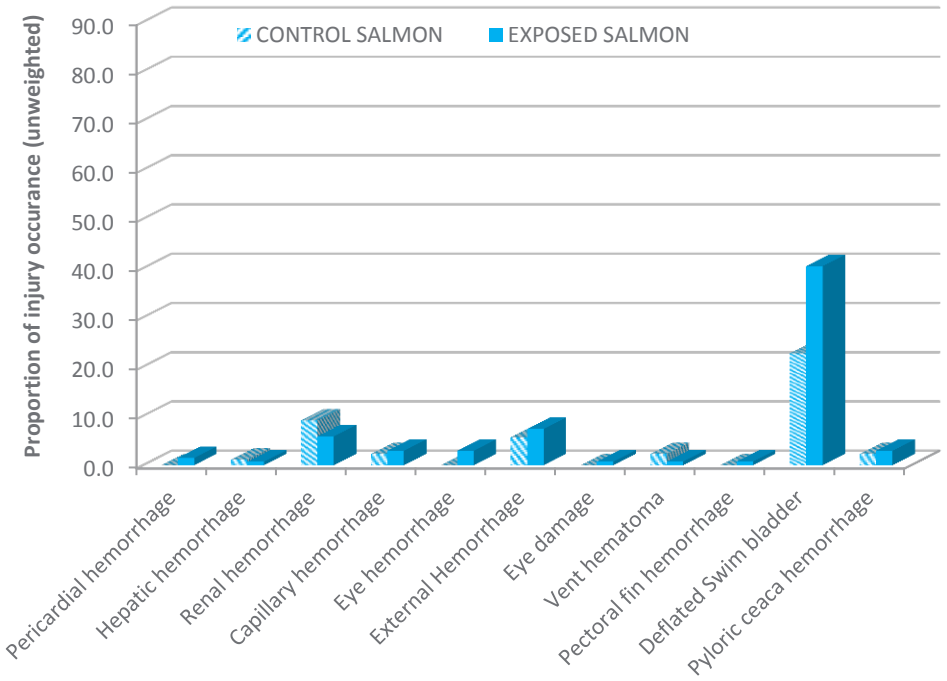
Physoclistous



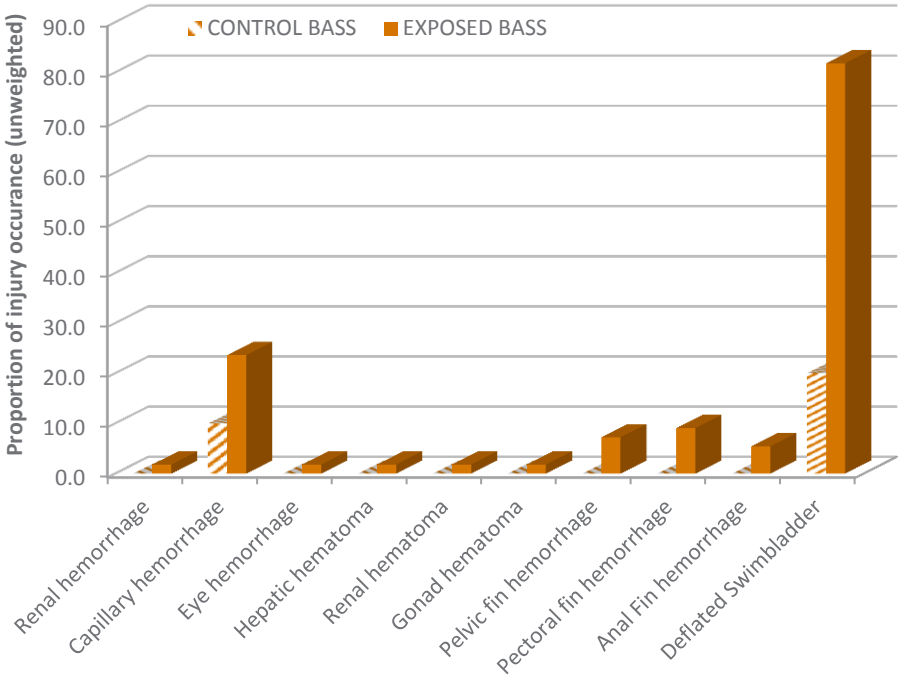
- Closed swim bladder
- Small organ for gas exchange to fill or empty swim bladder
- Need time – several hours to change swim bladder volume

Results - Barotrauma

Salmon



Largemouth Bass



Explanation of Barotrauma Results

- Salmon and bass showed low levels of hemorrhages in their tissues, considered to be recoverable
- Both species have deflated their swimbladders, probably due to combination of:
  - Stress
  - Active management
- Bass actively empty their swim bladder over time
- Salmon quickly empty swim bladder with a burp, then refill with gulps of air

Effects of Tidal Turbine Sound on Fish

- "Worst case" levels of noise for one turbine (OH)
  - Tested juvenile salmon and largemouth bass (surrogate for rockfish)
  - Noise equivalent to placing fish next to turbine, no avoidance
  - Exposure for up to 24 hours (continuous, longer than tidal cycle)
- Barotrauma appears to be minor, recoverable as fish moves away
- Hearing shift for salmon not significant

BUT need more info on:

- Hearing shift in other fish groups
- Effects in barotrauma and hearing shift on elasmobranchs
- Sound from other turbine types
- Effects of arrays of turbines (additive, multiplicative) at commercial buildout

Thank you!

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