Effects of Anthropogenic Sound on Fish
&
The Response of Clupeid Fish to Ultrasound

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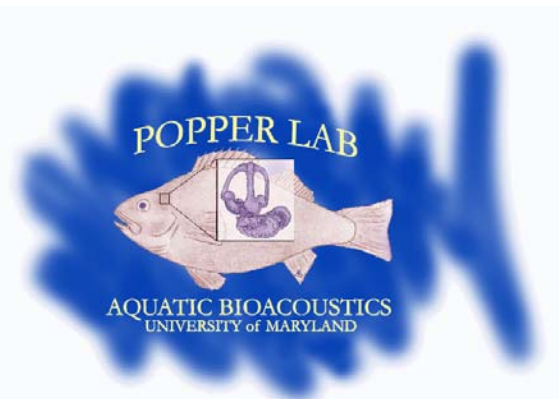
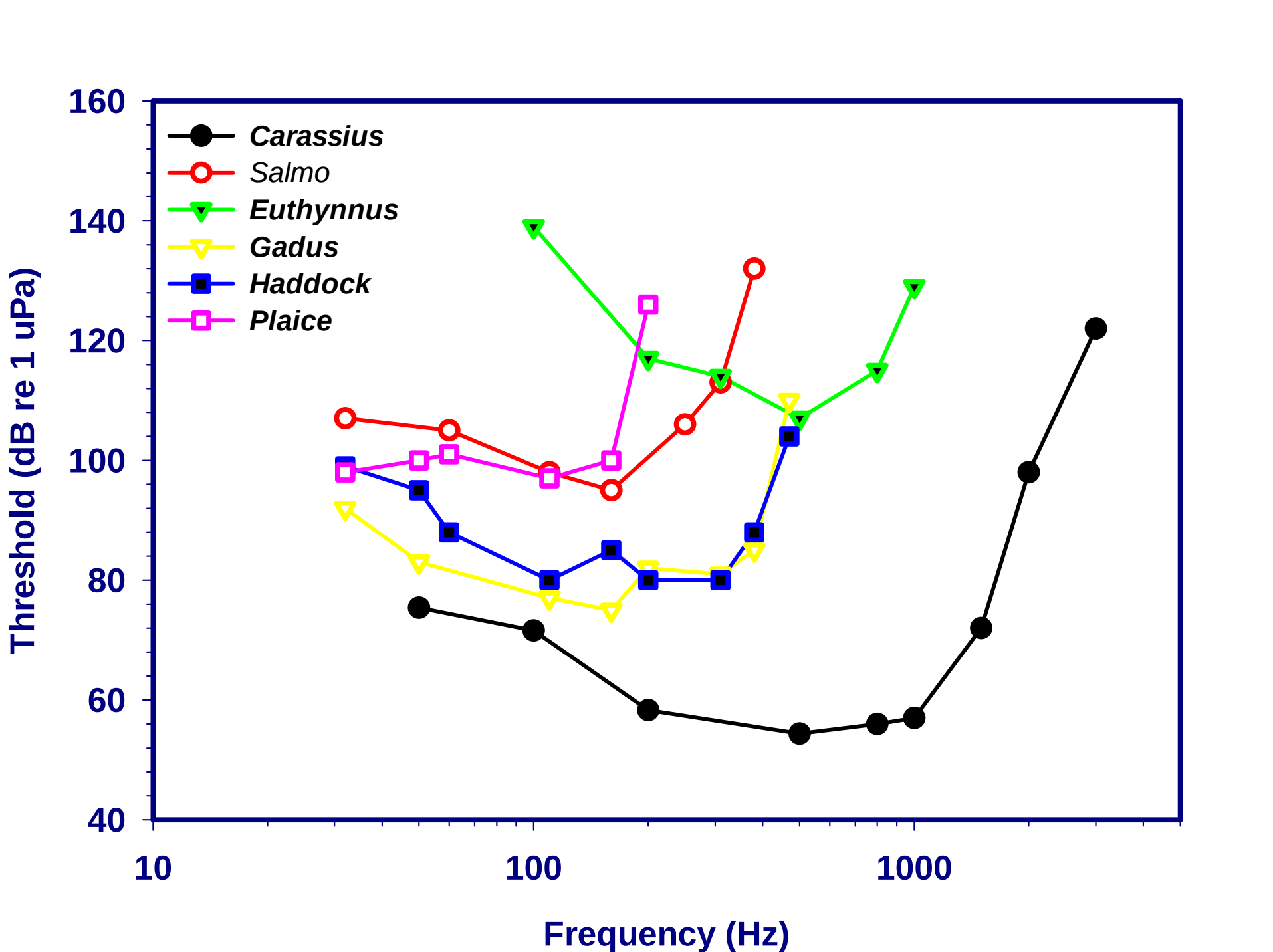


Overview

- Overview – what do fish hear
- Effects of anthropogenic sound
- Ultrasound detection
- Final thoughts on fish hearing

What do fish hear: Basic principles


160
140
120
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60
40
Threshold (dB re 1 uPa)
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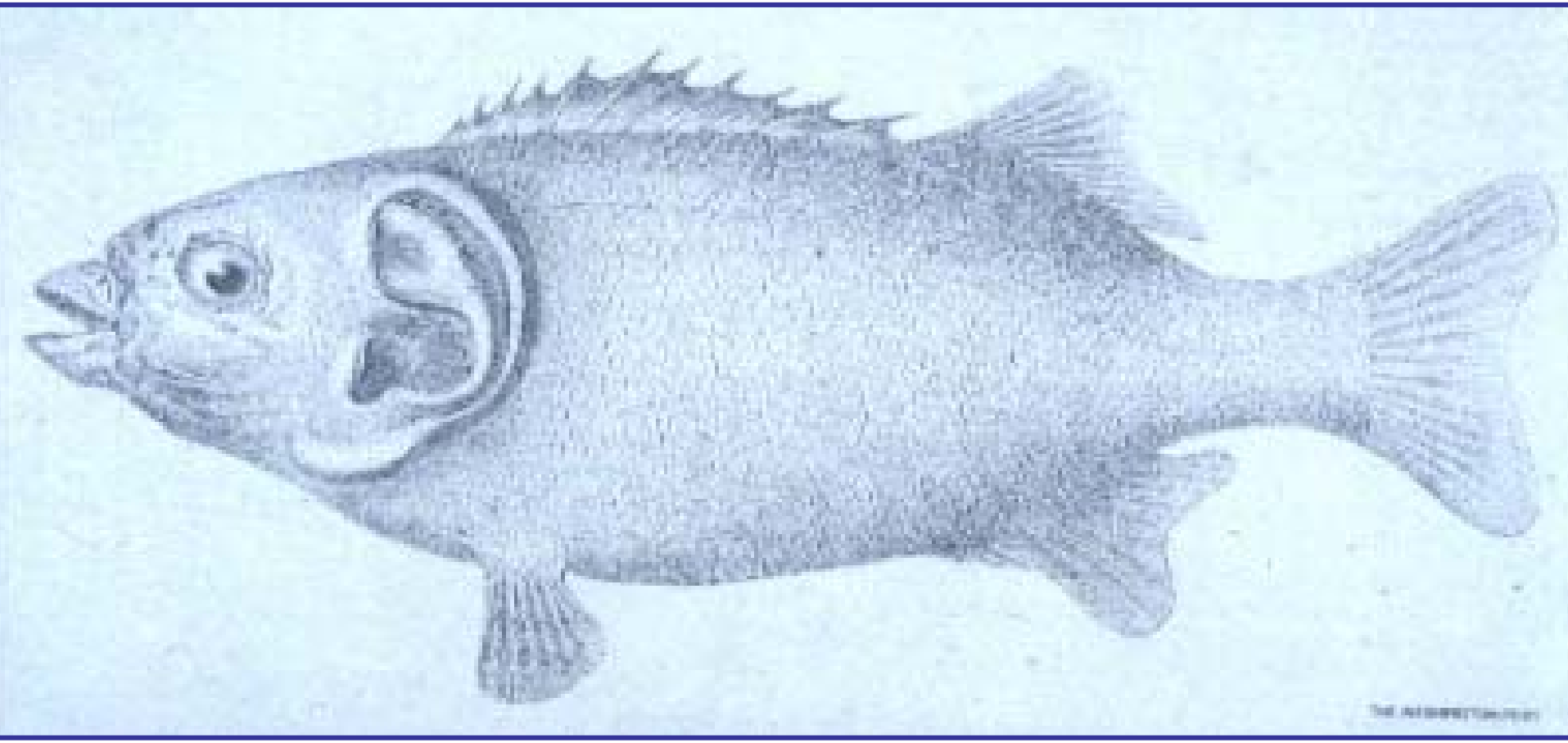
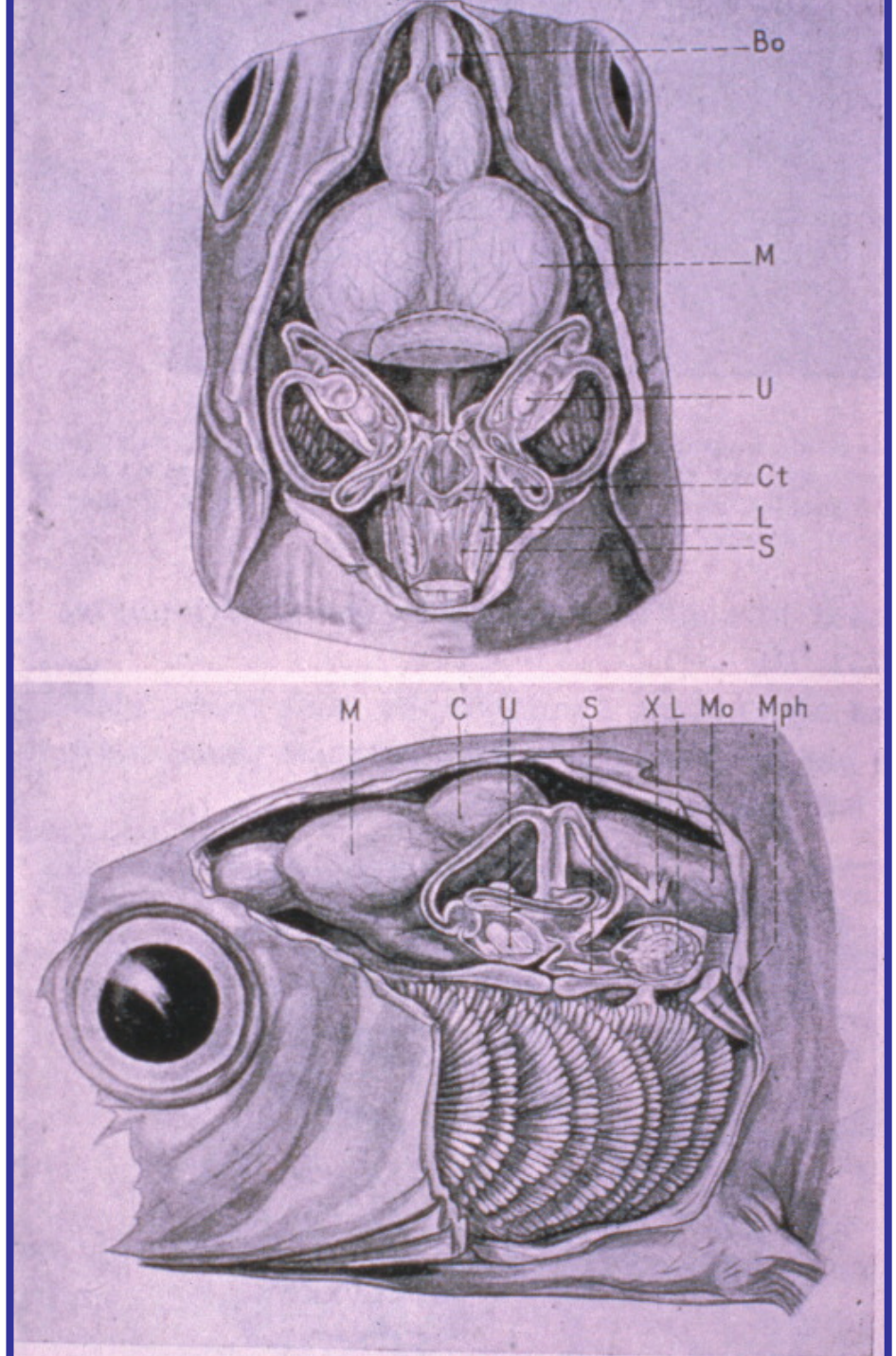
100
1000
Frequency (Hz)
Carassius
Salmo
Euthynnus
Gadus
Haddock
Plaice

Where is the ear?

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Effects of Anthropogenic Sound on Fish

Arthur N. Popper, Jane Fewtrell, Michael E. Smith, and Robert D. McCauley

Background

- Ocean noise has increased in the past decades
- This can impact animals by:
  - Loss of hearing (temporary or permanent)
  - Changes in behavior which reduce survival
  - Damage to sensory hair cells of ear and/or lateral line

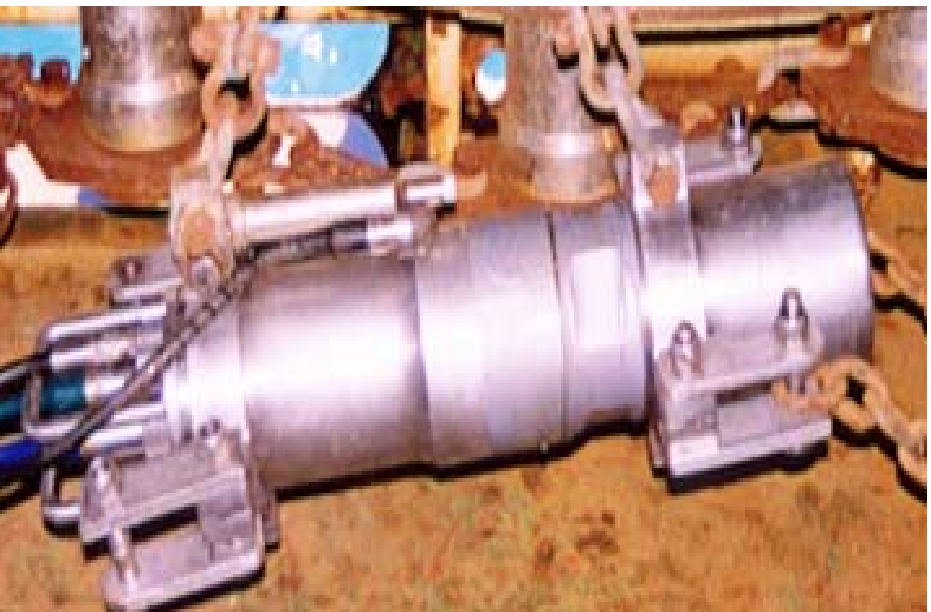
Present results of two studies

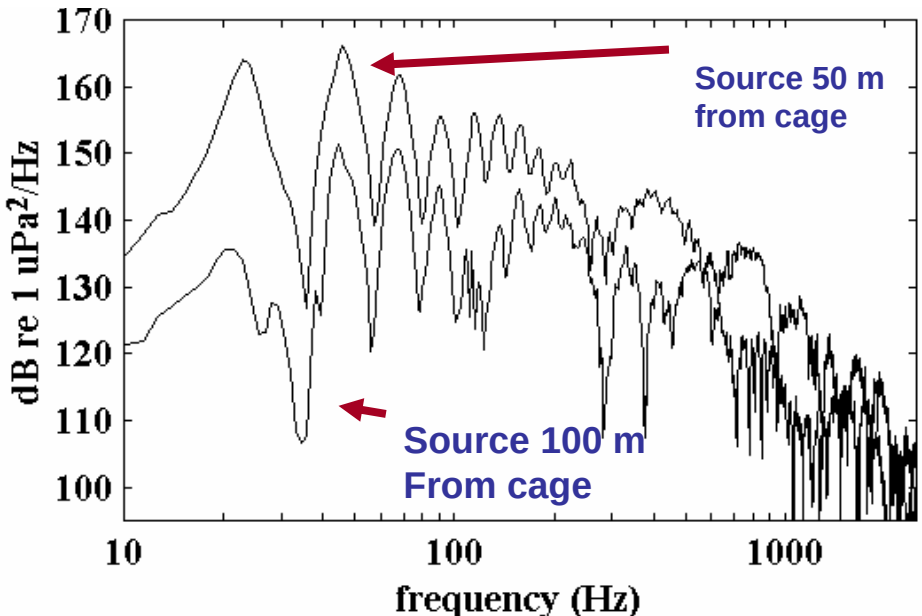
- Effects of seismic air guns on ears
- Effects of increased background noise on hearing

Effects of seismic air guns on fish ears

Seismic Air Guns

- Used for oil exploration
- Produces higher energy signals
- Low frequency – in range of fish audition
- Back and forth over large areas

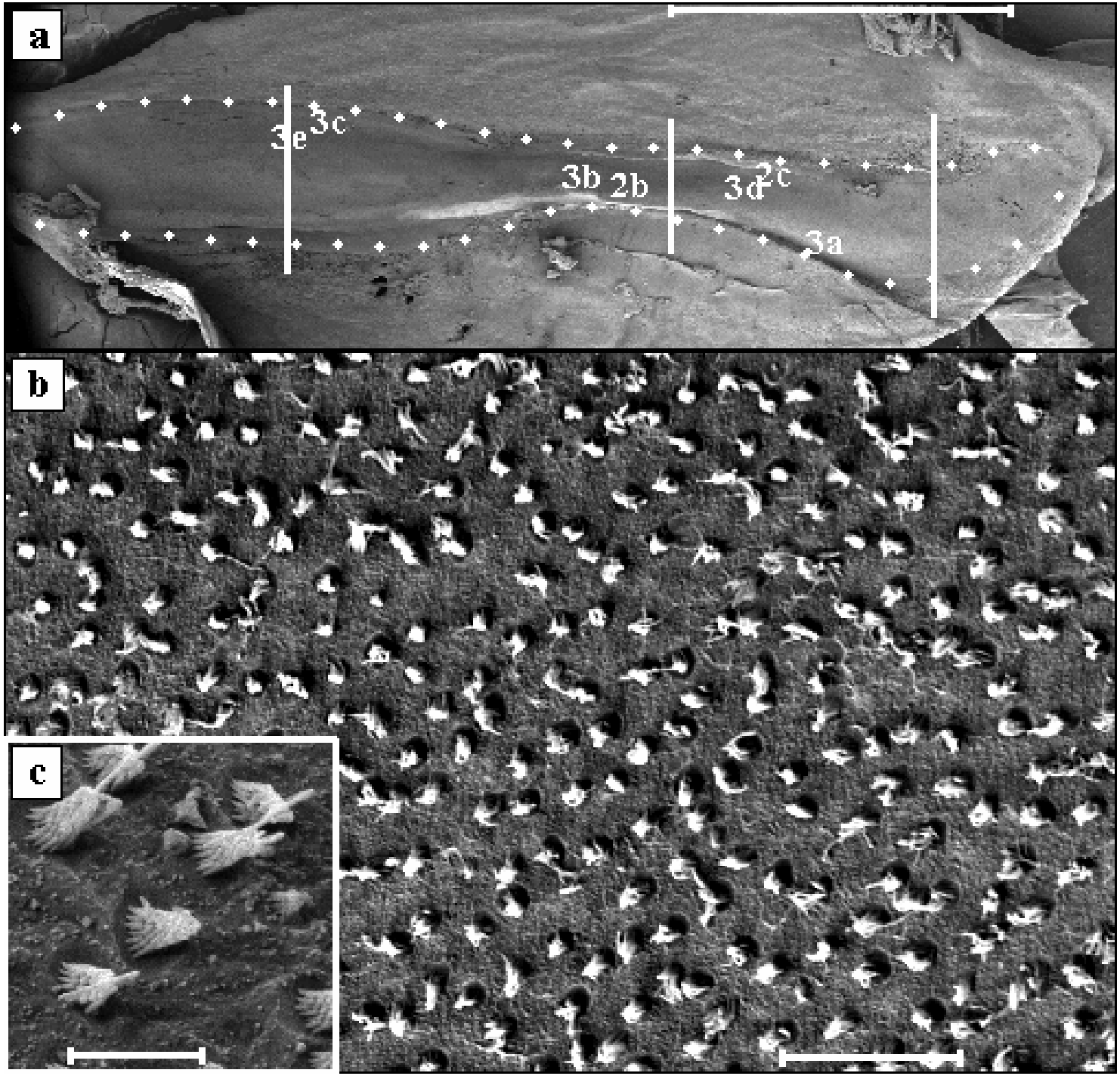




Basic paradigm

- Done in Perth, Australia
- Pink snappers
- Fish in cages in open body of water
- Exposure to air gun which moved to and away from fish
- Maximum about 180 dB re 1 μPa
- Fish sacrificed at different times after exposure
- Ears examined with SEM to determine damage

Results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3d
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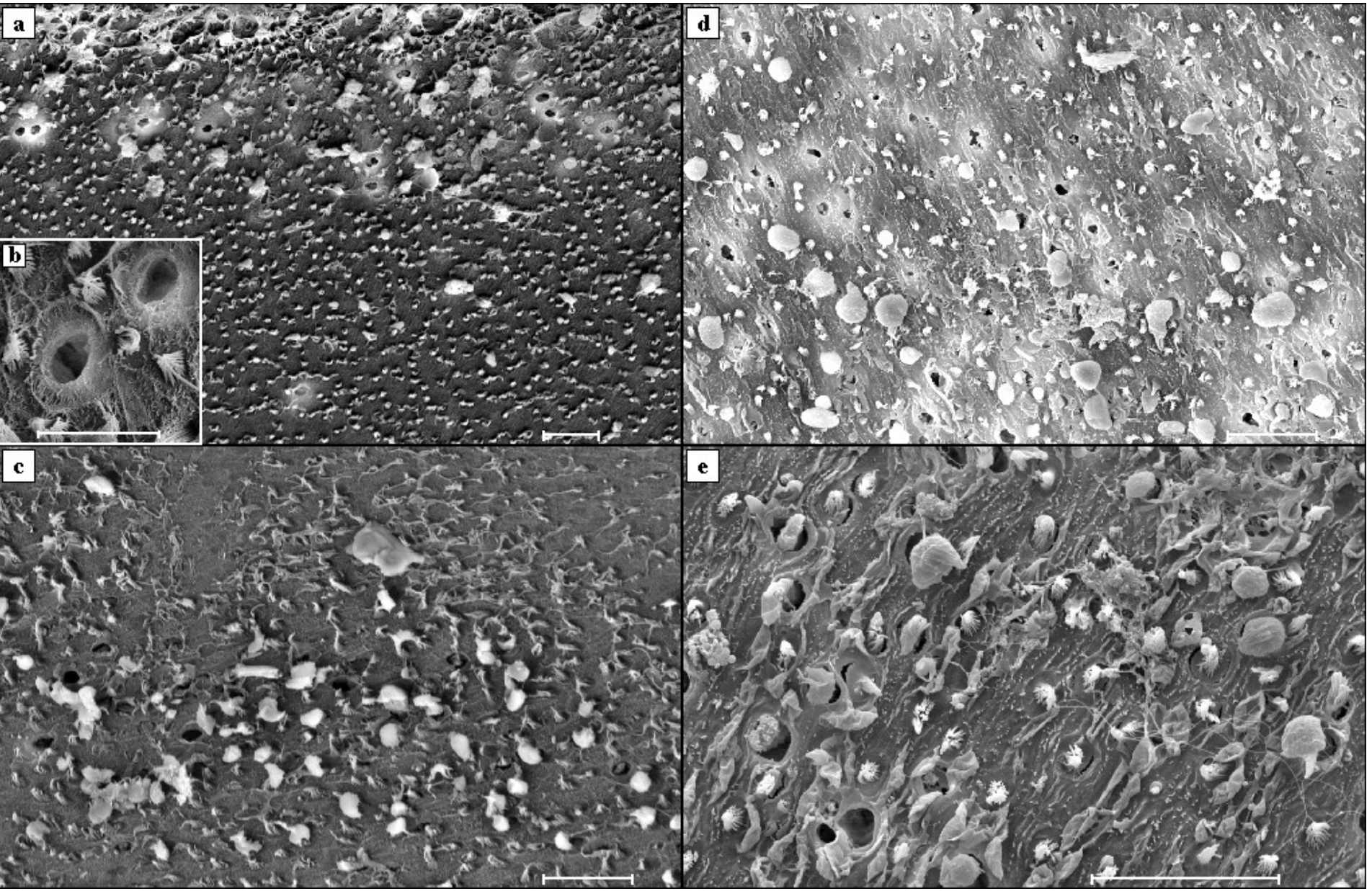
3a
b
c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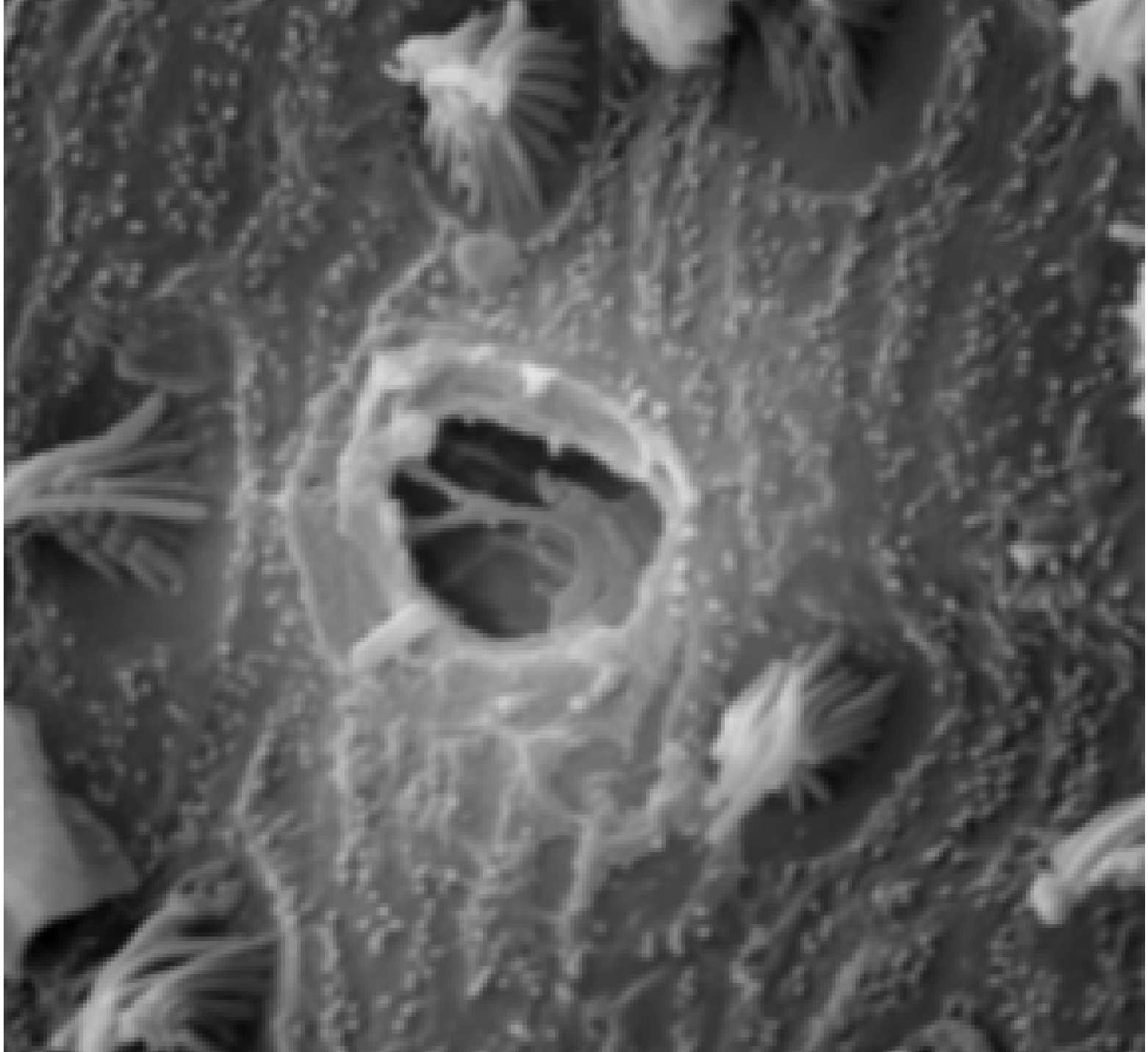


Findings

- Little or no damage immediately after stimulation
- After 18 hours get holes in epithelium and blebbing
  - Holes where hair cells had been
  - Blebs probably are extruding hair cells
  - Not significantly different than controls

- After 58 days more extensive hair cell loss and holes
- Statistically significant from controls and 18 hour animals
- No evidence of regeneration of damaged tissue

Caveats

- Animals were caged and could not escape
- Know nothing of pink snapper hearing
  - May have different sensitivity than other species
  - Known that hearing specialists are more sensitive than non-specialists to sound stimulation

Conclusions: Seismics

- Air guns have the potential to do major damage to fish ears
- While some fish might swim away, it is possible that as few as one or two exposures could damage ears
- Fishes that don’t swim away could be subject to significant damage
- Since hair cells in fish ears are similar to those in mammals, it is possible that there could be implications for the effects of air guns on marine mammals

Effects of increased noise on fish hearing

How does noise effect fish?

- Temporary threshold shift (TTS)
- Permanent threshold shift (PTS)
- Impact on endocrine system and possibly reproduction
- Changes in behavior which could impact reproduction or feeding
- *Are these effects general or species specific?*

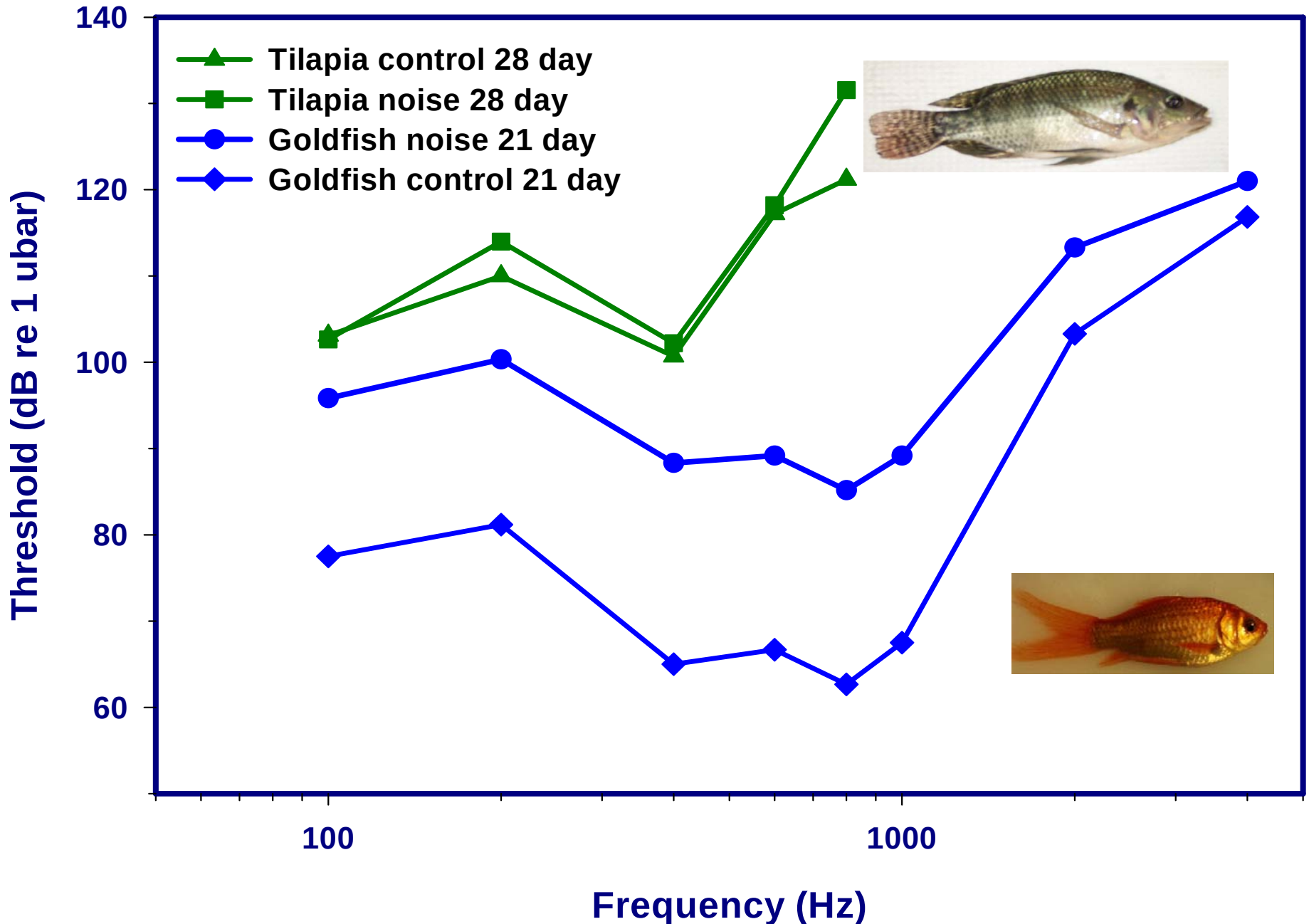
Questions in the study

- Are hearing specialists more prone to hearing loss than non-specialists (e.g., Hastings et al. 1996)?
- Is hearing loss cumulative with extended exposure?
- Is there recovery from hearing loss after long-duration exposure?

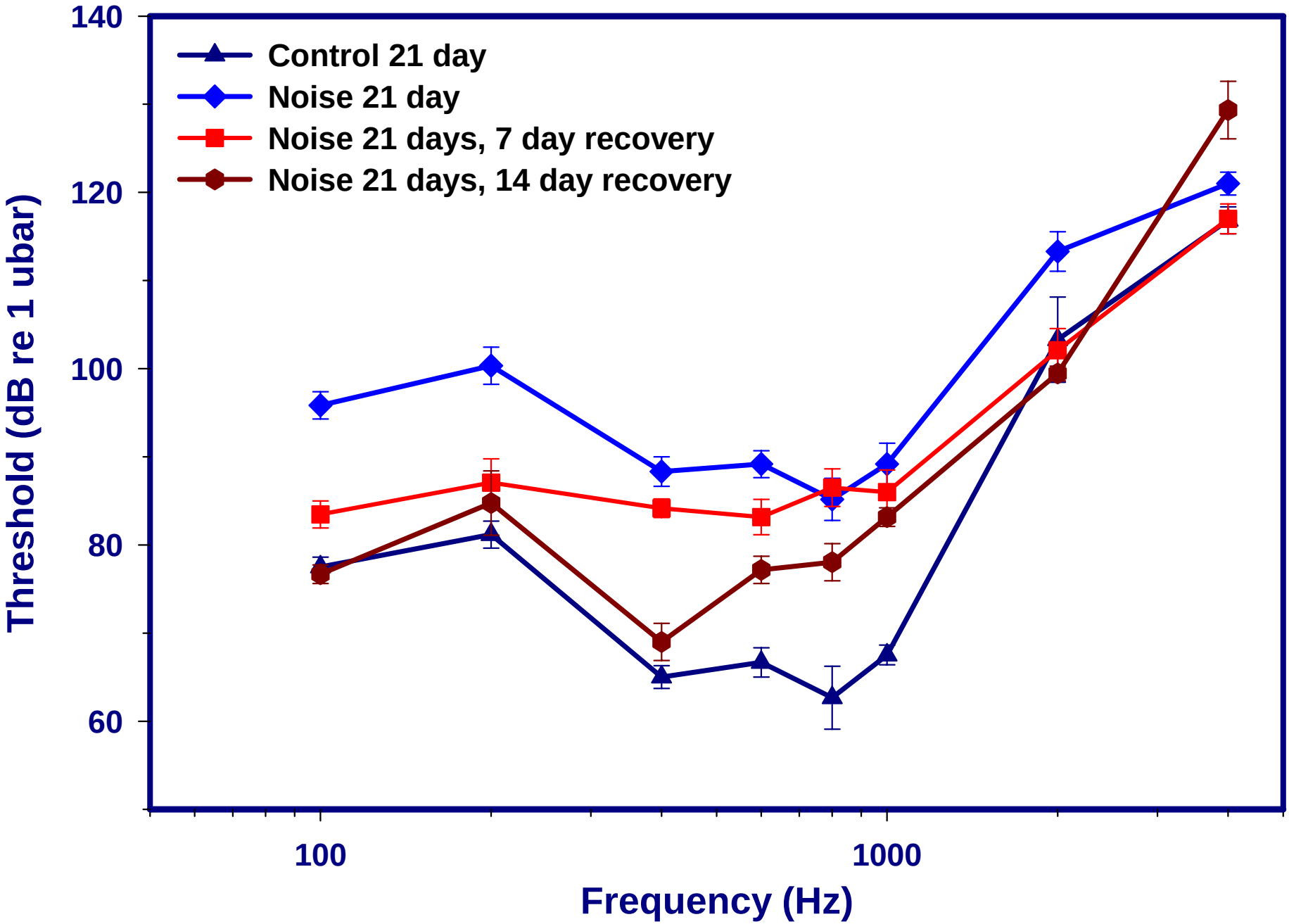
Experimental design

- *Tilapia* and *Carassius*
- Exposed to 170 dB re 1 □Pa white noise
- Controls at 110 dB re 1 □Pa.
- Measured hearing sensitivity and bandwidth using ABR

Goldfish 21 days vs Tilapia 28 days



Exposure vs Recovery in Goldfish



Conclusions: noise effects

- Hearing specialists are more likely to suffer hearing loss than non-specialists
- Exposure for 7 to 21 days results in the same degree of hearing loss
- Full recovery takes place over several days
- There is a linear relationship between SPL above baseline hearing threshold and TTS
- Need to determine if the TTS results from loss of hair cells or other factors

General Conclusions

- High intensity sounds may have profound effects on ear structure.
  - Thus, will cause significant changes in hearing for extended periods of time
- Increased, but not intense, background noise will alter hearing abilities of fish
  - Differs in fish depending upon overall hearing capabilities
  - Recovery is possible, but while loss is present this could put a fish at a strong disadvantage in finding food and avoiding predators

Caveat!!!!

- Far more work is needed before we can extrapolate between species and before we will understand the mechanism behind hearing loss and damage

The Response of Clupeid Fish to Ultrasound

Arthur N. Popper, Dennis T. T. Plachta, David A. Mann, and Dennis Higgs

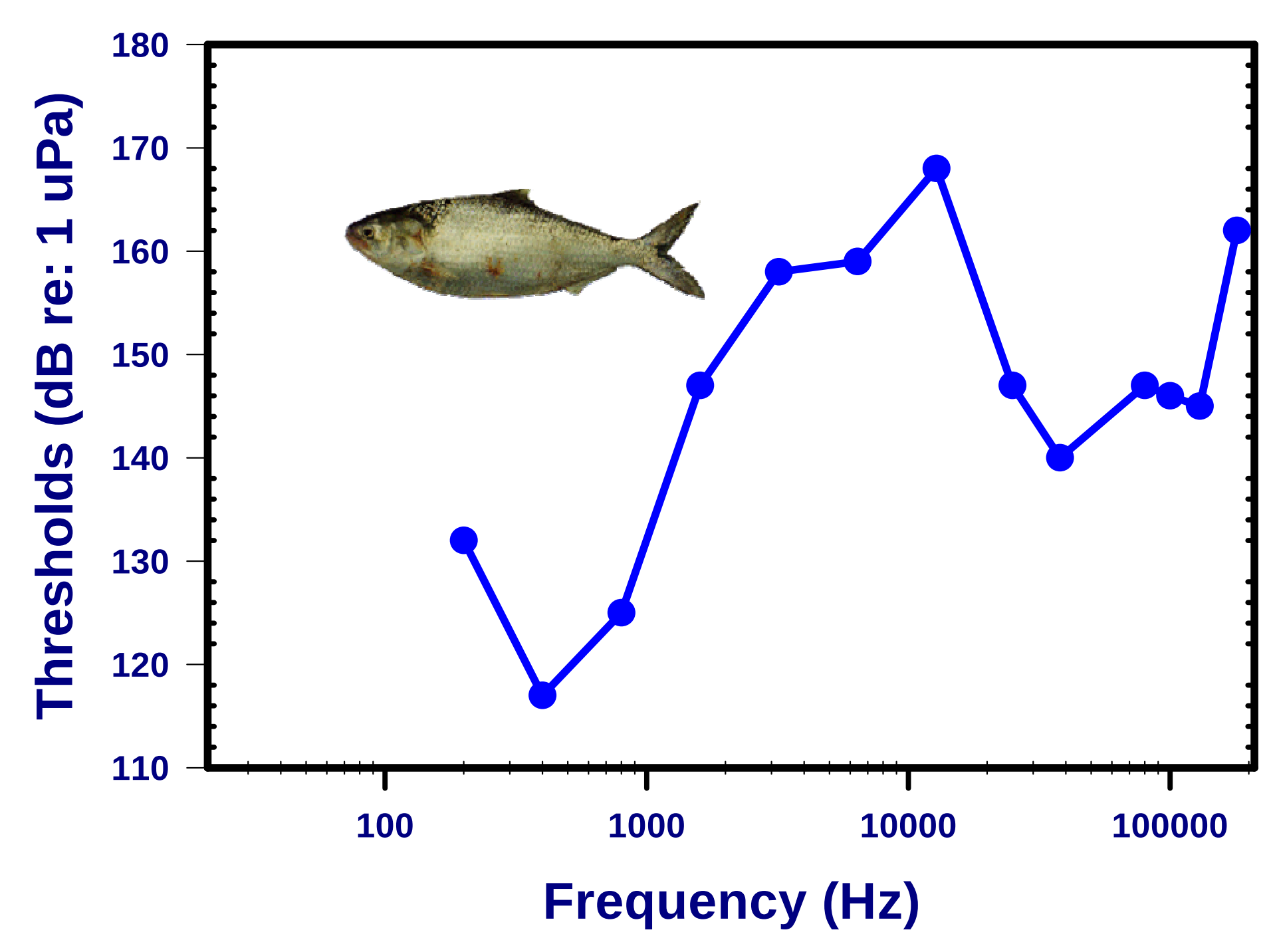
Prior Evidence for Ultrasound Detection by Clupeid Fishes

- Behavioral responses to echo sounders.
- Decrease in impingement at power plant intakes where ultrasound is used.
- But no prior studies had directly looked at ultrasound reception, or mechanisms of ultrasound detection

Experimental animals – American shad

Hearing capabilities of American shad

A behavioral study – Mann et al. 1997, 1998


180
170
160
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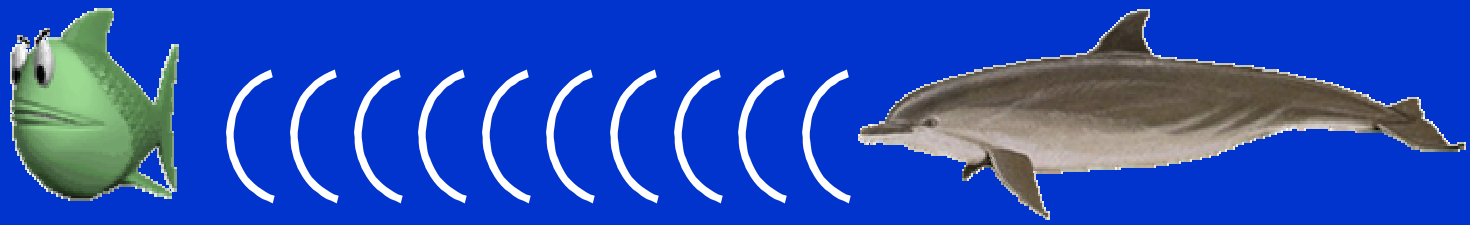
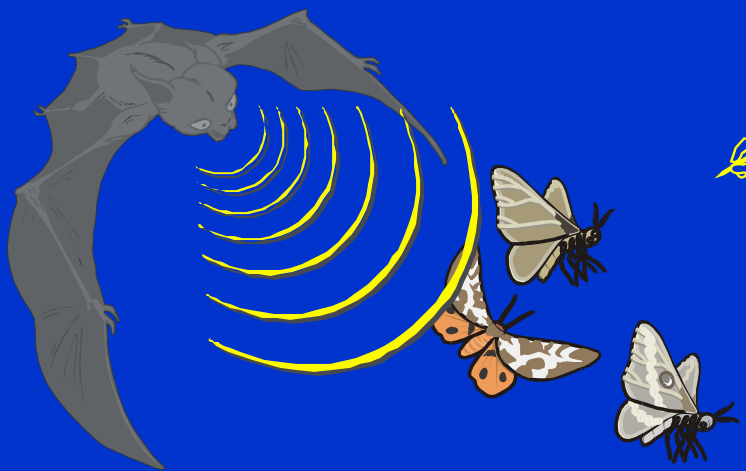
110
Thresholds (dB re: 1 uPa)
100
1000
10000
100000
Frequency (Hz)

Hypothesis





- A parallel to the sonar-mediated detection of bats by ultrasound-sensitive insects? (Mann et al., 1997, 1998, 2001)

Behavioral Evidence

Plachta and Popper 2003

Control

Dennis Plachta

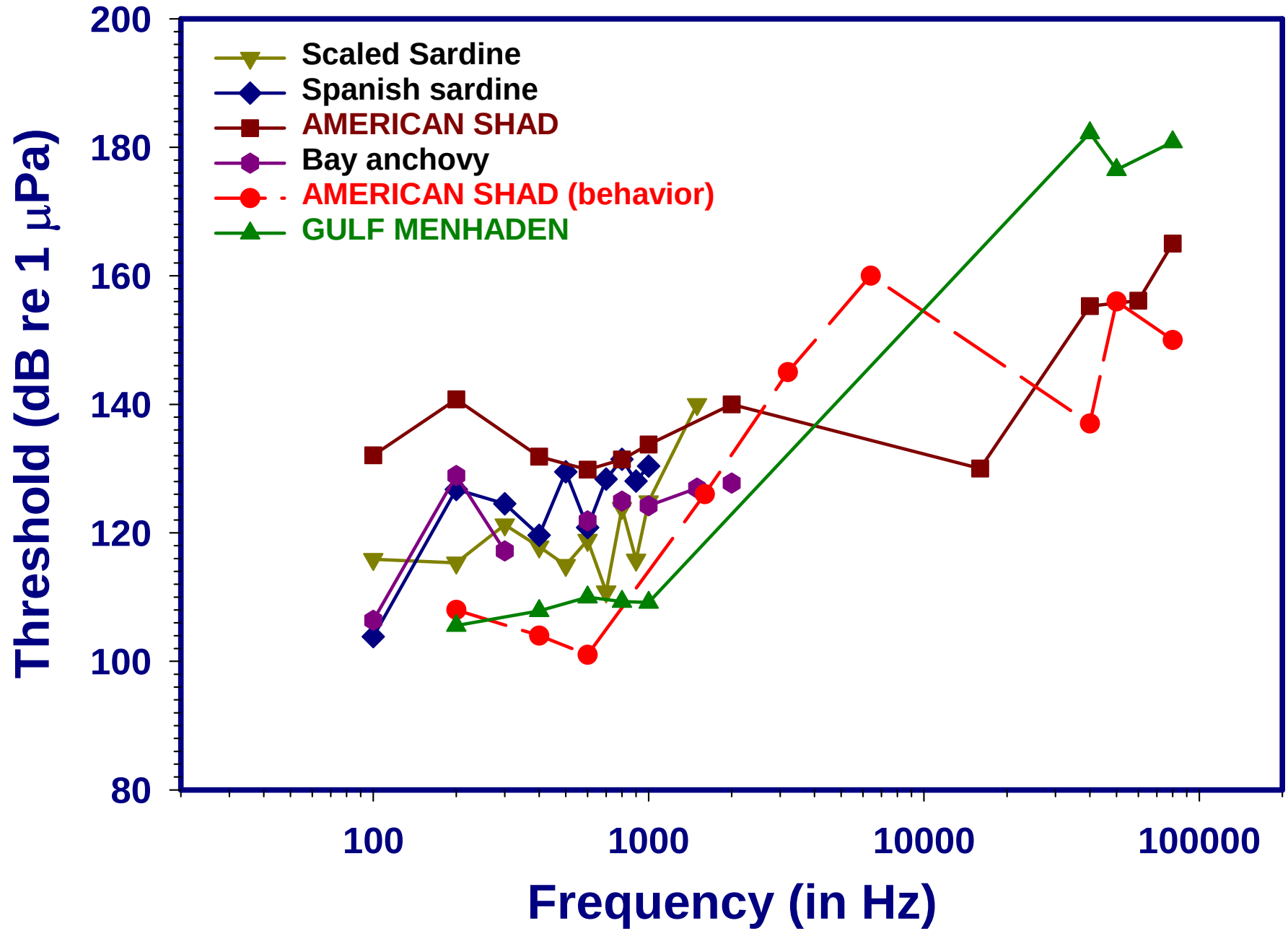

175 dB, 80 kHz
Dennis Plachta


186 dB, 90 kHz
Dennis Plachta

Do all clupeids detect ultrasound?

An ABR study, Mann et al. 2001

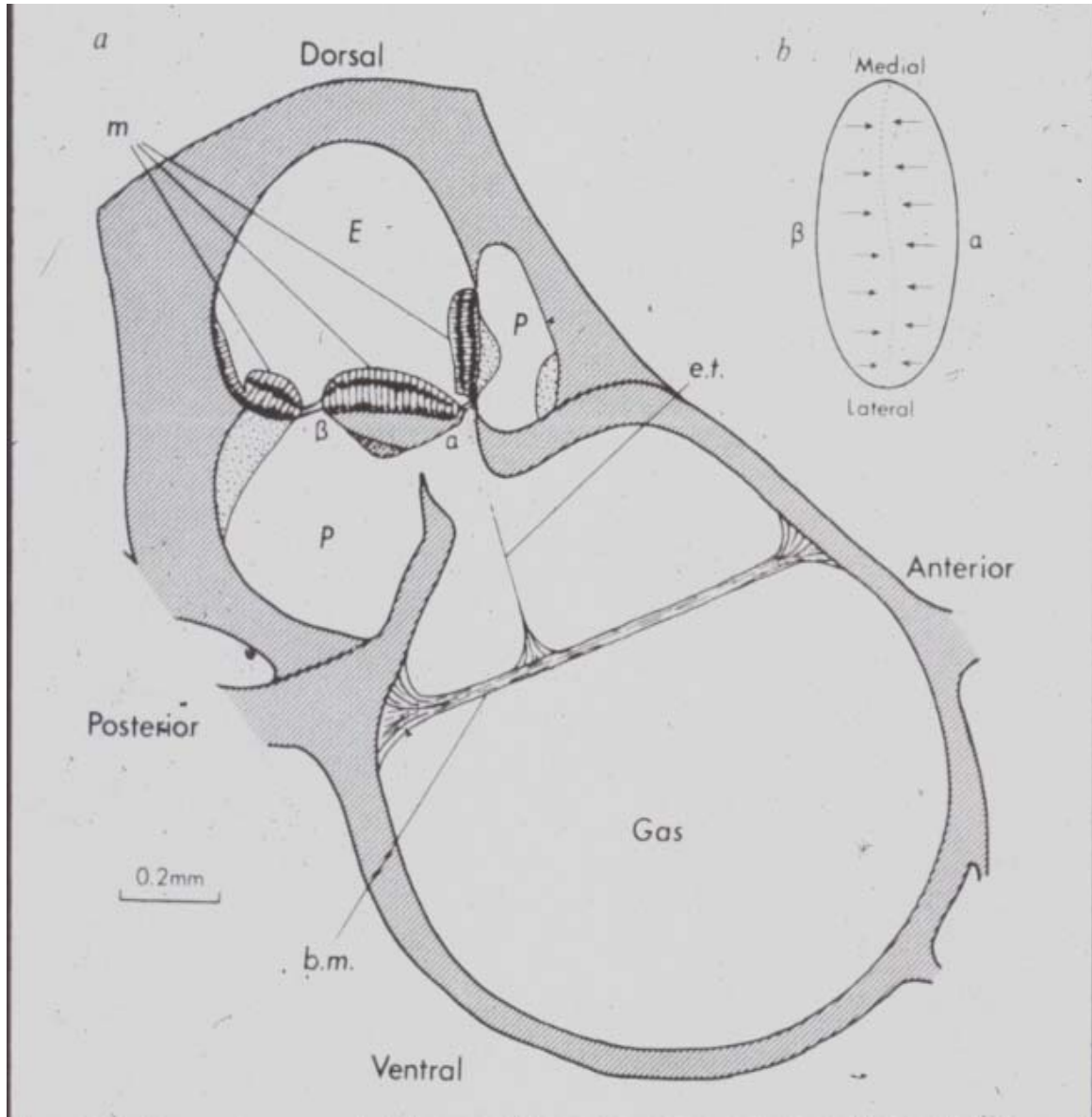
Thresholds for Several Clupiform Species



How is ultrasound detected?

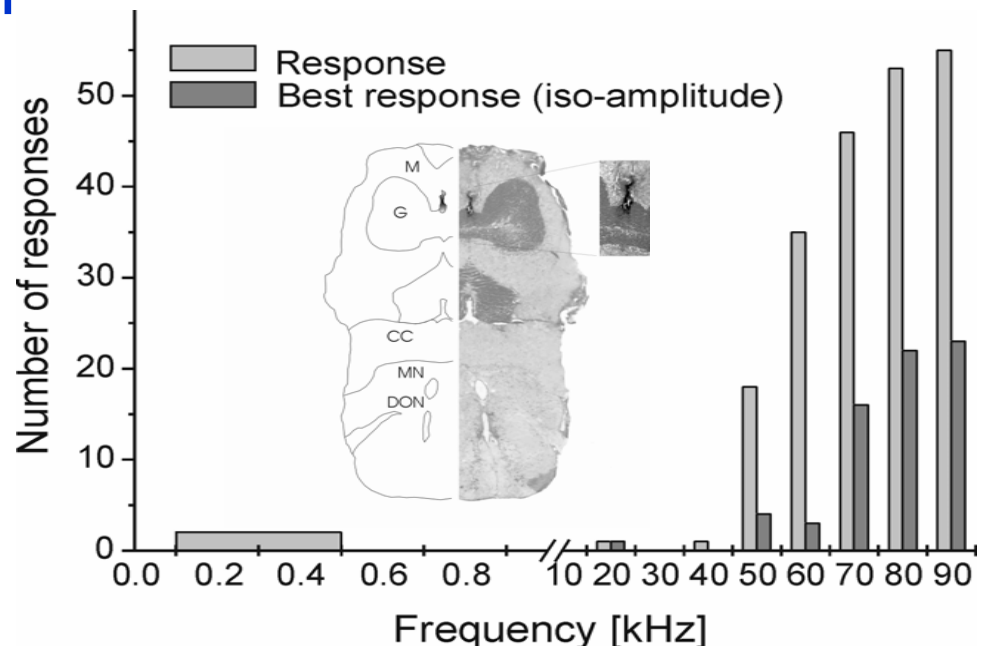
Utricle of the ear highly derived

- Very different than other vertebrates
- Three-part structure



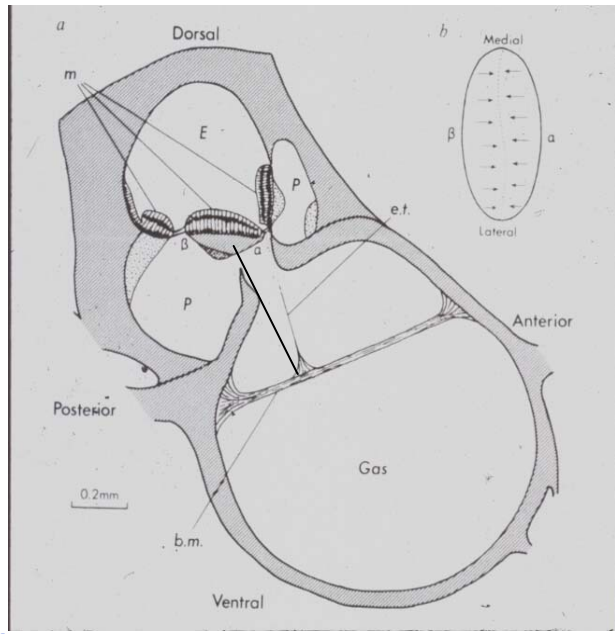
Other evidence supporting ear involvement

- Physiological studies show there are neurons in the auditory part of the brain that respond only to ultrasound
- Developmental studies show that response to ultrasound does not show up until the bulla and utricle are *fully* developed.



Proposed Mechanism

- Ultrasound detected by air-filled bulla in ear
- Causes motion of membrane between air and fluid-filled bullae
- Results in movement of thin fiber to middle epithelium
- Middle epithelium detects the movement, but motion is much lower frequency that ultrasound



Conclusions

- Some (not all) clupeids detect ultrasound
  - Primarily in family Alosinae
- Evolved to avoid echolocating predators
- Ultrasound detected by utricle of the ear
- Ultrasound detecting units found in the auditory regions of the brain

Final Thoughts on Fish Hearing

- All fishes hear and have sophisticated sound analysis capabilities
- Hearing evolved to listen to the environment – communication evolved as a secondary adaptation
- Sound provides fish with a “picture” of their environment from beyond the field of vision
- In using sound to study fish, we must keep in mind that they may detect such sounds!