ScattrLab EPISODE ONE:
HOW DO FISH HEAR?

Master Material Packet

Contents

It's a wonder how and why fishes hear!

In this special *pilot episode* of ScatterLab, Samantha shares EVERYTHING from the basics to the bizarre in the world of fish hearing and sound perception. We are one step closer to discovering what would happen if we threw an underwater rave for our fishy friends!

NOTE: This content was made originally as an honors project for the University of Washington course: FISH311 – Biology of Fishes. **This content is free and accessible to any and all.** *Have fun!*

Materials:
Video: HOW DO FISH HEAR? | ScattrLab Ep1

Assignment/Questions: (multiple formats available)
>   Google Docs (copy and edit)
>   PDF

Optional Materials:
Assignment Key
Additional Resources/Activities

Otolith Poster/Sticker/Pin:
>   PDF
>   Redbubble

various saggital otoliths

Course/Syllabus Learning Objectives:
- How do fishes hear, and what are some unique adaptations?
- Be able to make predictions about the brain of a fish, and the senses that are important, based on the environment.

HOW DO FISH HEAR?

In this <u>video</u>, you will...

LEARN how sound moves differently in water than it does in the air, and that fishes have plenty of great reasons to rely on the sense of hearing

EXPLORE the anatomy and physiology of a modern fish's inner ear

DISCOVER that some fishes can hear beyond the frequencies audible to humans

EXAMINE case studies of unique adaptations that impact hearing abilities in different fishes

LEARN about the Lateral Line and how it connects to sound and pressure reception

After this video, try your hand at <u>these questions</u> and...

PRACTICE reading and interpreting figures from scientific articles about the hearing ability case studies presented in the video

DESIGN your own experiments to test the limitations and adaptations of different parts of the hearing apparatus in fishes.
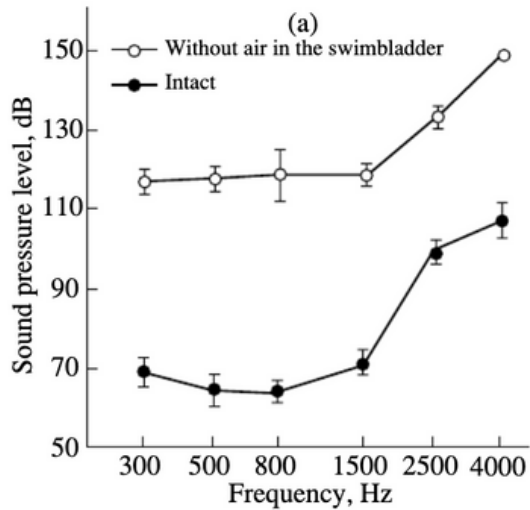
HYPOTHESIZE and JUSTIFY how evolutionary trends in fish hearing may have occurred based on information about life history

Swim bladder Swindle

In a 2000 study, scientists examined the impact of intact versus deflated swim bladders OR the removal of suprabranchial chambers on hearing perception in goldfish and blue gouramis.

1) Based on the Figure 35, what difference does an intact swim bladder make on sound reception, and which impediment is most detrimental to fish with swim bladders? Removal of air from the bladder, or removal of air from the suprabranchial chamber?
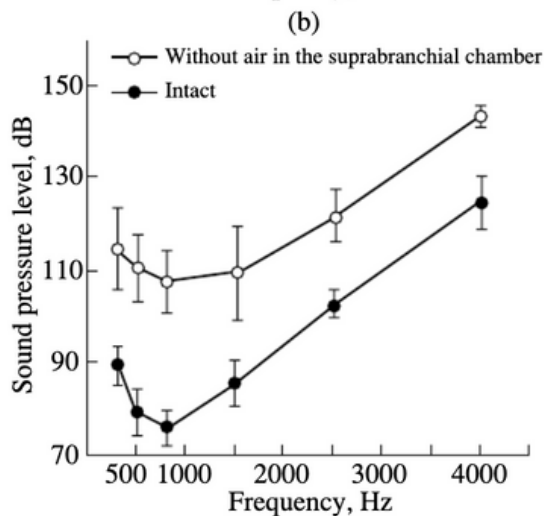
How can you tell?

Fig. 35. Audiograms of the (a) goldfish *Carassius auratus* before and after the removal of air from the swimbladder and (b) blue gourami *Trichogaster trichopterus* before and after the removal of the air vesicle from the suprabranchial chamber. The sound-pressure level is expressed in dB relative to 1 μPa (from Yan *et al.*, 2000).

Swim bladder Swindle (cont.)

In the same study, Yan and colleagues conducted the following experiment, measuring intact, deflated, and reinflated swim bladders of goldfish.

2) Based on Figure 35, What does the data suggest about the overall impact of having a swim bladder full of air, versus a swim bladder that has no air?

3) Does refilling a swim bladder have the same effect as a completely intact/untouched swim bladder? What evidence supports your answer?
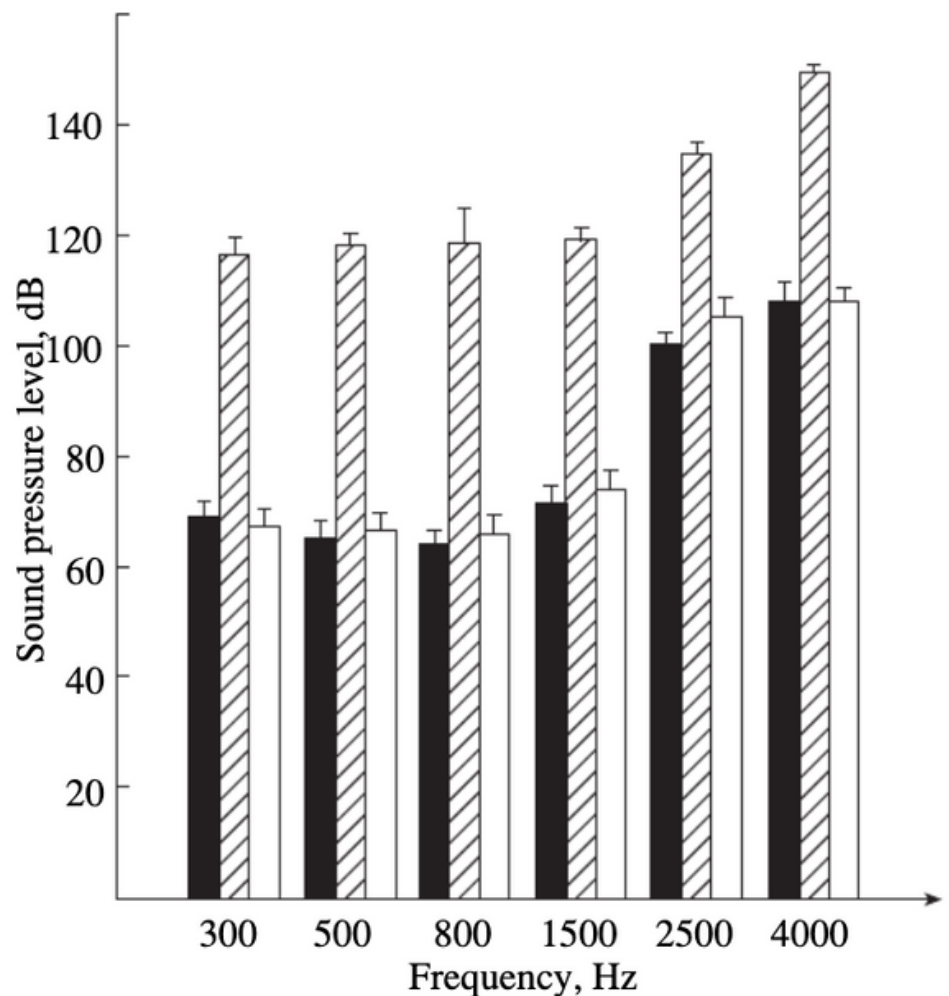

Fig. 36. Auditory thresholds in the goldfish *Carassius auratus*. Intact individuals, dark columns; after the removal of air from the swimbladder, stippled columns; after the repeated filling of the swimbladder by air, light columns. The sound-pressure level is expressed in dB relative to 1 μPa (from Yan *et al.*, 2000).

Swim bladder Swindle (cont.)

The Common dab is known to have lost a functional swim bladder over the course of evolutionary history. In a 1974 study by Chapman and colleagues, scientists installed an artificial gas-filled balloon next to the fish during sensitivity studies and recorded what volume/dB of sound fish would react to with and without the balloon.

1) What is artificial the balloon trying to simulate/emulate?

2) Even though this species has lost its swim bladder over the course of evolution, what does the data say about the overall impact of having any type gas-filled space on hearing ability?
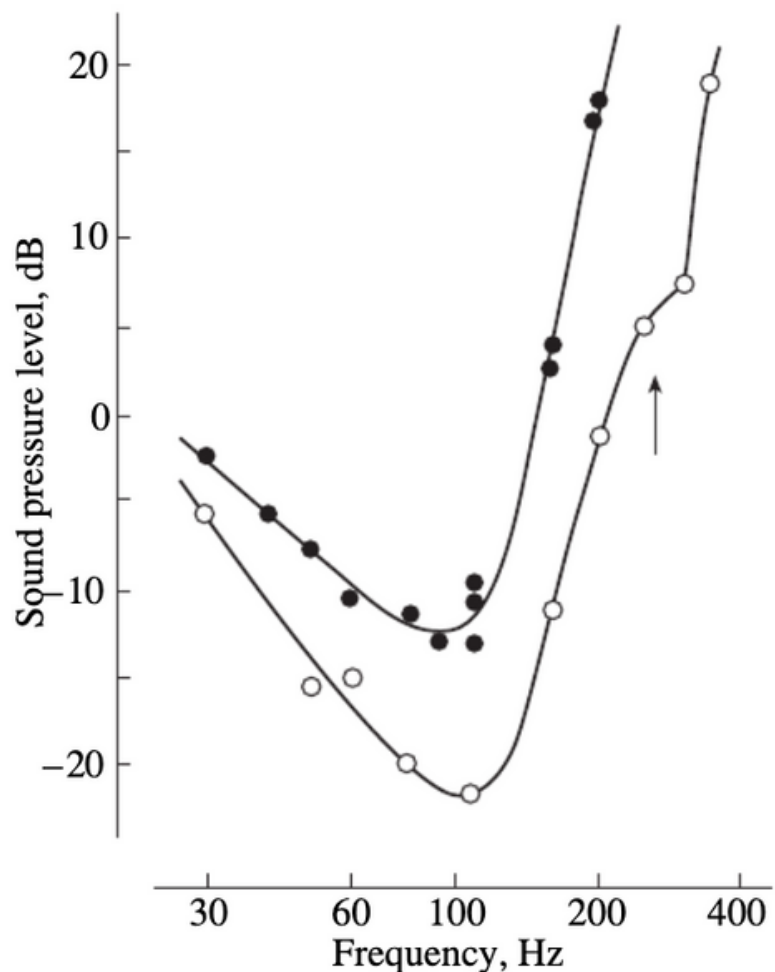

Fig. 39. Audiogram of the common dab *Limanda limanda*. Intact individuals, the dark circles; individuals with a small balloon filled by air, the light circles. The arrow indicates a resonance frequency of the balloon (from Chapman and Sand, 1974).

Heard of Life History?

Think about the living conditions of a fish living in the bathypelagic (like members of the Melamphaidae family), against an open-water predator like the Bull Shark, and a larvae of an open-water forage fish like a herring.

1) Predict which senses would be most helpful to each fish to best fit their life histories/habitat. How does hearing compare to their other senses?

2) What morphological clues can you look for to test your predictions if you had access to specimens of each species?

Hearing Above and Beyond

Many clupeid fishes (like herrings, shads, and sardines) have been known to recognize a wider and higher range of frequencies compared to most hearing generalist fishes. For example, the Black Sea Shad has been recorded reacting to frequencies from 6 to 36 kHz (Lebedev et al. 1965, 1966), breaking into the ultrasonic range. See the video for reference about clupeid fishes and their soundscape.

1) What kind of information do fish receive with the sense of hearing? What are some of the things that exist in the soundscape of the open ocean that might be of interest to clupeid fishes?

2) Make a prediction as to why this range of reception is advantageous to this group of fishes based on their life history and/or habitat.

Design and Designate

When studying fish hearing, scientists often record signs of sound perception based on a fish's activity, or physical response to a stimulus. But as you have discovered, fish often have two sensory systems that work incredibly close together when detecting sound, pressure, and positioning: the lateral line and the inner ear.

1) Design a hypothetical experiment to isolate and study the limitations of the lateral line and inner ear in a way that scientists can better understand which system is triggered by a given stimulus.

Think about treatment groups, results you'd want to compare, and examples of past studies presented here on fish hearing. There are no right or wrong answers, just answers with more depth into considerations and parameters.
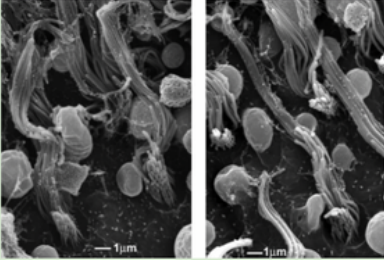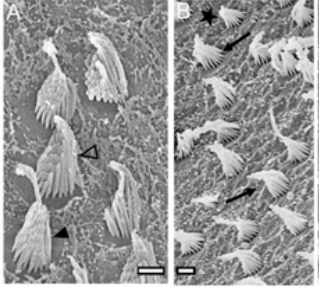
Low-Rollers

Many small fishes have been recorded to produce pressure waves/sound when swimming and moving, around 10-20 Hz in frequency (Kalmijn, 1989). Many species of fish have been recorded to express physical avoidance reactions to artificial sound matching this range of 10-20 Hz when produced within 2 meters of the fish's body.

1) What sensory system is this fish MOST LIKELY relying on to perceive such low frequencies, aka infrasounds?

2) Make a prediction as to why it is advantageous for fishes to recognize low frequencies by providing two examples of fishes with different lifestyles, diets, or life stages, and how they might use low-frequency reception.

Melamphidae Case Study

Thorough morphology investigations of the inner ear system of the deep-sea dwelling family Melamphidae have unearthed some interesting adaptations! To help you discover and explore the purpose of the detailed components of the inner ear, follow along with these figures and guiding questions from this study, specifically about hair cells/sensory epithelium of the inner ear.

Family	Melamphidae	Clupeidae	Poeciliidae
SEM Photo of Hairs in Macula	*"Hair bundles as tall as 15-20 μm comprise more than 80% of all bundles on the saccule"*	*"In the herring utricle there are large numbers of bundles which have a kinocilium at least 6-7 μm long and some stereocilia which are nearly as long."*	*"Ciliary bundle with a kinocilium at least three times longer than the longest stereocilium. Scale bars=1 μm."*
Depth Range	150 – 3,400 meters	20 meters – 200 meters	0 – 1 meter (in fresh-brackish water)
Hearing Range	**unknown**	Up to 3000 Hz	200 – 1500Hz
Predators	large seabirds, large squid, oceanic dolphins, and large pelagic fish, like tuna.	Large fish, sharks, skates, marine mammals, and seabirds	Bull Frogs, Racoons, and Snowy Egrets
Prey	Zooplankton and other small crustaceans	planktonic crustaceans, occasionally other fish larvae	Small invertebrates, and algae

Compare and contrast these SEM photos of the sensory epithelium hairs within the maculas of Clupeid and Melamphid fishes, and information about their life histories.

Consider the lifestyle, habitat, and the "exceptionally tall hair bundles" of Melamphidae fishes, in comparison to the well-studied Clupeidae and Poeciliidae specimens on the right, which have known hearing ranges.

Melamphidae Case Study (cont.)

1) What could you predict about the relationship between hair cell length and hearing ability based on comparisons you've made from this table?

2) What other variables in inner ear or body morphology impact hearing ability that isn't shown in the table above? AKA, what morphology information would be helpful to know and test if you had to determine the relationship between hair cell length and hearing ability)?

3) Optional: How would you test your prediction about hair length and hearing ability?

IF YOU WISH TO CHECK YOUR ANSWERS, ACCESS THE KEY HERE!

Additional Resources/Activities

To make this content more accessible and **fun to folks of all ages,** included are some extra resources and activities related to the topic of sound and fish hearing!

Many activities directly reference learning objectives from the video, so **if you're stuck, scrub the** ScattrLab Episode for your topic!
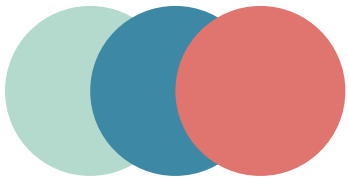
Look out for the difficulty/complexity markers on the top left of each activity page! Colors moving to the right increase in complexity.

Otolith Oddity

create your own otolith, age your otolith, and recall the materials that make up an otolith's structure

Swim Bladder Bonanza

Recall the types of swim bladder connections to the inner ear, and if they are direct/indirect

Sensitive Much?

Melamphid Mayhem

Use real Melamphid Otolith photos and genetic data results to construct a phylogenetic tree

Check your understanding of gas gladder impacts on hearing sensitivity by crafting your own graph of theoretical data.

OTOLITH ODDITY

Name: _____   *Date:* _____

Make your own otolith!

Draw new layers of this growing otolith starting with the shape below.
This is the start of your otolith, your fish is a larva right now! Generate a
random shape using this <u>site</u> (blob generator) for an extra challenge
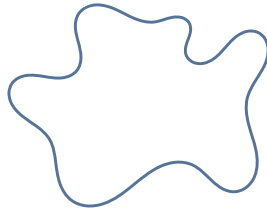
How old is the fish that you drew? Draw + on each layer you count!

_____ *years old*

What material is each new layer made out of?

_____

Name: _____ *Date:* _____

Do you know the ways swim bladders connect to the inner ear?

Draw an otophysic connection

SWIM BLADDER

Is an otophysic connection DIRECT or INDIRECT?
(circle one)

Draw a Weberian apparatus

SWIM BLADDER

Is a Weberian apparatus connection DIRECT or INDIRECT?
*(circle one)*

Name: _____ Date: _____

Do you know the impact of gas-filled chambers on hearing ability?

A fish biology friend of yours ran an experiment on a new-discovered species of fish and recorded the following data about when the fish recognized and reacted to sounds. **Their fish has an intact swim bladder.**

Make a prediction and draw what the data may look like if the swim bladder was popped/damaged.

INTACT   **DAMAGED**
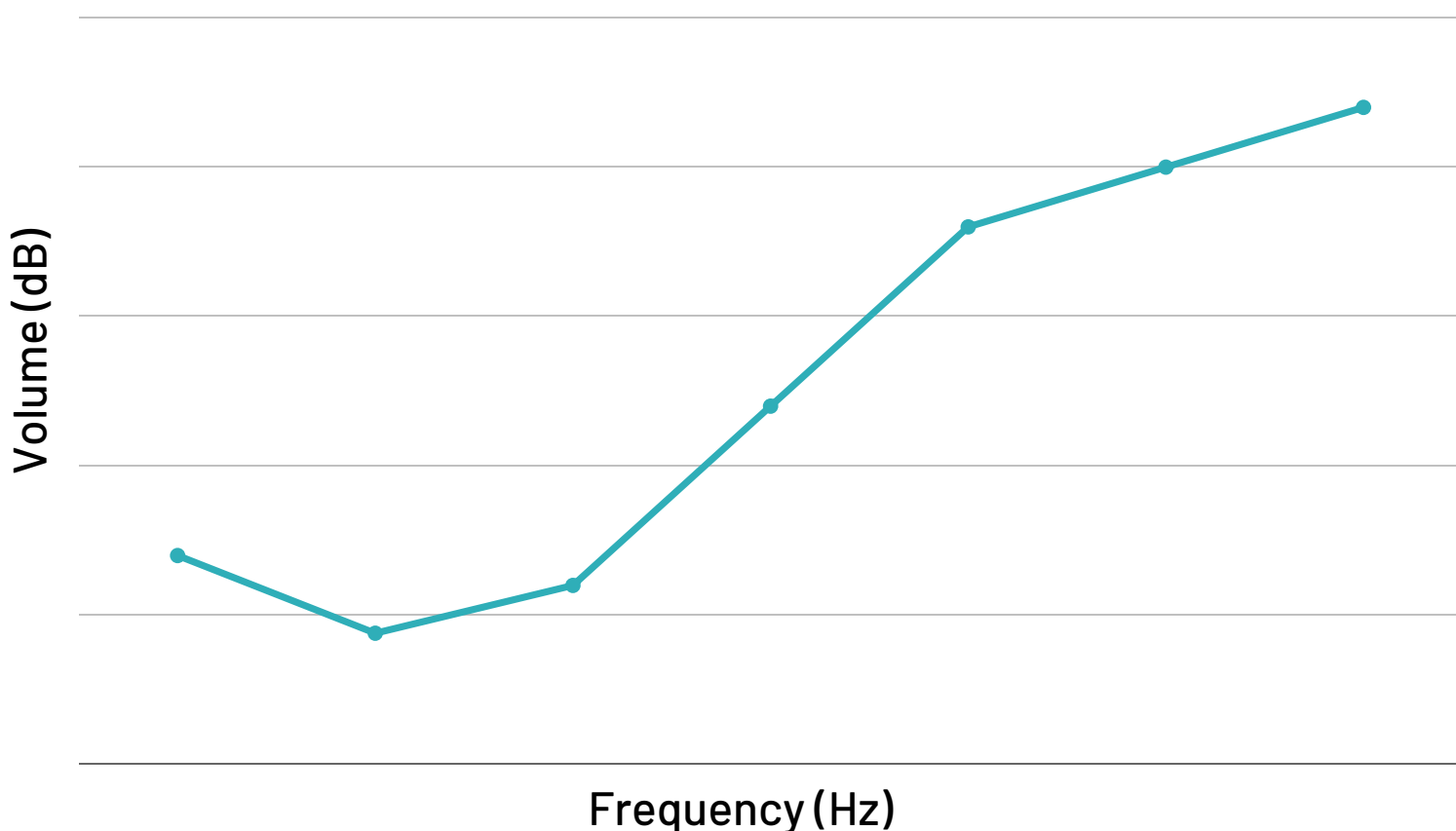
With the data from the studies featured in the advanced assignments and the graph you made above, you conclude that...
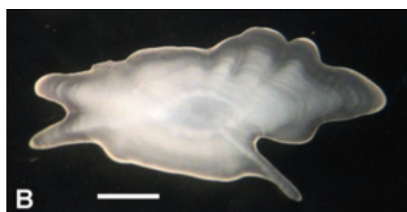
Fish hearing is <u>more sensitive</u> with a _____ swim bladder.

↳ hearing/recognizing frequencies at lower dB

MELAMPHID MAYHEM

Name: _____ Date: _____

Can you use otoliths to predict phylogenetic relationships?

These are the Saggital Otoliths of fishes within the
Melamphid family and close relatives.

Melamphaes Sister Taxa   *Poromitra*   *Scopelogadus*

PREDICT: Draw a phylogeny using otolith morphology clues to relate these fishes to one another. Starting hint: A and B are sister taxa to each other.

root (start)
_____

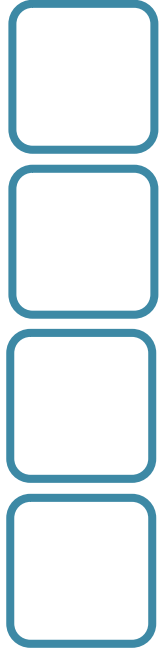**What are you predicting is the more ancestral trait/feature?** _____

What are you predicting is the more derived trait/feature? _____

An analysis of DNA samples of representative species in the three Genera above found that Melamphaes and Scopelogadus diverged from each other around ~15 MYA (Million Years Ago), and that these two genera were separated from an ancestor of Poromitra at 25 MYA.

CHECK: With this divergence data, readjust your phylogenetic tree (if needed)

root (start)

REASON: What change(s) did you make based on the new genetic/dating information of the three genera? What traits or loss of traits arose?

_____

_____

_____

APPLY: Based on your experience with this activity, why can't we create the perfect phylogenetic tree based on morphology alone? What do you think is more reliable: morphological or genetic data?

_____

_____

_____

ASK ME ABOUT OTOLITHS

Acknowledgements

This content was created under the supervision and guidance of Luke Tornabene, Curator of Fishes at the Burke Museum of Natural History and Culture, and Instructor of FISH311 in Autumn 2022. Thank you for your patience, enthusiasm, and support!

Thank you to Katherine Maslenikov, the Ichthyology Collections Manager at the Burke Museum of Natural History and Culture, for letting me explore our collection of Melamphidae specimens and otoliths!