Fundamentals of Underwater Sound

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Fundamentals of Underwater Sound

I. Background Information

II. Underwater Sound Creation

III. Sound Transmission

IV. Passive and active acoustics

V. Sound scattering

I. Background Information

Francis Barraud, 1898

A. What is a sound ?

B. How can we measure a sound ?

C. How do we graphically represent sounds ?

I strongly recommend watching Dr. Tracianne Neilsen's DOSITS webinar from 2 June 2020 which covers these topics in greater detail.

https://dosits.org/decision-makers/webinar-series/2020-webinar-series/fundamentals/

A. What is a sound ?

Sound is a pressure vibration that travels through a medium and is received by a listener.

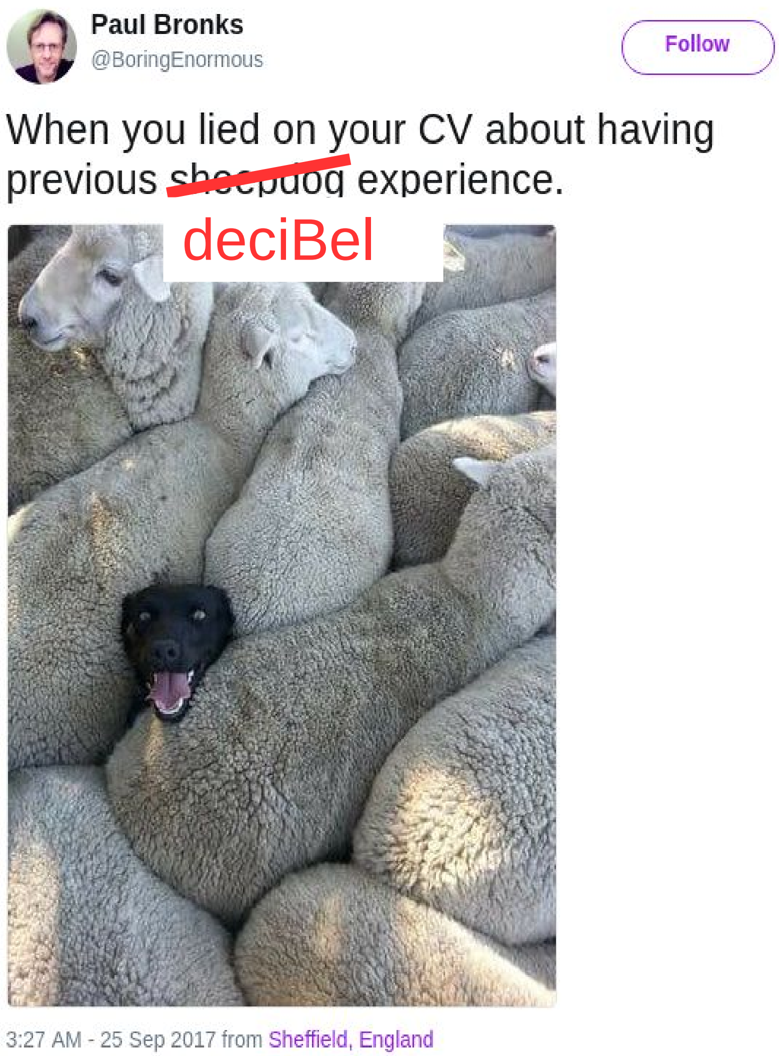
www.nsta.org

B. How can we measure a sound ?

Record how pressure varies with time.

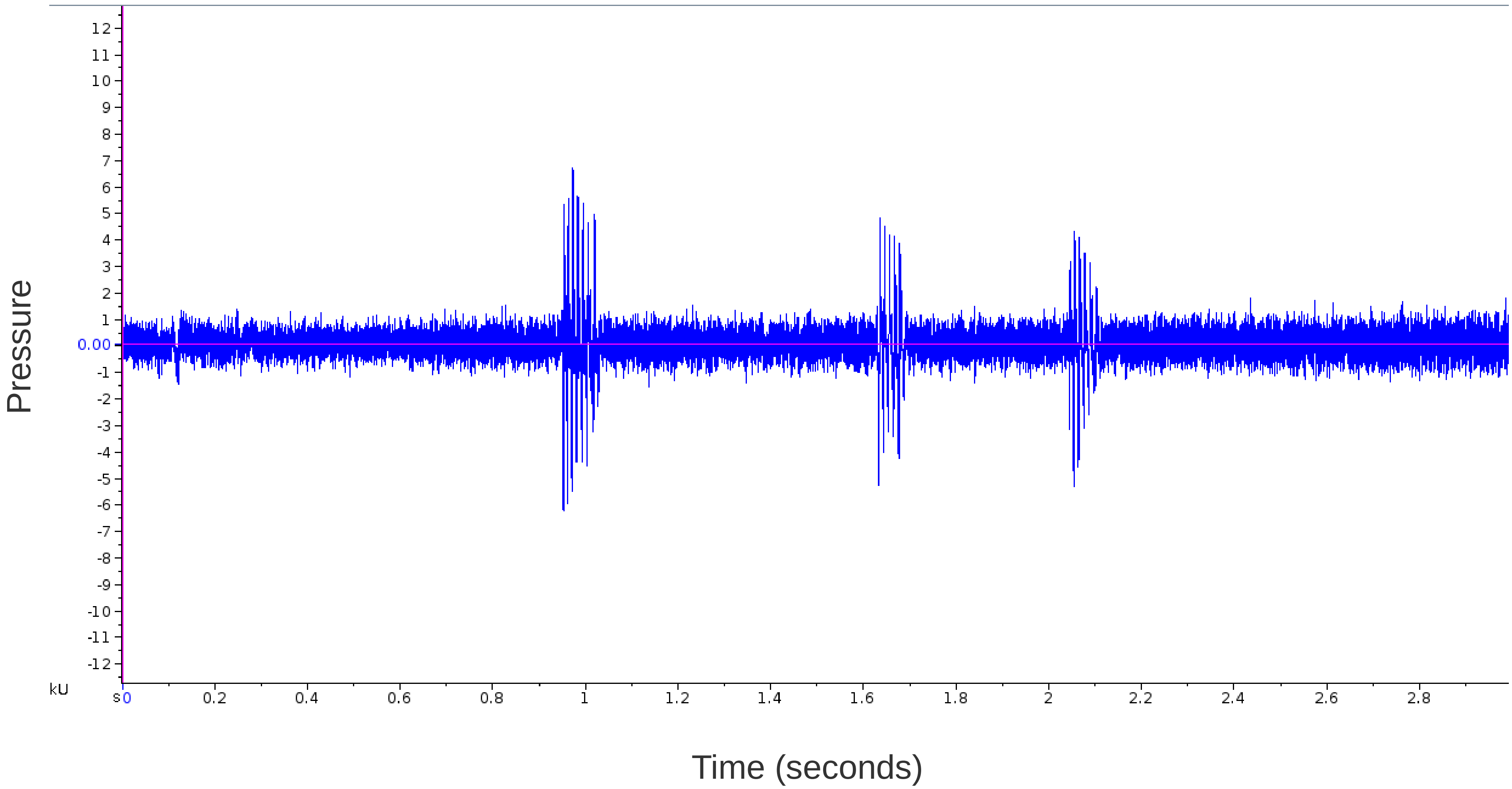
Pressure can vary greatly so we use deciBels (dB) to describe the amplitude of the signal relative to a reference value

deciBels are a logarithmic measure



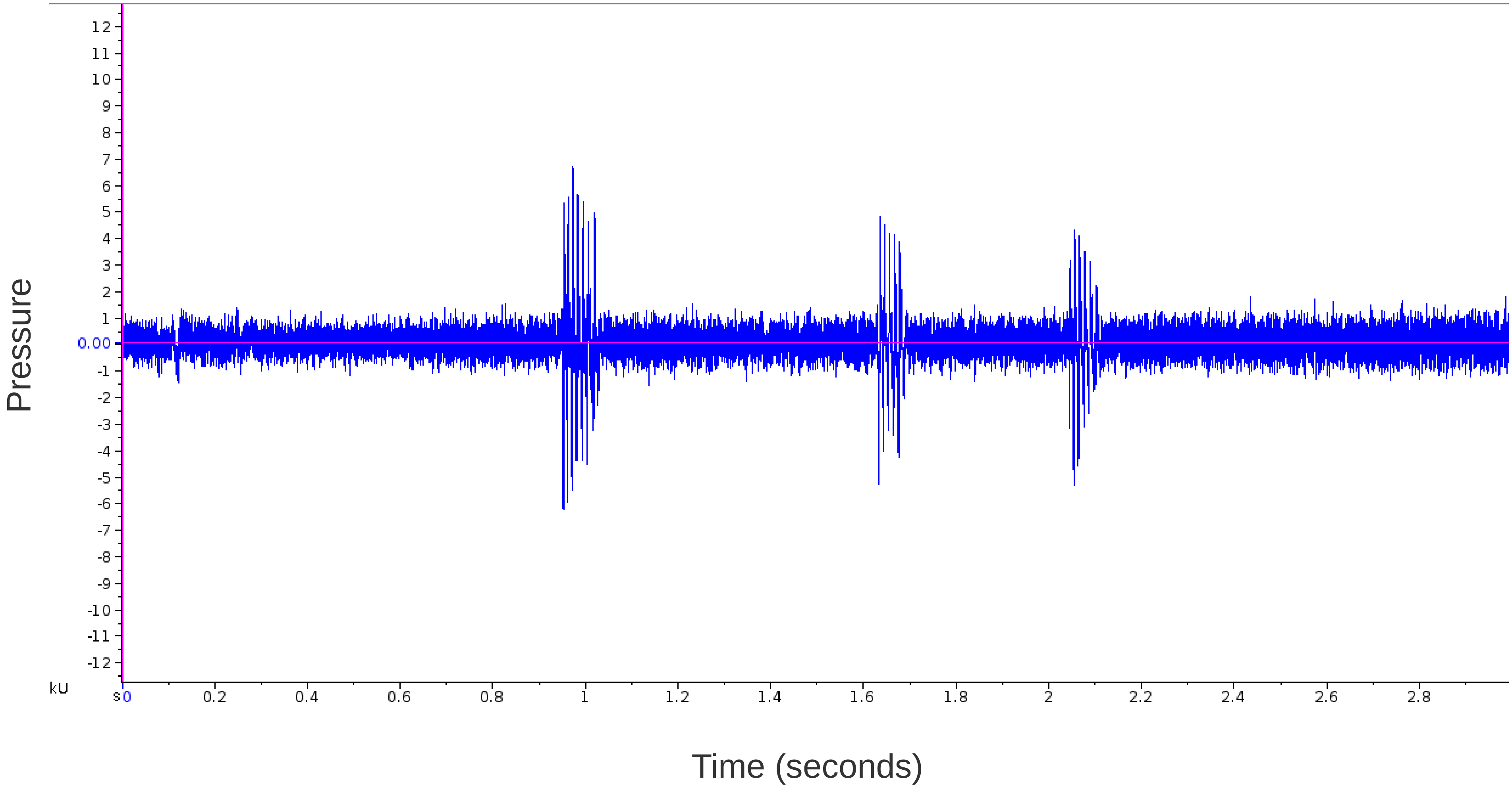
C. How do we graphically represent sounds ?

waveform (pressure vs time)



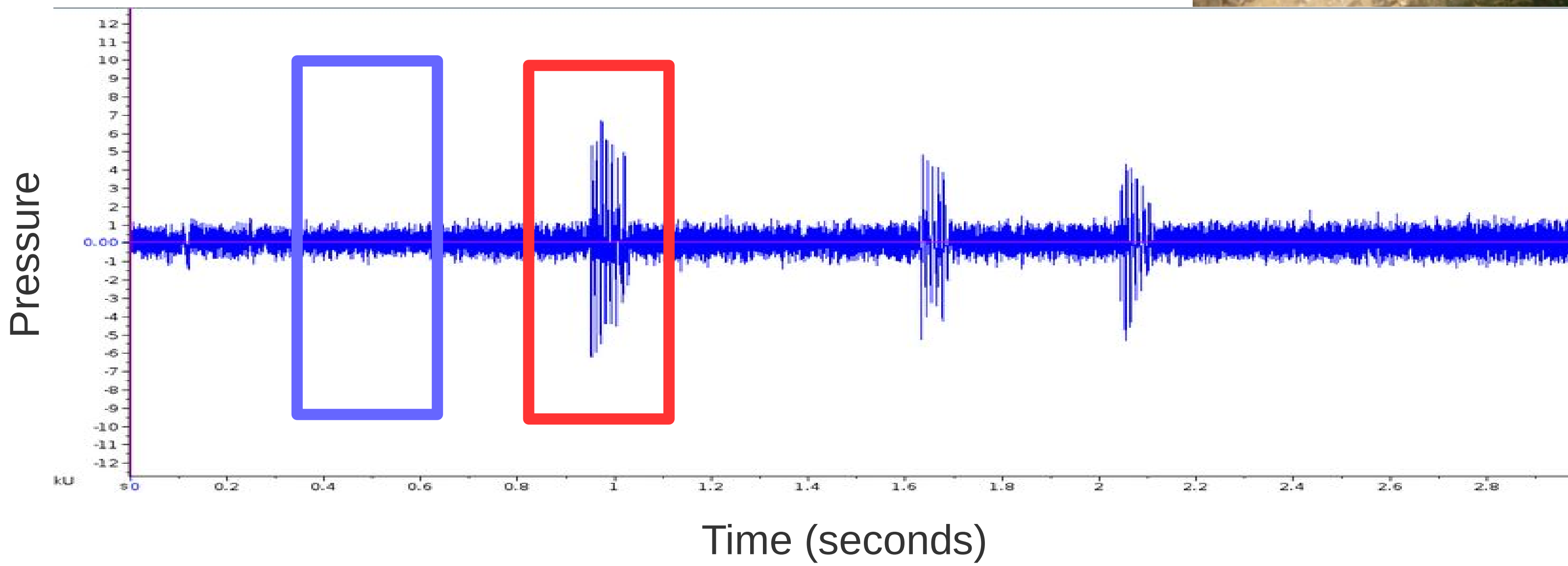
C. How do we graphically represent sounds ?

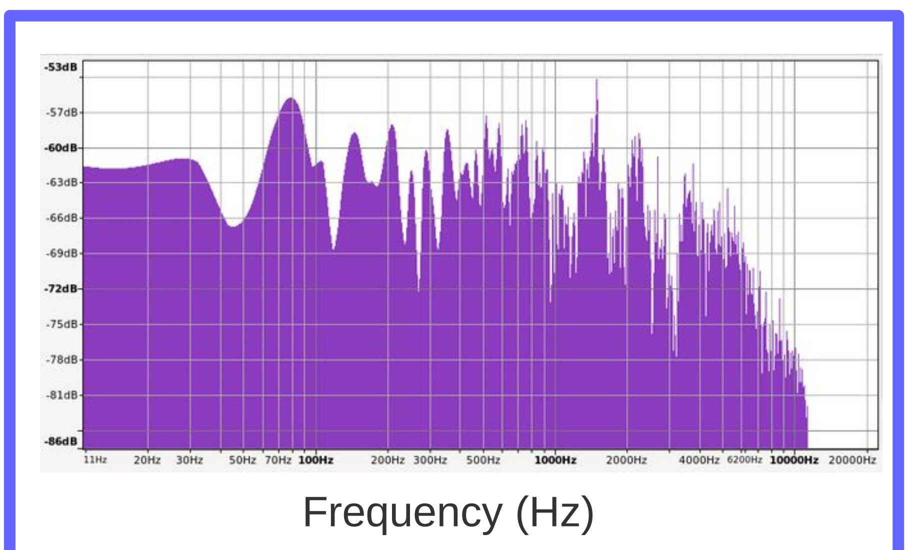
waveform (pressure vs time)

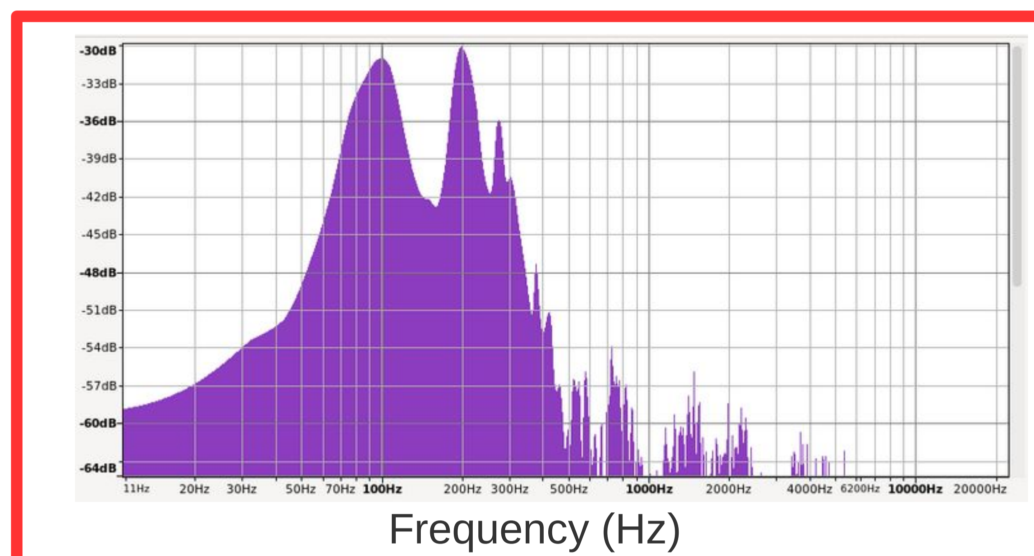


C. How do we graphically represent sounds ?

spectrum (energy vs frequency)

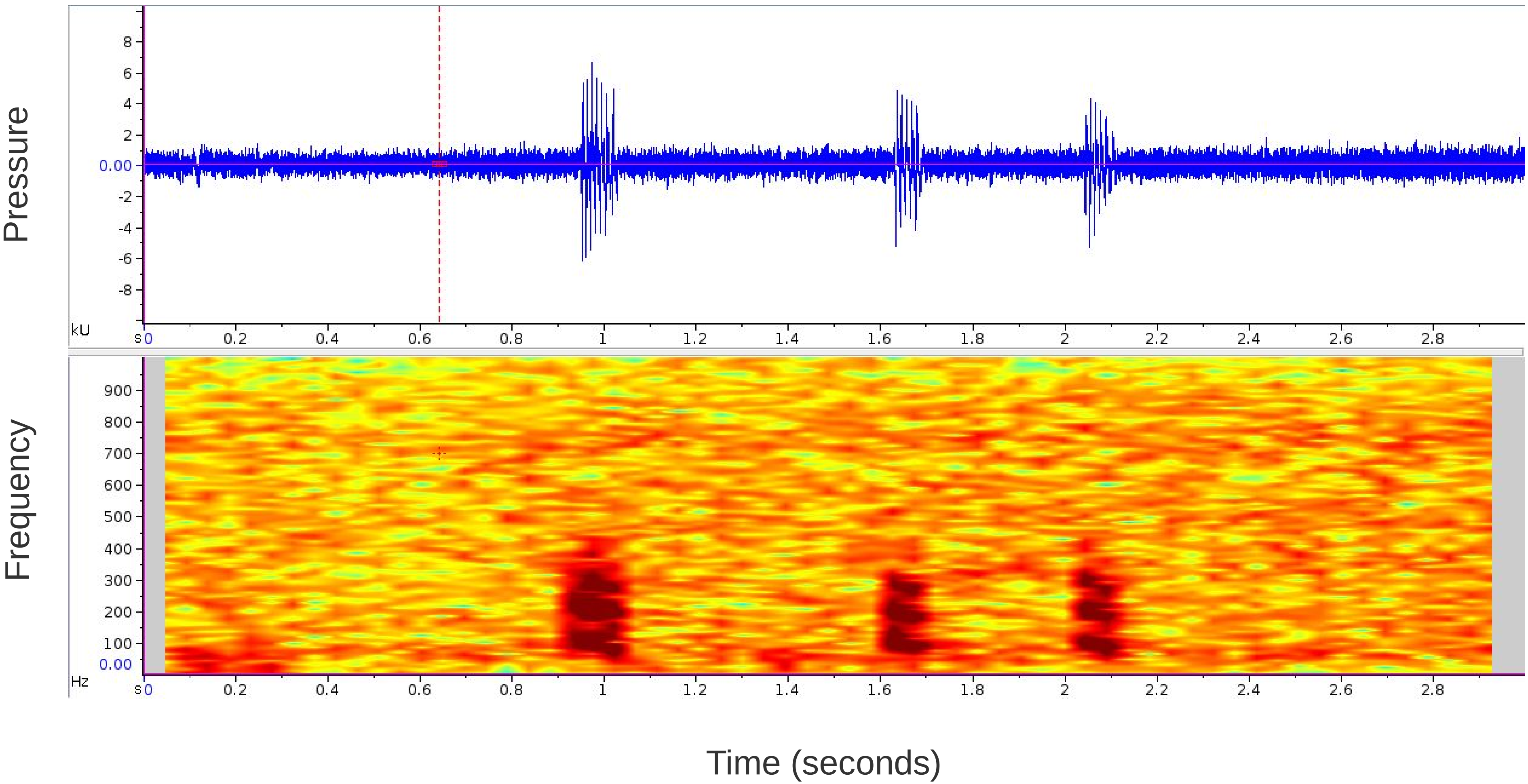






C. How do we graphically represent sounds ?

spectrogram (energy vs frequency vs time)

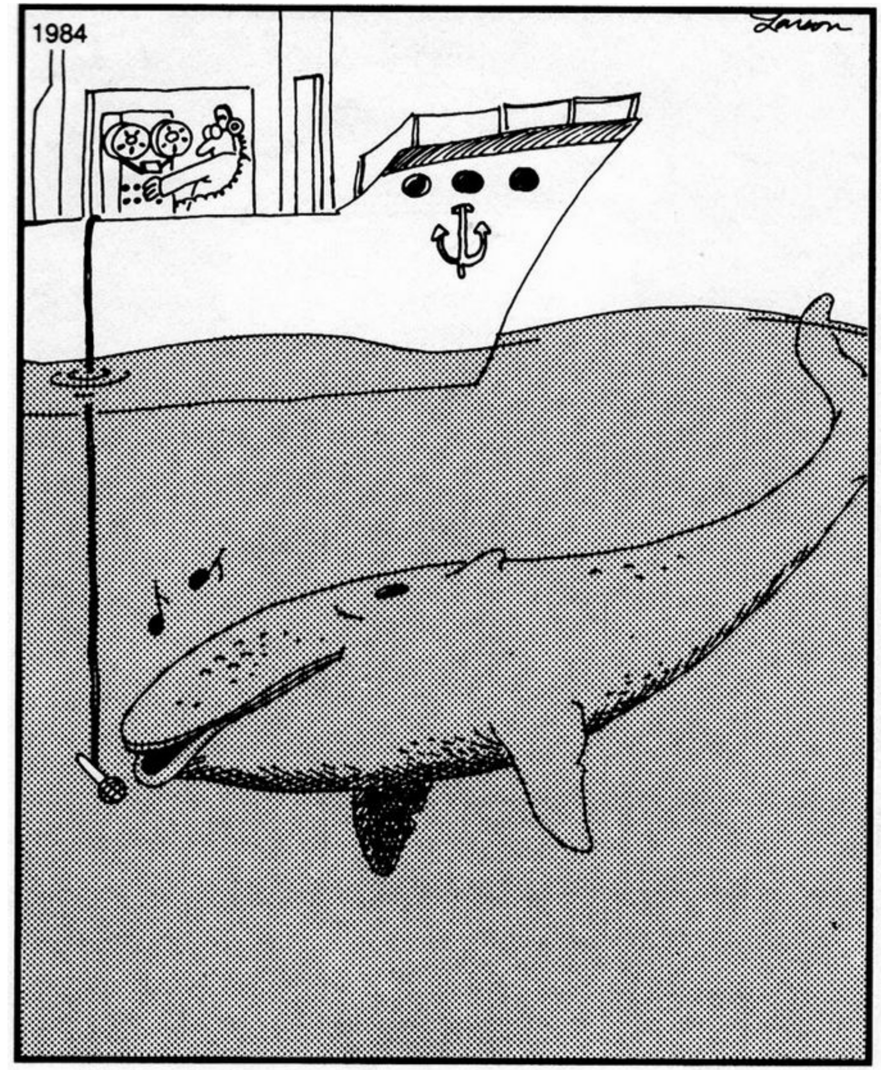


II. Underwater Sound Creation

A. Different sources of underwater sound

B. Types of Sounds

C. Soundscape



"A Louie, Louie… wowoooo… We gotta go now…"

The Far Side, Gary Larson

A. Different sources of underwater sound

1. Geophony – naturally-occurring sounds in the environment

a. Geological processes – undersea earthquakes, volcanoes

https://www.nytimes.com/interactive/2022/04/14/upshot/tonga-pressure-wave.html

A. Different sources of underwater sound

1. Geophony – naturally-occurring sounds in the environment

b. Physical processes – wind, waves, storms, and rain

The anatomy of underwater rain noise

Herman Medwin, Jeffrey A. Nystuen,[a] Peter W. Jacobus,[b] Leo H. Ostwald,[b] and David E. Snyder[b]
Physics Department, Naval Postgraduate School, Monterey, California 93943

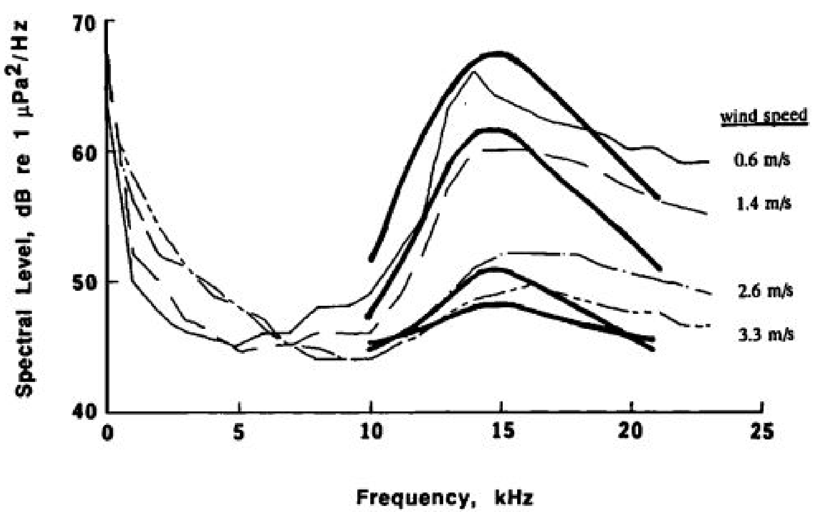
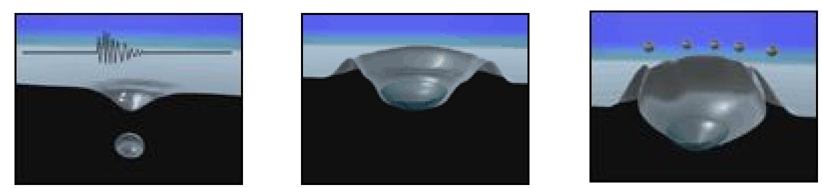


FIG. 2. Field observations (light dashed lines) and predictions (heavy solid lines) based on angles of incidence of small drops at four wind speeds (Nystuen, 1992).



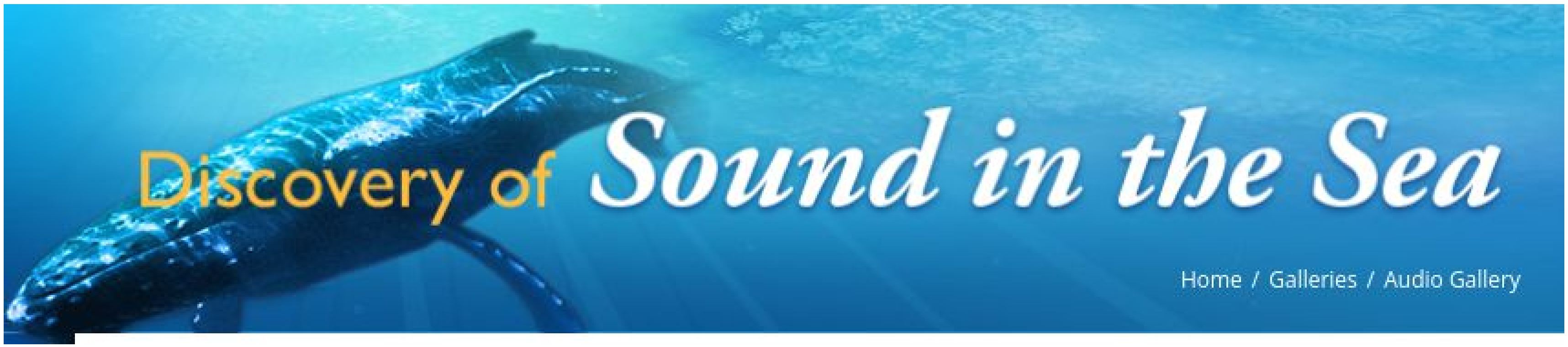
NASA
https://earthobservatory.nasa.gov/features/Rain

Medwin et al., 1992, Journal of the Acoustical Society of America

Audio clip available at:
https://dosits.org/galleries/audio-gallery/other-natural-sounds/rainfall/

A. Different sources of underwater sound

2. Biophony – organisms creating sounds in the environment



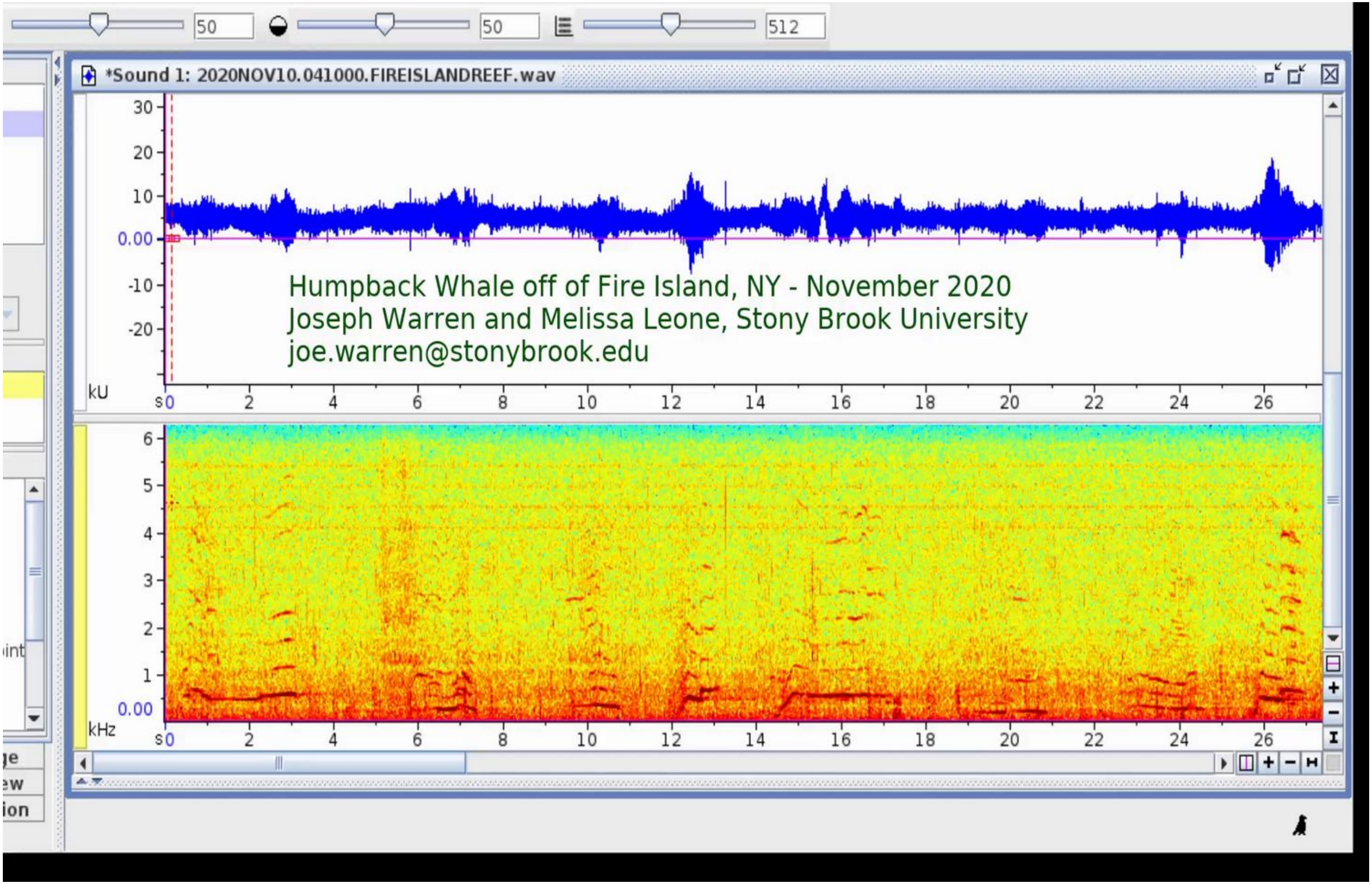
Audio Gallery

Sections:

- BALEEN WHALES
- TOOTHED WHALES
- PINNIPEDS
- SIRENIANS
- MARINE INVERTEBRATES
- FISHES
- OTHER NATURAL SOUNDS
- ANTHROPOGENIC SOUNDS

https://dosits.org/galleries/audio-gallery/

Listening to – humpback whale



A. Different sources of underwater sound

3. Anthrophony – human-created sounds

Airgun

Icebreaker

Dredging

Ocean Acoustic Tomography Transmission

Personal Water Craft (PWC)

Torpedo

Wind Turbines

ATOC Transmission

Bubble Curtain

Explosive Sound Sources

Outboard Motor

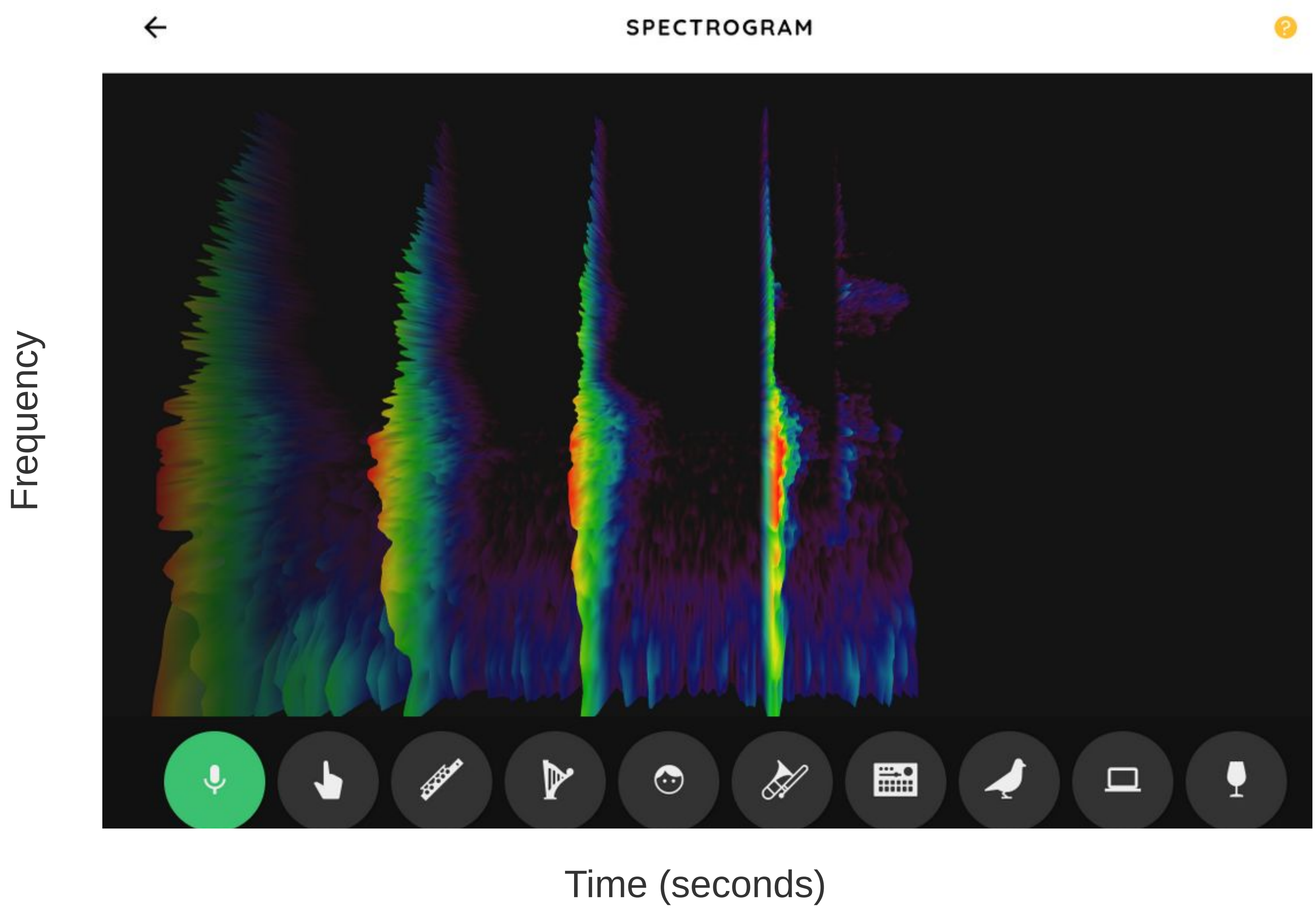
SURTASS LFA Sonar

Underwater Breathing Apparatus

https://dosits.org/galleries/audio-gallery/#manmade

B. Types of Sounds

1. Broadband sounds – short duration, energy at many frequencies

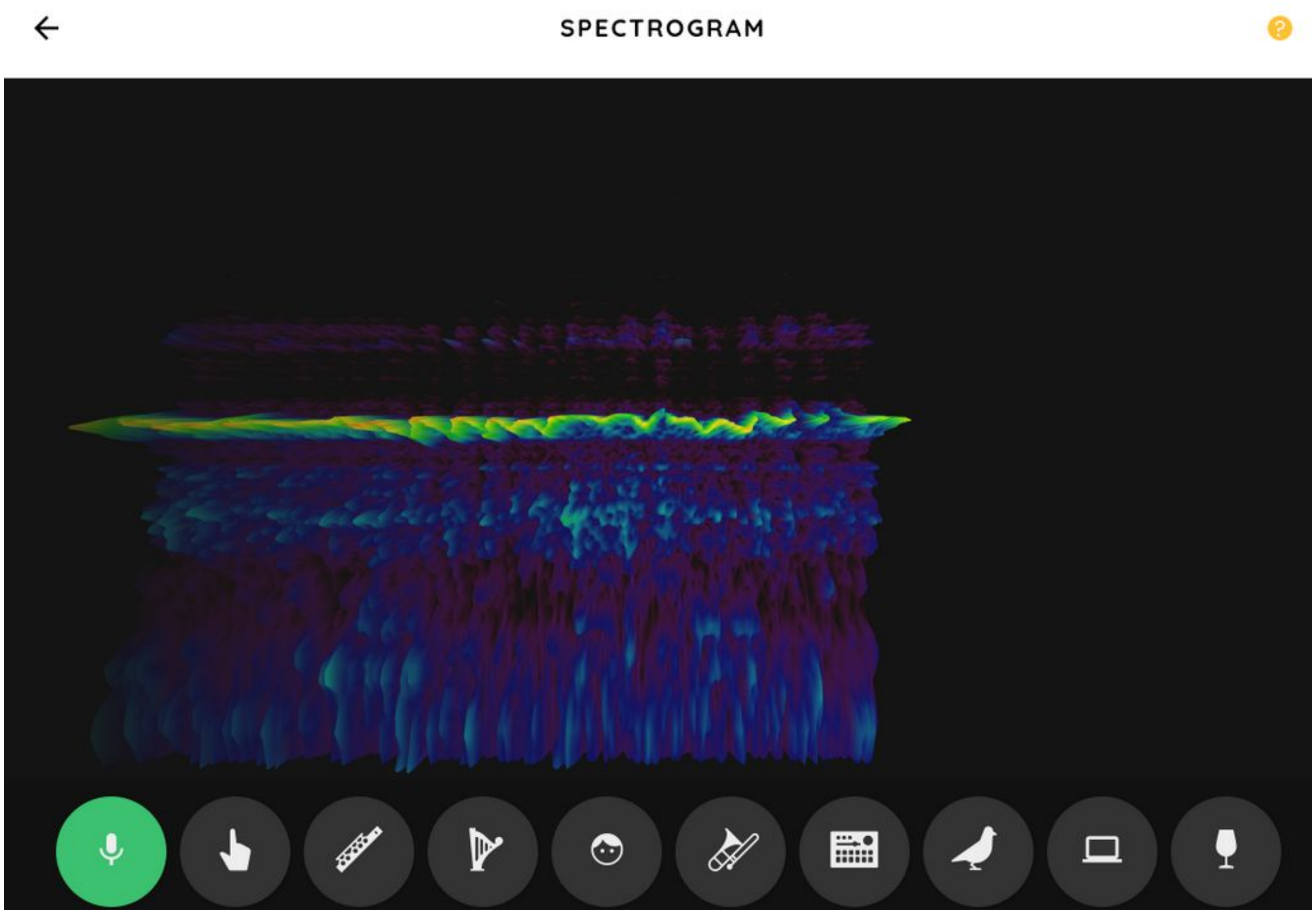


https://musiclab.chromeexperiments.com/spectrogram/

B. Types of Sounds

2. Narrowband sounds – energy at single/few frequencies, longer duration

Frequency

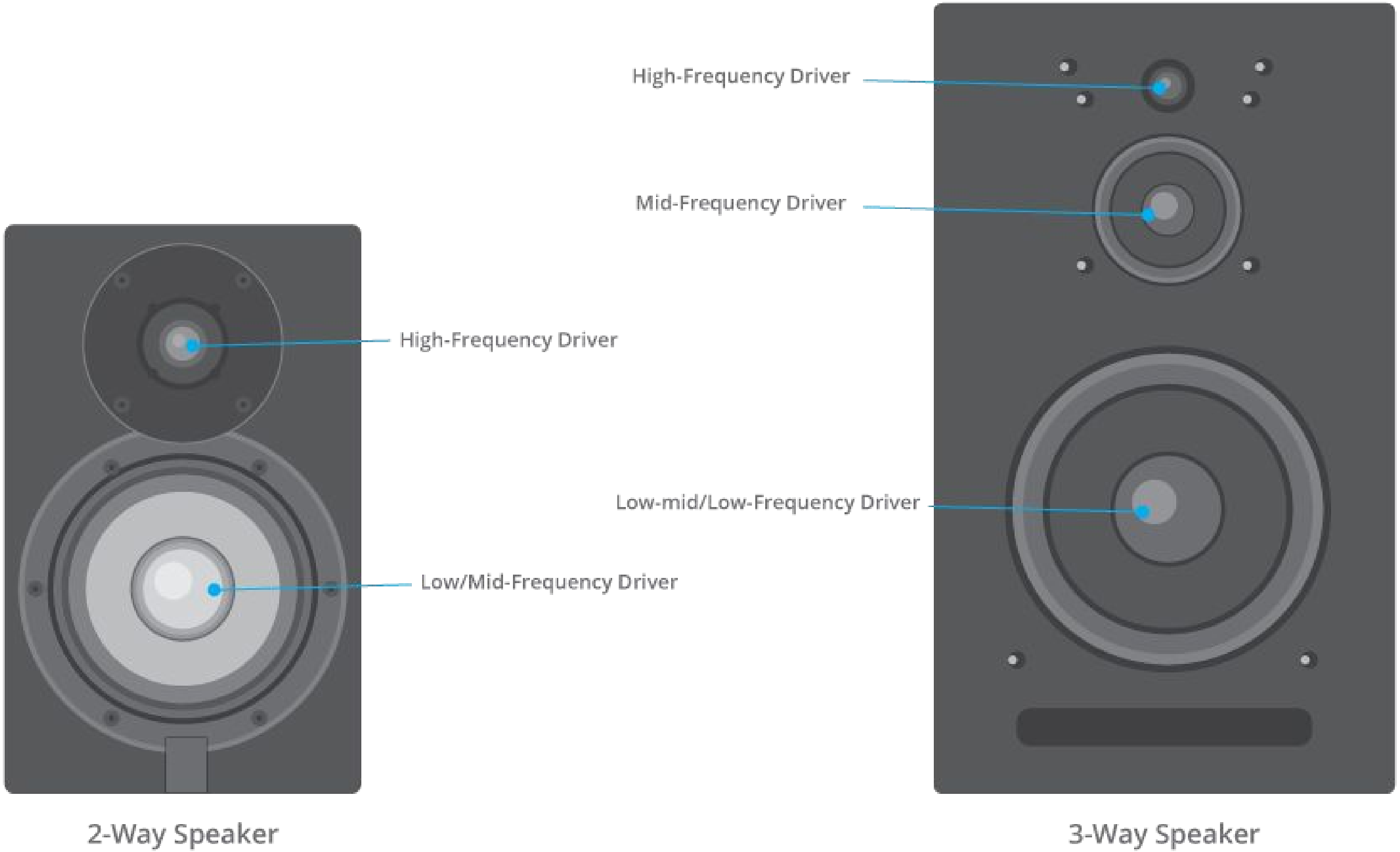


Time (seconds)

https://musiclab.chromeexperiments.com/spectrogram/

B. Types of Sounds

3. “Low” and “High” frequency sounds
   - larger driver needed to create lower frequencies
   - “low/high” are dependent on listener or context
     (human vs dog vs bat)



Drawing: B&H Photo Video

B. Types of Sounds

4. Amplitude – loud vs soft

Amplitude of a pressure signal is easy to measure

How a human perceives that signal as being “loud” or not ?

Complex process involving pressure, duration, and frequency

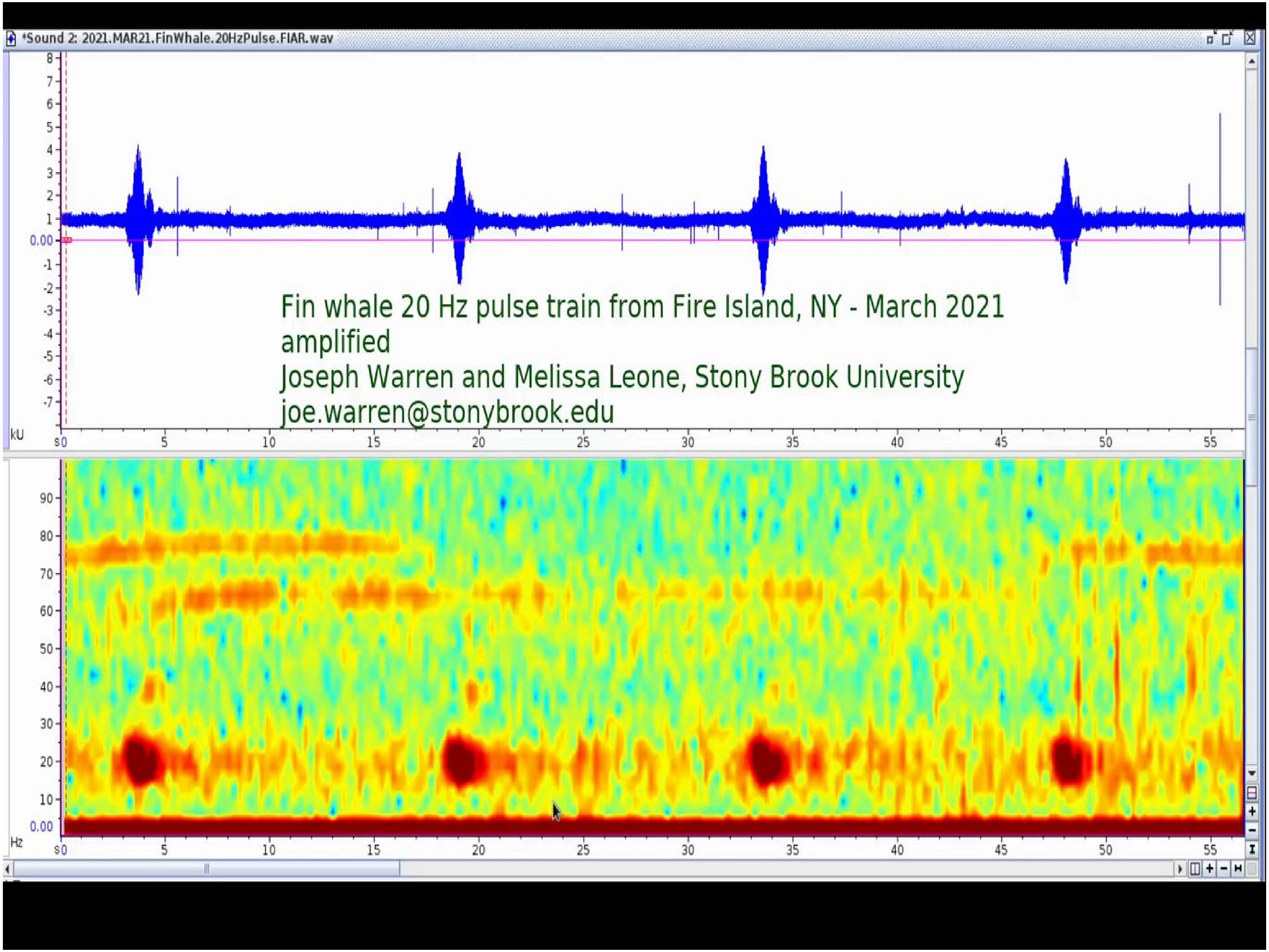
Sound can seem “louder” depending on above and listener

Audio salesman “trick”: humans think louder is better

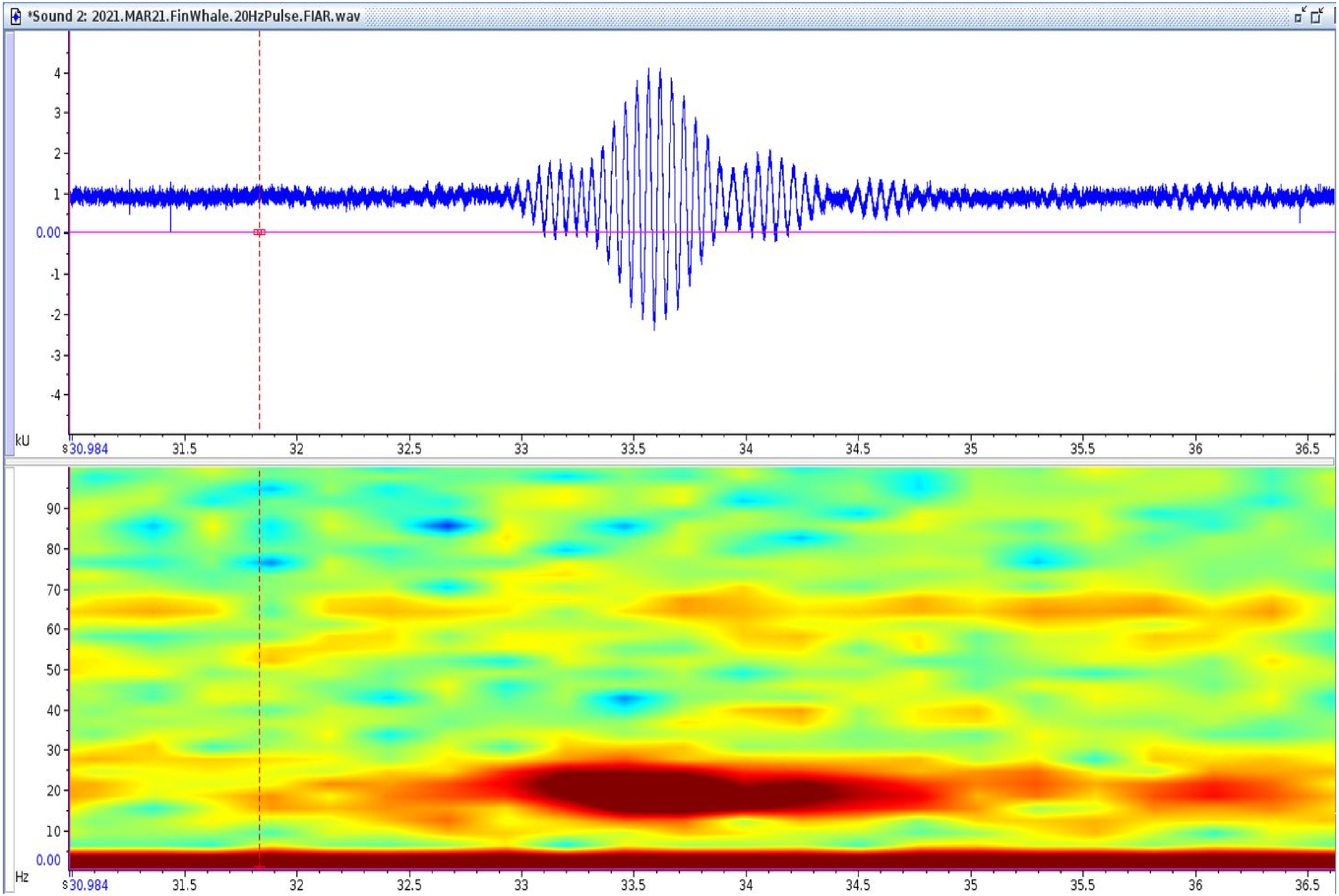
* reference pressure is different for underwater sound than in air

Interesting website to test your headphones and loudspeakers:
https://www.audiocheck.net/index.php

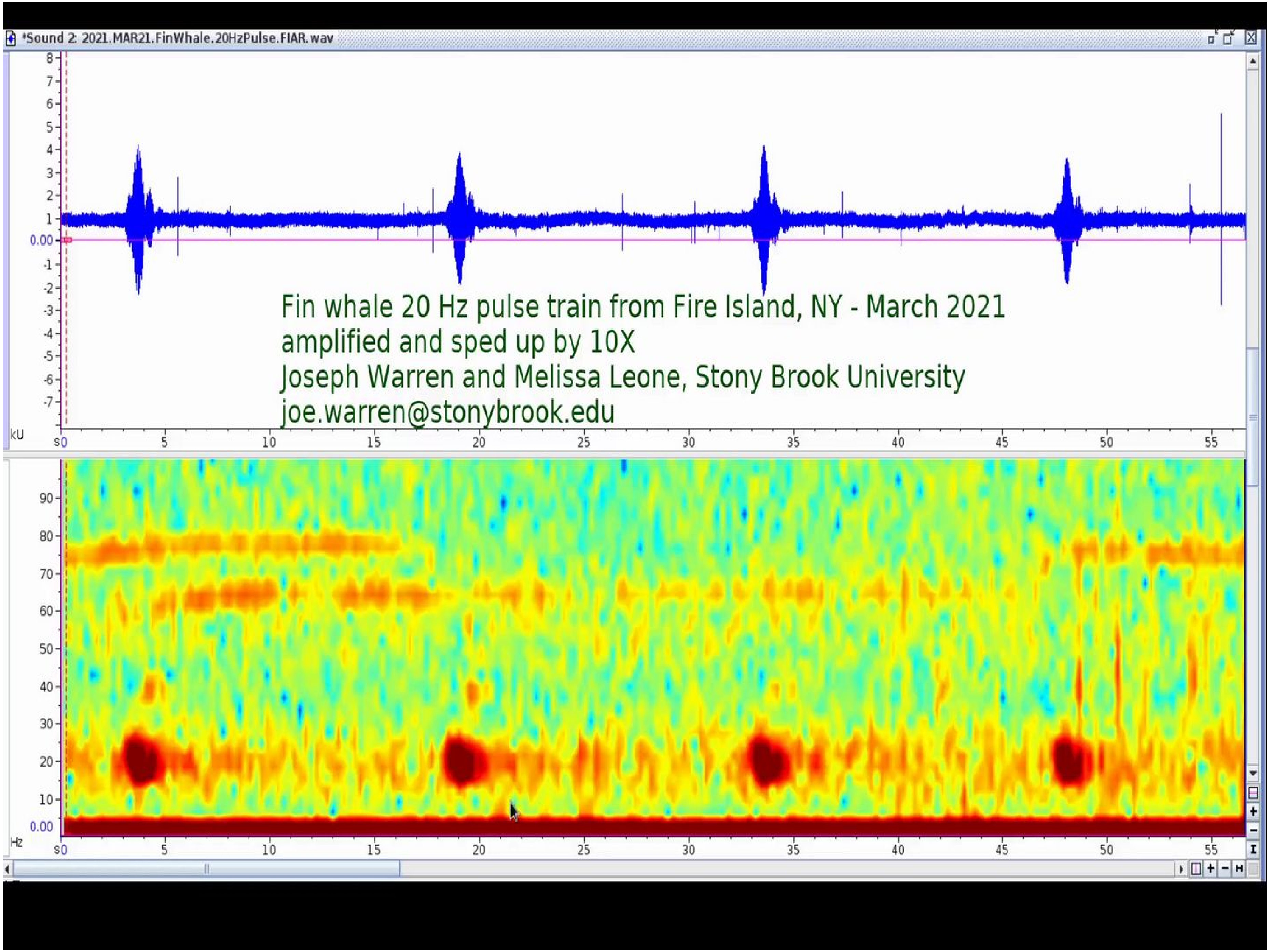
Listening to – fin whale



Listening to – fin whale 20 Hz pulse



Listening to – fin whale (sped up 10X)



B. Types of Sounds

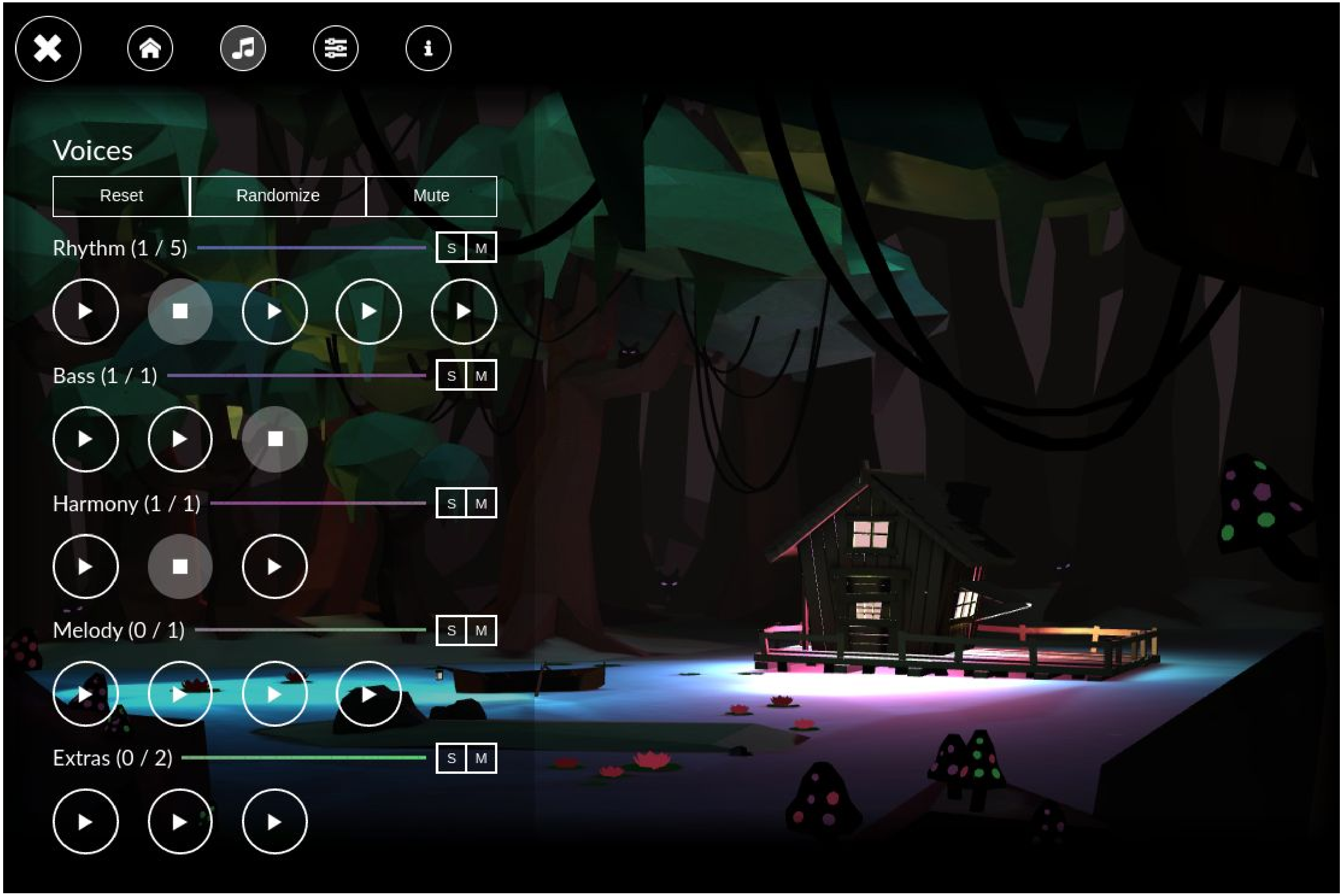
5. Repetition – continuous vs intermittent

- Listener perception is important
  - whirr of a fan at night
  - low battery “chirp” of a smoke detector
- Amount of energy received (integrated by the ear) is important
  - hearing loss or damage
  - temporary or permanent threshold shifts

WEAR [GOOD] EARPLUGS TO LIVE MUSIC PERFORMANCES

C. Soundscape

the acoustic environment as perceived by a listener



https://soundscape.world/play/swamp

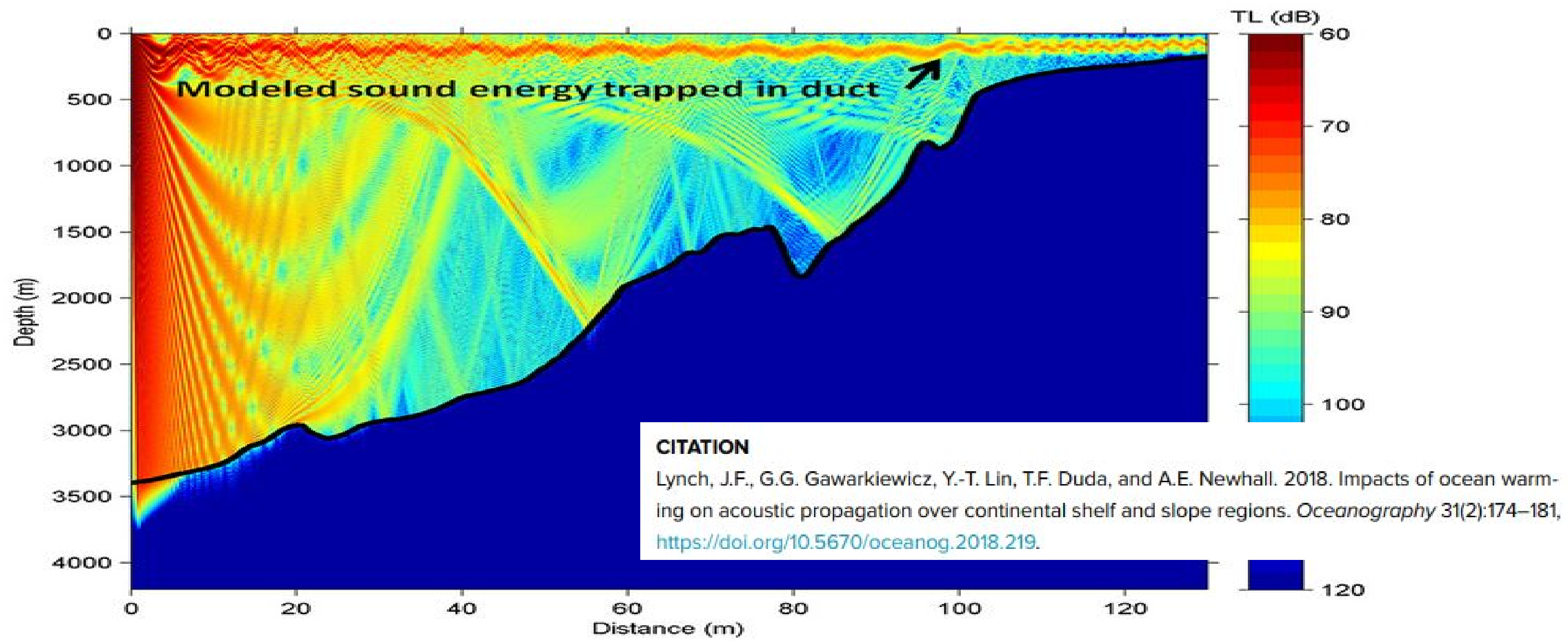
III. Sound Transmission

Sound travels from the source to the receiver

1. Sounds become quieter the further you are from the source

2. Sounds can reflect or scatter

3. Sounds can refract (or “bend”) as they travel



Next month’s DOSITS seminar by Aaron Thode is on this topic

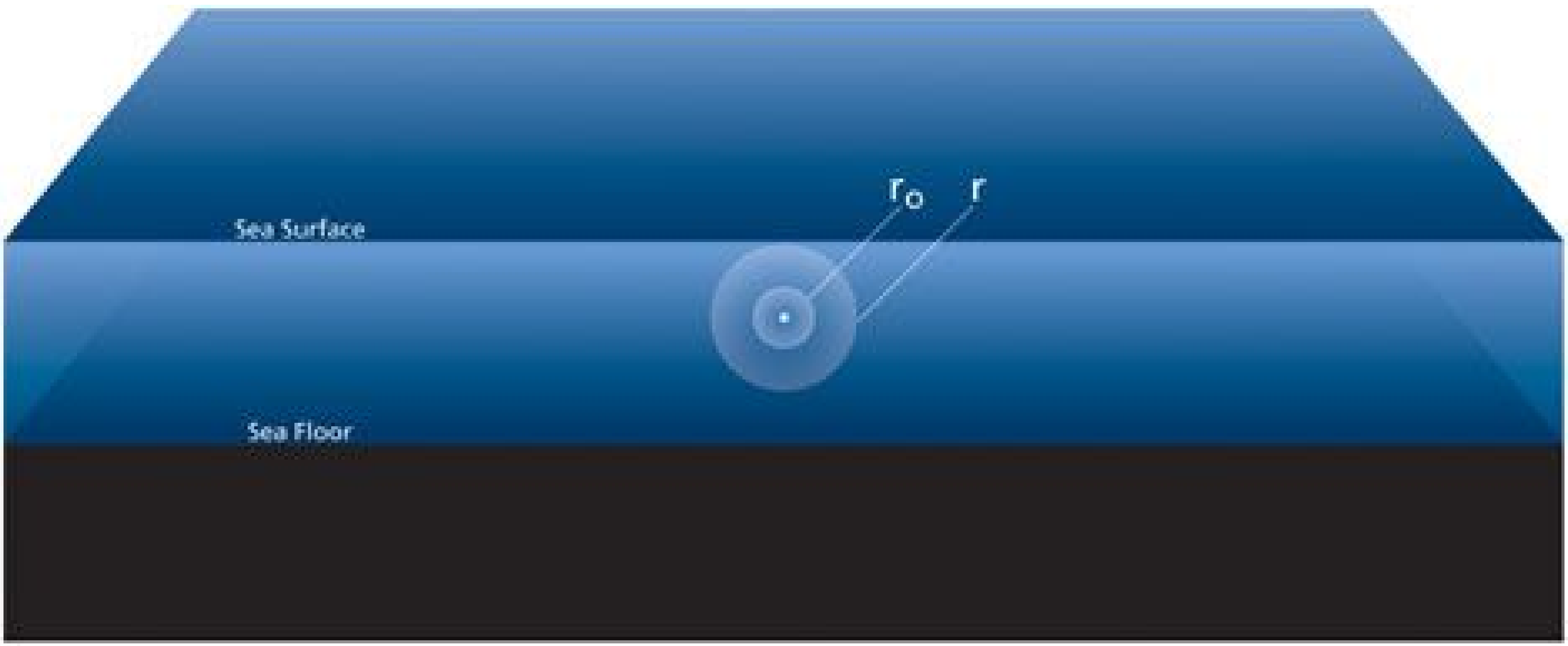
III. Sound Transmission

1. Sounds become quieter the further you are from the source

Transmission Loss – result of two processes

a. Geometric spreading

Spherical spreading if no boundaries



https://dosits.org/science/advanced-topics/cylindrical-vs-spherical-spreading/

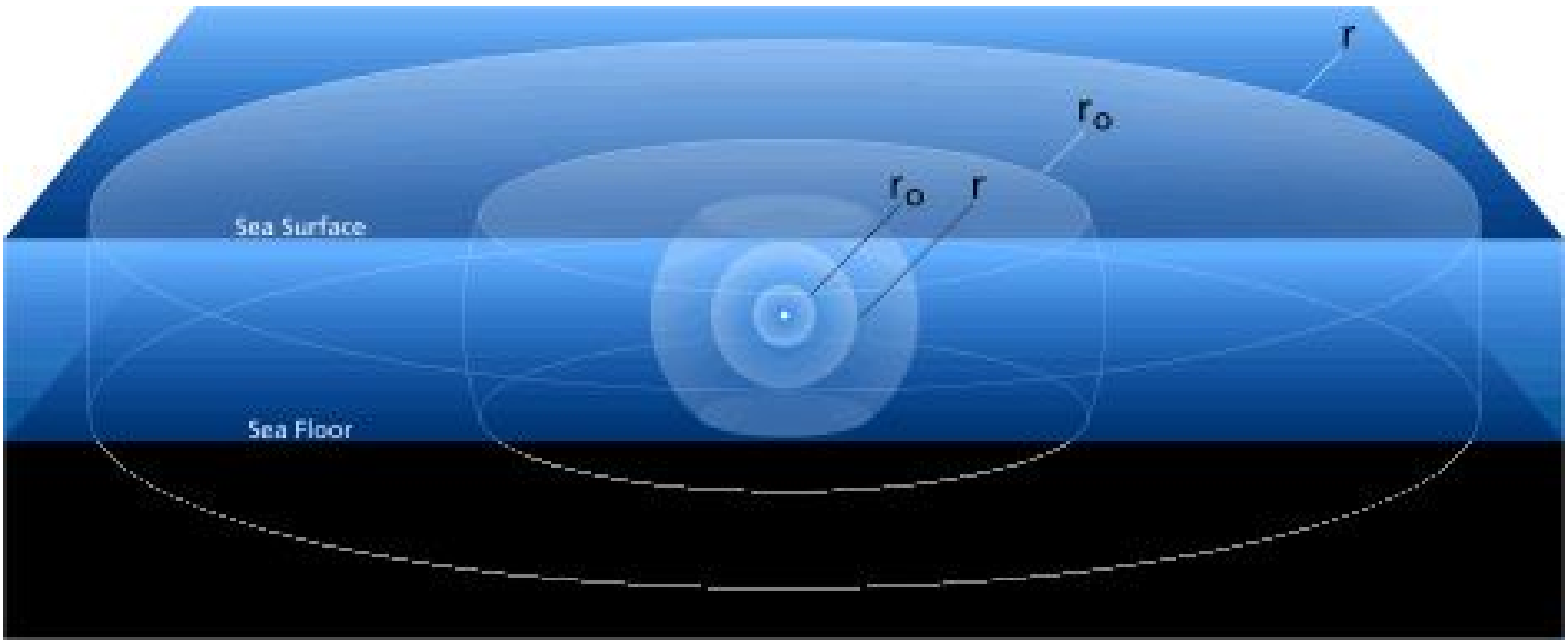
III. Sound Transmission

1. Sounds become quieter the further you are from the source

Transmission Loss – result of two processes

a. Geometric spreading

Cylindrical spreading if boundaries hit



https://dosits.org/science/advanced-topics/cylindrical-vs-spherical-spreading/

III. Sound Transmission

1. Sounds become quieter the further you are from the source

Transmission Loss – result of two processes

a. Geometric spreading

b. Absorption

Frequency-dependent process where energy is lost as sound moves from molecule to molecule in water

Higher frequencies lose more energy than lower frequencies

Salt ions ($MgSO_4$ and Boric acid) play an important role

Absorption coefficient (Francois & Garrison, 1982)

$$\alpha = f^2\left\{\frac{A_1 f_1}{f_1^2 + f^2} + \frac{A_2 P_2 f_2}{f_2^2 + f^2} + A_3 P_3\right\} \qquad \text{in salt water}$$

$$= f^2 A_3 P_3 \qquad \text{in fresh water}$$

where:

$$A_1 = \frac{8.86 \times 10^{0.78\,pH - 5}}{c}$$

$$A_2 = \frac{21.44 S(1 + 0.025T)}{c}$$

$$A_3 = 4.937 \times 10^{-4} - 2.59 \times 10^{-5} T + 9.11 \times 10^{-7} T^2 - 1.5 \times 10^{-8} T^3 \qquad T \le 20$$

$$= 3.964 \times 10^{-4} - 1.146 \times 10^{-5} T + 1.45 \times 10^{-7} T^2 - 6.5 \times 10^{-10} T^3 \qquad T > 20$$

$$f_1 = 2.8\sqrt{\frac{S}{35}}\,10^{4 - \frac{1245}{T+273}}$$

$$f_2 = \frac{8.17 \times 10^{8 - \frac{1990}{T+273}}}{1 + 0.0018(S - 35)}$$

$$P_2 = 1 - 1.37 \times 10^{-4} D + 6.2 \times 10^{-9} D^2$$

$$P_3 = 1 - 3.83 \times 10^{-5} D + 4.9 \times 10^{-10} D^2$$

This algorithm applies to all oceanic conditions and 200 Hz < f < 1 MHz.

https://dosits.org/decision-makers/tutorials/science/absorption/

III. Sound Transmission

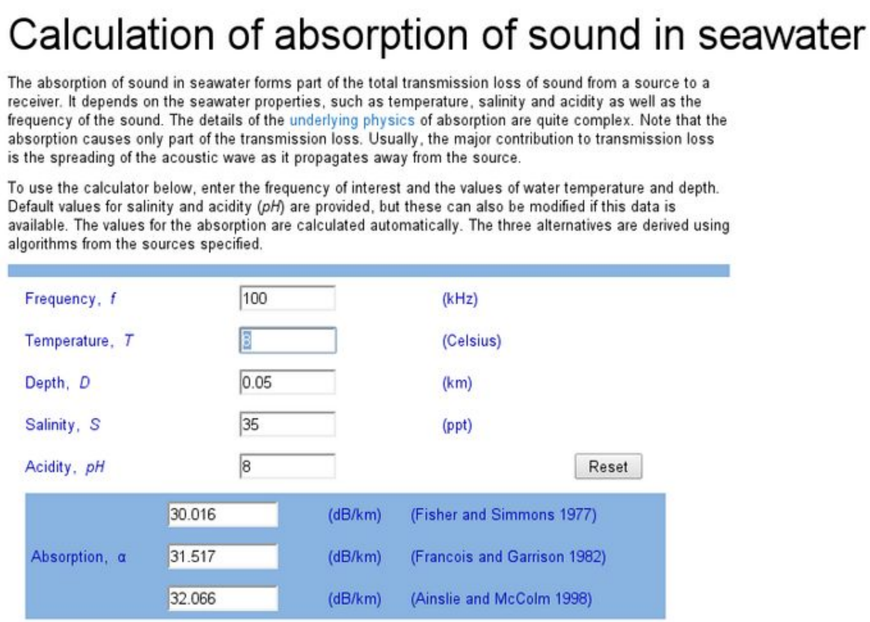
1. Sounds become quieter the further you are from the source

Transmission Loss – result of two processes

a. Geometric spreading

b. Absorption

If we know environmental parameters and frequencies, we can predict transmission loss fairly well.



http://resource.npl.co.uk/acoustics/techguides/seaabsorption/

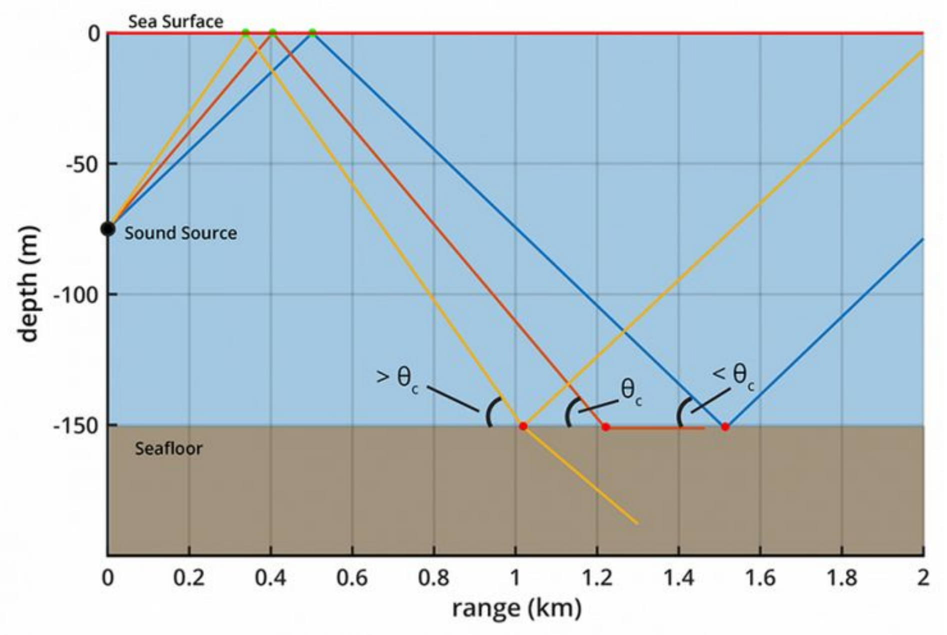
III. Sound Transmission

2. Sounds can reflect or scatter

scattering occurs when a sound wave encounters
any change in density or soundspeed of the medium

Sea surface and sea floor can reflect sound

Variations in the ocean (temperature and salinity, fish schools)
can also scatter energy



https://dosits.org/science/advanced-topics/shallow-water-propagation/

III. Sound Transmission

2. Sounds can reflect or scatter

Blue and fin whale call source levels and propagation range in the Southern Ocean

Ana Širović,[a] John A. Hildebrand, and Sean M. Wiggins
Scripps Institution of Oceanography, 9500 Gilman Drive, La Jolla, California 92093-0205

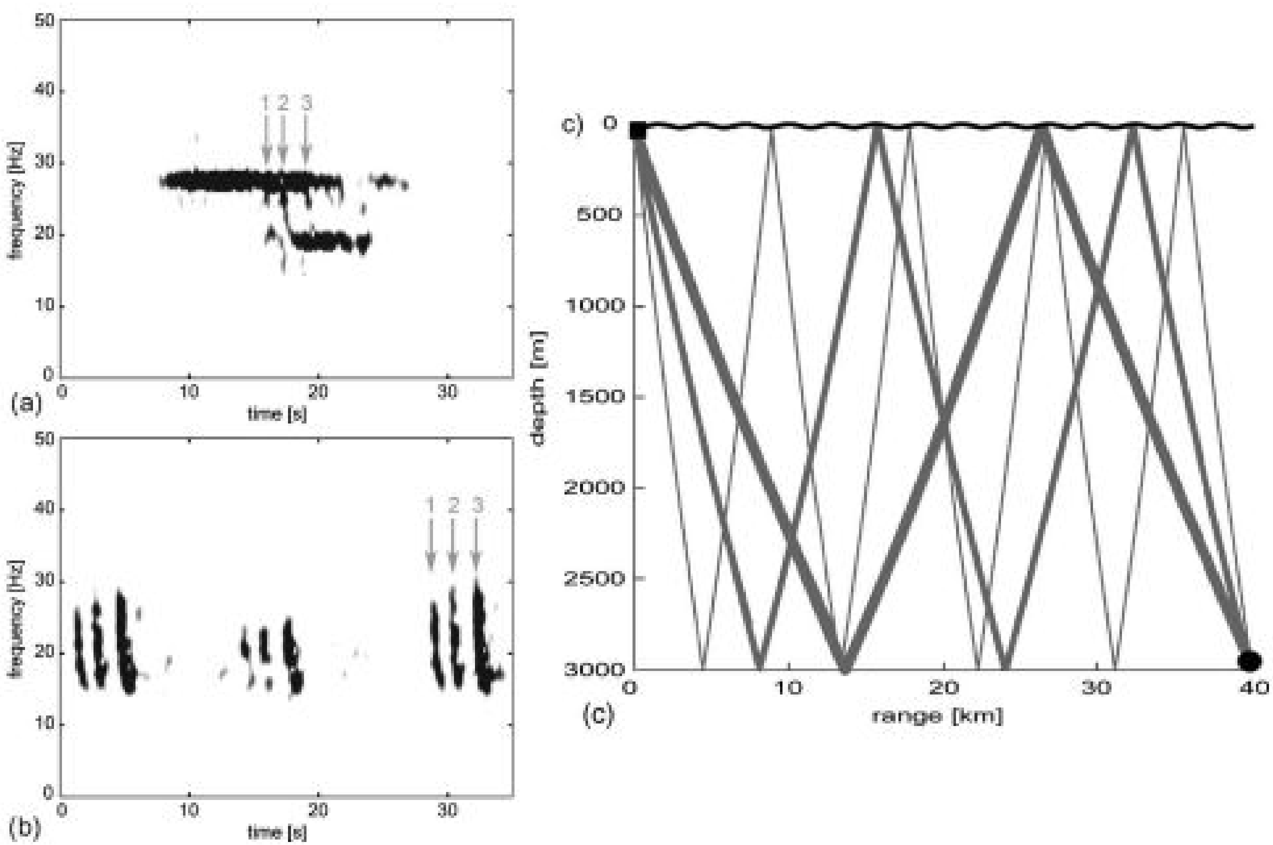


FIG. 1. Blue (a) and fin whale (b) calls recorded off the Western Antarctic Peninsula, showing multipath arrivals. In both examples, paths shown were first, second, and third bounces (marked 1, 2, and 3, respectively); direct path is not visible. Calculated ranges were 33 km for the blue whale and 40 km for the fin whale. Theoretical contributing bounces for the fin whale path arrivals are shown in part (c), with the thick line representing the first bounce, the medium thickness line for the second bounce, and the thin line for the third bounce. Calling whale location is denoted with a black square and the receiving ARP location is shown by a black circle.

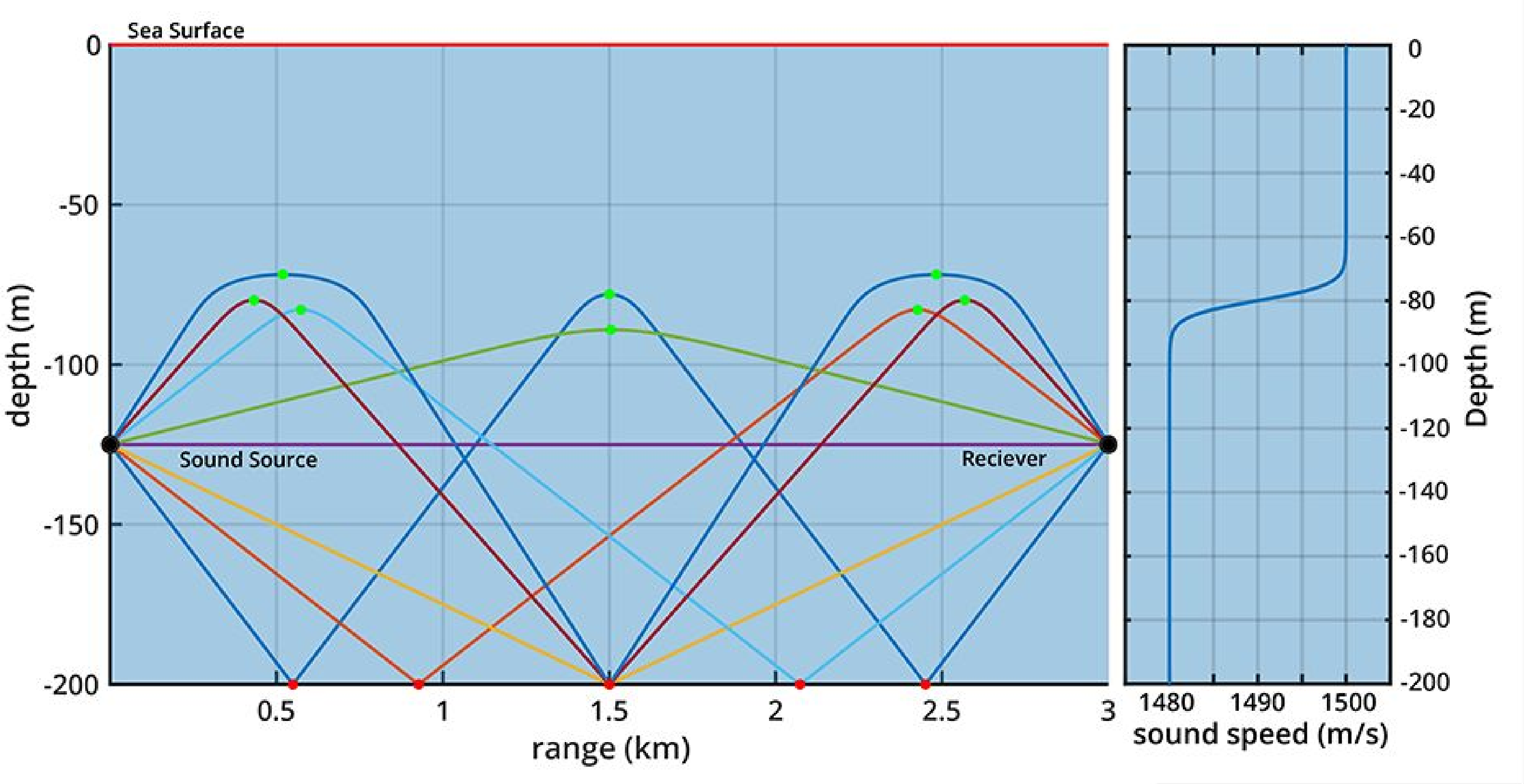
https://asa.scitation.org/doi/pdf/10.1121/1.2749452

III. Sound Transmission

3. Sounds can refract (or “bend”) as they travel

Variations in soundspeed will cause sound waves to change their direction (or refract).

Soundspeed varies w/ temperature, salinity, and pressure (depth)



https://dosits.org/science/advanced-topics/shallow-water-propagation/

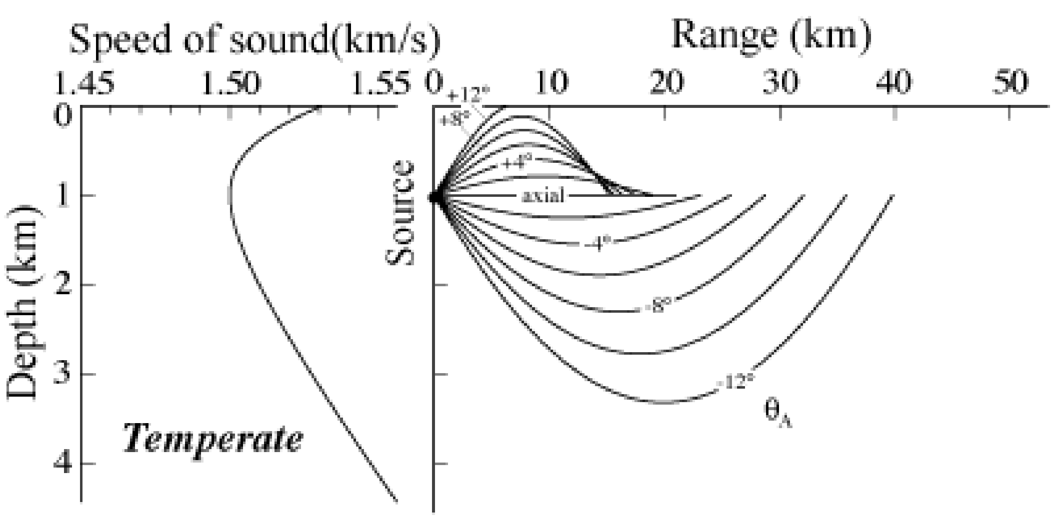
III. Sound Transmission

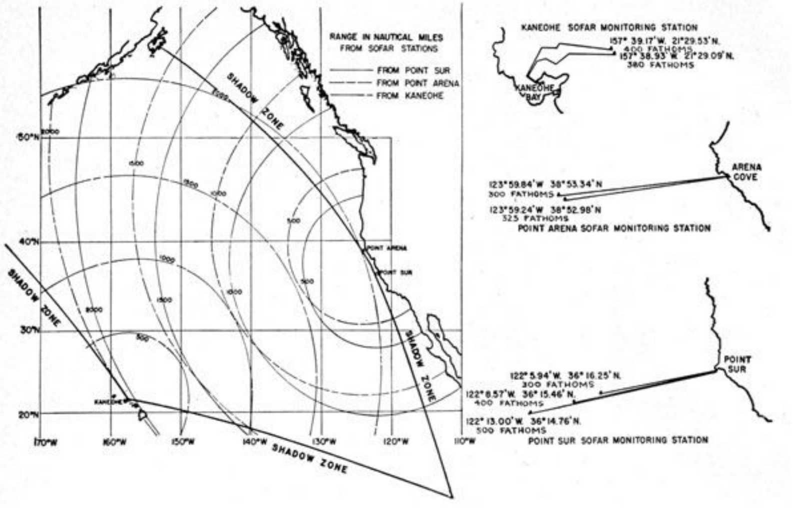
3. Sounds can refract (or “bend”) as they travel

Much of the ocean has a deep sound waveguide
(called the SOFAR channel)

Allows some sounds (whale calls) to travel very long distances

Was utilized to locate downed pilots during WW2





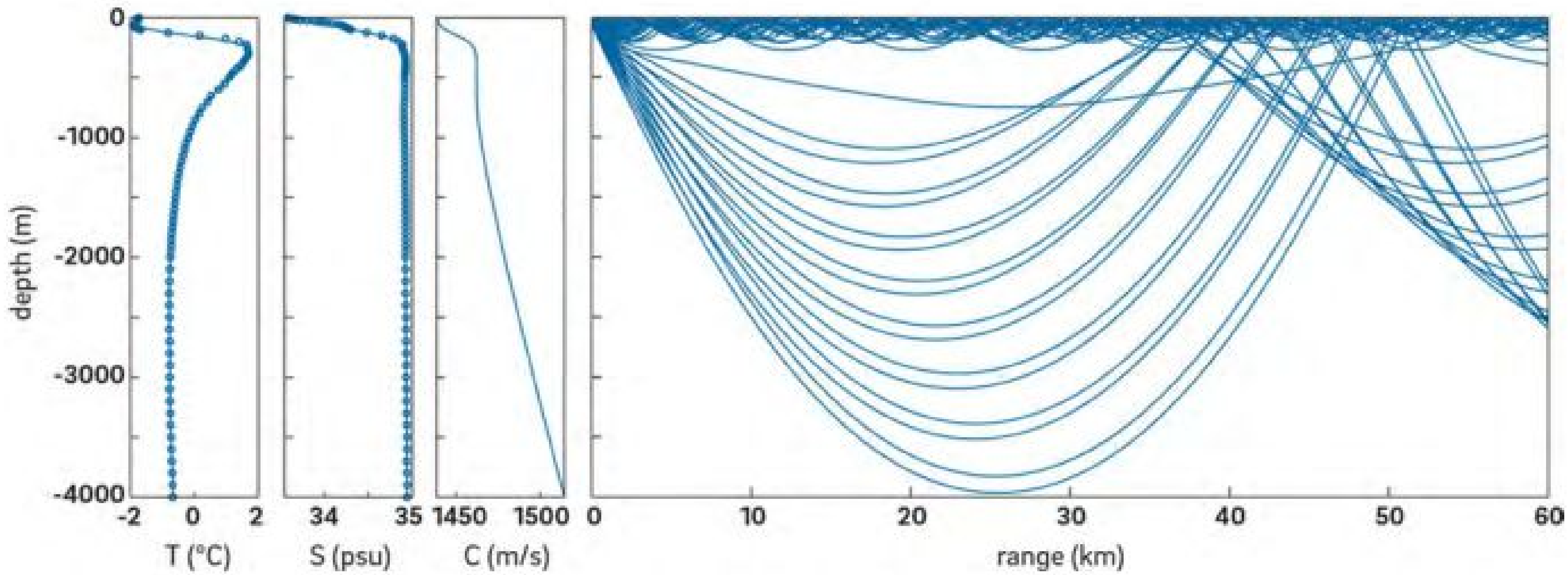
http://archive.hnsa.org/doc/sonar/chap16.htm

III. Sound Transmission

3. Sounds can refract (or “bend”) as they travel

Can get regions with higher (or lower) than expected signals

Figure 4. Left three: *temperature (T), salinity (S), and sound speed (C) profiles at 84°N, 28°E in the eastern Arctic Ocean from the 2013 World Ocean Atlas. The temperature maximum at about 300 meters is associated with the Atlantic layer.* **Right:** *geometric ray paths for an acoustic source at a 60-meter depth. Rays with positive (**upward**) and negative (**downward**) launch angles of the same magnitude give rise to the closely spaced ray pairs. The ray with a positive launch angle reflects from the surface before starting downward.*



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https://acousticstoday.org/wp-content/uploads/2020/02/Ocean-Acoustics-in-the-Rapidly-Changing-Arctic-Peter-F.-Worcester.pdf

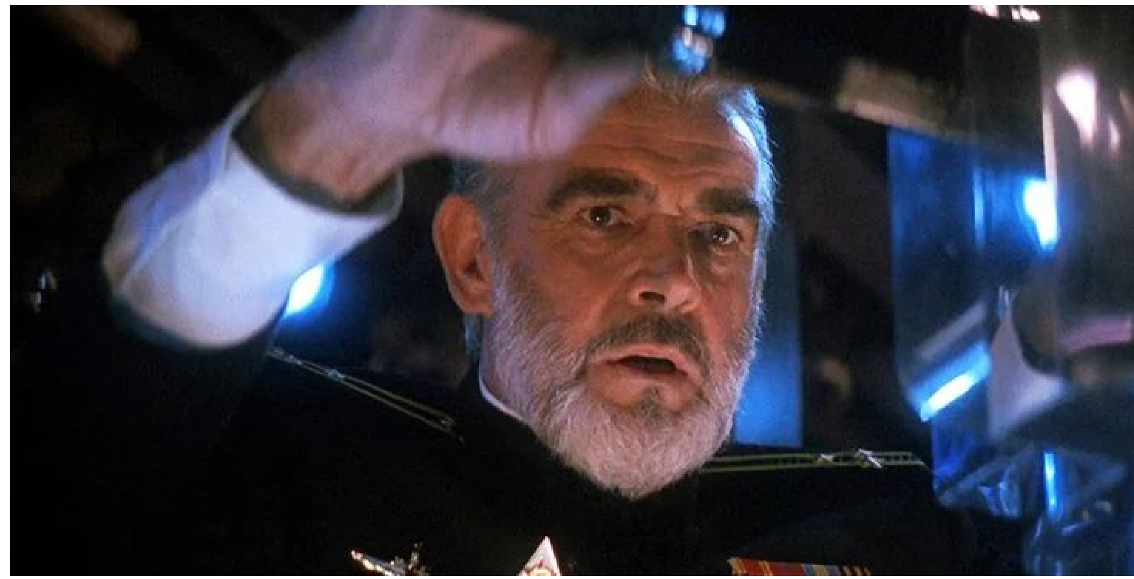
IV. Passive and active acoustics

A. Passive acoustics “listens” to an environment’s soundscape

B. Active acoustics transmits a sound, then listens for echoes

“A whale, Seaman Beaumont, a whale. A marine mammal that knows a hell of a lot more about sonar, than you do.”

- Seaman Jones [Courtney B. Vance]



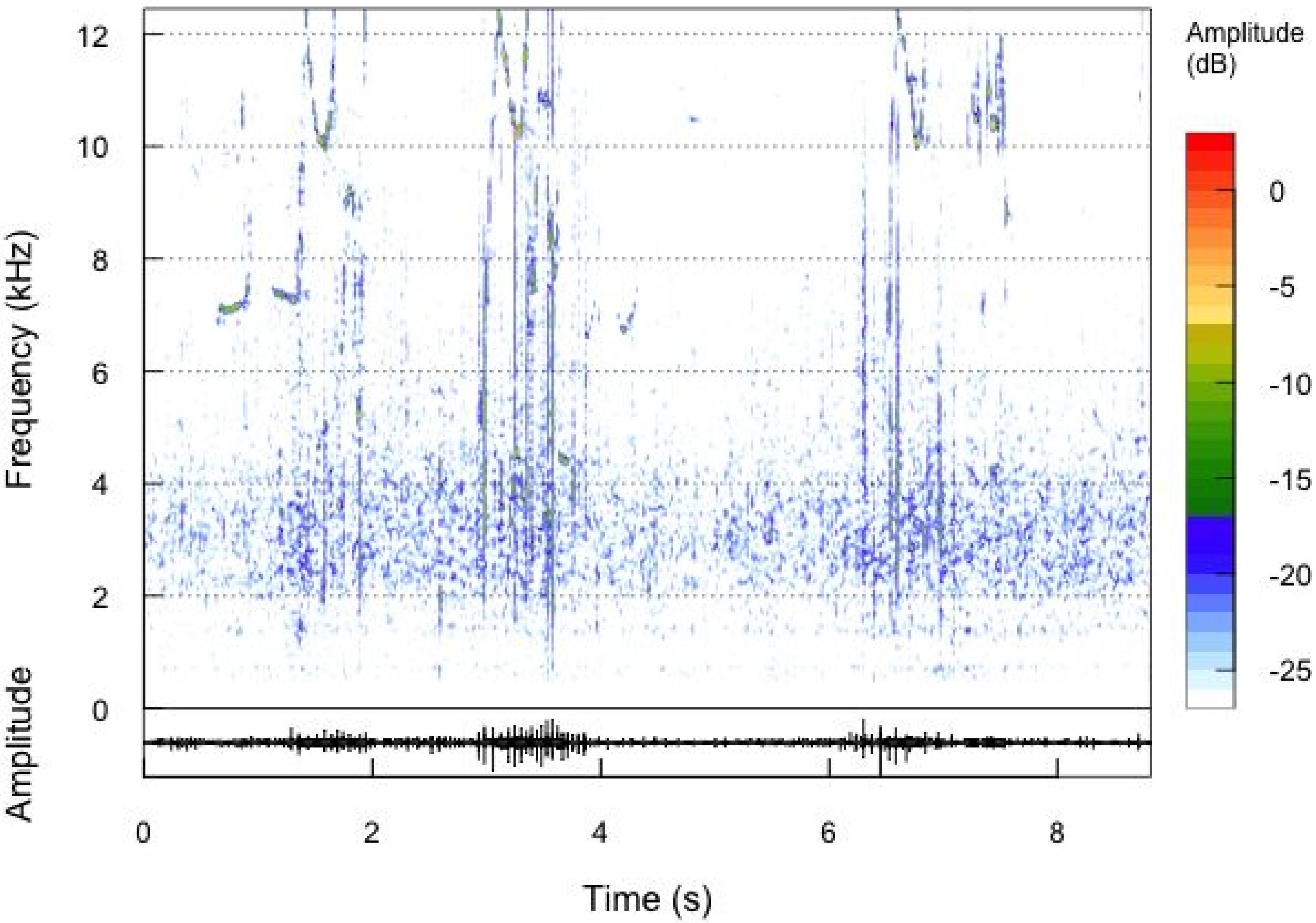
“Give me a ping, Vasili. One ping only, please.”
- Captain Ramius [Sean Connery]

The Hunt for Red October, 1990

A. Passive acoustics "listens" to an environment's soundscape

1. Silent animals can not be detected

2. Some animal sounds indicate specific behaviors



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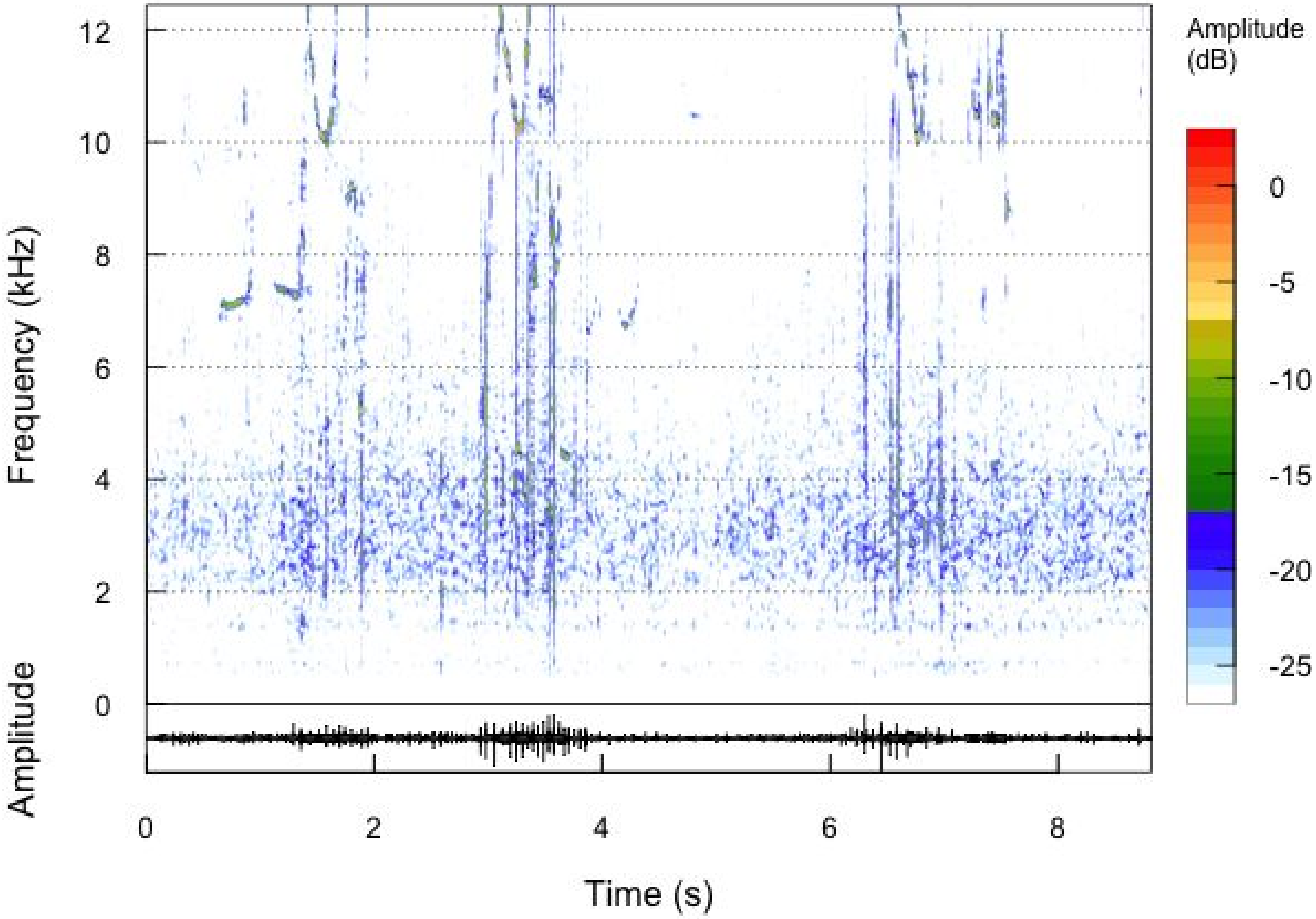
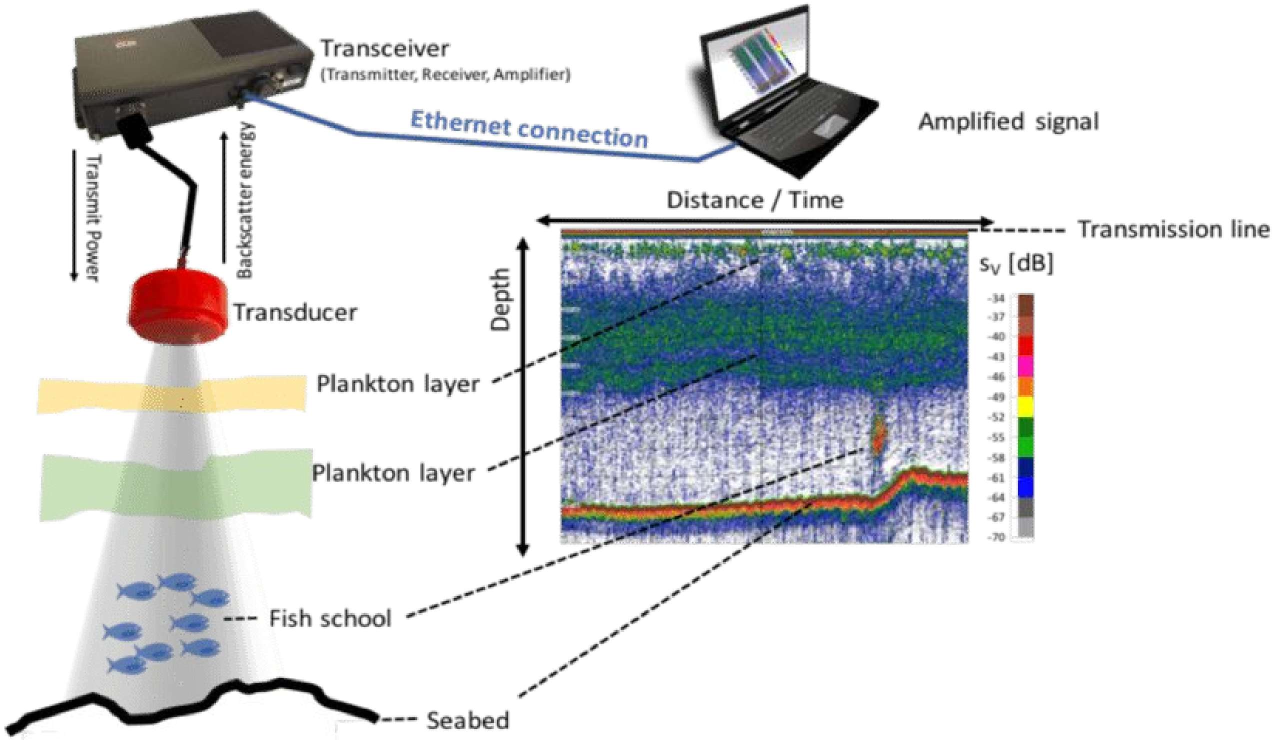


B. Active acoustics transmits a sound, then listens for echoes

1. Navigation and vessel safety
2. Geophysical exploration
3. Fisheries and biological monitoring
4. National security (vessel detection)



Graphic: Simrad Kongsberg

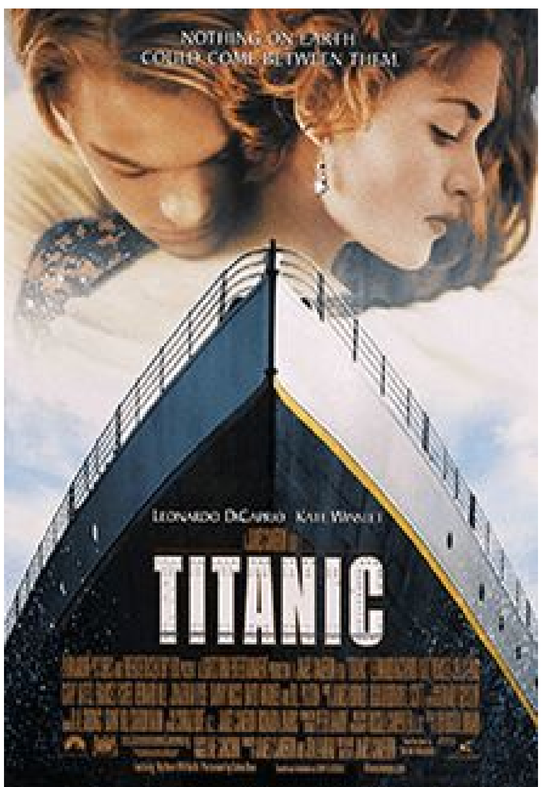
V. Sound scattering

A. Echosounder invention

B. Discovery of biological scatterers by fishers

C. Echograms provide a unique view of the ocean interior

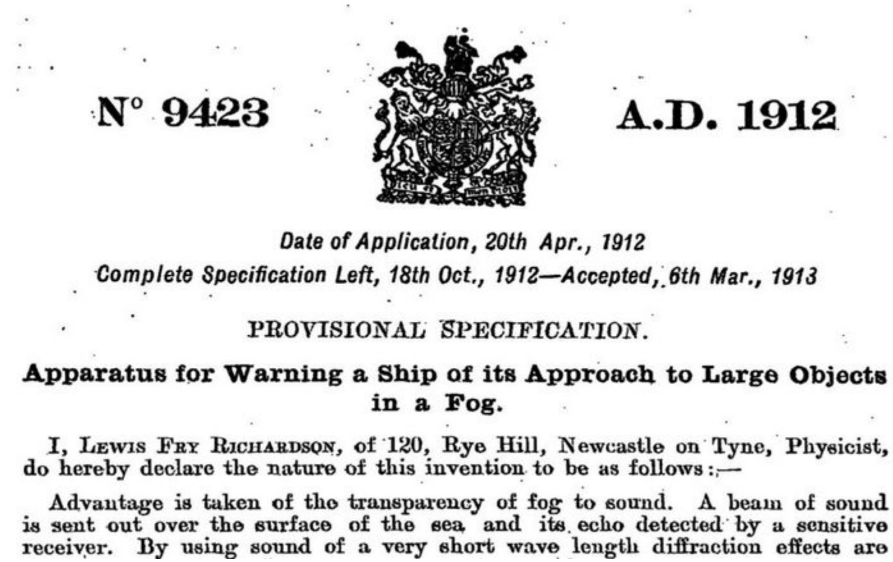
D. Examples of applied active acoustics



14-15 April 1912

A. Echosounder invention

20 April 1912 (6 days after Titanic) Lewis Fry Richardson files a British patent: “Apparatus for Warning a ship of its approach to large Objects in a Fog” (GB191209423)


N° 9423 A.D. 1912

Date of Application, 20th Apr., 1912
Complete Specification Left, 18th Oct., 1912—Accepted, 6th Mar., 1913

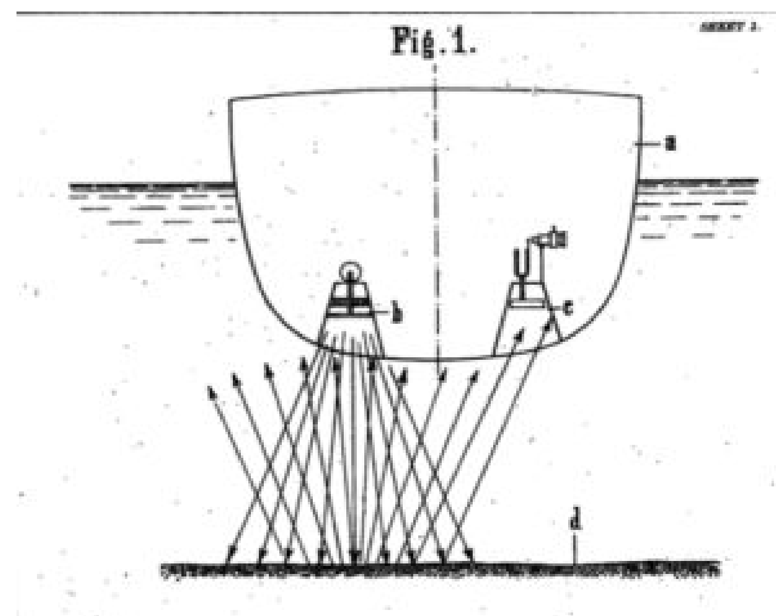
PROVISIONAL SPECIFICATION.

Apparatus for Warning a Ship of its Approach to Large Objects in a Fog.

I, LEWIS FRY RICHARDSON, of 120, Rye Hill, Newcastle on Tyne, Physicist, do hereby declare the nature of this invention to be as follows:—

Advantage is taken of the transparency of fog to sound. A beam of sound is sent out over the surface of the sea and its echo detected by a sensitive receiver. By using sound of a very short wave length diffraction effects are

A year later, German Alexander Behm files (DE 282009) for an “Improvement in or relating to a Method of and apparatus for Measuring Distances under Water by means of Reflected Sound waves”



B. Discovery of sound scattering layers

1927 - Raymond Rallier du Baty, 1927
Detects “false bottom,” attributes to fish

1929 - K. Kimura, 1929
Proves fish can produce echoes in experimental pond

1930s - Ronnie Balls (UK) and Reinert Bokn (Norway)
Fishing captains, start using echosounders

1935 - Oscar Sund First published echograms of fish in Nature

Echo Sounding in Fishery Research

THE vessel used for the annual oceanographical investigations in the Lofoten area (the *Johan Hjort*) had a Hughes echo sounding gear (magnetostriction system, frequency 16,000 cycles per second) installed the conclusion of this investigation on April 5. Concurrently, the temperature in the 'fish' water-layer had decreased from 6·5°–6·0° to about 3·0° C. In some instances a perceptibly lower oxygen and hydrogen ion concentration was observed in this water-layer than in the layers immediately above and below.

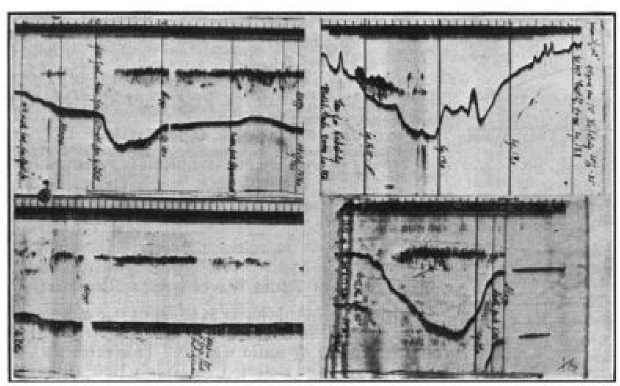


FIG. 1. Four 'echo'-records showing spawning cod in midwater at Lofoten. The left-hand diagrams partly with ship stopped. The bottom right-hand record is somewhat disfigured by oscillations set up by excessive shaking of ship's motor; but it shows also a second echo from the bottom, reflected from the surface. Marks on top of each diagram are produced every minute and are 6·7 mm. apart.

Although two zigzag trips were made across the entire bank area of the West Fjord, strong marks such as those shown in the records reproduced were only obtained at the locality referred to above; in other places only small and widely separated dots. Still a certain amount of fishing, if not very successful, was going on everywhere. A true estimate of the quantity of fish represented by marks of different types can, however, be gained only by further study in connexion with the use of suitable fishing implements.

OSCAR SUND.

Johan Hjort,
Kabelvåg, Lofoten.
April 6.

B. Discovery of sound scattering layers

Noon | Midnight | Noon

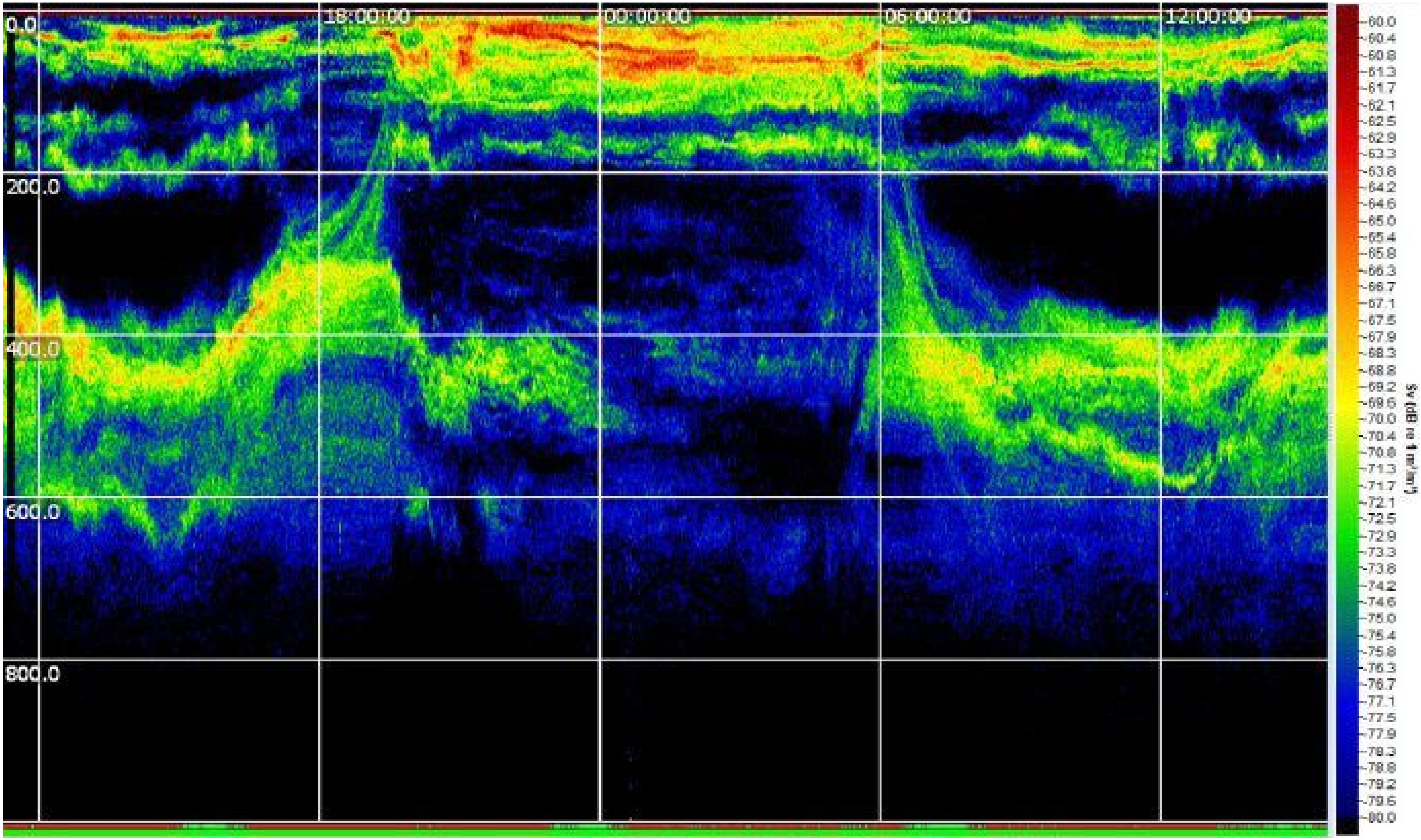
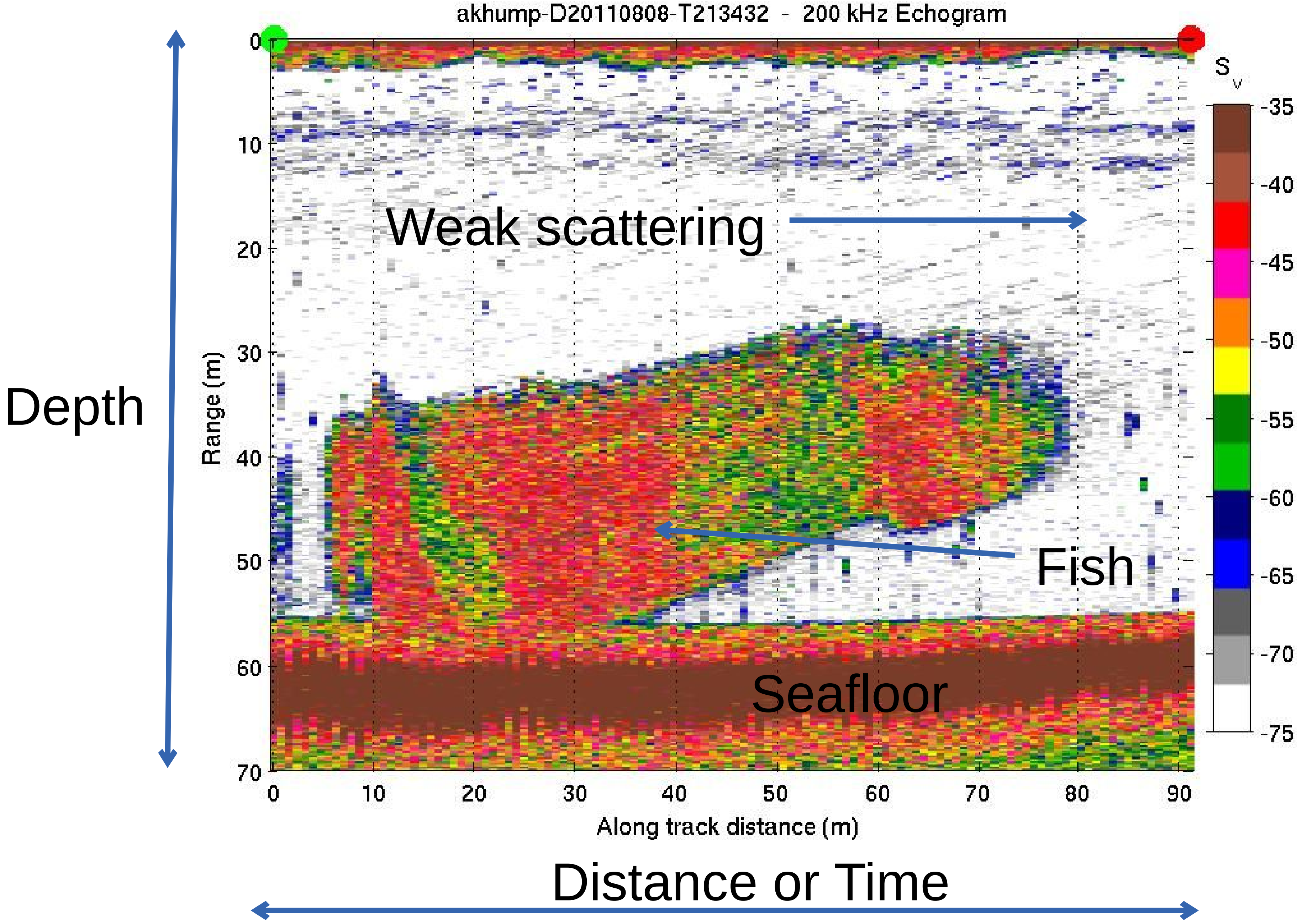
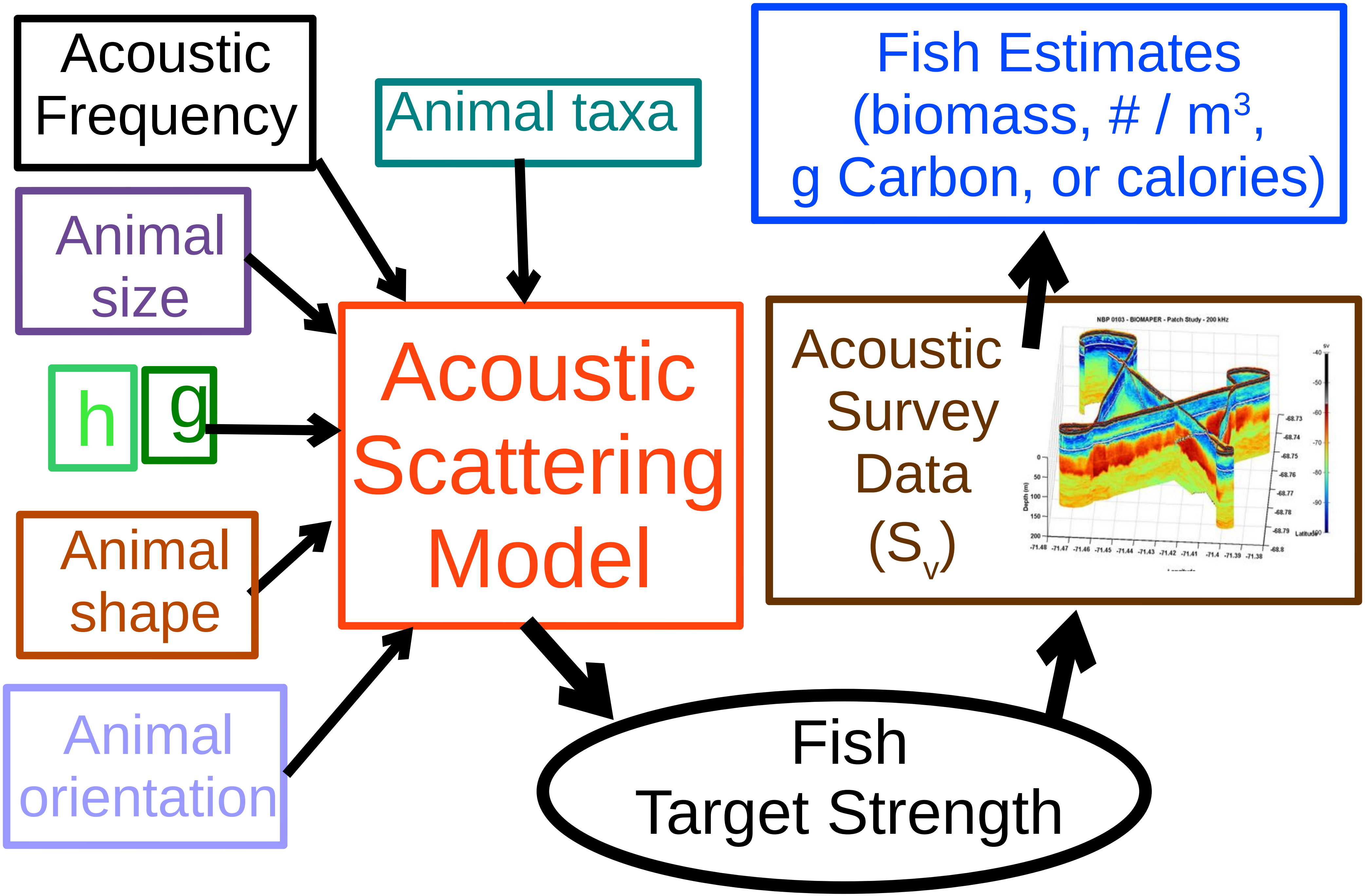


Figure courtesy of Dr. Kevin Boswell (FIU)

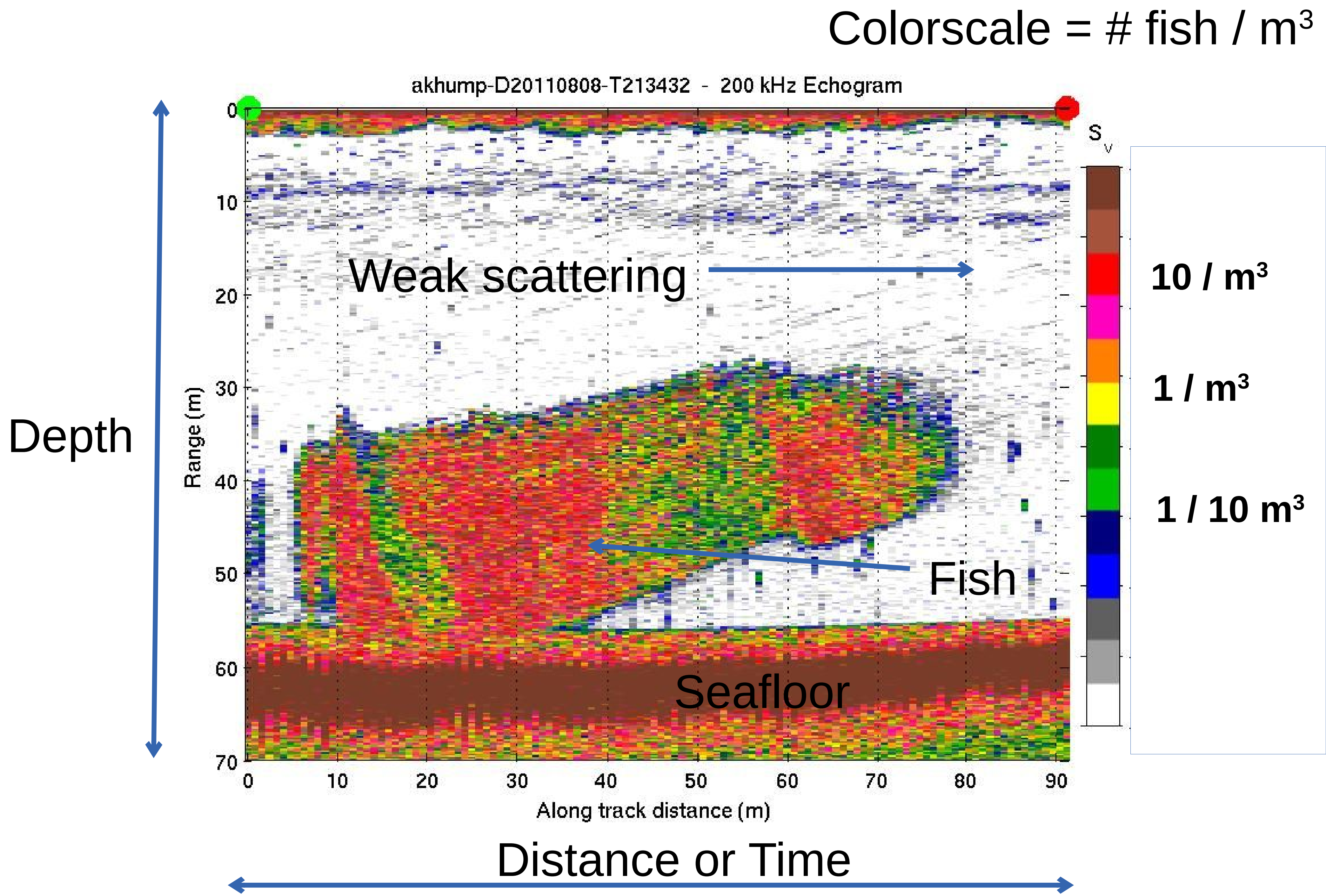
C. Echograms show what happens below the surface



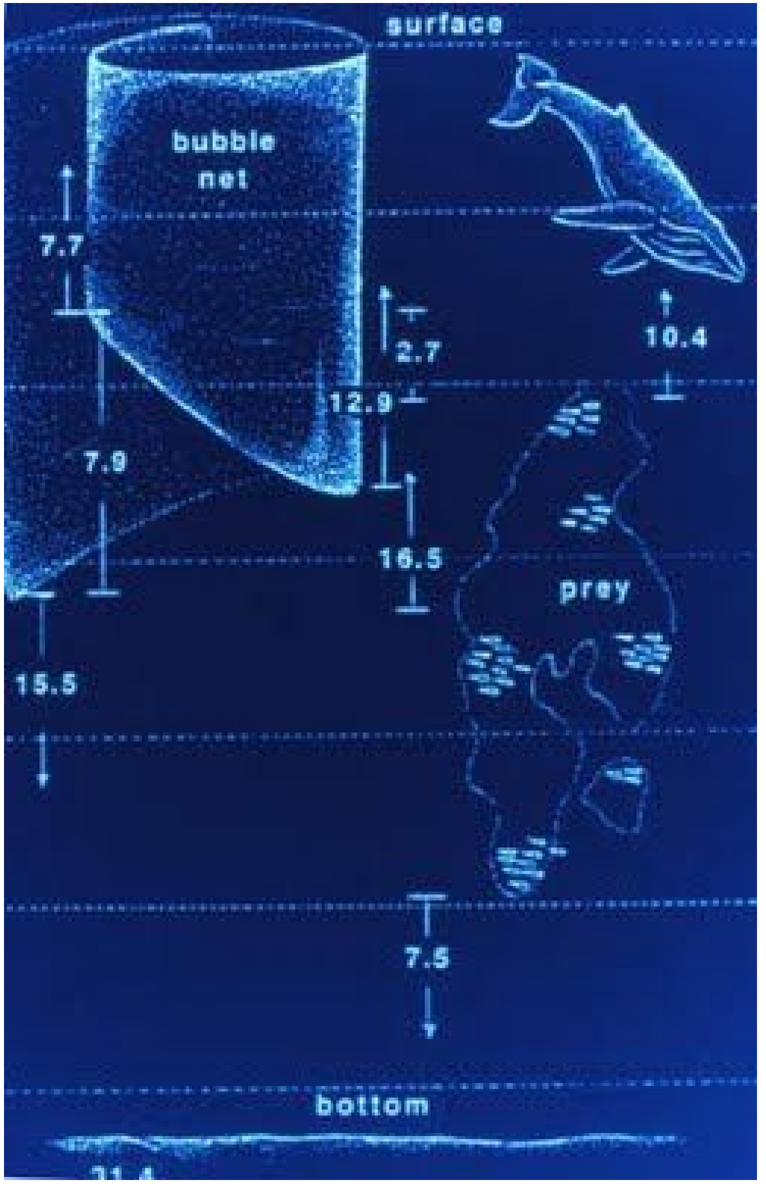
C. Estimating Biology from Acoustic Measurements

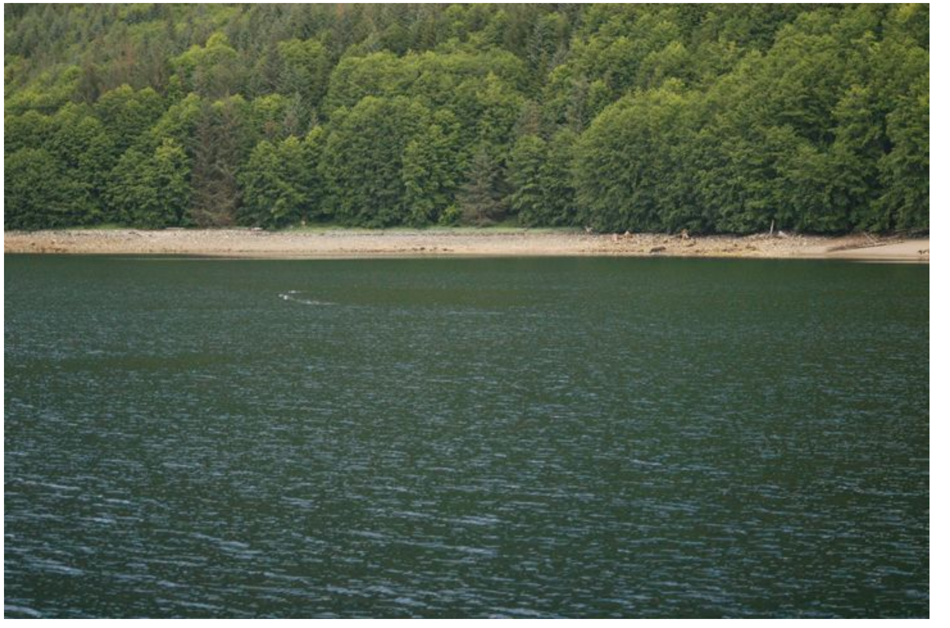


C. Estimating Biology from Acoustic Measurements



D. Applied active acoustics – Foraging humpback whales in Alaska (work done w/ Dr. Heidi Pearson, U. Alaska Southeast)





D. Applied active acoustics – Foraging humpback whales in Alaska

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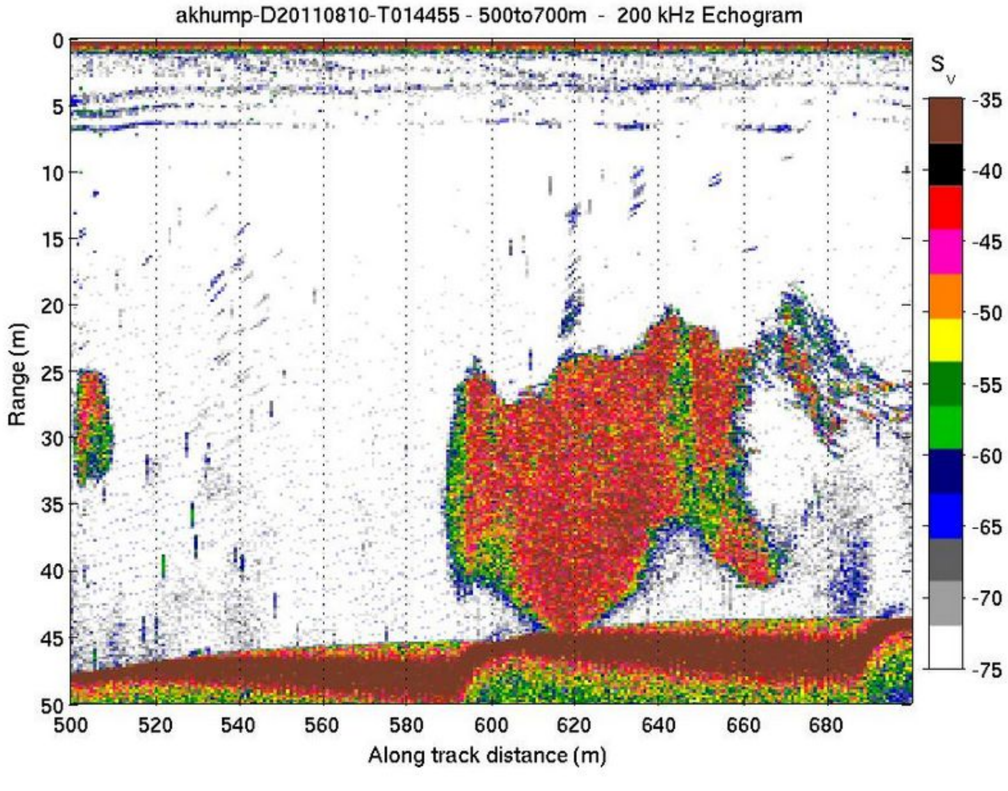
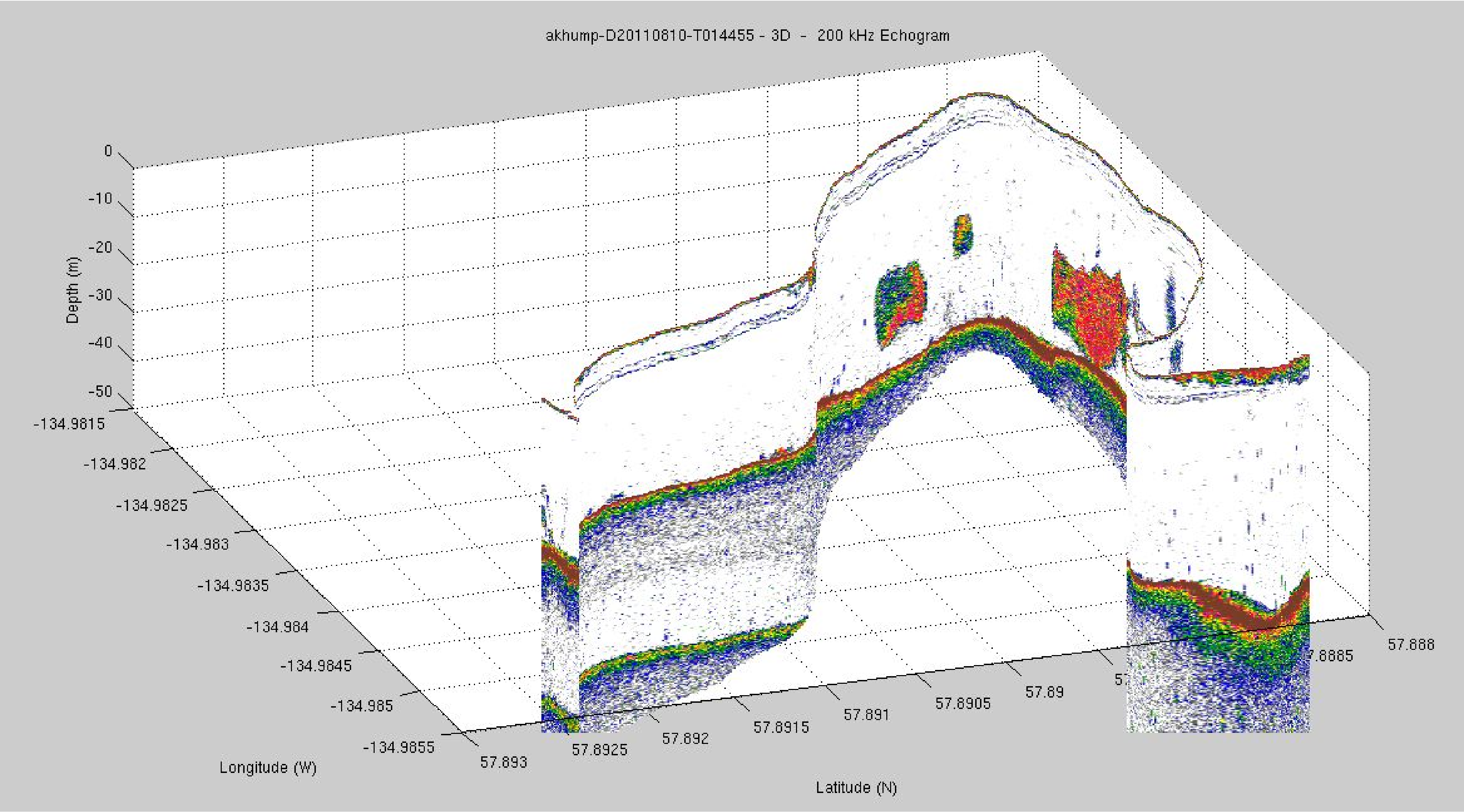
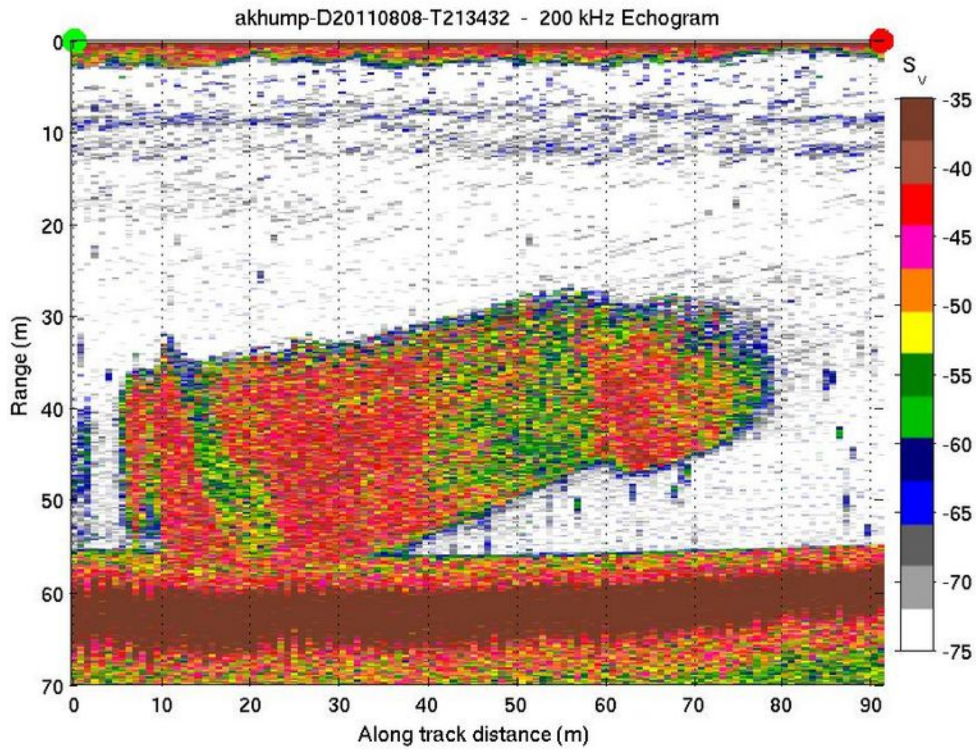


D. Applied active acoustics – Foraging humpback whales in Alaska



D. Applied active acoustics – Foraging humpback whales in Alaska

How many fish are in a bubble-net 'corral' ?



Volume of corral ?

~ cylinder 20 m dia/ht

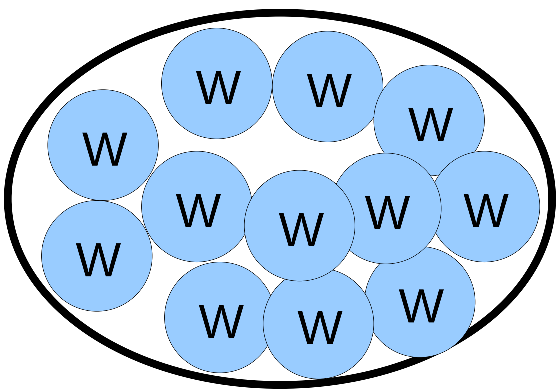
# of fish / m^3 in corral ?

~ 10 / m^3 [red areas]

# of whales feeding ?

12

Efficiency ? 70%-20%



95%-50%

D. Applied active acoustics – Foraging humpback whales in Alaska

How many fish are in a bubble-net 'corral' ?

63,000 fish / corral

“most efficient feeding”

3,500 fish / whale gulp

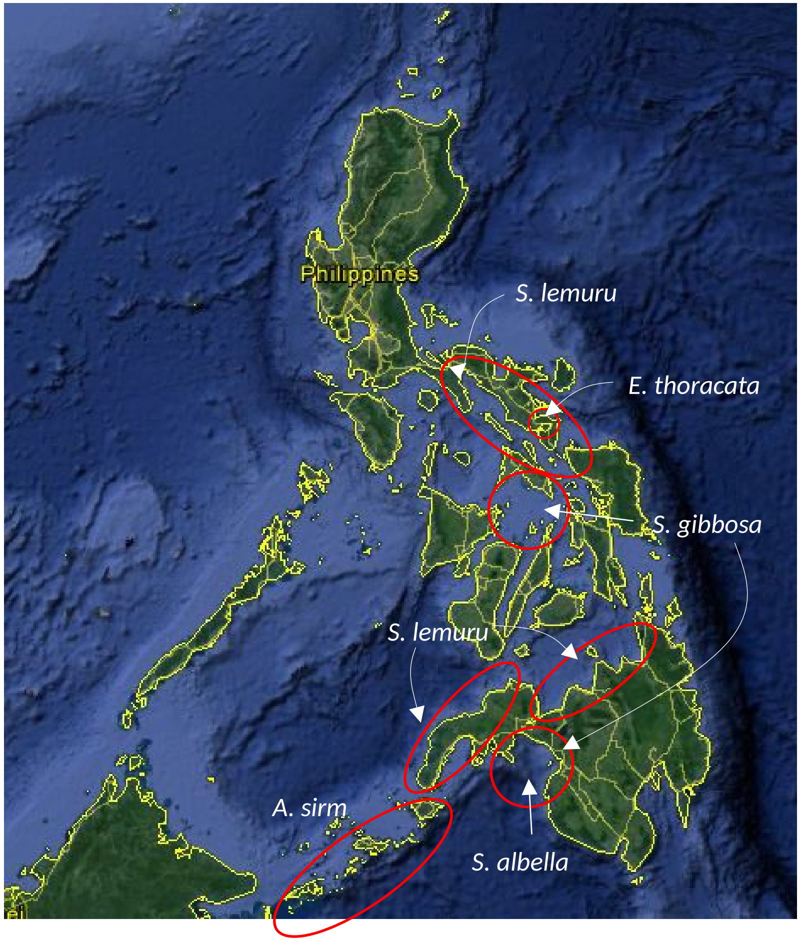
2 gulps / whale / day

“least efficient feeding”

250 fish / whale gulp

32 gulps / whale / day

D. Applied active acoustics - Philippine Sardines



> 7,000 islands in the Philippines

10^{th} in the world in seafood production

- 90% of catch consumed domestically
- 72 lbs of fish / person / year

Sardines are ~ 20% of catch

1.6 million fishermen

70% of stocks are likely overfished
potentially 800 million people at risk (food security)

BFAR (enforcement agency) has very limited resources

Moalboal Sardine Shoal

Regular (daily) near-shore aggregation of **A LOT** of sardines

Tourist attraction for ~ 10 local dive/snorkel operators

Diving Moalboal and Pescador Island

Swimming With Millions of Sardines in Moalboal, Philippines

Snorkeling, Island Hopping and Sardine Run -Moalboal Cebu

BEAUTIFUL MOALBOAL (DRONE IS BACK!)

Moalboal Sardine Shoal

Regular (daily) near-shore aggregation of **A LOT** of sardines

Tourist attraction for ~ 10 local dive/snorkel operators

Snorkeling, Island Hopping and Sardine Run -Moalboal Cebu

BEAUTIFUL MOALBOAL (DRONE IS BACK!)

Moalboal Sardine Shoal

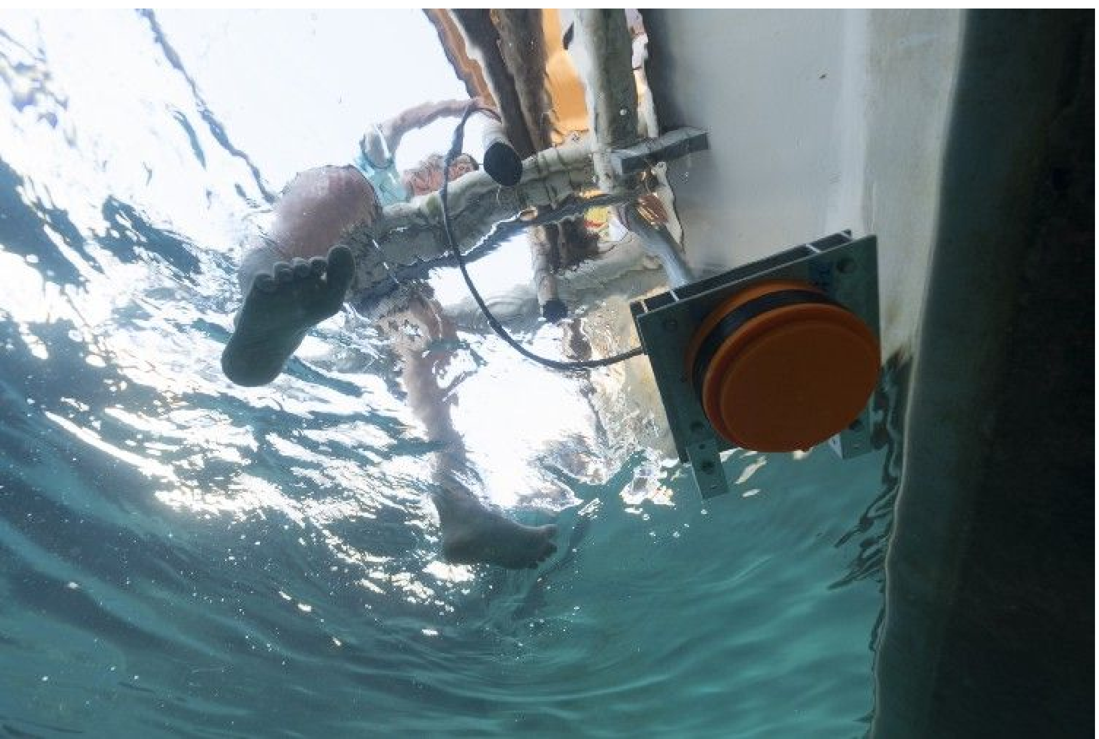
Shoal has been stable for ~ 5 years

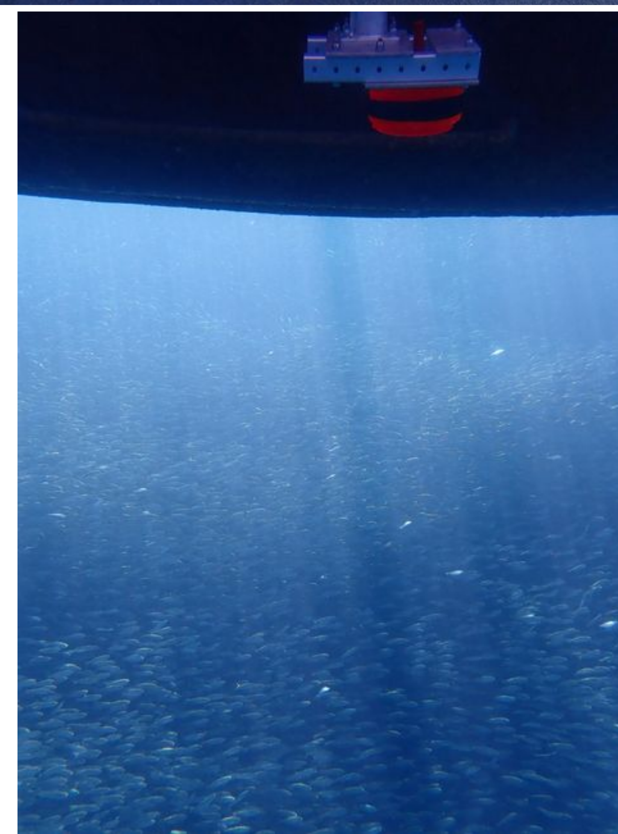
It is also fished

What is the economic value of shoal
- as a source of fish for food
- as a tourist resource

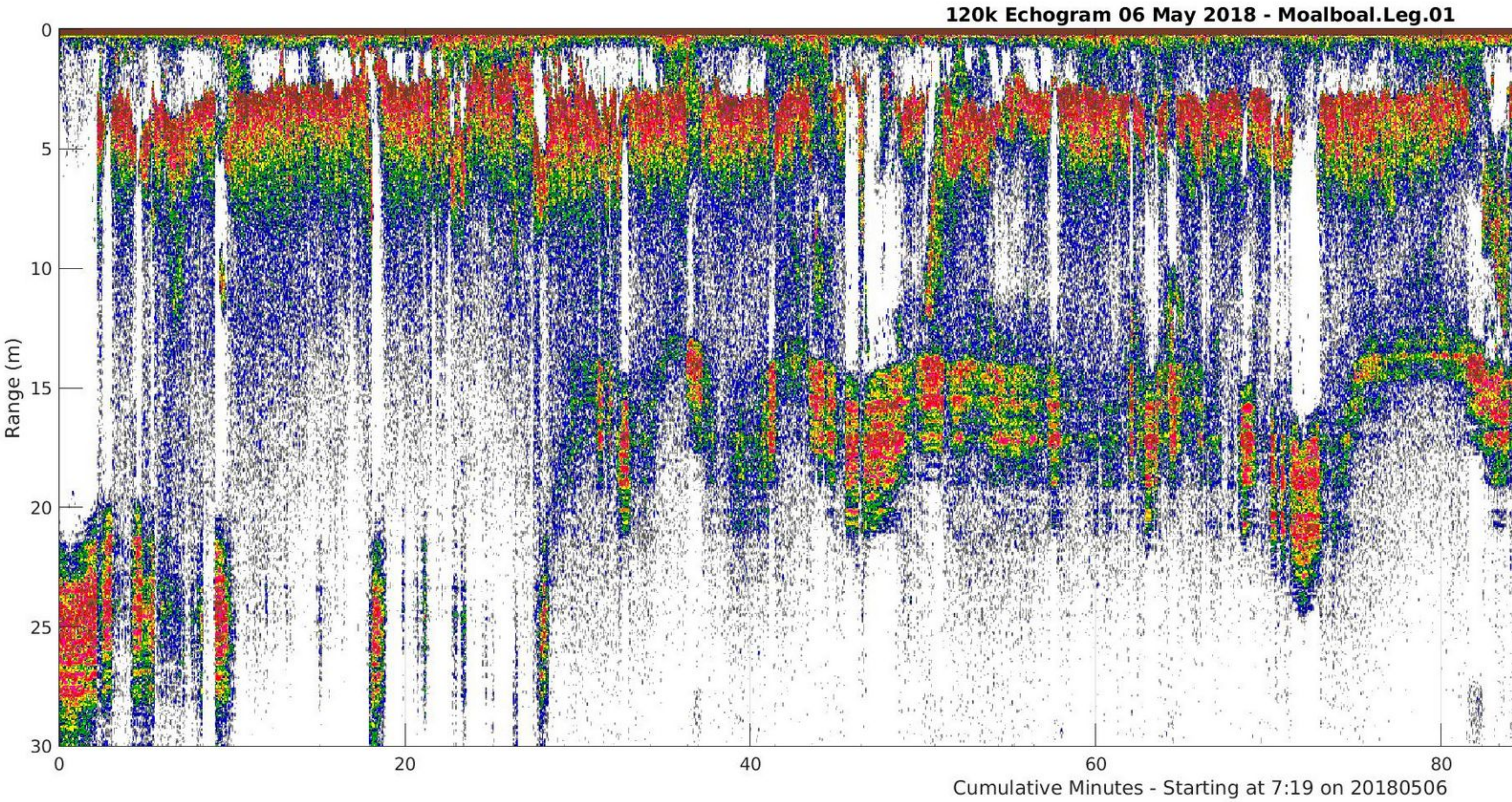
How many fish are there in the shoal ?


DAVIES

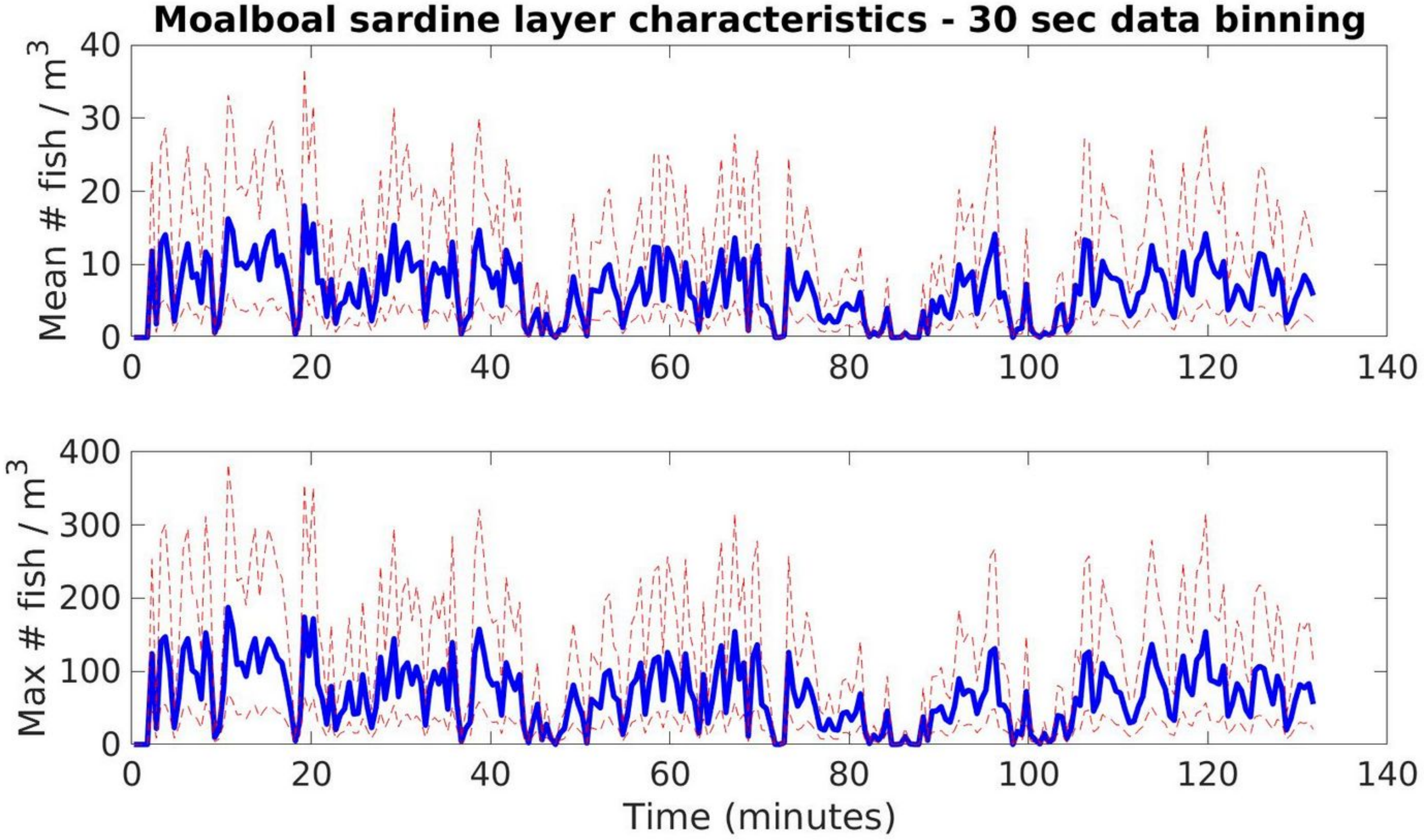




Estimating # of Sardines



Estimating # of Sardines



Measured packing density agrees with theoretical estimates (~ L^{-3} ~ 250-500/m^3)

Estimating # of Sardines

Fish = School Volume * Packing density

Acoustics

H (2 – 4 m)

Mean packing density (5-10/m^3)

L, W estimated (200 - 600 m, 3 – 10 m)

Fish ~ 150,000 sardines

(10,000 to 250,000 sardines)

So don't believe youtube video titles !

Estimating # of Sardines

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Marine ecotourism for small pelagics as a source of alternative income generating activities to fisheries in a tropical community

Christopher Cusack[a,*], Suresh A. Sethi[b,c], Aaron N. Rice[c,d], Joseph D. Warren[e], Rod Fujita[a], Jose Ingles[f], Jimely Flores[f], Edwina Garchitorena[f], Sheryll V. Mesa[g]

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[f] Environmental Defense Fund, Metro Manila, Philippines
[g] National Stock Assessment Program, Bureau of Fisheries and Aquatic Resources, Regional Field Office VI, Iloilo City, Philippines

Estimated fishery value ~ $19,000 USD

Tourism economic value ~ $17,000,000 USD

Thanks for attending and I’m happy to answer questions ?

Feel free to contact me: joe.warren@stonybrook.edu