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

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.
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,\textsuperscript{a) }Peter W. Jacobus,\textsuperscript{b) }Leo H. Ostwald,\textsuperscript{b) }and David E. Snyder\textsuperscript{b) }

\textit{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).

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

https://dosits.org/galleries/audio-gallery/
Listening to – humpback whale

Humpback Whale off of Fire Island, NY - November 2020
Joseph Warren and Melissa Leone, Stony Brook University
joe.warren@stonybrook.edu
A. Different sources of underwater sound

3. Anthrophony – human-created sounds

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

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)
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

Fin whale 20 Hz pulse train from Fire Island, NY - March 2021
amplified
Joseph Warren and Melissa Leone, Stony Brook University
joe.warren@stonybrook.edu
Listening to – fin whale 20 Hz pulse
Listening to – fin whale (sped up 10X)

Fin whale 20 Hz pulse train from Fire Island, NY - March 2021 amplified and sped up by 10X
Joseph Warren and Melissa Leone, Stony Brook University
joe.warren@stonybrook.edu
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
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 (MgSO₄ and Boric acid) play an important role

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.

Calculation of absorption of sound in seawater

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
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.

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

1. Silent animals can not be detected

2. Some animal sounds indicate specific behaviors
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)
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
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)

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
B. Discovery of sound scattering layers

Figure courtesy of Dr. Kevin Boswell (FIU)
C. Echograms show what happens below the surface

Weak scattering

Fish

Seafloor

Distance or Time

Depth
C. Estimating Biology from Acoustic Measurements

**Acoustic Scattering Model**

- Acoustic Frequency
- Animal size
- Animal shape
- Animal orientation
- Fish Target Strength

**Acoustic Survey Data** ($S_v$)

**Fish Estimates** (biomass, # / m³, g Carbon, or calories)
C. Estimating Biology from Acoustic Measurements

Colorscale = \# fish / m$^3$

- Weak scattering
- Fish
- Seafloor

Depth

Distance or Time

akhump-D20110808-T213432 - 200 kHz Echogram
D. Applied active acoustics – Foraging humpback whales in Alaska (work done w/ Dr. Heidi Pearson, U. Alaska Southeast)
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![3D echogram of humpback whale foraging](image-url)
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 / m³ in corral?
~ 10 / m³ [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\textsuperscript{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
Moalboal Sardine Shoal

Regular (daily) near-shore aggregation of a lot of sardines

Tourist attraction for ~10 local dive/snorkel operators
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?
Estimating # of Sardines
Estimating # of Sardines

Measured packing density agrees with theoretical estimates (~ L⁻³ ~ 250-500/m³)
Estimating # of Sardines

# Fish = School Volume * Packing density

Acoustics

H (2 – 4 m)
Mean packing density (5-10/m³)

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!
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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e School of Marine and Atmospheric Sciences, Stony Brook University, Southampton, NY, USA
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