Sanctuary Splash: Acoustics of Cetaceans

Photo:Yoshihiro Shimada, Your Shot, National Geographic

Grade Level

- 5th

Time Frame

- 90 minutes

Materials

- Computer, projector, and screen
- Audio/visual materials:
  - Vocalization PowerPoint
- Program materials:
  - Metal Slinky
  - Tuning forks and rubber strikers (rubber erasers), small cups of water, towels for clean up
  - Dolphin skull
  - Stop-watch
  - Laminated blank spectrogram handouts, whiteboard markers, and eraser

Photo: Ed Lyman/NOAA

Activity summary

Students will experience listening to whale vocalizations and will participate in simulations of sound perception and efficiency of sound transfer through matter. Students will also gain a basic understanding of how sounds are measured and recorded when studied in a marine environment, and how various cetacean species communicate and are identified by the vocalizations they make.

Learning objectives

Students will be able to:

- Understand and be able to hypothesize about the reasons that whales make vocalizations, and why they depend on hearing rather than vision;
- Listen to whale vocalizations;
- Understand that sound travels more efficiently in solids and liquids than through air;
- Discuss the reasons why different species of whales have different calls;
- Recognize that whales and other marine animals have ear structures different from land animals; and
- Understand the scientific process involves trial and error.

Key Words

- acoustics
- auditory
- bulla
- cetacean
- frequency
- Hertz
- hydrophone
- spectrogram
- sound waves
- vocalization

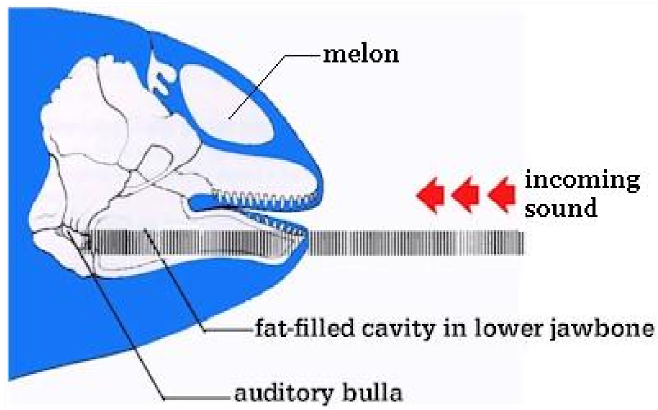
Instructor background information

National marine sanctuaries

Managed by the National Oceanic and Atmospheric Administration (NOAA), the Office of National Marine Sanctuaries is a network of 15 national marine sanctuaries and two marine national monuments encompassing more than 600,000 square miles of marine and Great Lakes waters. These sanctuaries seek to preserve the extraordinary scenic beauty, biodiversity, historical connections, and economic productivity of these underwater treasures. The West Coast of the United States hosts an oceanographic phenomenon known as upwelling, a wind-driven process where cold, nutrient rich water from the ocean floor moves upwards to replace warmer, nutrient-depleted surface waters. This influx of nutrients stimulates the growth of primary producers such as phytoplankton, fueling their activity and thus strengthening the ocean food web. Upwelling along the West Coast has created incredibly diverse and unique ecosystems and five national marine sanctuaries have been designated to protect this special region: Olympic Coast, Greater Farallones, Cordell Bank, Monterey Bay, and Channel Islands national marine sanctuaries.

Olympic Coast National Marine Sanctuary

Olympic Coast National Marine Sanctuary (OCNMS) protects the wildlife and habitats of one of the most diverse and productive marine environments in the world, an area of 3,188 square miles off the Washington coast. The waters within Olympic Coast National Marine Sanctuary support an abundance of life, including many threatened or endangered species.



Graphic: Scienceblogs.com

How cetaceans and humans use sound

Sound is very important to lots of organisms, including cetaceans, for communicating, hunting, and navigating. Whales and dolphins have a very well developed and acute sense of hearing. Sound travels four times faster in water than in air, and much farther, so whales can hear sounds from very long distances away.

Baleen whales and toothed whales use sound very differently. Baleen whales (such as minke whales and humpbacks) produce a series of sounds which are frequently called vocalizations or "songs" that are used for communication. Dolphins and toothed whales (such as killer whales and sperm whales) use sounds for communication, as well as for hunting and navigating. Research has shown that toothed whales are able to communicate and navigate at the same time.

In humans, the ear drum conducts vibrations in the ear to the bones in the inner ear, where "hearing" takes place. What we consider "hearing" is the brain interpreting vibrations as sounds. In whales, when vibrations in the water hit the fat-filled cavity (bulla) located in the jaw bone, vibrations are transmitted to their inner ear, so they actually "hear" sounds through their middle ear bones, just like humans.

Whale vocalizations

Unlike humans, whales do not possess vocal cords. Sounds are produced primarily in the nasal or air sac region of the head. Researchers believe that sound is produced by moving air in the trachea and air sacs around the blowhole.

The songs of whales are made up of distinct sequences of boings, moans, bellows, grunts, sighs, and high-pitched squeals that may last up to 10 minutes or more. Researchers think these sounds could be used for navigation, as well as for communication to identify other individuals, to maintain long-range contact with one another, for courtship, and to alert others to food sources or warn them of threats. Whale vocalizations may be the loudest sounds produced by any animal, and these sounds travel for long distances under water.

Whale vocalizations vary in intensity, wavelength, frequency, and pattern based on the behavior and purpose of the sound. High frequency sounds are usually called clicks, whistles and squeaks; low frequency sounds are usually called grunts, moans, pulses, and tones. Toothed whales typically produce high-frequency sounds above 1,000 Hertz (Hz = wave cycles per second), while baleen whales vocalize mostly low frequency 10-1000 Hz. Humans hear sounds best between the frequencies of 1000 Hz to 5,000 Hz, where human speech is centered, so some low frequency and high frequency whale vocalizations may not be audible to the human ear.

Photo: NOAA / OCNMS

Humpback and baleen whale acoustics

Humpback and other baleen whales produce repeating sequences of sounds, known as phrases which repeat in patterns that make up "songs." These patterns can last from 20 minutes to several hours, repeating the song several times. These songs are only produced by males, and only while they are in their breeding grounds. Researchers speculate that these songs may serve to attract females, keep males spaced apart, locate individuals, and communicate information such as location, species, sex, mating status, and readiness to compete with other males for a mate. On-going research is necessary to fully understand the function and meaning of whale songs.

Vocalizations vary both among species and within species, and can even vary within species by geographic location. Similar to humans who speak the same language but have different dialects or accents based on where they live, whales have distinct geographic "cultures" or "clans" where vocalizations occur in specific dialects called "codas." All males in a population sing the same song, but those songs change from year to year, and vary by location. Like "Top Forty" music, popular whale songs can spread across the ocean. Scientists have found that one song from Pacific humpbacks have been recorded making it all the way to the Atlantic. Whales within the same song group or coda share the same behaviors and occupy the same geographic areas. It has been suggested that sharing the same songs helps to keep them together in their own cultural groups.

Researchers recently found that surface-active behaviors, such as breaching or tail or fin slapping are another form of communication. Whales use their body parts as mallets to strike the water like a drum, which makes a loud noise that can be heard over long distances. Scientists think these sounds travel better than a vocalization would. Just imagine a whale leaping out of the water and splashing down is like a student in your classroom jumping up and down, waving his arms to get your attention. That often works better than talking!

Education Standards

Common Core State Standards	• **ELA/Literacy**
	  • **RI.3.1**: Ask and answer questions to demonstrate understanding of a text, referring explicitly to the text as the basis for the answers.
	  • **RI.3.3:** Describe the relationship between a series of historical events, scientific ideas or concepts, or steps in technical procedures in a text, using language that pertains to time, sequence, and cause/effect.
	  • **W.3.1:** Write opinion pieces on topics or texts, supporting a point of view with reasons.
	• **Mathematics**
	  • **MP.4:** Model with mathematics. (3-LS2-1)

Next Generation Science Standards	**3 Ecosystems:** Interactions, Energy, and Dynamics: **3-LS2-1.** Ecosystems: Some animals form groups that help members survive. **4 Waves:** **4-PSR-4.** Waves and their applications in information transfer. **Science and Engineering Practices:** • Developing and Using Models **Crosscutting Concepts:** • Cause and Effect • Patterns
Ocean Literacy Principles	• 5. The ocean supports a great diversity of life and ecosystems • Ocean biology provides many unique examples of life cycles adaptations, and important relationships among organisms (symbiosis, predator-Prey dynamics, and energy transfer) that do not occur on land.

Echolocation – Toothed whales only!

Toothed whales (such as sperm whales, killer whales, and dolphins) have developed echolocation, which is a sensory ability used for navigating under water and for locating food.

Toothed whales send out powerful clicks or pings by moving air between the air sacs near their blowhole called phonic lips. Also, many species have a fat deposit in the forehead called the melon. Toothed whales can change the shape of their melon to direct or focus the outgoing sound waves. Their oil-filled lower jaw receives and carries the returning sounds to the inner ear. When the signal returns to the whale, it can determine the location, distance, direction of movement, speed, shape, and internal structure of the object causing the echo. Many of the sounds used in echolocation are high-pitched and inaudible to the human ear. This is how, by emitting continuous clicks and interpreting the returning echoes, whales "see" through murky water or in complete dark.

How whale vocalizations are seen

Whale researchers can monitor whale vocalizations using two different methods. One method uses a hydrophone array, an underwater microphone towed behind a ship or placed in a stationary location. The other acoustic monitoring method uses Navy surplus sonobuoys which were originally developed to detect submarines. Signals picked up from hydrophones or sonobuoys are transmitted to a radio receiver connected to a computer. The computer must be visually monitored, and it takes a keen eye to be able to pick out the vocalizations from other "noise" such as the ship's engine, sounds of the water hitting the buoy, and even the ship's radar!

Human hearing is most sensitive between the frequencies of 1 kHz (1000 Hz) and 5 kHz (5000 Hz), so we can hear some of the clicks, whistles, songs, and "boings" of some dolphins and whales ("Boings" are made by minke whales). For low frequency sounds, we have to "visually hear" sounds that are too low for our ears to hear.

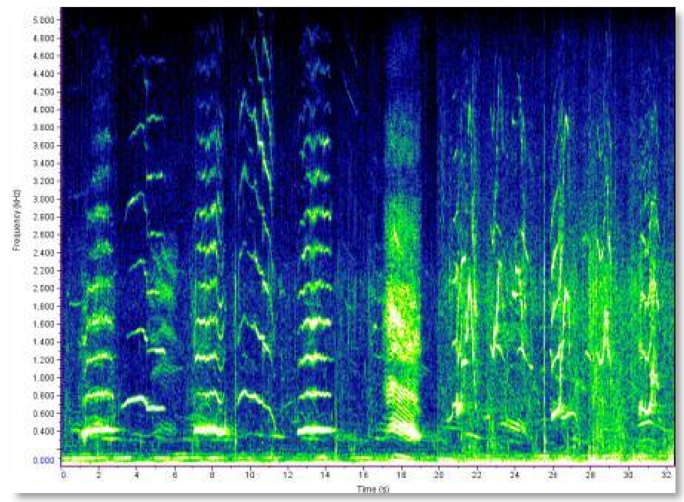
Vocabulary

- Acoustics: The science that deals with sound and sound waves -- the transmission and receiving of sound.
- Bulla: In whales, the middle/inner ear located inside the jaw. It is curved like a shell, which helps to amplify sound.
- Cetacean: A member of the order of aquatic mammals, Cetacea, which includes whales, dolphins, and porpoises.
- Frequency: The number of cycles per unit of time, measured in cycles per second, called Hertz (Hz).
- Hydrophone: A microphone used under water for recording or listening to underwater sound.
- Sound waves: A wave formed when a sound is made and that moves through water (or air or solid) as it moves away from the source of the sound. The source is an object that causes a vibration.
- Spectrogram: A visual representation of the frequency, duration, and intensity of a sound as it changes through time. Also called a "voiceprint" or "voicegram."

A spectrogram is a way to visualize the energy and pitch of a particular sound. In the pictured example of a humpback whale song, the spectrogram plots time in seconds (horizontal axis) versus frequency in KHertz (1,000 Hz) units (vertical axis).

All data, including measurements of a vocalization's frequency range and duration are recorded on a computer program and also logged in a hand-written journal. In addition to just listening to whale vocalizations, scientists collect data by recording the sounds made by cetaceans, and the locations of whale occurrences are also noted in science journals for later analysis.

Whale sounds are recorded from the hydrophones or sonobuoys in the water, connected, and monitored on the computer with headphones. Whale vocalizations that fall within human hearing range can be heard as well as seen on the computer monitor.



Humpback whale spectrogram. To listen to this vocalization, go to: http://www.nefsc.noaa.gov/psb/acoustics/sounds.html

Preparation

- Open vocalization PowerPoint, connect computer to projector, and test videos and audio clips. Ensure that spectrogram files play without crashing computer.
- Prepare cups of water, fill them to the brim.
- Hand out tuning forks and rubber strikers.
- Display dolphin skull and slinky for students to see.
- Hand out blank spectrograms and expo markers

Procedure

What is sound? (10 minutes)

- Go through the PowerPoint with the students (be certain to review notes on slides first).
- Ask your students the following guiding questions:
  - What is sound?
  - Ask two students to hold the slinky apart and demonstrate a longitudinal compression wave
    - It is like a sound wave

Compare humans vs. cetaceans (10 minutes)

- Discuss how both humans and cetaceans use sound to communicate.
  - Can communicate by vocalizing or by other means (waving vs. saying hello)
- Go through the visual examples of how the ear structures of humans and cetaceans differ.
  - Use dolphin skull to demonstrate this difference.
    - Point out the cavity in the jaw bone that would be filled with fat to help amplify and transfer sound to the inner ear of a whale.
    - Show that cetaceans do not have an outer ear flap like humans do.

Baleen vs. toothed whales (5 minutes)

- Discuss the different methods baleen and toothed whales use to vocalize.
- Elaborate on toothed whales and echolocation: What is it used for? What other animals use it? What is a melon?
- Ask the students to define frequency:
  - Toothed whales usually use higher frequencies (sound waves are all scrunched together).
  - Baleen whales usually use lower frequencies (sound waves more spread apart).
- Explain that there are some frequencies that humans cannot hear
  - Whales make the loudest sound in the ocean, but we cannot always hear it.

Humpback whales (10 minutes)

- Focus on humpback whale vocalizations: how, where, when, who, why?
- Listen to audio clips and short documentary provided in PowerPoint.

States of matter (15 minute game)

- Have the students work together to define and describe the three main states of matter (solid, liquid, gas). If students do not have a good understanding of states of matter, quickly give an explanation of the spacing of molecules within the three states.
- Let the students hypothesize which state of matter allows sound to travel fastest.
- Play the "States of matter" game: In this game, students will emulate molecules in the three different states of matter. Students will be able to time how quickly "sound waves" travel through the states of matter in order to understand *that sound travels most efficiently in solids and liquids*.
  - Ask for a total of four student volunteers: Three will come up to the front of the class and be molecules and the last will be a time keeper and data recorder.
  - Have the three "molecules" stand shoulder to shoulder to emulate a solid. Explain the spacing.
  - Choose a short phrase (such as "whales chew blubber gum") and whisper it in the starting molecule's ear. Have the three molecules pass the "sound wave" down the line by whispering in the next person's ear (like playing telephone).
    - Have the time keeper record how long it takes for the phrase to pass from the first student to the last student.
  - Repeat this process next as a liquid (have the students stand one arm's length apart) and then as a gas (have the students stand two arm's length apart). Ensure that the students are walking to whisper the phrase to the next person.
  - Let the time keeper and data recorder show the class the results.
    - If done well, it should take less time for the "sound wave" to pass through the solid and liquid than it does to pass through the gas
  - Explain that this is why whales depend on sound to communicate in water. They can hear for hundreds to thousands of miles, but have limited vision in water, especially at night.

Tuning fork exploration (15 minutes)

- Based on the results of the game, have the students hypothesize which state of matter is the most effective conductor of sound.
- Divide the class into small group (of two of three students) and provide each group a tuning fork, rubber striker, and small glass of water. Remind the students to only tap the tuning forks on the rubber striker, not on their desks or each other. Model appropriate use of the tuning fork before handing them out.
- Have the students explore how tuning forks perform in water, air, and solids (if students have trouble using the forks walk around and assist them as appropriate):
  - **Air:** have the students strike the tuning fork and then hold it near their ear. They should hear a faint hum or ring.
  - **Solid:** have the students strike the tuning fork and then hold the ball of the stem to their lower jaw or cheek bone. Let them describe what they hear or feel. If done well, the students should be able to feel the vibrations and hear the hum/ring of the tuning fork better than they could in the air. Sound travels well through solids! That is why a whale uses their jaw bone to hear underwater.
  - **Liquid:** have the students strike the tuning fork and hold the two tines in the water of the cup. The vibrations of the tuning fork should cause ripples in the water, and occasionally even a little splash. Those ripples are the sound vibrations/sound waves moving away from the source. We can actually see the sound moving!
- Come back together as a class and discuss how it is more efficient for sound to travel through solids and liquids than through air.
  - Also discuss how it is possible to see and feel sound, not just hear.

Spectrogram guessing game (20 minutes)

- Introduce the concept of a spectrogram and what they are used for.
- Explain the key features of a spectrogram:
  - The little waves are the whale sounds. The brighter the color, the louder the sound. The y-axis is frequency, x-axis is time. That means a whale sound that is high in pitch will be at the top of the graph (higher frequency). If a sound goes from a high pitch to a lower pitch over time, it will look like a gradual slope on the spectrogram.
- Listen to several examples of spectrograms:
  - Use PowerPoint slides to point out that echolocation sounds, such as clicks, show up as vertical lines on the spectrogram.
- Once students understand spectrograms and what they show, play the Spectrogram guessing game:
  - Hand out a blank, laminated, spectrogram graph to each student, along with a dry erase marker and an eraser.
  - Go through the PowerPoint slides for the guessing game.
    - When only an audio clip appears, have the students listen to the clip and then attempt to draw what the spectrogram would look like. Encourage the students to do their best and draw the most defined sounds.
    - When only a spectrogram appears, have the students try to "sing" the spectrogram like a whale. They can do this as a class or have a volunteer sing it. It is a good chance to be a little goofy!
  - Check the "answers" by either looking at the spectrogram or listening to the audio clip.

Conclusion (5 minutes)

End the lesson by listening to the vessel spectrogram (PowerPoint slide 24)

- Briefly describe the issues surrounding noise pollution and how we can each help at home and in our communities by buying locally, less, and for the long-term. What do you think ship noise does to whale communication? How can we help reduce ship noise in the ocean?
- See Healthy Humpback Habits handout for personal and community actions to help reduce ocean noise pollution

For More Information

There are many websites available on whale vocalizations, as well as audio and video, spectrograms, and recordings. Here are a few great sites that are easy to use:

NOAA Pacific Marine Environmental Laboratory Acoustics Program. Excellent site on ocean noise, marine mammal sounds, and current research. http://www.pmel.noaa.gov/acoustics/whales/sounds/sounds_akhump.html

Voices in the Sea: The Humpback Whale, University of California San Diego Scripps Whale Acoustic Lab. Games, videos, and activities. cetus.ucsd.edu/voicesinthesea_org/species/mobile/baleenWhales/humpback.html

Humpback Whales Songs, Sounds, Vocalizations. National Park Service. Downloads and streaming. https://archive.org/details/HumpbackWhalesSongsSoundsVocalizations

Ocean Conservation Research: Humpback Whale. Sound library, video, and general information. ocr.org/sounds/humpback-whale

Discovery of Sound in the Sea introduces you to the science and uses of Sound in the Sea, including an audio gallery. https://dosits.org/

Salish Sea Hydrophone Network. Listen live to underwater sounds from locations on San Juan Island, Port Townsend, Seattle Aquarium, and Neah Bay. orcasound.net

Bioacoustics Research Program, Cornell Lab of Ornithology. Right Whale Listening Network. www.birds.cornell.edu/page.aspx?pid=2713
http://blip.tv/nasa-goddard-tv/nasa-nasa-for-kids-intro-to-engineering-4722805

NASA SCI Files®: *The Case of the Radical Ride*
Join the tree house detectives in this 60-min video as they learn about the engineering design process. An educator guide is also available for download.
http://www.knowitall.org/nasa/scifiles/index2.html

How Whales Hear. KCTS9 PBS Learning Media. Online lesson plan and activities and great resources!
http://kcts9.pbslearningmedia.org/resource/tdc02.sci.life.colt.lp_whalehear/how-whales-hear/