Exploring Fish Sounds in National Marine Sanctuaries

Lesson Specifications

Grade Level

5th grade

Timeframe

90 minutes

Materials

Computer, projector, screen, speakers, optional sticky notes or scrap pieces of paper.

Key Words

Fish chorus, frequency, trophic role, overfishing, hydrophone, passive acoustic monitoring, long term spectral average (LTSA), invasive methods, sound vs. noise, spectrogram

Standards

NGSS: 5-ESS3-1
CCS: RI.5.7, SL.5.5, MP.2
OLP: 2,4,5,6,7
CLP: 2,3,6

Photo: Claire Fackler, NOAA

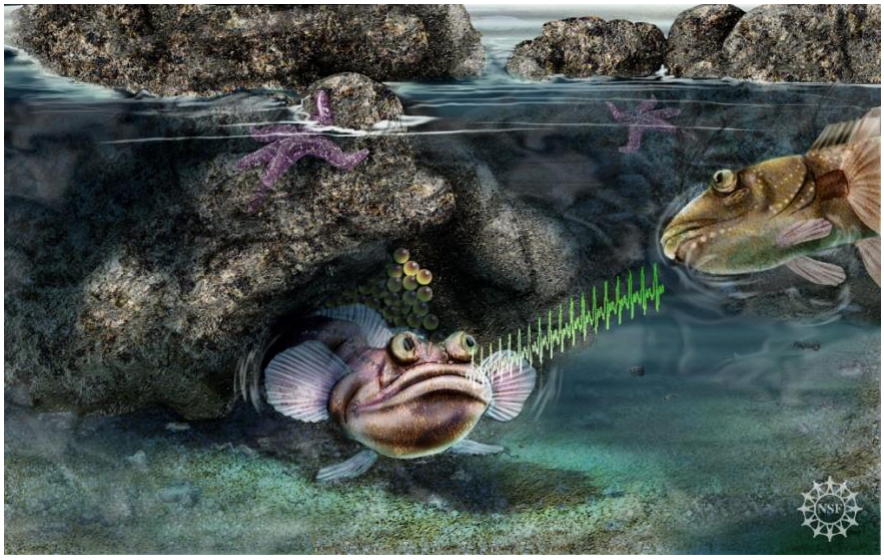

Illustration by Nicolle Rager Fuller, National Science Foundation

Activity Summary

- Students will play a Guessing Game – "One Fish, Two Fish, What Fish, Who Fish?"
  - Objective: To enhance students' ability to differentiate between fish sounds and sounds from other organisms or human-made noise.
  - Description: Students engage in an interactive guessing game where various sounds, including fish sounds, are played. The challenge is to correctly identify whether the sound is produced by a fish or something else. This activity promotes active listening, sound recognition skills, graph interpretation, and a sense of wonder for sound produced in the ocean.
- Students will create an underwater fish orchestra and take part in an activity called – "Finding Harmony"
  - Objective: To explore how fish modify their sounds to communicate and draw parallels to human interactions.
  - Description: In small groups, students create unique fish sounds and practice them together. To the tune of a song chosen by the teacher, students dance, freeze, close eyes, and point to classmates producing same sound. Afterward, a classroom-wide discussion explores challenges, strategies, and parallels to fish communication. The instructor emphasizes how fish adjust their behavior based on factors like location, time, and frequency. This prompts a discussion on strategies to find "fishy" friends, drawing parallels between the activity and real-world fish communication.

Learning Objectives

Students will be able to:

- Articulate the significance of fish to the ocean and humanity.
- Define how fish produce sound and fish chorusing, and explain the importance of sound to fish.
- Compare fish acoustics with other fish research methods, understanding the benefits and limitations of each approach.
- Identify different underwater sounds, including those from fish, other organisms, and human sources.
- Explore how fishes adapt their behavior to communicate effectively in noisy underwater environments.

Background Information

National Marine Sanctuaries

Managed by the National Oceanic and Atmospheric Administration (NOAA), the Office of National Marine Sanctuaries serves as the trustee for a network of underwater parks encompassing more than 629,000 square miles of marine and Great Lakes waters from Washington state to the Florida Keys, and from Lake Huron to American Samoa. The network includes a system of 18 national marine sanctuaries and Papahānaumokuākea and Rose Atoll marine national monuments. These special places 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 off California have been designated to protect this special region: Olympic Coast, Greater Farallones, Cordell Bank, Monterey Bay, Channel Islands, and Chumash Heritage national marine sanctuaries.

Why are fish important?

- **Overall importance:** Fish play a crucial role in maintaining the health and balance of the ocean, linking plankton to top predators in the ocean food web. Their significance extends beyond the environment to impact people, economies, and global ecosystems.
- **Ocean Food Web:** Throughout the intricate dance of the ocean food web, fish occupy many key trophic roles. Tropic roles are the position of an organism in a food chain or food web, indicating its feeding relationships with other organisms. Fish bridge the gap between microscopic plankton and apex predators, like orca whales. Some, like tuna, also function as top predators, balancing the delicate equilibrium of marine ecosystems. Fish larvae (baby fish), are also plankton, so they occupy many trophic roles!
- **People and Fish:** Fish are a primary source of protein for approximately 3 billion people globally, with a substantial portion of people relying on fish as a vital protein source. Fisheries

and human livelihoods are intertwined, which underscores the importance of sustainable fisheries management.

- **Fish are in trouble:** The United Nations Food and Agricultural organization has estimated that 3 billion people globally are dependent on fish for protein and one third of marine fish stocks are overfished. Therefore, it is important for scientists to study fish to better understand them and help policy makers keep fish stocks healthy.

Fish produce sound

- **How many fish sing?**
    - Fish are a remarkably diverse group of vocal performers in the underwater symphony. A substantial 989 fish species are recognized for their ability to produce unique sounds, yet the sonic repertoire of most fish remains unexplored. With over 34,000 fish species in existence, it is possible that around 24,000 species may have the capability to produce sounds, so there is still a lot of room for scientific exploration!
- **How fish produce sound:**
    - Unlike human vocalization, fish do not open their mouths to communicate. Instead, they employ three primary methods for sound production:
        - Contracting Sonic Muscles: Fish use specialized muscles near their swim bladders—gas-filled organs that control buoyancy—to create sound.
            - Passing gas: Releasing gas produces sound! Herring produce sound through squeezing swim bladders and passing gas.
        - Stridulation: Some fish produce sounds by rubbing skeletal parts or teeth together.
        - Changing Swimming Movements: Altering swimming direction or movements also contributes to sound production.
- **Why do fish produce sound?**
    - Fish produce sound for various reasons:*
        - Territorial defense: When they are feeling tough and protecting their homes.
        - Foraging: To chat about where to find food.
        - Mating rituals and spawning coordination: The most important reason is when they are looking for love! Often, male fish sing to impress female fish to lay eggs in their guarded nest just like male peacocks who show off their feathers. Also, sound can be used to coordinate spawning, making sure that gametes are released into the water at the same time for external fertilization.
- **Fish chorus:**
    - Now if you can imagine sitting on the seafloor and hundreds of fish (of the same species) are all singing together at the same time (over multiple hours), and for many months at a time, this is called a fish chorus. Each fish species has their own unique fish chorus signature, which allows us to distinguish sounds from each other, especially when many different species chorus at the same time. Fish chorusing happens during reproductive season when males will sing to attract females, or to time the release of sperm and egg so they can successfully fertilize externally in the ocean.

- **Importance of studying fish chorusing:**
    - Studying fish chorusing is very important! It allows us to understand which species of fish are in a given area, identify their reproduction locations, and pinpoint the timing of their reproductive activities. This valuable information can be utilized to inform policymakers and fisherfolk, contributing to better-informed decisions on where and when fishing activities can take place sustainably. The conservation of these underwater concerts becomes a shared responsibility for the preservation of marine ecosystems.

How are fish traditionally studied, and how can they be studied using Passive Acoustic Monitoring?

- **Traditional methods to study fish:**
    - Historically, studying fish involves invasive techniques that have big ecological impacts. Common practices have included the use of nets, tows, bottom trawls, and tagging. These methods, while effective in revealing fish stock, spawning locations, estimating biomass, and tracking movements, come at a considerable cost.
    - Traditional approaches result in harm to fish and their eggs. Many do not survive, while others undergo on-deck surgery. Additionally, these shipboard collections are labor intensive and costly—and because of this do not happen very frequently—which make it challenging to produce long timeseries to answer meaningful scientific questions.
- **Alternative methods: Passive Acoustic Monitoring:**
    - So, what if instead we could study fish through just listening to them? This method involves deploying hydrophones—underwater microphones—on the seafloor for extended periods, typically 4–6 months. These hydrophones collect underwater sound data, allowing researchers to study specific organisms based on their unique sounds.
- **Process of Passive Acoustic Monitoring:**
    - Data Collection: Hydrophones capture a diverse array of underwater sounds over an extended period.
    - Processing: Data is processed and stored on hard drives.
    - Visualization and Analysis: Data then can be visually represented in spectrograms (visualizations of sounds in graphs) and Long-Term Spectral Averages (LTSAs), to find which sounds are present.
    - **Explanation of Long-term spectral averages:**

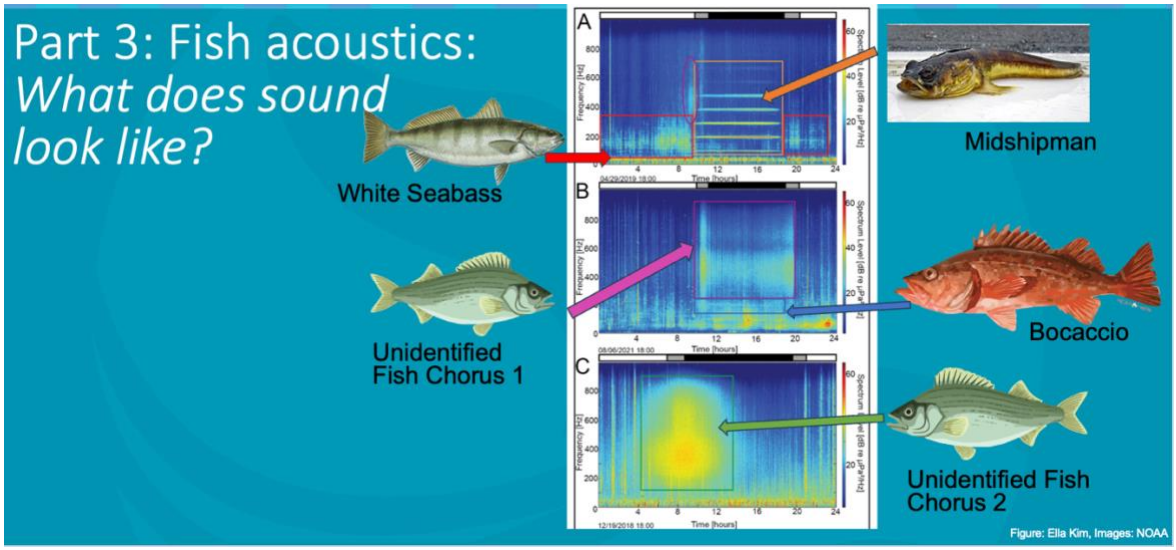

Image: Ella Kim, NOAA Dr. Nancy Foster Scholar.

- (Above) LTSAs of fish choruses found in national marine sanctuaries along the West Coast. LTSAs show time on the x-axis and frequency on the y-axis, where warmer colors represent higher sound level, and cooler colors represent lower sound level. These LTSAs show 24 hours from 1–1000 Hz. Choruses are encircled by the following: (A) Orange box around plainfin midshipman chorus, red boxes around white seabass chorus, magenta oval around UF440 chorus (see *note below); (B) Magenta box around Unidentified fish chorus 1 (with increased intensity at sunset and sunrise), blue box around bocaccio chorus (with increased intensity at sunset at 200 Hz); and (C) Green box around Unidentified fish chorus 2 chorus. Colored bars at top of each LTSA indicate night as black, astronomical twilight as gray, and day as white. Time is in UTC. *Note unidentified fish choruses are those in which we know it's being produced by fish, but the species producing the sound is still a mystery.

What have we learned about fish chorusing in national marine sanctuaries of the West Coast?

- Analyzing fish chorusing in national marine sanctuaries on the West Coast, we have found that fish show distinct spatial and temporal patterns.
- **Key Findings:**
  - **Diversity of Choruses:** In Channel Islands, Monterey Bay, and Chumash Heritage national marine sanctuaries, researchers identified five distinct fish choruses, including two from unidentified fish species, and others attributed to these three species: bocaccio rockfish, white seabass, and plainfin midshipman toadfish. Each chorus is unique!
  - **Timing Patterns:** Fish chorusing exhibits specific timing patterns, with the majority in national marine sanctuaries on the West Coast occurring at night and during the summer months. More specifically, each fish species choruses during their unique mating seasons (usually during the summer).
  - **Acoustic Characteristics:** Fish choruses have unique frequencies (pitches) for optimal communication. The varied frequencies serve as a unique language for each species, enabling efficient interaction within the cocktail of ocean choruses.

- **Spatial Distribution:** Spatially, the distribution of fish chorusing across the national marine sanctuaries paints a dynamic picture. Fish choruses were present in Monterey Bay, Channel Islands, and Chumash Heritage national marine sanctuaries, but not in Olympic Coast National Marine Sanctuary. Understanding the geography of these choruses provides valuable insights into essential fish habitat within the national marine sanctuaries. See a map of the California coast of the United States below, from Monterey Bay in the north to Los Angeles in the south:

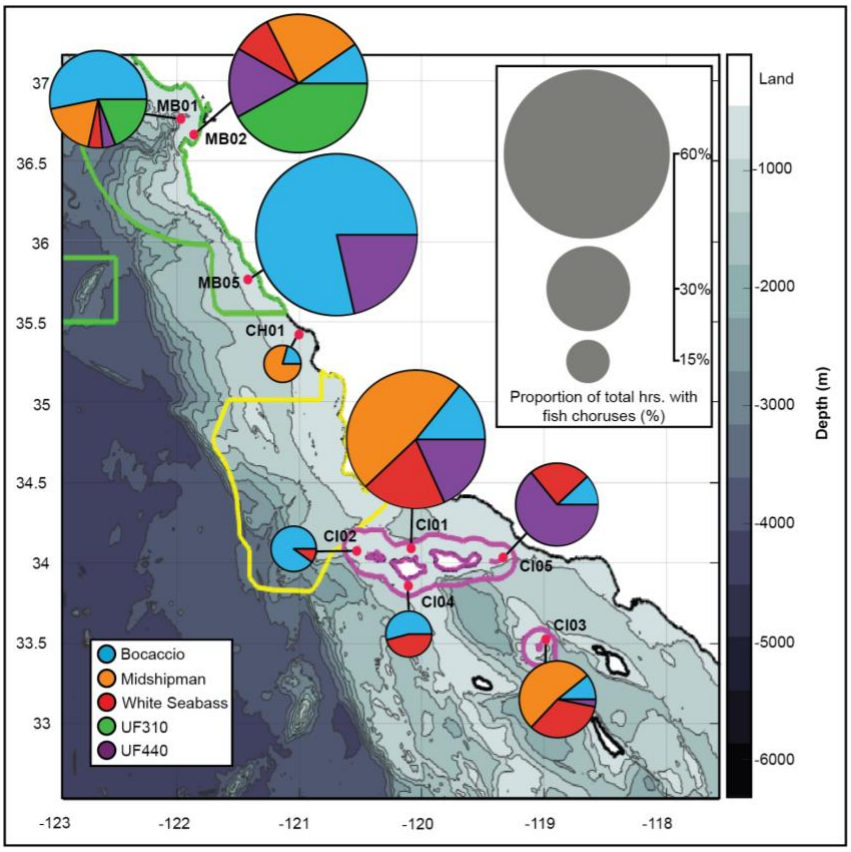

Image: Ella Kim, NOAA, Dr. Nancy Foster Scholar.

- (Above) Spatial patterns of fish chorusing in California national marine sanctuaries. Sanctuary boundaries are outlined: Monterey Bay (green), Chumash Heritage (yellow), and Channel Islands (pink). Pie charts represent normalized hours of presence over a cumulative ~18 years of acoustic data collection through the Sanctuary Soundscape Project. Bigger pie charts represent more fish chorusing (normalized by sampling effort), and various colors represent different choruses found.

- **Overall Significance of the Research:** These findings not only deepen our understanding of fish behavior and distribution but also emphasize the intricate ways in which marine life adapts their behaviors to optimize communication in response to environmental factors. The research underscores the importance of preserving the acoustic integrity of marine environments, as disruptions could impact the delicate balance of underwater communication networks.

Vocabulary	
Fish Chorus	Many fish of a particular species, all singing at the same time, usually over multiple hours, and over the course of their mating season. Usually for courtship or reproductive coordination.
Frequency	Number of cycles of a sound wave that occur in a unit of time. Or simply, higher frequency sounds have a high pitch (think ringing telephone), and low frequency sounds have a low pitch (rumbling of thunder). Frequency of sound plays a big role in how far sound can travel. Fish sounds are low frequency from ~10–2000 Hz.
Trophic Role	The position of an organism in a food chain or food web, indicating its feeding relationships with other organisms.
Overfishing	The state of a fish stock being harvested at a rate that is too high, endangering the population's ability to replenish itself.
Hydrophone	Underwater microphones designed to record ocean sound data, which can be used to study biology (fish, whales, etc.), anthropogenic effects (ships, explosions, seismic surveys), and geophony (geologic, environmental noise).
Passive Acoustic Monitoring	A technique for studying marine life by listening to sounds in the ocean using hydrophones (underwater microphones).
Long Term Spectral Average (LTSA)	A way to visualize sound data: showing time, frequency, and volume. With LTSAs, one can analyze and visualize underwater sound data over an extended period and look for specific animal sounds.
Invasive Methods	Techniques that involve physically interacting with or disturbing the organisms being studied.
Sound vs. Noise	Scientists studying sound (acousticians) usually refer to sounds produced by the living organisms that they are studying as "sounds" and human-made sounds as "noise."
Spectrogram	A graph of sound data, helping us "see" what we hear! The graphs show how loud (amplitude) different sounds are at different pitches (or frequencies) over time. Spectrogram axes are time on x-axis, frequency on y-axis, and sound level or amplitude as color (warmer colors are louder). Long-term spectral averages are spectrograms that show 24-hours of time.

Preparation

- Open Fish Sounds PowerPoint, connect the computer to the projector, and test videos and audio clips. Sound is crucial for this lesson, so make sure that spectrogram files play with enough volume for everyone to hear. Note there are slides for each part of this lesson plan organized by part 1 through part 7, that are annotated with notes for each slide when in presenter view.

Procedure

Part 1: Why fish are important (15 minutes)

- Open slideshow part 1 (all below is annotated in presentation notes).
- Share the importance of fish to the ocean, people, economy, and environment.
    - Key trophic role
    - People: food for 3 billion people.
- Explain that fish are in trouble and it is important for scientists to study them, to better protect them and so that we can take better care of them. Also, that it is especially important to do so in national marine sanctuaries, which aim to provide safe habitat for vulnerable marine species.

Part 2: Reflection on fish importance to the world and to their own lives (think, pair share) (5 minutes)

- Open slideshow part 2 (all below is annotated in presentation notes).
- Think-pair-share: students will reflect on prompt and jot down notes (1 minute), then share with a partner (2 minutes), and then 2–3 partners volunteer to share with the larger group (2 minutes).
- Prompt: "Reflect on your daily life and consider the various ways fish are involved. From the food you eat, like tuna sandwiches or sushi, to their role in keeping the ocean and planet healthy. Share your insights on what you think might be important for scientists to learn about fish to better protect them?"

Part 3: Fish acoustics vs. traditional methods (15 minutes)

- Open slideshow to part 3 (all below is annotated in presentation notes).
- Explain traditional methods to study fish and how they are invasive and can be harmful to the fish.
    - Net and tow, bottom trawling, tagging.
    - Useful for: showing numbers of fish, where fish are having babies, and tracking movements, but these methods can hurt fish: killing and on deck surgery. Also requires lots of labor and boat-time, which is time and money intensive, so these research surveys do not happen very frequently.
    - So, what if instead we could study fish through just listening to them?
- Instructor talks about how fish sounds can be used to study fish, through passive acoustic monitoring, in which hydrophones—underwater microphones—are placed on the seafloor from 4–6 months and collect underwater sound data. Data is processed and then can be visually viewed to find which sounds are present in the spectrograms.
    - Script: "On the left you see a hydrophone, which is an underwater microphone that sits on the seafloor for 4–6 months at a time and collects underwater sound data. Scientists go out on boats and toss the hydrophones overboard, where they fall to the seafloor. There, the instrument sits listening for many months, which is cheaper than taking out a boat constantly, and is more continuous data collection for scientists. When we retrieve our instruments, we are able to hear sounds like this:" play the sound of the bocaccio rockfish.
- Fish sounds. First instructor poses question—why do you think fishes produce sound? Can either take volunteers directly or think-pair-share if slow to participate.
    - Explain reasons why fishes produce sound:
        - Territorial defense: When they are feeling tough and protecting their homes.
        - Foraging: To chat about where to find food.
        - Mating rituals and spawning coordination: The most important reason is when they are looking for love! Often, male fish sing to impress female fish to lay eggs in their guarded nest just like male peacocks who show off their feathers. Also, sound can be used to coordinate spawning, making sure that gametes are released into the water at the same time for external fertilization.

- Explain what a fish chorus is:
  - Script: “You may have heard me say fish call vs. fish chorus. So, what is a chorus?
  - “Try imagining you are sitting at the bottom of the ocean and many fish are all calling at the same time for hours at a time, over the course of many months. When many fish call together, this is called a chorus. Why does this happen? Fish chorusing is thought to be associated with mating as male fish, mostly big ones that live on the bottom of the ocean, will sing to attract females to their nest to lay eggs.”

- Visualizing sound in a spectrogram:
  - Explain what a spectrogram is. A spectrogram is a graph of sound data, helping us “see” what we hear! The graphs show how loud (amplitude) different sounds are at different pitches (or frequencies) over time. Spectrogram axes are time on x-axis, frequency on y-axis, and sound level or amplitude as color (warmer colors are louder).
  - Point to each of the five different fish choruses in the spectrogram.
    - Students either volunteer to explain what they notice about how the sounds look in the spectrogram, or do a think-pair-share, where they speak with a buddy and then share out with the class.

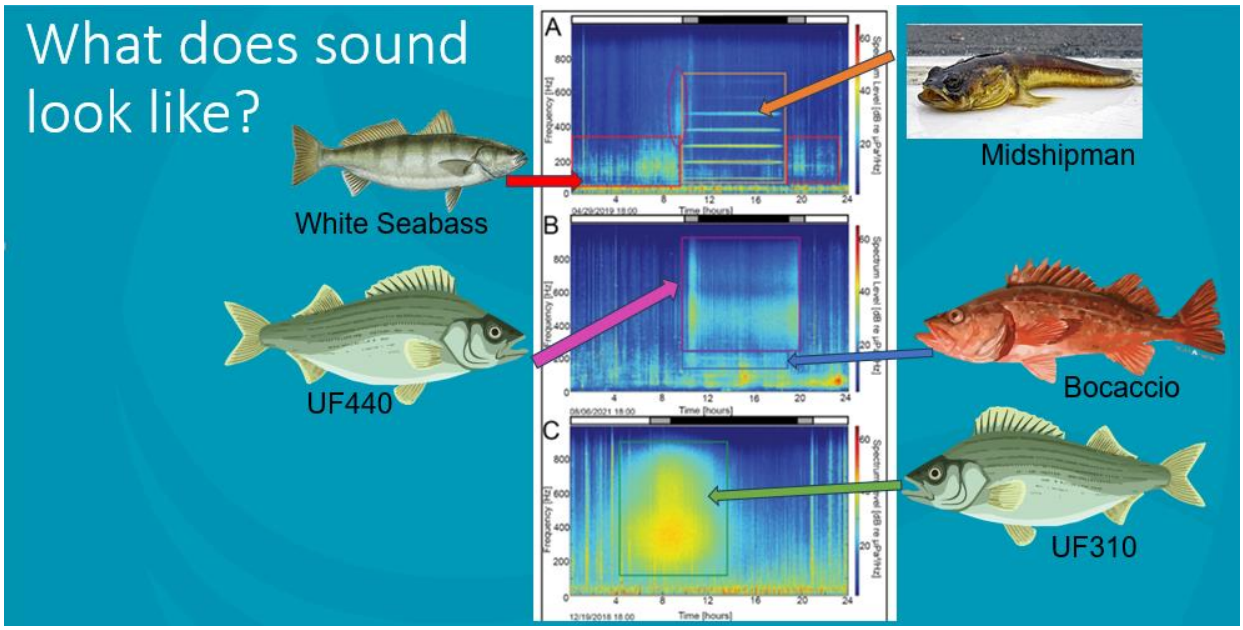

Image: Ella Kim, NOAA Dr. Nancy Foster Scholar

Part 4: Muddiest point (5 minutes)

- Open slideshow part 4 (all below is annotated in presentation notes).
- Prompt students to take 2 minutes to think about their “muddiest point” (points of confusion), if is there anything that confused them about what you learned about how and why fish produce sound, as well as its importance? Have them jot down notes and then have a few students share with the points, and clear up confusion.

Part 5: Activity: Guessing Game: "One Fish, Two Fish, What Fish, Who Fish?" (15 minutes)

- Open slideshow to part 5 (all below is annotated in presentation notes).
- Explain directions of activity in which students vote collectively as a class to guess whether or not the sounds are produced by a fish or not.
- Students can raise their hand if they think the sound is coming from a fish and leave them down if they think they are not from a fish.
- Alternatively, students can draw what they think it is—and if it is a fish what they think it looks like and hold it up in the air for the instructor to see.
- Once the collective guess is in, the instructor shares if the sound was a fish or not.
- Instructor shares that these are all fish sounds that are found within U.S. national marine sanctuaries.
- *Optional: call on one student to come to the projected slide and identify on the slide where the sound can be seen visibly. You can also print out the sound slides and have students circle where the sound is visible in the spectrogram.*
- *Optional: lead a short discussion if time allows to discuss if they noticed any similarities between sounds, what surprised them, and what they think the fish vocalizations sound like to them (e.g., drums, helicopters, pogo sticks, boats).*

Part 6: Activity: "Finding Harmony" (25 minutes)

- Open slideshow to part 6 (all below is annotated in presentation notes).
- *Come up with a key word that you will use to have students quiet down or have them put on imaginary snorkels and goggles. Or a sound off, this will be used throughout the activity. Ex: "Hammerhead shark," you can explain that hammerhead sharks don't make sound, and they must be silent when you say hammerhead.*
- Instructor explains "finding harmony" guidelines without giving away the punchline: do not give the class all the information at once, but rather divide them into small groups, and tell them that each group should come up with their own unique fish chorus and practice it together. (5 minutes).
- Then explain to the students that they are going to play freeze dance, that they should move around the room as they dance or swim around like a fish, and when you call freeze, have them stop moving and close their eyes. The goal is for the students to get jumbled around the room, randomly intermixed, and not close to students from their original chorusing group.
    - *Alternatively, if you do not want to introduce movement, while students are coming up with their chorus sounds, you can write each of their names on post it notes, and randomly jumble these names on desks/spots through the room. Have them find their names and then close their eyes.*
- With their eyes closed (and while stationary) instruct each student to sing out their chorus with and point to individuals from their group (producing the same sound). Give them 30 seconds to 1 minute, then have them open their eyes to see if they were successful.
- Afterward, organize a classroom-wide discussion, in which you share how successful or not the fishy groups were in finding their fishy friends. Then ask them the following discussion questions:
    - Raise your hand if you were able to find one of your fishy friends? Two? None?
    - What was challenging about the activity?

- What were some strategies you developed? What would have made the activity easier?
- How do you think this relates to actual singing fish in the ocean?
- Explain that just like them, fish in national marine sanctuaries along the West Coast are in the dark, singing at night (to avoid getting eaten by predators), trying to find each other to survive! It's like a big orchestra with multiple choruses all singing at the same time.
    - So, in order to communicate with each other and effectively find each other, fish use strategies: singing during particular times of the night (i.e., just at sunset or right before sunrise), singing in particular frequencies (different pitches for different species), singing during particular seasons, and in specific locations (e.g., shallow water, in kelp forests).

Part 7: Conclusion (5 minutes)

- Open slideshow to part 7 (all below is annotated in presentation notes).
- End with having a class-wide discussion first summarizing the main points: fish are important, fish can be studied through just listening to them, and we can learn so much about fish behavior through their sounds, in order to better understand and protect them.
- Then pose a question to the class: what is one thing that you can do to better protect fish this year? Have them take a minute to think about it, and then share out.

Education Standards	
Next Generation Science Standards	5-ESS3-1. Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.
Common Core State Standards	ELA/Literacy - RI.5.7 Draw on information from multiple print or digital sources, demonstrating the ability to locate an answer to a question quickly or to solve a problem efficiently. (5-PS3-1) SL.5.5 Include multimedia components (e.g., graphics, sound) and visual displays in presentations when appropriate to enhance the development of main ideas or themes. (5-LS2-1) Mathematics - MP.2 Reason abstractly and quantitatively. (5-LS2-1)
Ocean Literacy Principles	(2) The ocean is a major influence on weather and climate (4) The ocean makes Earth habitable. (5) The ocean supports a great diversity of life and ecosystems. (6) The ocean and humans are inextricably interconnected. (7) The ocean is largely unexplored.

Education Standards	
Social Emotional Learning Concepts	(1) Self-awareness (2) Self-management (3) Social awareness (4) Relationship skills (5) Responsible Decision Making

Additional Resources

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

- Information on the Sanctuary Soundscape Project: https://sanctuaries.noaa.gov/science/monitoring/sound/ as well as the data portal, which includes various sounds as well as other data: https://sanctsound.portal.axds.co/
- NOAA story on fish sounds: https://sanctuaries.noaa.gov/news/mar21/calling-fish.html
- Voices in the Sea: The Humpback Whale, University of California San Diego Scripps Whale Acoustic Lab. Games, videos, and activities. https://voicesinthesea.ucsd.edu/species/baleenWhales/humpback.html
- 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/

**The inclusion of links in this guide does not imply endorsement or support of any of the linked information, services, products, or providers.*

For More Information

This lesson plan was developed by Ph.D. Candidate and Dr. Nancy Foster Scholar, Ella Bea Kim. Feel free to get in touch with Ella if you have any questions: ebkim@ucsd.edu.