LISTEN IN

Acoustic Monitoring of Estuarine Communities Facing Ecosystem Change

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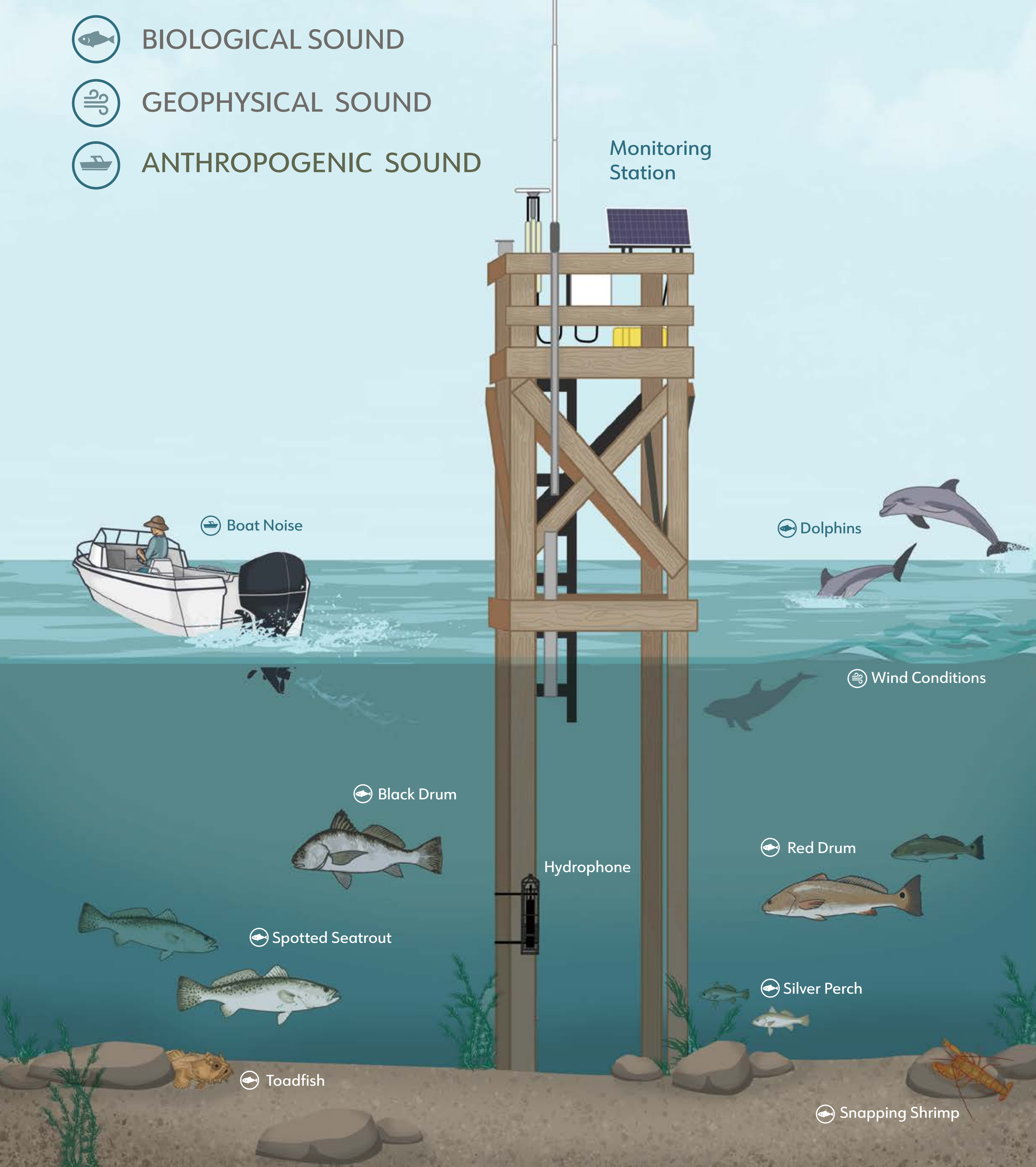
LISTEN IN

SOURCES OF SOUND

Figure 1.



ACOUSTIC MONITORING
of Estuarine Communities Facing Ecosystem Change

Overview

Acoustic monitoring provides time-series data with a high temporal resolution to understand short-term variability and long-term change in aquatic ecosystems. Passive listening devices (hydrophones) record sounds at multiple levels of biological complexity which can be used to investigate and monitor biodiversity, habitat utilization, species distributions, behaviors such as feeding and spawning, phenology, and anthropogenic noise [1,2,3,4,5]. By monitoring these parameters, soundscape ecology has the potential to provide insight into the response and resilience of ecosystems, habitats, and individual species to rapidly changing environmental parameters, climate change, and human ocean use[6,7,8]. The products and outputs of this research and data collection will inform management decisions regarding fisheries productivity, habitat restoration and rates of restoration of ecosystem function, while building a baseline of acoustic activity associated with the timing of important phenological events, such as spawning seasons.

By combining acoustic data with traditional environmental monitoring, scientists and managers can identify key habitats for protection and measure how ecological communities respond to environmental changes (e.g. storm events, coastal development, eutrophication) in a cost-effective and low-impact manner[9,10]. In addition to providing information on biodiversity and population status, acoustic monitoring also provides information on ecological processes and habitat status. For example, baseline acoustic data can help to identify deviations in behavior, biodiversity or habitat use due to stochastic events or changing climate patterns/environmental variables[4,6]. The monitoring and research framework outlined below aims to catalyze a multi-sector regional collaboration that can leverage expertise and resources to advance acoustic monitoring for use in research, management, stewardship, and education.

Passive acoustic monitoring can enhance current monitoring efforts by:

- Providing high resolution temporal coverage via continuous sampling or high-frequency intervals (e.g. every 20-60 min.), while leaving recorders deployed for months at a time
- Operating in poor weather and visibility
- Utilizing recording systems that are affordable and easily deployed/retrieved

Data Collected

- Soundscape metrics which correlate with biodiversity, abundance, and indicate ecosystem function
- Remote sensing presence & behavior
- Habitat use: spawning sites, species of interest/concern
- Anthropogenic and physical noise
- Changes in phenology: spawning & reproductive productivity

Sources of Sound

There are three main types of underwater sound[11,12]:

Biological sound is often associated with species-specific behavior such as communication, navigation, foraging, and reproduction. Acoustic monitoring provides a noninvasive, continuous method to monitor animal behavior, habitat quality, habitat use, and community structure over space and time and utilizes sound-producing species as indicators of ecosystem health.

Examples: shrimp, fish, dolphins, manatees, whales, alligators

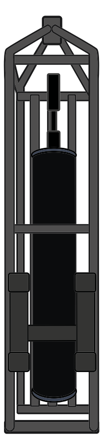
Geophysical sound is sound that is attributed to geophysical processes. Within estuaries, wind, waves, rain, and thunder are common components of the soundscape.

Examples: wind, waves, rain

Anthropogenic sound or human generated noise associated with commercial shipping, recreational boating, dredging, pile-driving, seismic exploration, and energy production have increased dramatically over the last century, and these human activities expose marine organisms to increasing levels of low-frequency noise. This noise can affect marine life by causing hearing threshold shifts, direct physical damage to auditory structures, masking of communication signals, and increased stress levels.

Examples: recreational boats, container ships, dredging, ferries

Sound Measurement



> Passive acoustics uses **hydrophones** to detect and measure sound waves, which can be used to identify soniferous species present in an area over space and time. The sounds recorded can be characterized by their loudness (amplitude) and pitch (frequency)13.

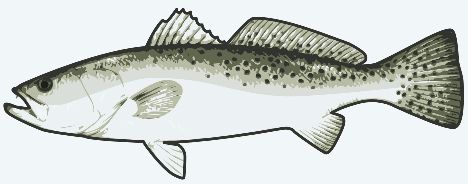
> The most common metric is the acoustic pressure or the sound pressure level (SPL) measured in dB (decibel relative to 1 μPa).

> Additional metrics include counts of species, number of shrimp snaps, calling intensity, number of vocalizations or noise occurrences

> Soundscapes in an estuarine environment contain a range of different species of fish and marine mammals vocalizing at different pitches/frequency ranges.

- Low frequency SPLs may include fish calls from a variety of species, the lower bandwidth of snapping shrimp snaps, physical sounds, anthropogenic noise, bottlenose dolphin, North Atlantic right whale, and manatee vocalizations.

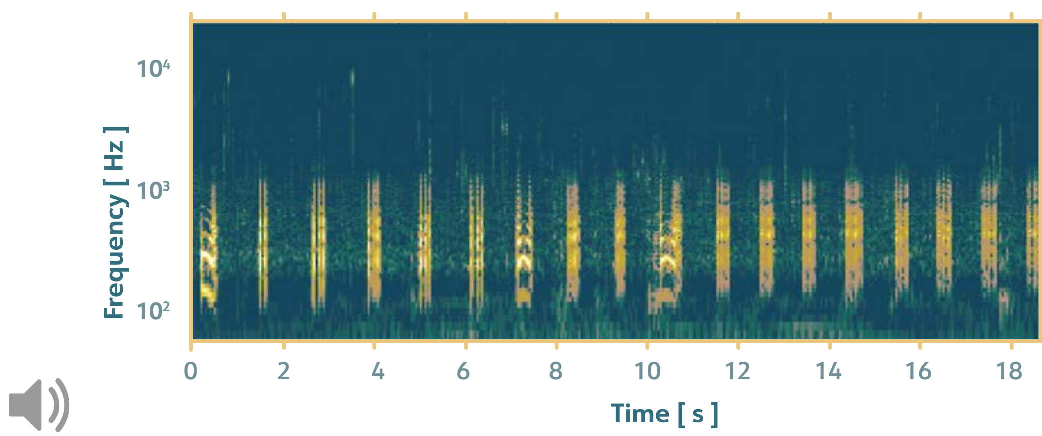
- High frequency SPLs may include bottlenose dolphin vocalizations and the upper bandwidth of snapping shrimp snaps, non-biological sounds such as physical sounds (i.e. waves, rain, wind) or anthropogenic noise (i.e. recreational boats, ships, dredging).



Spotted Seatrout

Recording and spectrogram of a Spotted Seatrout *(Cynoscion nebulosus)* vocalization produced during courtship and spawning. The sound contains grunts and staccato sounds centered around 250-500 Hz[5, 14].

Figure 2:



Data Collection & Analysis

The equipment needed to collect passive acoustic data and monitor soundscapes includes a hydrophone and data recording device, which are usually contained within the same housing, and a deployment apparatus. The type and sensitivity of the hydrophone can vary based on the application and intensity of the sounds being measured. The recorded .wav files are analyzed by listening, visually inspecting graphical representations (spectrograms) (Fig.2), and with digital signal processing to identify the sources and intensity of the sounds. Time series of soundscape metrics can be produced to monitor short-term variability and long-term change. A flow chart of the pre-deployment, deployment, retrieval, and analysis process is outlined below.

Pre-deployment

Testing and calibrating the hydrophone for sensitivity and gain, programming duty cycle (e.g. 2 min. recording per hour), and applying ant-fouling material.

Deployment

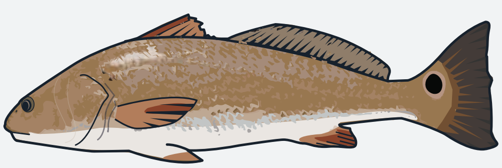
Deployment apparatus can vary by site. Instruments may be attached to PVC anchored in the sediment, contained within an instrument frame, or strapped to a piling or structure.

Retrieval

Retrieve data logger and dowload data. Audio files are manually reviewed by listening and visually inspecting spectrograms to identify sources of sound using the unique frequency and temporal characteristics. (Figs. 2, 3, 5, 6)

Analysis

Temporal patterns of sound production, pressure levels and frequency composition are analyzed (spectral analysis) to produce additional soundscape metrics. (Fig. 4)



Red Drum

Red Drum *(Sciaenops ocellatus)* vocalization consisting of a low frequency "knock" in the frequency range of 140 – 160 Hz. The number of knocks and pulses of repetition vary among individuals. Sounds are produced by male fish and are associated with spawning[5,15].

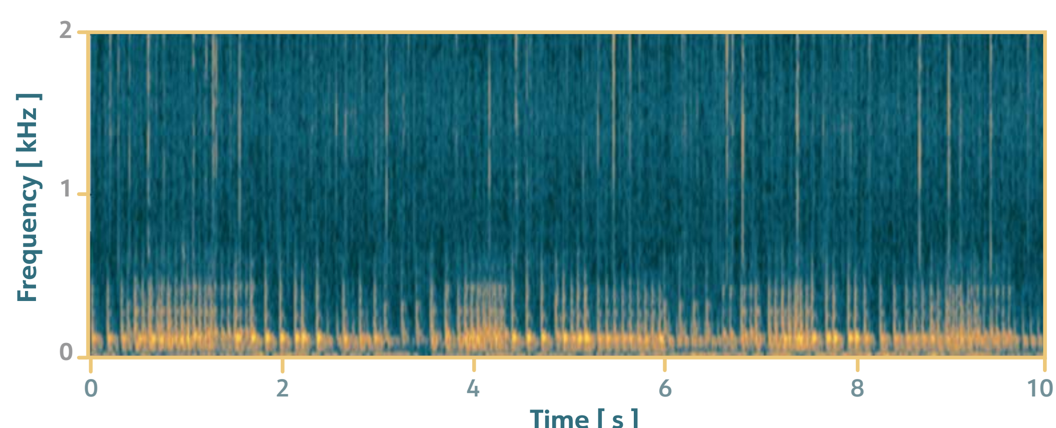
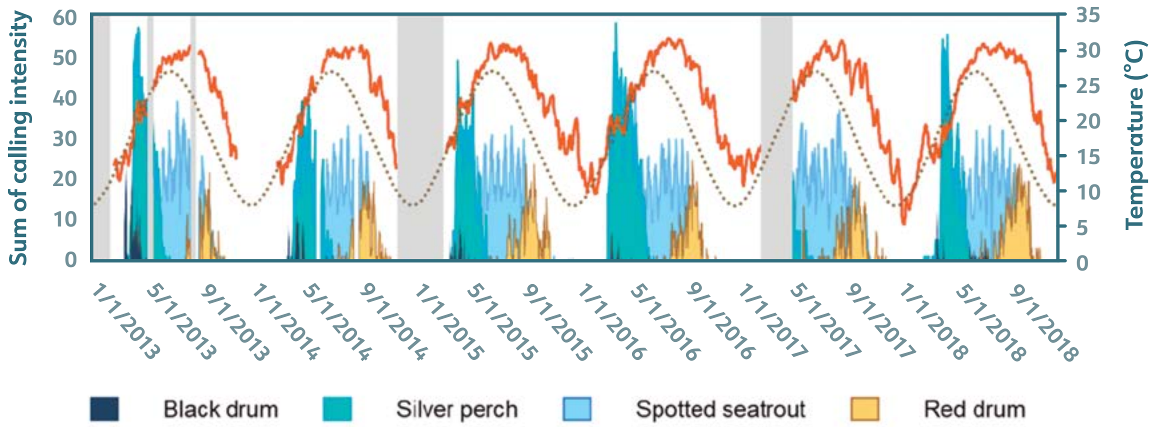


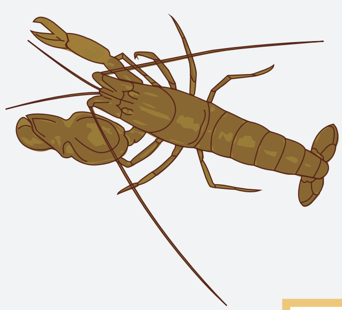
Figure 3:

Short-term Variability & Long-term Change

Figure 4:



Time series of courtship and spawning associated vocalizations from Black drum, Silver Perch, Spotted Seatrout, and Red Drum in the May River Estuary, South Carolina, between 2013 and 2018. Acoustic monitoring can be used to identify the onset and duration of spawning seasons and provides a base line from which to assess short-term variability and long-term change[16].



Snapping Shrimp

Snapping shrimp (*Alpheus* spp.) have one claw that can grow to up to half the size of their bodies, and they make a loud snapping sound by rapidly closing it, which creates a cavitation bubble. The snap covers a frequency range of 0-200 kHz, is very short (<0.1s), and loud.

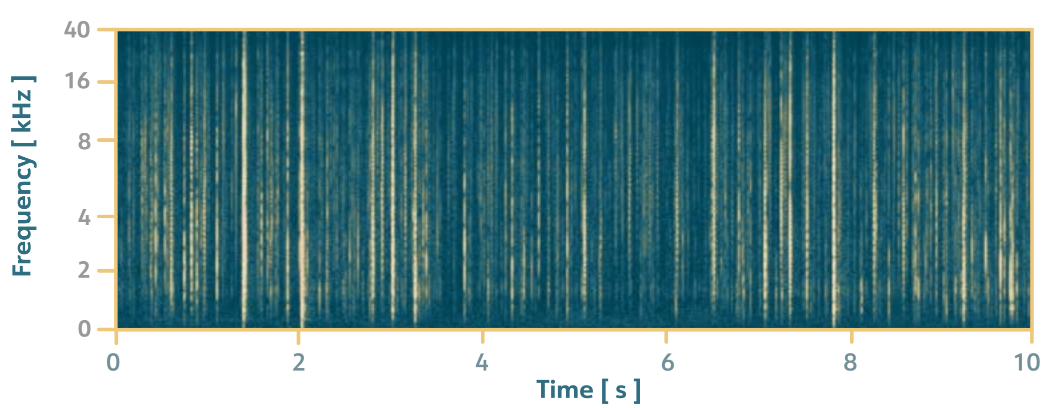
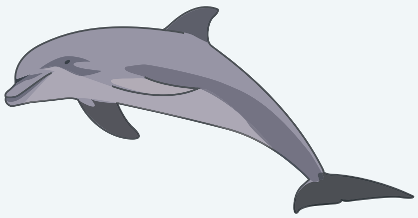


Figure 5:

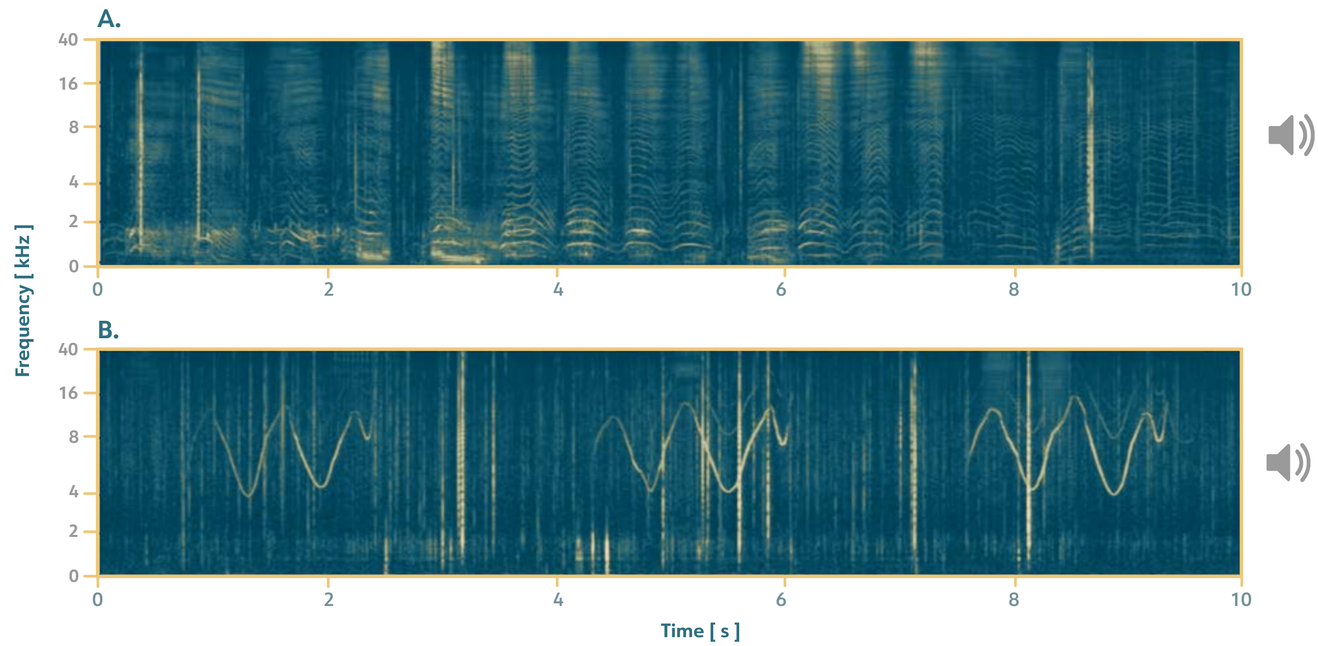


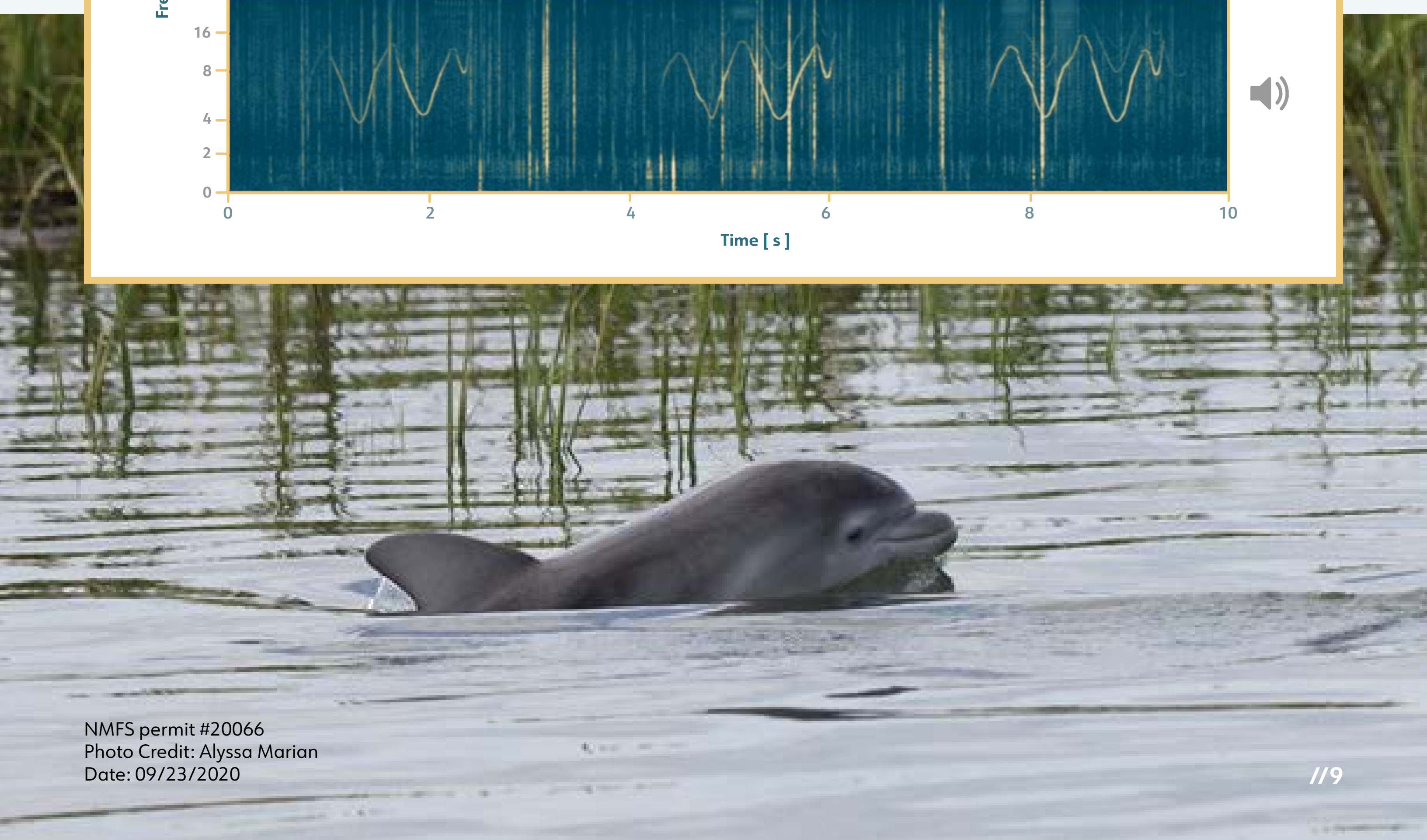
Common Bottlenose Dolphins

Two types of vocalizations produced by Bottlenose Dolphins *(Tursiops truncatus)*. A) Burst pulses with harmonic lines, which can vary across a broadband frequency range of 0-160 kHz. and B) Whistles, which range from 2-20 kHz and modulate in frequency.

Echolocation bouts (not shown) are also abundant and the predominant vocalization used for foraging[17].

Figure 6:





NMFS permit #20066
Photo Credit: Alyssa Marian
Date: 09/23/2020

ACOUSTIC MONITORING

System Wide Monitoring & Habitat Assessment

The System Wide Monitoring Program of the NERRS

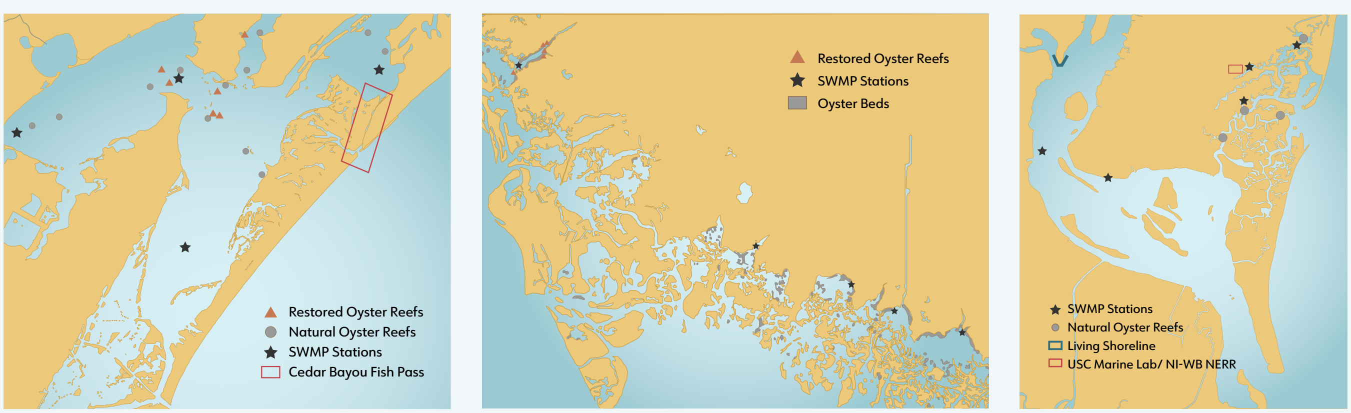
The National Estuarine Research Reserve System (NERRS) is a network of 29 coastal sites designed to protect and study estuarine systems.

Established through the Coastal Zone Management Act, the reserves represent a partnership between NOAA and the coastal states. NOAA provides funding and national guidance, and each site is managed on a daily basis by a lead state agency or university with input from local partners.

Long-term monitoring of meteorological conditions, water quality, and primary production are collected via the System-Wide Monitoring Program (SWMP) at multiple locations within each NERR, with the goal of identifying trends in short-term variability and long-term change in coastal ecosystems. All SWMP data is publicly available and can be downloaded.

Implementing acoustic monitoring at existing SWMP monitoring stations will provide high temporal resolution data of biological, geophysical, and anthropogenic sounds. This approach will provide information on short-term variability and long-term change in higher trophic level organisms beyond what is currently targeted by SWMP.

The three Reserves currently being considered are the Mission-Aransas NERR, Rookery Bay NERR, and North Inlet-Winyah Bay NERR.



Mission-Aransas NERR, Texas

Rookery Bay NERR, Florida

North Inlet-Winyah Bay NERR, South Carolina

Figure 7:

ACOUSTIC MONITORING // SWMP Stations

Benefits of hydrophones installed at SWMP stations:

- Passive acoustic monitoring enhances the resolution of biodiversity assessments[4,18]
- Can detect cryptic species that otherwise have gone undetected by visual surveys[19]
- Monitors biological activity at higher trophic levels, which are not currently monitored
- Useful in estuarine waters with limited visibility
- Understanding when spawning, nesting, and feeding occurs can inform decisions on protecting key habitats and passive acoustics can help provide this information [5,6,16,17]

Targeted Habitat of Interest (Oyster Reefs)

Healthy, Degraded, Restored Oyster Reefs

The ecological functions of oyster reefs feed either directly or indirectly into several critical ecosystem services. These ecosystem services include oyster production, water filtration, carbon sequestration, recreational fisheries production, habitat provision, and habitat and shoreline stabilization[20].

Transient fishes including red drum, black drum, and spotted seatrout are commonly captured near oyster reefs during community sampling, suggesting that oyster reefs are important foraging areas for predatory fishes[21].

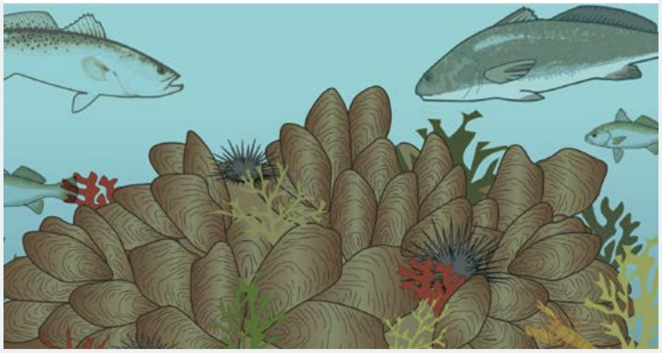
Sound intensity and diversity is greater on healthy oyster reefs compared to degraded reefs or soft-bottom habitats (Fig.8), and oyster larvae settle in response to reef-associated sounds[2,22].

Acoustic signatures of oyster reefs convey information about the habitat quality and the organisms that inhabit them. Monitoring the acoustic signatures of natural and restored reefs can help evaluate the rate of recolonization and ecosystem function[23]. Acoustic monitoring also provides biodiversity metrics for these areas, which are difficult to sample using traditional methods (trawls).

Figure 8:

Signs of a Healthy Reef:

- High biodiversity across trophic levels
- High density of oysters
- Numerous resident fish and invertebrates
- Rich biological sounds associated with foraging, communication, & movement
- Elevated sound pressure levels



Signs of a Degraded Reef:

- Low biodiversity, especially at higher trophic levels
- Dominated by algal species and sediment
- Diminished sound pressure levels
- Lower SPL and acoustic diversity indices

Mission Aransas NERR

Acoustic monitoring of low-frequency (50 - 2500 Hz) sound production (sound pressure level) at an established oyster reef (blue line) and a newly restored oyster reef (orange line) within in the Mission-Aransas NERR. Initially there is a large difference in sound production between the two sites indicating a lack of biological activity at the restored oyster reef (A). Both sites were affected by a flooding event and experienced a decrease in salinity, which corresponded with a cessation of sound production (B) followed by a period of recovery of biological activity and convergence of ecosystem function between the healthy and restored reef (C).

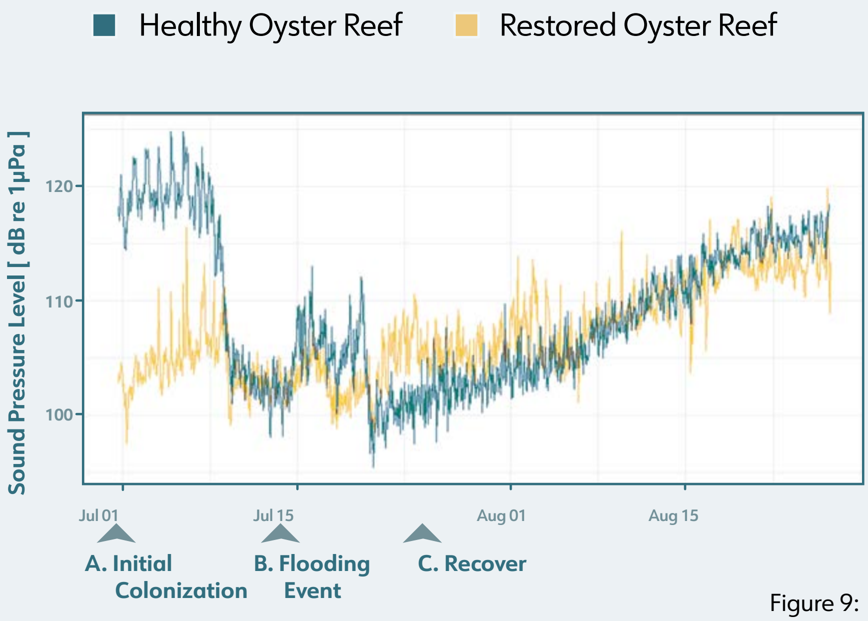


Figure 9:

Impacts of Anthropogenic Noise

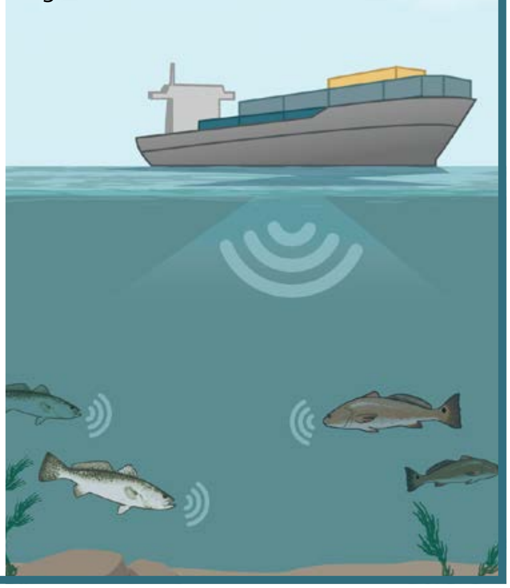
The ocean has become a very noisy environment due to coastal development, commercial shipping, recreational boating, dredging, pile-driving, energy production, and other human activities. Marine organisms are impacted by these activities in a variety of ways including increased stress levels, masking of communication signals, hearing threshold shifts, and damage to auditory structures[7, 8, 24]. Passive acoustics provides a measure of human generated noise and a means to assess potential ecosystem impacts.

Vessel noise varies with the size and speed of ship as well with the type of engine, but generally produces broadband sound that is often loudest within lower frequencies. The high-intensity low-frequency sounds of boat engines coincide with the frequency of biological sound production (Figure 10). Anthropogenic noise may be persistent (e.g active shipping channels), temporary (e.g. areas of dredging) or intermittent (e.g. recreational boat traffic).

Impacts of anthropogenic noise
\are largely unstudied in organisms other than marine mammals. However, some of the likely impacts include:

- Disruption of communication through masking (noise at the same frequency of communication)
- Interruption of courtship calls produced by male fish during the spawning process
- Increased stress hormone levels
- Alteration of behavior

Figure 10:



Boat Noise

Spectrogram of sound produced by a 17' boat with a 90 hp outboard engine passing within 1 m of a hydrophone at a depth of ~ 10 m.

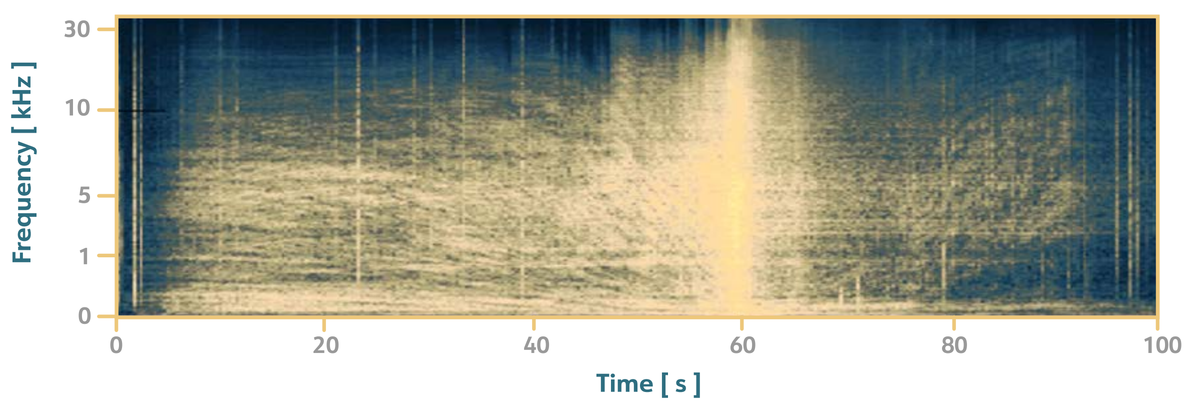


Figure 11:

Monitoring Visitor Use

Vessel presence and visitor use are important metrics in assessing ecosystem value and management effectiveness. Acoustic monitoring can provide this information continuously over extended periods of time. Boat noise and other anthropogenic sources of sound can be identified via manual detections or automated processes. The data can be used to measure seasonal, daily, or hourly usage, and duration of visit. Monitoring the level of compliance with regulations may also be of interest as the data collected can indicate when patrols or enforcement measures would be most effective.

EDUCATION
Teachers on the Estuary (TOTE)

Teacher Training Workshop

A Teachers on the Estuary (TOTE) workshop is a research and field-based training program held at various research reserve sites. TOTE workshops offer a minimum of 15 contact hours, giving teachers the opportunity to:

EXPLORE
coastal habitats and conduct field investigations

INTERACT
with local scientists and experienced coastal educators

INTEGRATE
local and national monitoring data into the classroom

LEARN
hands-on field activities highlighting various estuary education resources

Teachers use TOTE to increase their understanding of estuary science, and they learn how to engage students in the investigation of changes in their local environment using data from the NERRS System-Wide Monitoring Program.

Calling all Spotted Seatrout // Can you hear me?

Description: Students will explore the reasons for and challenges to organisms using sound for their survival in an aquatic environment, such as the bays, estuaries, and waterways within the NERR. They will conduct experiments, gather evidence and examine data to better understand the role sound plays in the lives of Spotted Seatrout, and how researchers study the Seatrout sounds to inform the management of their populations.

Learning Objectives: Students will...

- Explain why and how animals use sound for their survival, considering both land/terrestrial and water/aquatic environments.
- Conduct experiments that demonstrate two to three important characteristics of sound, such as amplitude/intensity (loudness), frequency (pitch) and rhythms, and how a water/aquatic environment influences these characteristics.
- Identify and predict how human activities might impact Spotted Seatrout communication (and their survival).
- Recognize how scientists use specialized equipment, such as hydrophones and acoustic receivers, to capture and measure sounds natural and human-produced in the water/aquatic environment.
- Describe why and how scientists study and measure Spotted Seatrout sounds in an estuary.

Spotted Seatrout Research

Scientists have been investigating the sounds that fish make for many years. They study fish sounds to better understand when and where particular fish species are aggregating to spawn and how these aggregations are overlapping with various habitats and recreational fishing efforts. Spotted Seatrout are of particular interest to these scientists due to their importance as a piscivorous predator, a recreational fishery and the economic importance of the fishery to the regional economy. Scientists have been combining local knowledge sourced from the fishing community with hydroacoustic data to generate spawning aggregation "maps." These maps, along with other research findings, can be used to inform management practices that protect valuable seatrout habitat as well as the fish themselves.

Excercise 1: Animal Sounds

> *Why do animals make sounds?*
> *How do animals make sounds?*

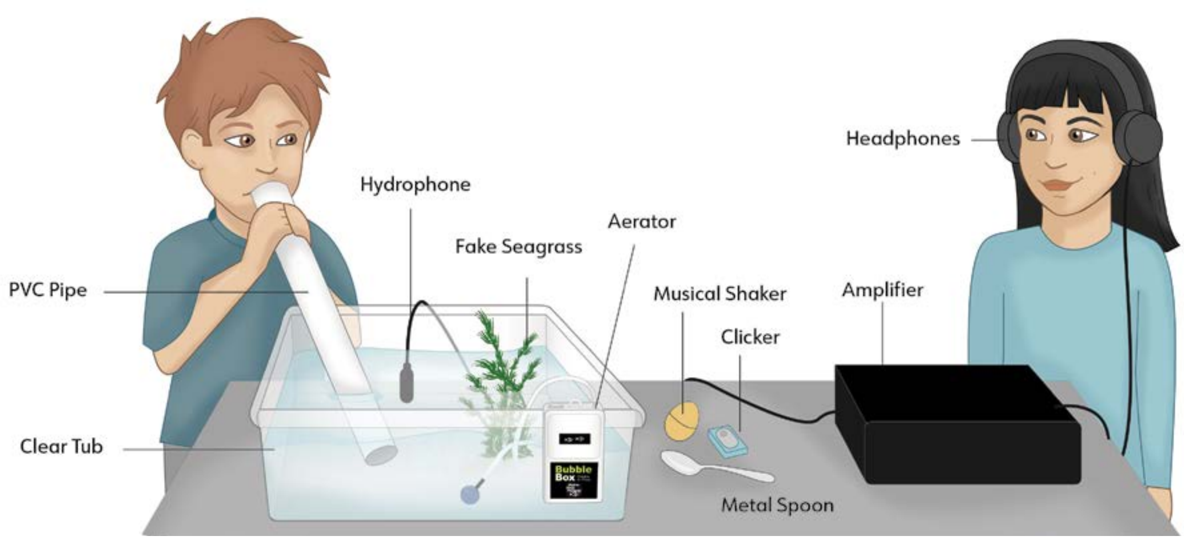
Students will draw on prior knowledge and provided references as they **Think/Pair/Share** answers to these questions, while learning the basic sound characteristics of pitch/frequency and loudness/intensity as it relates to how we perceive (hear) sound and how we measure sound. They will also learn about the units used to measure sound, decibels (dB) for loudness/intensity and hertz (Hz) for pitch/frequency.

Activity: Sounds Underwater

Students will explore sound perception (how we hear sound) in both air and water environments. They will conduct a series of experiments that demonstrate the differences and similarities of sound in different mediums.

Experiment: Exploring Sounds Underwater

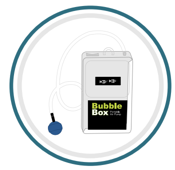
Figure 12:



A clicker, shaker and metal utensils are used as instruments to investigate how sounds with different acoustical properties (frequency & intensity) sound underwater

The fake seagrass imitates the underwater environment as seagrass tends to attenuate sound.

Make different sounds through a PVC pipe or an empty, wide mouth 20 oz. sport drink bottle with the bottom cut off



A bubbler (aerator) imitates boat noise in the water.

Figure 13:

Excercise 2: Studying Sounds

> Why do scientists study animal sounds?

> How do scientists study animal sounds?

This exercise introduces the reasons why scientists study animal sounds, and some of the methods they use to listen, record and document animal sounds.

Activity: Hearing Sounds

Students will listen to a variety of animal sounds, as well as other geophysical and anthropogenic sounds generated underwater from a soundscape recording. They will consider what created the sound (what type of animal or what type of activity) and what identifiable characteristics each sound has, such as loudness, pitch and pattern. They will articulate the sound characteristics in writing or illustration.

Play sounds at individual sound stations, or for the whole group.

Aid students in their identification of the sounds by providing them with a set of images of the animal or machine/activity to choose from and match up.

Listening through headphones will provide the best listening experience, especially to limit background noise and to focus their attention.

After listening to recordings, students should compare their identifications (what/who made the sound) and their sound descriptions.

Some people can hear a wider range of sounds than others and our description of sounds is solely based on our perception and interpretation of the sound. The sound source (who/what) discussion can be extended to include a consensus making component where all the students work together to identify who/what made the sound.

Activity: Seeing Sounds

Students will observe sound recording spectrograms, which illustrate the frequency and intensity of sound through time. Students will use what they know about sounds, including their own sound notes/illustrations, to match up the sound source (who/what made the sound) with the spectrogram.

- What do you notice about the graph?
- Can you identify the units of measurement? Is it decibels or hertz? What does this tell you about the sound?
- Which animal or human activity/machine made the sounds graph you are looking at? Explain your reasoning.
- How did your description of the sound compare with the graph? How did it differ?

Exercise 3: Spotted Seatrout Case Study

Students will be introduced to a specific research project being conducted at a NERR. Students will engage in an exercise that highlights how the scientists used sound to answer their research question.

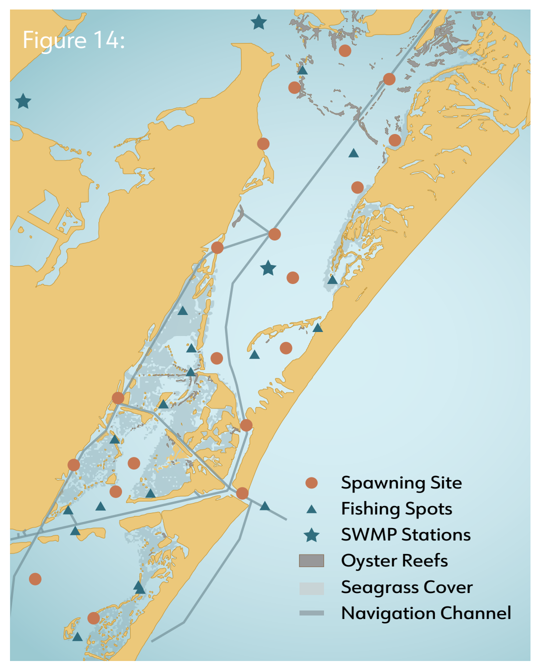
Activity: Monitoring Sounds

Scientists were interested in learning more about Spotted Seatrout spawning aggregations within an estuary, specifically, where they are located, when they occur and how fishing activities overlap or coincide with these events. This knowledge can be very valuable to scientists that seek to understand recreational fishery populations and provide insight on how to conserve them for future generations. Knowing seatrout make sound to communicate during spawning, scientists randomly sampled sites in the estuary to see where spawning was occurring and then compared those sites with known fishing locations.

Students will observe and interpret maps illustrating "prime fishing locations" as well as known habitat locations, and spawning sites.

> Observe the map of sea trout spawning locations. Determine where human activities might impact or overlap with sea trout. What locations are most at risk of noise pollution or interference? Why do you think that?

> How might the noise interference impact the seatrout communication?



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RESOURCES

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