It's a Snap! an Inquiry-Based, Snapping Shrimp Bioacoustics Activity

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Source: The American Biology Teacher, 75(7):470-475. 2013.
Published By: National Association of Biology Teachers
URL: http://www.bioone.org/doi/full/10.1525/abt.2013.75.7.5

It's a Snap! An Inquiry-Based, Snapping Shrimp Bioacoustics Activity

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Abstract

This bioacoustics activity combines concepts in invertebrate taxonomy, animal communication, and acoustical physics while providing a unique opportunity for physics and biology teachers to collaborate and introduce their students to an exciting, interdisciplinary research field. Here, we propose a lab- and field-based activity that uses hydrophones to explore how shrimp snapping behavior changes in response to different stimuli and introduces students to the process of scientific inquiry. Using free software, students use spectrograms to visualize and analyze their experimental data. Furthermore, we propose potential modifications to the lab for classrooms without easy access to marine environments or snapping shrimp.

Key Words: *Hypothesis testing; experimental design; marine biology; sound; amplitude; wavelength; animal behavior.*

Our oceans are filled with sounds. The ambient, or background, noise at any given place in the ocean is a highly variable mixture of sounds from any number of different sources. Natural sounds originate from marine life such as fish, marine mammals, and snapping shrimp, as well as from meteorological events (e.g., wind, rain, lightning strikes) and geological events (e.g., seismic activity, grinding sea ice) (Hildebrand, 2004; Lammers et al., 2008). The other major contributors to background ocean noise are both purposeful and unintentional anthropogenic sounds, including large commercial ships, sonar, polar ice-breakers, underwater explosions, and offshore drilling operations. Consequently, anthropogenic underwater noise has increased to a level 10 times higher than it was only 20 years ago (Hildebrand, 2004).

Sound is caused by vibratory or pressure disturbances in a medium.

Sound is caused by vibratory or pressure disturbances in a medium (i.e., gases, liquids, or solids). In comparison to air molecules, the higher density of liquid molecules allows sound to travel across vast distances of the ocean with great speed and efficiency. Additionally, how a sound propagates through the ocean depends on local environmental conditions such as water temperature, salinity, bathymetry, and depth (Au & Hastings, 2008). Thus, the temporal and spatial heterogeneity of the marine environment makes the study of marine bioacoustics a highly complex subject. The fundamental nature of underwater sound, however, is similar to that of sounds produced in other media: when an object vibrates, it produces a pressure wave that radiates in all directions. As it radiates outward from the source, this wave of energy produces a pattern of alternating compression and decompression (higher and lower density of molecules, respectively). Our ears, as well as man-made sound-detecting devices such as hydrophones (i.e., underwater microphones), detect this pressure pattern as sound.

Sound waves can be depicted by sinusoidal graphs of pressure versus time (Figure 1), and quantified by amplitude, wavelength, and frequency. A sound's amplitude is depicted by the height of the sinusoid, whereby the taller the wave, the louder the sound produced. Often, this is measured in units of decibels (dB). On the other hand, the wavelength of a sound wave is the distance between two peaks or two troughs of the sinusoid. Wavelength is inversely related to frequency, which is a measure of the number of cycles, or waves that pass a given point over a given amount of time. For example, Hertz (Hz) is a measure of the number of cycles per second. Both frequency and wavelength provide information about a sound's pitch. High-pitched sounds have shorter wavelengths and higher frequencies, whereas low-pitched sounds have longer wavelengths and lower frequencies.

Bioacoustic scientists study sound production and reception in animals. For example, they study hearing and echolocation of dolphins and small whales, characterize the social acoustics of marine mammals such as chorusing by humpback whales, and develop technologies to better understand sound production and perception by these animals. In an effort to better understand and possibly prevent the stranding of marine mammals due to anthropogenic noise, scientists are also investigating the effects of man-made noises such as Navy sonar on marine mammal physiology. Efforts are even under way to create a comprehensive acoustic library for reef fish, in order to assist in monitoring the underwater environment and improve management and conservation efforts on these reefs (Lammers et al., 2008).

The American Biology Teacher, Vol. 75, No. 7, pages 470–475. ISSN 0002-7685, electronic ISSN 1938-4211.
DOI: 10.1525/abt.2013.75.7.5

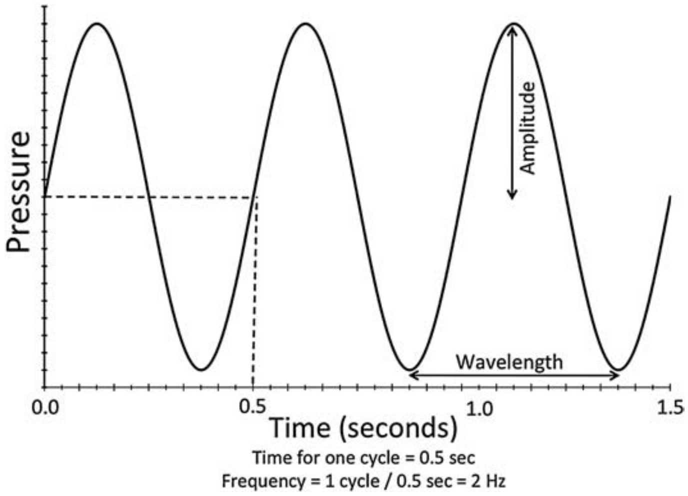

Figure 1. A sound wave as a sinusoidal graph of pressure versus time, showing the wave's basic components: frequency, wavelength, and amplitude.

Interestingly, the most significant source of biological sounds on coral reefs is snapping shrimps (Readhead, 1997; Au & Banks, 1998). Their importance to the acoustic symphony of the coral reef ecosystem makes them an interesting study organism for this lab activity. Each species has a modified claw, which, when rapidly closed, causes rapid changes in the surrounding water pressure and produces an air pocket known as a "cavitation bubble." The implosion of this bubble results in a very loud snap. These sounds are used not only for communication, but also in predation: the pressure and heat produced by the cavitation bubble is capable of stunning prey (Versluis et al., 2000).

○ Lesson Plan

This inquiry-based lesson is divided into three parts, but we encourage teachers to modify this lesson plan to their preference. The first activity is a teacher-led classroom discussion lasting approximately 1 to 2 hours. The second activity combines both field and laboratory work. For a class of 40 students, divided into groups of 4, we estimate that the second activity should take about 3 hours (not including transportation to and from the field site). The lab concludes with an individual or group project. A more detailed lesson plan and other instructional materials can be found at http://www2.hawaii.edu/~HIMBed/inquiry-fieldtrips.html.

○ Part I: Activities for the Classroom

On the first day, teachers should prepare their students with the background information described here. Students should also listen to the brief (2 minutes each) example sounds provided online by the U.S. National Oceanic & Atmospheric Administration's Pacific Marine Environmental Laboratory Vents Program to get an idea of the enormous variation in underwater sounds (http://www.pmel.noaa.gov/vents/acoustics/sounds.html). A video introduction to marine bioacoustics as well as additional sound files are also provided online by the Cornell Lab of Ornithology at http://www.birds.cornell.edu/Page.aspx?pid=2207. Finally, teachers should download the free software Raven Lite 1.0 (http://www.birds.cornell.edu/brp/raven/RavenOverview.html; Charif et al., 2006) and demonstrate its use to the students using pre-recorded audio data. In our experience, it is generally easy to orient students in the basic use of Raven Lite 1.0 because the program is relatively intuitive for graphical analysis of acoustic data.

When demonstrating the software, instructors should explain that although we do not need the aid of a hydrophone to hear the sound produced by a snapping shrimp, recording the sound and collecting more detailed and quantitative data allows for the analysis of subtle differences between sounds that would otherwise be undetectable by the human ear. Data are typically analyzed by researchers in the form of spectrograms (Figures 2 and 3). Using this software, students should be able to generate two separate audio spectrograms: a waveform (amplitude measured in kU vs. time) and a spectral frequency (frequency measured in kHz vs. time). Teachers can also point out the difference between tonal and broadband sounds. Rather than producing a tonal sound composed of only one or a few frequencies (such as in a musical note), snapping shrimp produce broadband sounds composed of many frequencies and, thus, have no characteristic pitch. Note that although decibels (dB) are a more popular unit of amplitude measurement, Raven Lite expresses this in terms of its own amplitude units (U). It is essential that students understand how to read these graphs, because they will be important tools to keep in mind when they develop their hypotheses during part II.

○ Part II: Field Trip & Laboratory Day

In this activity, students will work in groups to collect snapping shrimp as well as a wide variety of other invertebrate organisms. There are ~600 species of snapping shrimp found worldwide, the most common of which can be found in tropical and subtropical waters (Johnson et al., 1947). Snapping shrimp can often be found in the water surrounding boat ramps, docks, and harbors, living among mussels, barnacles, or other fouling organisms. One species, *Alpheus heterochaelis*, is common among oyster beds or salt marshes along the U.S. mid-Atlantic seaboard. Other good collection sites include algae- or seagrass-dominated sandy bottoms. For example, *A. formosus* is commonly found in the western Atlantic from North Carolina down to the Caribbean in either coral reef or seagrass-dominated areas (Anker et al., 2008). Another species, *A. clamator*, can also be found in cold to temperate waters from Central to Baja California in the rocky intertidal among kelp or sponges (Chace & Abbott, 1980). Collecting in areas where students can wade in ankle to knee-deep water is highly recommended for safety and logistical reasons. Lastly, we encourage instructors to consult local experts, species identification guidebooks, the Internet, and/or references mentioned here for more detailed information.

Field Materials

- Shoes to get wet/muddy
- Hand net or shovel (depending on the substrate)
- Buckets with lids
- Battery-operated aerators (optional)

Laboratory or Classroom Materials

- Metal forceps
- Rubber gloves

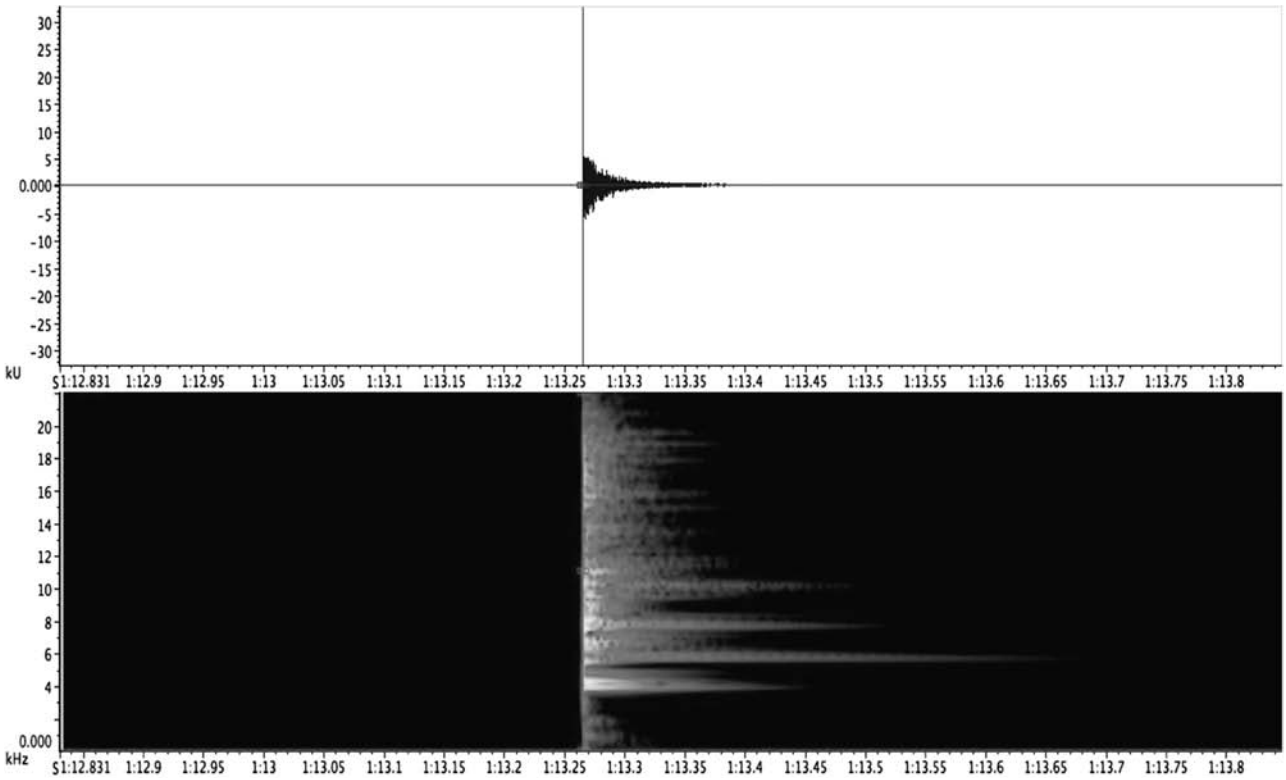

Figure 2. Two ways in which students can visualize underwater acoustic data of a single snap from a shrimp (*Synalpheus heeia*) using the software Raven Lite 1.0 (Chaif et al., 2006). The top image displays the data as a waveform (amplitude measured in kU vs. time). According to the data, this snap had a peak intensity of ~6 kU and the snap had a duration of ~0.2 seconds. The bottom image displays the same snap in the form of a spectral frequency (frequency in kHz vs. time).

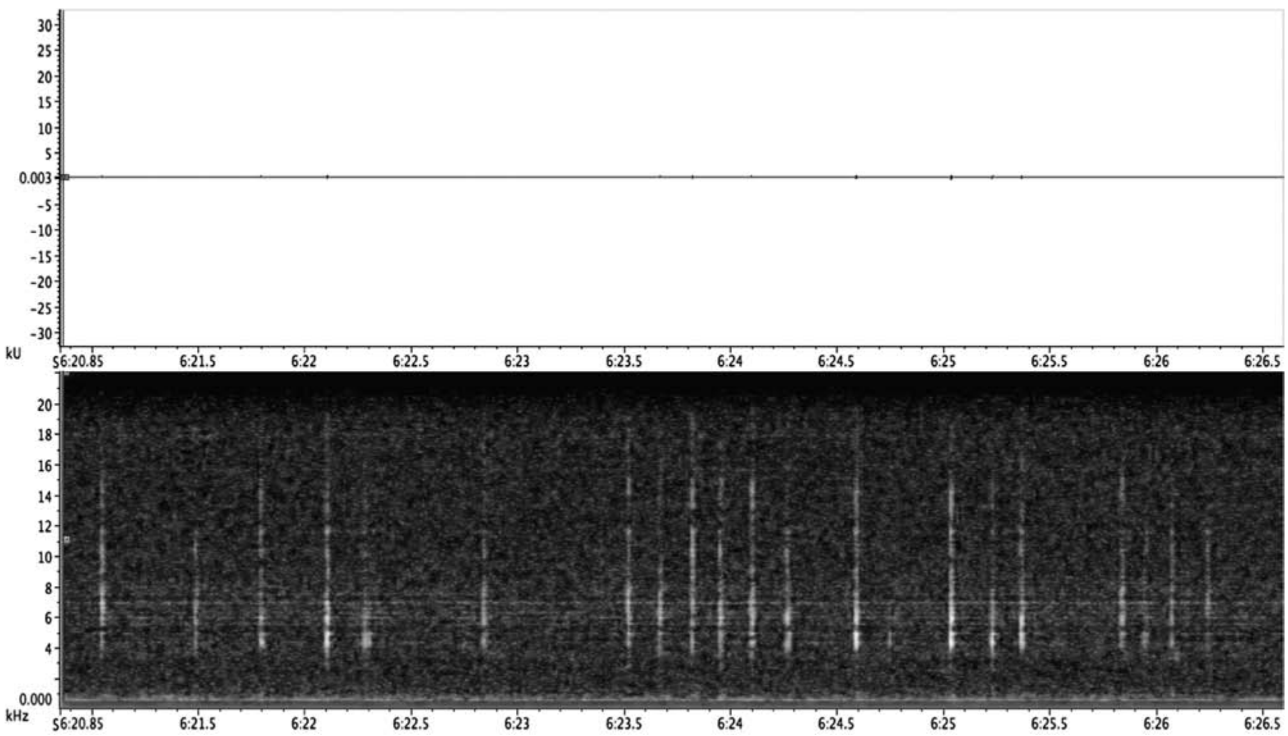

Figure 3. An example of one of the lower-frequency and lower-decibel-level sounds made by *Synalpheus heeia* in a glass aquarium. Three snapping shrimp were housed individually in separate plastic chambers placed in a single glass aquarium. Frozen squid was placed at the entrance to the chambers, and after ~5 minutes, the shrimp began to make the sounds displayed by the spectrogram here. These "feeding" sounds have not been previously reported in scientific literature and are examples of the kind of new information you may discover in this activity.

- Flat-bottom vials (25 × 150 mm, depending on the size of the snapping shrimp)
- Petri dishes (60 × 15 mm)
- Dissecting microscope
- 2.5-gallon glass aquarium
- Handheld recorder (e.g., Marantz Model PMD661)*
- Hydrophone with pre-amplifier (e.g., High Tech Model HTI-96-Min)
- Raven Lite 1.0 software
- Personal computer with speakers
- Frozen squid, fish, shrimp, or pellet feed

*These models are recommended by bioacoustic scientists and listed here only as a suggestion. Less expensive versions are available and work just as well for this activity. For example, at half the cost of the Marantz Model suggested above, we have also successfully used the Zoom H2 Handy Recorder.

The details of the collection method will differ depending on the particular collection site. Here, we outline procedures used in our classes in Kāneʻohe Bay, Hawaiʻi. Many species of snapping shrimp in the family Alpheidae are commonly found throughout the reefs of Kāneʻohe Bay and are responsible for the bay's high ambient noise level (Au & Banks, 1998). Luckily, in Hawaiʻi, one species of snapping shrimp, *Synalpheus heeia*, can also be found in muddy-bottom algal zones, dominated by tufts of the invasive algae *Gracilaria salicornia* (Figure 4). Collection involves using a hand net to quickly (so that the shrimp do not escape) scoop up tufts of *G. salicornia* as well as some of the underlying mud substrate. We have found as many as 4 or 5 snapping shrimp in just a 5-L bucket filled with *G. salicornia*. They were able to survive out of water for at least 1 hour; however, if transportation back to the classroom is expected to take several hours, the buckets should be filled with seawater and bubbled with a portable aerator. Additionally, clear seawater should be collected in separate buckets for the experiment.

Back in the laboratory or classroom, students sort through their bucket of *G. salicornia* using forceps and rubber gloves to protect themselves against stinging fireworms. Students will have an easier time finding the shrimp if they sort through their samples on top of a lunch tray or other surface whose color contrasts sharply with that of the snapping shrimp. At our collection site, students always find an amazing diversity of animals associated with these algal mats (Figure 5). In fact, teachers can expand this portion of the laboratory exercise into an invertebrate taxonomy lesson with the aid of identification guidebooks and/or dissecting microscopes. Finally, snapping shrimp that will be used during the experiment should be isolated individually in their own Petri dish so as not to allow them to become accustomed to other animals prior to experimentation.

Below is a series of guiding questions that will help students develop their own hypotheses and experiments. During this time, the teacher can also introduce the concept of a control experiment (i.e., an additional experiment where the variable is not changed, to verify that the changed variable in the test experiment is the cause of the result). Thus, when testing the response of snapping shrimp to the presence of other organisms, the control experiment is a recording of the acoustic behavior of an individual snapping shrimp isolated from all other organisms.

Guiding Questions

Below is a series of questions that can be provided to students to stimulate ideas about different hypotheses and experiments they can perform.

- Will a snapping shrimp make sounds when isolated from others?
- What are the biological uses of creating a powerful snap under water?
- Do snapping shrimp of different sizes, sex, or species make different snaps (e.g., in terms of their amplitude, frequency, or snapping rate)?
- Do snapping shrimp make sounds when they feed? How do these sounds differ from the sounds they produce when the

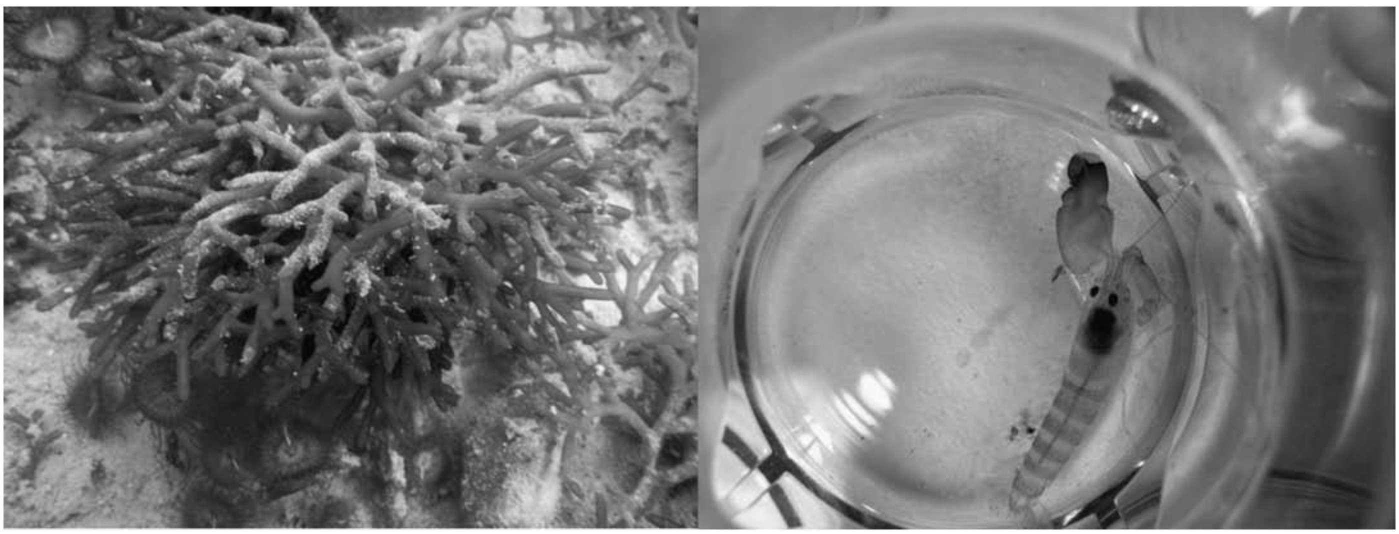

Figure 4. Left to right: a tuft of *Gracilaria salicornia* in Kāneʻohe Bay and a snapping shrimp (*S. heeia*). Photo credit: Malia Rivera and Bradley Fox.

Figure 5. Top row, left to right: iridescent fireworm (*Eurythoe complanata*), brittle starfish (*Ophiocoma brevipes*), small crab no. 1 (*Liomera* sp.). Bottom row, left to right: feeble shrimp (*Palaemon debilis*), small crab no. 2 (*Liomera* sp.), and Hawaiian blood-spotted crab (*Portunus sanguinolentus hawaiiensis*). Photo credit: Bradley Fox.

stimulus is not food (e.g., gently touching them with a plastic rod)?

- Will snapping shrimp make different sounds in response to different types of food?
- Which other species of invertebrate found in the microhabitats (e.g., crab, fire worm, feeble shrimp) will elicit a snap from the snapping shrimp? Do you think the snap is a "predatory" or "defensive" snap?
- How many snaps do you expect a snapping shrimp to make in a given period? Will there be a pattern to the snaps, or will they be singular in nature?

To set up the experiment, a flat-bottom glass vial is first placed upright inside the aquarium. Both the aquarium and glass vial are then filled with the collected clear seawater, up to a level exactly equal to the height of the glass vial. The snapping shrimp can then be placed inside the glass vial. Students must ensure that the snapping shrimp cannot swim over the top of the glass vial, and they can adjust the water level as needed to correct this. Hydrophone recordings can begin as soon as students add stimuli (i.e., other invertebrate organisms) into the same vial. Although this setup may seem unnatural, we have found that maximizing the interaction between the snapping shrimp and stimulus in this manner helps with eliciting snapping responses from the snapping shrimp. Students should also be reminded to take both notes about observed behaviors and, if possible, video of the experiment to be used as supporting experimental evidence.

Recording time will depend on the constraints of the class time, but in our experience, recording a total of 5 minutes per group was a good balance between moving the class along while still allowing students to collect sufficient data for their hypotheses. For large groups, we highly recommend having at least two or three instructors available for making recordings. Alternatively, a series of experiments can be conducted together as a class.

○ Part III: Data Analysis & Discussion

Using Raven Lite 1.0, students should generate spectrograms of the time interval that was recorded and zoom in on specific interesting sounds they observed within the recording to be used in more in-depth analyses.

Teachers should lead a class discussion about students' findings. Some guiding questions include the following. Were your hypotheses supported by the data? Was there a pattern to the snap, and did the number of snaps vary? How do the amplitudes and frequencies of the snaps vary in relation to individual shrimp or stimuli? Do your findings influence the way you view the ocean? During the discussion, teachers should emphasize to the students that this particular activity should only be considered as a preliminary study, as more extensive data (e.g., several hours or more of sound recordings) would be required to more carefully test their hypotheses. In the absence of such conclusive data, however, students can be guided to think about how they would design a more in-depth study. Instructors should be prepared to discuss the importance of replicating experiments and the difficulties of experimental design. Finally, students can complete the scientific research process by then writing up their results in a lab report.

Possible Modifications

If snapping shrimp are not readily accessible, the lab could also be modified in several ways while still introducing many important concepts in bioacoustics and scientific inquiry. Hydrophone recorders fitted with headphones, for example, could be taken into the field to take passive (i.e., listening) recordings of snapping shrimp by simply dipping hydrophones into the water surrounding boat ramps, docks, and harbors. Alternatively, some species of snapping shrimp (also commonly known as pistol shrimp) can be purchased at local pet stores or over the Internet. We have even successfully kept field-collected snapping shrimp in aquaria for at least 1 month. Instructors should ask a knowledgeable local aquarist for instructions on maintenance, feeding, and water parameters, because these may vary for different species. Hydrophones could also be used to characterize sounds from freshwater fishes or frogs. Certainly, any modification to this lab activity will require some additional research about the acoustic signaling of organisms specific to your area.

Bioacoustics could also be used to study terrestrial systems. By using recorders outfitted with shotgun microphones and/or parabolic dishes, classes could also focus on recording bird songs. These purely field-based projects could still incorporate an experimental element, thus maintaining the inquiry-based method of this lesson. For example, students can test for geographic variation in sound production between different populations of songbirds, some of which have been shown to sing at different frequencies, depending on whether they live in urbanized or rural areas (Slabbekoorn & Peet, 2003). In fact, the effect of urban noise levels on the acoustic behavior of local populations is a largely unexplored area of conservation research (Pijanowski et al., 2011) that could be used to engage students from urban schools. Certainly, any modification to this lab activity will require some additional research about the acoustic signaling of organisms specific to your area.

○ Conclusion

The interdisciplinary field of bioacoustics combines concepts in biology and physics as well as methodologies in the field and laboratory, making it broadly suitable to students with diverse interests. At the time of this publication, we have led more than 30 high school and undergraduate student classes of diverse socioeconomic and ethnic backgrounds through this activity. On the basis of our experience, we believe that the preparatory work for implementing this lab in a classroom setting is outweighed by the positive feedback we receive from students and teachers with regard to increased interest in the STEM fields and marine biology as a career.

○ Acknowledgments

We thank Kelly Boyle, a former graduate student in the lab of Dr. Tim Tricas, and Dr. Marc Lammers, researcher from the Hawai'i Institute of Marine Biology's Marine Mammal Research Program, for their helpful contributions. Funding was provided by the Hawaiian Islands Humpback Whale National Marine Sanctuary (MOA-2005-008 Amend. 002/7189) and the National Marine Sanctuary Program Pacific Islands Region (MOA-2005-008 Amend. 004/7471).

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